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Laboratory Bioassays of Vegetable Oils as Kairomonal Phagostimulants for Grasshoppers (Orthoptera: Acrididae)

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Abstract Vegetable oils have kairomonal attractant properties to grasshoppers primarily due to the presence of linoleic and linolenic fatty acids. These fatty acids are dietary essentials for grasshoppers and, once volatilized, can be detected by the insects' olfactory receptors. A laboratory bioassay method has been developed to identify vegetable oils that have fatty acid profiles similar to grasshoppers and that induce grasshopper attraction and feeding. Such oils could be useful kairomonal adjuvants and/or carriers for acridicide formulations. Three sets of laboratory bioassays demonstrated that the addition of a standard aliquot of different vegetable oils resulted in varying degrees of grasshopper feeding on otherwise neutral substrates. Addition of olive oil stimulated the greatest feeding in all three sets of assays, regardless of the age of the tested insects. Furthermore, addition of canola or flax oils markedly enhanced grasshopper feeding. These three oils—i.e., olive, canola, and flax oil—proved to be the best performing grasshopper stimulants. A second group of oils included rapeseed-flax mix and rapeseed oils; however, their performance was not as consistent as oils in the first group—especially with regard to nymphal feeding. A third group of oils consisted of soybean, corn, peanut, and sunflower oil. Theoretical expectations regarding these oils varied wildly, suggesting that the results of a single bioassay should be cautiously interpreted as being negative.

Keywords Vegetable oils · Fatty acids · Phagostimulants · Attractants · Grasshopper control

Introduction

Insecticidal baits have been used for the control of acridid pests worldwide for more than a century. Nowadays, baits are used on a regular basis in North America to control rangeland

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grasshoppers and Mormon crickets. A typical bait formulation consists of wheat bran or other solid carrier impregnated with an insecticide. Adding attractants and phagostimulants could result in greater bait acceptance, lure susceptible species to bait particles, and enhance palatability. Such additions to bait formulation make bait treatment more efficacious (Latchininsky and VanDyke 2006).

Vegetable oils have kairomonal attractant properties toward grasshoppers primarily due to the presence of linoleic and linolenic fatty acids (Bomar and Lockwood 1994a). These fatty acids are dietary essentials for grasshoppers and, once volatilized, can be detected by the insects' olfactory receptors (Bomar and Lockwood 1994b). Furthermore, fatty acids may be token stimuli for necrophagic grasshoppers seeking other nutrients, such as proteins, which are abundant in insect cadavers. Due to the presence of these fatty acids, certain vegetable oils used as insecticide carriers can function as "liquid baits" and markedly enhance the efficacy of grasshopper control programs (Lockwood et al. 2001).

The goal of this study was to develop a sensitive and efficient laboratory bioassay method and to apply this approach to identify particular vegetable oils that induce grasshopper attraction and feeding. Such oils may be useful kairomonal adjuvants and/or carriers for acridicide formulations.

Materials and Methods

Fatty Acid Analysis The initial selection of oils for screening was based on considerations of chemical profile, availability to pest managers, and cost. We sought oils with a fatty acid profile similar to that of the grasshopper *Melanoplus sanguinipes* (F.) (Barlow 1964), a common rangeland pest grasshopper, and that were widely available and inexpensive. A literature search and market investigation yielded eight candidate vegetable oils: canola, corn, linseed or flax, olive, peanut, rapeseed, soybean, and sunflower (Table 1). Subsequently, samples of these oils were obtained from available suppliers and analyzed for their actual fatty acid composition as described in Broughton and Wade (2002; Table 2). Lipids were extracted sequentially with chloroform-methanol (1:2, *v/v*), chloroform-saline (1:1, *v/v*), and one part chloroform (2×) following the method of Bligh and Dyer (1959). Chloroform fractions were pooled, evaporated to dryness, and suspended in minimal quantities of chloroform. After extraction, lipids were saponified in toluene and 0.5 mol/l KOH in methanol (8 min at 86°C)

Table 1 Typical fatty acid percent composition of some common vegetable oils (White 2000) as compared to *Melanoplus sanguinipes* adult grasshoppers

Fatty Acid Oil	Palmitic	Stearic	Oleic	Linoleic	Linolenic	Other	Total
Canola	4	2	64	19	9	2	100
Corn	12	2	28	57	1	0	100
Flax*	5	5	20	16	53	1	100
Olive	14	3	71	10	1	1	100
Peanut	12	3	47	32	0	6	100
Rapeseed	3	1	24	15	7	50	100
Soybean	11	4	23	53	8	1	100
Sunflower	7	5	19	68	1	0	100
*Melanoplus sanguinipes***	11	4	19	20	43	3	100

