Growth Responses of Seedling Canola to Simulated Versus *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae) Feeding Injury to Seedling Canola[1]

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Abstract Greenhouse studies were conducted in 2003 and 2004 to quantify and compare plant growth and yield of canola in response to simulated and crucifer flea beetle, *Phyllotreta cruciferae* (Goeze), feeding injury. Seedlings of 2 canola varieties, 357 RR a hybrid and Raider RR an open pollinated, were subjected to simulated and actual crucifer flea beetle feeding injury. Canola growth responses were determined for growth rate, seed yield and percent oil of seed at 10, 30, 50 and 70% injury levels. In both years, differences in canola growth rate responses were significant between the injury types and ranged from 2.6-14.9% across injury levels. Differences in growth responses for yield (i.e., seed yield and percent oil content) were significant between simulated and insect injury and ranged from 3.1-33.5% in 2003, and 1.3-67.9% in 2004 across injury levels. Both canola varieties generally showed a greater response in growth rate and yield parameters in response to simulated than crucifer flea beetle feeding injury. Simulated feeding injury tested in this study did not adequately mimic actual *P. cruciferae* feeding injury. Therefore, until an appropriate technique is found, mechanical injury cannot be relied on to substitute for *P. cruciferae* feeding injury.

Key Words canola, flea beetle, injury, growth response, yield

The United States produces approx. 1% of the world's canola production. Canola is grown on slightly greater than 450,000 ha in North Dakota and Minnesota which accounts for 98% of the canola production in the U.S. (USDA-NASS 2005a, 2005b, 2006). Crucifer flea beetle, *Phyllotreta cruciferae* (Goeze) (Coleoptera: Chrysomelidae), is an economically significant pest of canola grown in the Northern Great Plains of North America (Burgess 1977, Lamb 1984). *Phyllotreta cruciferae* can be a limiting factor to canola production, and costs to control this pest forms a significant portion of the crop's production costs (Lamb and Turnock 1982, Thomas 2003).

Crucifer flea beetle overwinters as adults under leaf litter, grass and debris in sheltered areas, ditches, and other areas near canola stubble and volunteer cruciferous plants (Burgess 1977, 1981, Wylie 1979). Adults emerge from overwintering sites as air temperatures exceed 14°C and initially feed on wild *Brassica* hosts (Lamb 1984), then migrate to canola fields as the crop emerges. Adults attack newly-

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emerged canola seedlings by chewing and making pits or small holes in cotyledons and leaves (Westdal and Romanov 1972, Burgess 1977, 1981, Wylie 1979, Lamb 1988, Brandt and Lamb 1993). This feeding injury during the seedling stage causes the greatest economic loss to canola (Lamb 1984).

Chemical insecticides are the first line of defense against crucifer flea beetle and are applied either as seed treatments or foliar sprays (Lamb and Turnock 1982). Most growers regularly plant insecticide-treated seed without knowledge of flea beetle population levels for protection against spring feeding injury (Lamb and Turnock 1982, Weiss et al. 1994). Postemergence foliar insecticides can be effective; however, they require timely applications within a relatively small window of opportunity (Weiss et al. 1991). For this reason, treated seed is planted to almost 400,000 ha in North Dakota alone (USDA 2005b, 2006). In areas where flea beetle population levels are extremely high, significant feeding injury can occur, and plants developing from treated seed can be eliminated completely. Also, during cool growing seasons, flea beetle migration into canola fields can extend beyond the seed treatment protection period of 21 d post plant emergence. In these cases, a foliar insecticide, in addition to a seed treatment, may be necessary to reduce further feeding injury and subsequent yield loss (Lamb 1984, Bracken and Bucher 1986). A foliar insecticide application is recommended at 25% seedling defoliation (Thomas 2003).

Although growth-injury relationships between crucifer flea beetle and canola have been studied by many investigators (Putnam 1977, Lamb and Turnock 1982, Lamb 1984, Bracken and Bucher 1986), characterization of this relationship under field conditions is a challenge. The extent and progression of crucifer flea beetle feeding injury is influenced significantly by daily weather conditions. Adult flea beetle flight and feeding activities increase on calm, sunny, warm days, and these activities are reduced on cool, windy days (Osgood 1975, Burgess 1977, Lamb and Turnock 1982, Lamb 1983). Daily fluctuations in flea beetle feeding activity, coupled with varying beetle densities and changing climatic effects on canola growth can result in highly variable field evaluations of canola response to *P. cruciferae* feeding injury (Palaniswamy and Lamb 1992). Relating canola growth response to crucifer flea beetle feeding injury also can be a difficult task in the laboratory or greenhouse because it is not possible to rear large numbers of *P. cruciferae* (Lamb 1988). A comparative evaluation of simulated to actual crucifer flea beetle feeding injury would be of significant importance in determining if simulated damage accurately represents actual *P. cruciferae* feeding damage. This would permit simulated injury to be used in laboratory or greenhouse studies where actual feeding injury is difficult to achieve.