*Values from Panford and deMan (1990)

**Values from Barlow (1964)

Table 2 Fatty acid composition (% weight) of some common vegetable oils from available sources analyzed at the university of wyoming nutrition laboratory, and percent similarity to fatty acid composition of *Melanoplus sanguinipes* adult grasshoppers

Vegetable Oil	Fatty Acid Source	Palmitic	Stearic	Oleic	Linoleic	Linolenic	Other**	Percent Similarity
Canola	Puritan®	5	2	65	20	6	2	54
Corn	Safeway®	13	2	25	59	1	0	53
Flax	Rhône-Poulenc	5	4	19	14	58	0	85
Olive	Bertolli® Extra Virgin Oil	2	3	80	12	1	2	39
Peanut	Planters®	13	3	52	29	0	3	56
Rapeseed	Rhône-Poulenc	6	1	63	20	9	1	56
Rapeseed+Flax	Rhône-Poulenc	6	3	41	17	33	0	71
Soybean	Safeway®	12	5	25	51	7	0	65
Sunflower	Wesson®	8	5	15	72	0	0	47
*Melanoplus sanguinipes**	NA	11	4	19	20	43	3	100

*Values from Barlow (1964)

**Small amounts of fatty acids like Myristic, Palmitoleic, and Erucic

to liberate free fatty acids, cooled on ice, and acidified with 0.7 mol/l HCl in methanol. Free fatty acids were extracted with hexane (×2), evaporated to dryness, and methylated with ethereal diazomethane. The methyl esters were redissolved in hexane and analyzed by gas chromatography [Hewlett-Packard 5890 gas chromatograph with a DB23 capillary column (0.25 mm× 30 m, J & W Chromatography, Folsom, CA, USA) with hydrogen as the carrier gas]. Fatty acids were quantified by using pentadecanoic acid (NuCheck Prep, Elysian, MN, USA) as an internal standard.

Fatty acid profiles of the oils did not agree exactly with previously published data (Table 1). This is not surprising as fatty acids produced in any one type of oilseed may vary widely with geographic location, soil type, climate, agricultural practices, and even exposure to pesticides (White 2000).

Comparisons among the fatty acid profiles of the vegetable oils and *M. sanguinipes* were based on percent similarity (Kotila 1986). Furthermore, three fatty acids were of particular interest—linoleic, linolenic, and oleic—because they (mostly the first two and, to a lesser extent, the third) are the primary olfactory attractants of grasshoppers (Bomar and Lockwood 1994a, b). Consequently, the oils were ranked according to (1) percent similarity of their fatty acid profiles with *M. sanguinipes*; (2) combined, linolenic and linoleic acid content; and (3) oleic acid content. The ranking of each oil reflected the theoretical expectations of the oil performance as phagostimulants based on previous studies. The final ranking of vegetable oils as grasshopper attractants and feeding stimulants was developed after three sets of laboratory bioassays were performed with the selected oils.

Bioassay The non-diapausing strain of *M. sanguinipes* was selected for laboratory experiments. It is one of the few grasshopper species continuously available in laboratory colonies in the USA, and is a significant component of the rangeland grasshopper pest community (Pfadt 1988). In addition, its fatty acid profile is known (Barlow 1964).

Assays 1 and 3 were conducted on fourth instar nymphs. Nymphs were used in bioassays because the nymphal stage is when control programs generally should be conducted on

rangeland grasshoppers, fourth instar nymphs can be handled without injury, and feeding behavior is more consistent and reliable than in fifth instars (Bomar and Lockwood 1991). Nymphs were raised from eggs provided by the USDA-ARS Northern Plains Agricultural Research Laboratory in Sidney, Montana. Grasshoppers were hatched and reared according to Henry (1985). Assay 2 was conducted on adult insects, with equal numbers of males and females.

Pairs of grasshopper nymphs were used in assays, rather than single individuals. Adult grasshoppers were tested with just one individual per assay chamber. Before testing, all grasshoppers were held without food or water for a period of 4 h. Gladware® brand storage containers (739 ml capacity) were selected as an optimal assay chamber.