Studies have been conducted on canola compensation to herbivory (Gavloski and Lamb 2000a, 2000b, 2000c) and artificial injury with a mechanical pencil has been used to simulate flea beetle feeding injury (Nowatzki and Weiss 1997). The former studies simulated the pattern of defoliation by *P. cruciferae* using the tube of a mechanical pencil to remove 25 or 50% of the cotyledon tissue. These studies quantified the effect of crucifer generalist and specialist insect herbivores feeding on canola seedlings, as unit reduction in shoot biomass (Gavloski and Lamb 2000a). In the latter study, flea beetle feeding was mimicked to evaluate resistance of oilseed rape, *B. napus*, to feeding injury at 25, 50 and 75% seedling defoliation under drought-stressed conditions. Previous research has not evaluated compensatory plant growth responses to progressive levels of simulated versus flea beetle feeding injury to seedling canola. The objective of this research was to evaluate plant growth responses to progressive levels of simulated and actual flea beetle feeding injury to seedling canola, and determine whether simulated injury accurately reflects injury by *P. cruciferae*.

Materials and Methods

Greenhouse studies were conducted in 2003 and 2004 to examine the effects of simulated and *P. cruciferae* feeding injury on canola growth with emphasis on crop biomass production across progressive levels of injury.

Plants. Canola was seeded into individual plant cones (3.8 cm diam × 21 cm) (Stuewe and Sons, Inc., Corvallis, OR) filled with Sunshine LC1 Mix potting media (Sun Gro Horticulture Distribution Inc., Bellevue, WA) on 23 August 2003 and 9 August 2004. Two seeds were placed into each cone, and seedlings were thinned to 1 plant per cone at 7 d after plant emergence.

Mechanical damage to seedlings. Simulated feeding injury was applied to 32 cotyledon-stage plants for each canola type using a 0.5 mm diameter Pentel® mechanical pencil tip (Pentel of America Ltd, Torrance, CA). Simulated feeding pits were created by pressing the pencil tip into individual cotyledons when laid on top of a wooden garden stake and punching a hole in the leaf. Injury levels are represented as 0% = 0 pits, 10% = 5, 30% = 15, 50% = 24 and 70% = 34 pits per cotyledon (Nowatzki and Weiss 1997).

***Phyllotreta cruciferae* damage to seedlings.** Seedlings of uniform size were placed into a ventilated cage (60 × 60 cm) with 1000 field-collected adult crucifer flea beetles. Flea beetles were field collected from non-insecticide treated canola and held without food for 24 h. Adult beetles were allowed to feed, make holes or scattered pits over the cotyledons, until injury levels of 10, 30, 50 or 70% were obtained on 32 canola seedlings for each canola type. These represent 10, 30, 50, and 70% cotyledon leaf surface area removed by adult *P. cruciferae*. Eight non-injured seedlings for each canola type were established as controls at the time of the mechanical damage and also at the time that the relevant seedlings were subject to *P. cruciferae* feeding damage. Flea beetles were exposed to high intensity light and maintained at 22 ± 1°C during the feeding period. The seedlings were 7 d old when they were subjected to both mechanical and *P. cruciferae* damage.

Arrangement of damaged seedlings in the greenhouse. Two canola types, an open-pollinated canola variety (Raider Roundup Ready) and a canola hybrid (357 Roundup Ready), were exposed to 5 levels of injury in each of 4 replications arranged in a randomized complete block design (RCBD). Trials of each variety and injury type (simulated and actual) were set up at the same time for each year in 2003 and 2004. For each simulated and *P. cruciferae* injury level, 2 injured seedlings were transplanted into individual pots (25 cm diam × 23 cm) filled with Sunshine LC1 Mix potting medium. Seedlings were then placed in the greenhouse and maintained at 16:8 (L:D) and 22 ± 1°C. Seedlings were watered daily and fertilized weekly using an aqueous solution of 0.004 g/l Peters soluble fertilizer (20-20-20, N-P-K) (J. R. Peters Inc., Allentown, PA).