Bioassays were developed using a 24-h time period from introduction of the grasshopper(s) to the test chamber until scoring of the results. This amount of time was the minimum necessary to assure that grasshoppers had passed through an entire circadian cycle, an important consideration in context of their feeding periodicity (Lockwood et al. 1996). A longer duration of assay increased the probability that the nymphs would molt into the next instar, thereby invalidating the results. Environmental conditions were standardized at 27±1° C, 14:10 h light/dark, and 30% RH.

Whatman 1 filter paper (55 mm diam) was chosen for assays because it provided a neutral and stable substrate following Bomar and Lockwood (1994a, b). Oils were applied to flat filter paper discs with an airbrush applicator as described by Lockwood et al. (2001). This method allowed oil to be deposited at a rate that simulated aerial field applications of 1 l/ha (0.2 µl per disc) and 10 l/ha (2 µl per disc). However, the airbrush method of applications was not optimal because the oil was evenly applied and subsequent grasshopper feeding on was highly dispersed and not always evident. Often, nymphs would simply scrape the surface of the paper, rather than remove a readily discernible portion of the substrate. This made accurate scoring of the paper feeding difficult.

As an alternative method, the paper discs were folded in half to create a tent-like shape, which made it easy for the insects to grasp and feed on the edges. At each end of the crease, we applied various amounts of canola oil (from 0.1 to10 µl) until we found a volume that would create a visible spot (ca. 1 cm diam) without bleeding over the entire disc surface. A 2 µl drop created a distinct semicircular area for feeding, and in preliminary tests with 20 pairs of grasshopper nymphs, 60% of them removed a detectable portion of the oil-treated paper from the folded disc. In some cases, the nymphs chewed the entire semicircle of oil-impregnated paper, leaving behind only the untreated substrate. The 4 µl of oil per 55-mm filter paper is 20 times greater than the average amount that would be applied to the same surface area via most ultra low volume (ULV) aerial applications (1 l/ha is a typical rangeland ULV rate), but the application method provided an optimal "target" for grasshopper feeding in context of the assay.

A simple binomial approach was used to score insect feeding: Either a detectable (by unaided human vision) portion of the substrate was removed, or it was not. Efforts to generate more refined estimates for substrate removal or to determine whether there was surface scraping eroded the interobserver reliability of scoring.

Previous studies suggested that adding a water source during a feeding assay may decrease grasshoppers' physiological stress and increase their feeding on tested substrates (Bomar and Lockwood 1994a, b). As such, we conducted preliminary tests with a water-soaked cellulose sponges (ca. 3 cm^3) placed in the assay chambers. The oils in this test included 5 vegetable oils (canola, olive, rapeseed, flax, and a 1:1 blend of rapeseed and flax) and crop oil (a paraffinic oil as positive control) by using a pair of 2 µl drops. Data were analyzed by Pearson's chi-square linear-by-linear association with SPSS 14.0 statistical software. Results showed that tests with no water were generally more sensitive to differences among oils

(Table 3). Grasshopper feeding on different oils increase inconsistently, and only in two cases (rapeseed and canola) did the presence of water significantly ($P<0.05$) increase feeding (Table 3). Given that the inclusion of a water-soaked sponge added logistic complexity (i.e., keeping the paper from being wetted), raised humidity to unnaturally high levels in the chamber, provided an alternative, confounding substrate for feeding, and yielded results that obscured differences between the potential feeding stimulants, we chose to conduct our assays with untreated Whatman 1, 55-mm diameter filter paper discs in the absence of a water source.

Three sets of laboratory bioassays were conducted following the standard protocol described above. In the first two sets, unsexed fourth instar nymphs and adult males and females of *M. sanguinipes* were used. Five vegetable oils were applied to filter paper discs: canola, flax, olive, rapeseed, and a 1:1 mixture of rapeseed and flax oils. In addition to the vegetable oils, as a positive control, we assessed an oil that is widely used as an adjuvant in agriculture sprays in the US: crop oil concentrate (United Agri Products brand), which is a paraffinic oil that contains a phosphate ester emulsifier. The third set of bioassays was conducted on fourth instar *M. sanguinipes* nymphs only. Ten vegetable oils were used: canola, corn, flax, olive, peanut, soybean, SoyStick (methylated soybean oil that is a chemically modified derivative of soybean oil often used as a non-ionic surfactant in herbicide sprays), sunflower, rapeseed, and rapeseed-flax 1:1 mix. As positive controls, we used both crop oil concentrate and mineral oil (Safeway brand, U.S.P.). The latter oil was composed of alkanes and cyclic paraffins derived from the distillation of petroleum that makes a colorless and odorless light oil.

In addition to the aforementioned qualities of oils, French rapeseed oil was tested because it was a carrier for an insecticide—Adonis® (a.i. fipronil)—used worldwide for grasshopper and locust control (FAO 2004). Flax oil was also tested in cooperation with Rhône-Poulenc, who was seeking at the time a highly available and economical carrier for other formulations of the insecticide fipronil. Although flax oil is usually not consumed by humans, it is high in linolenic acid.

Statistical Analyses In all three sets of assays, a minimum of ten replicates for each oil were tested in randomized order. The resulting data were analyzed with Pearson's chi-squared linear-by-linear association using SPSS 14.0 statistical software.

Table 3 Phagostimulation assay protocol development trial using 4th instar *M. sanguinipes* grasshopper nymphs. Two-choice tests of vegetable oils with and without water sources in the test arenas

Type of Oil	Pre-treatment Conditions	N Tested	N with Feeding Damage	Percent with Feeding Damage
None	Water	50	12	24
	No water	50	2	4
Crop	Water	10	1	10
	No water	10	1	10
Rapeseed	Water	10	10	100
	No water	10	2	20
Flax	Water	10	8	80
	No water	10	6	60
Rapeseed-Flax	Water	10	8	80
	No water	10	5	50
Canola	Water	5	5	100
	No water	5	3	60
Olive	Water	5	5	100
	No water	5	5	100

Results

Fatty Acid Analyses Fatty acid analyses of the vegetable oils studied and their percent similarity to *M. sanguinipes* are summarized in Table 2. Flax oil was the most similar to the fatty acid profile of *M. sanguinipes* (85%), followed in order by rapeseed-flax mix (71%), soybean (65%), peanut and rapeseed (56%), canola (54%), corn (53%), sunflower (47%), and olive oils (39%; Table 2). Peanut oil was the only oil to have any measurable quantity of erucic acid, a 22:0 carbon fatty acid. Both canola and rapeseed oils had less than 0.01% erucic acid. The latter was surprising because rapeseed oil typically contains between 25 and 50% of erucic acid (White 2000). As such, the rapeseed oil that we used should be considered as a variety of canola. However, the French rapeseed oil was unbleached and not deodorized, unlike canola or other food-grade vegetable oils tested. Unique to olive oil was the presence of 2% palmitoleic acid (16:1). The stearic acid (18:0) content of flax oil was closest to levels found in *M. sanguinipes* (Table 2). All analyzed vegetable oils lacked myristic (14:0) acid, which made up 1% of the fatty acid profile of *M. sanguinipes*.

Two of the tested oils, flax and sunflower, had higher amounts of linolenic and linoleic acids combined (72% each) than did *M. sanguinipes* (63%; Table 2). The other oils had lower amounts of these oils; olive oil had the least (13%), followed by canola (26%), peanut and rapeseed (29%), rapeseed and flax mix (50%), soybean (58%), and corn (60%).

The highest proportion of oleic acid (80%) was found in olive oil, followed by canola (65%), rapeseed (63%), peanut (52%), rapeseed-flax mix (41%), and corn and soybean (25%; Table 2). Flax oil had the same oleic acid content as *M. sanguinipes* (19%). Only sunflower oil contained a lower proportion (15%) of this fatty acid than the grasshopper.

Bioassays 1 and 2 Results of the first two sets of assays are presented in Tables 4 and 5. The untreated (negative control) papers had no nymphal feeding and a low level of feeding by adult grasshoppers (2 positives out of 60). Relative to the oil-treated papers, there was significantly ($P<0.05$) less feeding on plain paper than expected. The crop oil concentrate (positive control) had 10% feeding by the nymphs and 20% feeding by the adults. The positive control had significantly ($P<0.05$) less feeding than all of the vegetable oils except rapeseed. Feeding between vegetable oils differed from expectations ($P<0.05$). Olive oil was the most phagostimulatory of the oils, being fed on 100% of the time, by both nymphs and adult grasshoppers. Canola and flax had 60% feeding by nymphs and 80% feeding with adults. The rapeseed-flax mix had 50% feeding by nymphs and 70% by adults. Rapeseed oil had a 20% feeding response with nymphs and 70% with adults. Among the vegetable oils, only rapeseed showed significant ($P<0.05$) differences between the feeding of adults and nymphs.

Table 4 Assay 1: phagostimulation trial using fourth instar nymphs of *Melanoplus sanguinipes*

Oil	N	Percent with Feeding Damage	Preference Rank
None	60	0	6
Crop	10	10	5
Rapeseed	10	20	4
Flax	10	60	2
Rapeseed+flax	10	50	3
Canola	10	60	2
Olive	10	100	1

Table 5 Assay 2: phagostimulation trial using adult (50% males, 50% females) *Melanoplus sanguinipes*

Oil	N	Percent with Feeding Damage	Preference Rank
None	60	3	5
Crop	10	20	4
Rapeseed	10	70	3
Flax	10	80	2
Rapeseed+flax	10	70	3
Canola	10	80	2
Olive	10	100	1

Bioassay 3 Results of the third set of bioassays are presented in Table 6. The differences among vegetable oil treatments and the negative (untreated papers) and positive (mineral oil and crop oil concentrate) controls were significant ($P<0.01$). The oils could be grouped into those that induced low level feeding (crop 10%, rapeseed 20%, methylated soybean oil 20%); moderate feeding (flax 60%, rapeseed-flax mix 50%, canola 60%, peanut 60%, soybean 60%, and corn 70%); and heavy feeding (sunflower 90% and olive 100%).

Vegetable Oil Ranking The rankings of all studied vegetable oils with regard to three "theoretical" parameters (% similarity to *M. sanguinipes*, linolenic+linoleic acid content, and oleic acid content), as well as the results of three sets of bioassays are summarized in Table 7. Based on these data, the mean rank of every oil was calculated separately for theoretical expectations and for practical application of bioassays, and the oils were categorized accordingly (Table 8). The lowest rank reflected the highest attraction and phagostimulatory properties of oils to grasshoppers. Theoretical expectations resulted in the following ascending rank order: flax, rapeseed and soybean, canola and peanut, corn, rapeseed-flax mix, and, finally, sunflower and olive. Among the oils tested in all three sets of bioassays, olive oil performed best, followed by flax and canola, rapeseed-flax mix and rapeseed. Sunflower, corn, peanut, soybean and methylated soybean oils were tested only in one set of bioassays and corn and sunflower performed well.

Table 6 Assay 3: phagostimulation trial using fourth instar nymphs of *Melanoplus sanguinipes*

Type of Oil	N	Percent with Feeding Damage	Preference Rank
None	120	8	8
Crop Oil Concentrate	10	10	7
Rapeseed	10	20	5
Flax	10	60	4
Rapeseed+Flax	10	50	5
Canola	10	60	4
Olive	10	100	1
Corn	10	70	3
Mineral	10	0	9
Methylated Soybean	10	20	6
Peanut	10	60	4
Soybean	10	60	4
Sunflower	10	90	2

Table 7 Ranking of tested oils according to theoretical expectations and results of bioassays

Rank	Percent Similarity to *M. sanguinipes*	Linoleic+ Linolenic Content	Oleic Content	Assay no. 1 Nymphs	Assay no. 2 Adults	Assay no. 3 Nymphs
1	Flax	Flax Sunflower	Olive	Olive	Olive	Olive
2	Rapeseed+flax	Corn	Canola	Canola Flax	Canola Flax	Sunflower
3	Soybean	Soybean	Rapeseed	Rapeseed +Flax	Rapeseed Rapeseed +Flax	Corn
4	Peanut Rapeseed	Rapeseed+flax	Peanut	Rapeseed		Canola Flax Peanut Soybean
5	Canola	Peanut Rapeseed	Rapeseed +Flax			Rapeseed +Flax
6	Corn	Canola	Corn Soybean			Rapeseed
7	Sunflower	Olive	Flax			
8	Olive		Sunflower			

Discussion

Our expectations regarding the phagostimulatory properties of vegetable oils were based on two assumptions. First, the oil should have the fatty acid profile similar to *M. sanguinipes*. Second, to enhance feeding, the oil should have a significant amount of the fatty acids "behaviorally active" for grasshoppers (linoleic+linolenic, and oleic), and that are known to induce the insect movement toward a food source (Bomar and Lockwood 1994a, b, c). However, we found that none of the studied oils ranked consistently across all parameters. For example, the fatty acid composition of flax oil was most similar to *M. sanguinipes* (i.e.,

Table 8 Ranking of the tested vegetable oils according to theoretical expectations and results of three laboratory bioassays

Parameter/Rank Oil	Theoretical Expectation				Bioassays		
	Percent Similarity	Linolenic+Linoleic Content	Oleic Content	Mean	No. 1	No. 2	No. 3
Canola	5	6	2	4.3	2	2	4
Corn	6	2	6	4.7	–	–	3
Flax	1	1	7	3.0	2	2	4
Olive	8	8	1	5.3	1	1	1
Peanut	4	5	4	4.3	–	–	4
Rapeseed	4	5	3	4.0	4	3	6
Rapeseed+Flax	2	4	5	3.7	3	3	5
Soybean	3	3	6	4.0	–	–	4
Sunflower	7	1	8	5.3	–	–	2
Methyl. soybean	–	–	–	–	–	–	7

had the highest percent similarity), and had the highest content of linolenic and linoleic acids; however, it had one of the lowest proportions of oleic acid. In contrast, olive oil ranked lowest according to percent similarity and linolenic+linoleic acid content, but had the highest oleic acid content. Summation of the three theoretical parameters produced rankings that placed flax oil with the greatest potential, and olive and sunflower having the least, with the other oils somewhere in between.

There are reasons to be skeptical regarding the "theoretical expectations" criteria. Percent similarity comparisons were made to published data on the fatty acid content of adult *M. sanguinipes* (Barlow 1964). It is not known how close these data were to the actual fatty acid content of the tested insects, among which there were both nymphs and adults. Fatty acid content of oilseeds can vary depending on many different factors: for example, in the case of sunflower oil, even the position of the seed in the seed head matters (White 2000). Most probably, the fatty acid profiles of grasshoppers also vary depending on developmental stage, sex, source of food, etc. Hence, it is not surprising that our bioassay results did not agree fully with theoretical expectations. Despite its lowest "theoretical" rank, olive oil performed consistently and ranked as the best stimulant in all three sets of assays. It was followed by canola and flax, rapeseed-flax mix, and rapeseed oils. The five remaining oils were tested only once and, therefore, do not allow definitive conclusions to be drawn. Among them, sunflower and corn oil appeared to outperform peanut, soybean, and methylated soybean oils.

Laboratory bioassays demonstrate that addition of a standard aliquot of different vegetable oils result in varying degrees of grasshopper feeding on an otherwise neutral substrate. Addition of olive oil stimulated the greatest feeding in all three sets of assays, regardless of age of the tested insects. Furthermore, addition of canola or flax oils markedly enhanced grasshopper feeding. These three oils could be grouped together as best performing grasshopper stimulants. The second group included rapeseed-flax mix and rapeseed oils. Their performance was not as consistent, especially with regard to nymphal feeding. The third group consisted of soybean, corn, peanut, and sunflower oils. Theoretical expectations regarding these oils varied wildly, and results of a single bioassay should be cautiously interpreted as being negative.

Vegetable oils were shown to function as grasshopper attractants (Bomar and Lockwood 1994a, b, c). This quality makes the oils of particular interest when the insecticide to control a grasshopper infestation acts by ingestion (e.g., an insect growth regulator) and is applied with intervening untreated swaths. Such a management option is known as Reduced Agent and Area Treatment (RAAT; Lockwood and Schell 1997; USDA 2002). Since the mid-1990s, RAAT has been widely implemented on extensive areas in more than ten western states in the USA and in Eurasia (Lockwood et al. 2001; Latchininsky 2006). The ideal insecticide carrier would be attractive enough to move the target insect rapidly over tens of meters (the typical width of untreated swaths in RAAT programs) to the source and then phagostimulatory enough to prompt the insect to eat the treated substrate. This latter quality would both enhance the target efficacy of stomach poisons and reduce the impact on non-target arthropod fauna, compared to contact type insecticides. A vegetable oil that is both a kinetic and gustatory stimulant could be an ideal carrier for biological insecticides such as spores of the fungi *Beauveria bassiana* or *Metarhizium anisopliae*. Such a formulation would increase infection rates, as acridids seek out and eat the treated vegetation. Although fungal pathogens act by contact, the infection frequently occurs when spores enter the buccal cavity of grasshoppers along with food (Bidochka et al. 1997). Vegetable oils also may provide some UV protection to the fungal spores (S. Jaronski, *pers. comm.*). If so, this would also reduce the amount of the biological agent needed for control (Chernysh 2004).

Our laboratory bioassays are the first step in the search for an efficient, economical, and available carrier or adjuvant for insecticides used in grasshopper control. To validate our findings and generalize them towards other acridid pest species, other candidate oils need to be evaluated on operational-size plots under field conditions as has already been done with canola oil (Lockwood et al. 2001).

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