Growth and yield measurements. Beginning on 7 d after the feeding injury levels were obtained and at 7-d intervals for 28 d, plant data were recorded as leaf length (cm) and width (cm) to calculate leaf area. The total leaf area for each plant in a pot was determined and averaged for each of the 4 replications. The length (excluding the petiole) and width of each cotyledon and true leaf was measured at 7, 14, 21, and 28 d after defoliation or mechanical injury. Harvest data were recorded for seed yield (kg/ha) and percent oil of seed yield. Plants were harvested when seeds in the lower pods turned brown: 110 d after seedling for 357 RR and 120 d for Raider RR. The plants were cut with a pruner at the soil surface of the pots, placed in paper bags and dried in an oven at 50°C for 7 d. The bags were removed, placed in cloth bags and hit with a wooden stick in a tray. The trash was sieved through various screen sizes to retrieve the seeds. Seeds were further cleaned with an air blower and weighed for total seed yield. Percent oil was determined using Nuclear Magnetic Resonance (NMR) (Oxford Analytical Instruments Limited, Oxon, England) (Antwi et al. 2007). An amount of the seeds was removed and placed in the Nuclear Magnetic Resonance instrument which read the concentration (%) of oil in the seeds.

Data analysis. Growth rate was determined using the formula $(\ln A_2 - \ln A_1)/(t_2 - t_1)$, where A_2 is total leaf area at time 2 after seedling injury, A_1 is total leaf area at time 1 after seedling injury, and t_2 is time 2 (d), and t_1 is time 1 (d) (Hilbert et al. 1981). Percent compensatory growth rate for each time period 7-14, 14-21 and 21-28 d at each variety, injury type, injury level and replicate was determined as the ratio of growth rate of injured plant to that of uninjured plant multiplied by 100 (Belsky 1986, Gavloski and Lamb 2000b). This formula also was used to calculate percent compensatory growth for seed yield and percent oil of seed as: ([yield at a particular percent injury/mean yield for control] * 100). Analysis of variance (ANOVA) and Fishers's protected least significant difference (LSD) test were used to test for treatment differences in canola compensatory growth between levels of simulated and actual flea beetle feeding injury over time (SAS Institute 2003). Main and interaction effects on canola growth for growth rate and yield were determined using PROC MIXED procedure (SAS Institute 2003). The treatments in each year 2003 and 2004 were analyzed separately. Also the combined analysis is presented in Table 1.

Results

Canola growth in response to *P. cruciferae* feeding injury. Analysis of variances for main and interactive effects, as well as canola growth and yield responses, to simulated and *P. cruciferae* feeding are shown in Tables 1, 2, and 3. In 2003, canola growth rate for 357 RR generally compensated for both injury types at 7-14 d, compensated for insect and was reduced for simulated injury at 14-21 d, and mostly reduced for flea beetle and compensated for simulated injury at 21-28 d after seedling injury (Table 2). At 7-14 d after seedling injury, growth responses were significantly different at 10% simulated and actual *P. cruciferae* feeding injury ($F = 6.86$; df = 1, 6; $P = 0.0396$). At 14-21 d after seedling injury, growth rates of 94.3-96.8% for simulated compared with actual insect injury were significantly different at all levels of injury ($F = 16.17$; df = 1, 6; $P = 0.0069$; $F = 40.78$; df = 1, 6; $P = 0.0007$; $F = 48.23$; df = 1, 6; $P = 0.0004$; $F = 48.98$; df = 1, 6; $P = 0.0004$). At 21-28 d after seedling injury, significant differences between injury types were detected for 30, 50 and 70% injury, respectively ($F = 9.48$; df = 1, 6; $P = 0.0217$; $F = 9.70$; df = 1, 6; $P = 0.0207$; $F = 62.78$; df = 1, 6; $P = 0.0002$).

In 2004, growth rates for 357 RR plants were generally reduced at 7-14 and 14-21 d after actual or simulated *P. cruciferae* injury (Table 2). At 21-28 d after injury, growth rates were reduced for insect and compensated for simulated injury. Only at 7-14 d after 10% seedling injury and at 21-28 d after 30-70% injury were plant growth rates significantly lower for insect than simulated injury ($F = 9.94$; df = 1, 6;

Table 1. Analysis of variance for canola growth and yield in response to different levels of simulated and *P. cruciferae* feeding injury to two varieties of seedling canola (2003 and 2004)

	Growth rate			Seed yield			% Oil of seed		
Source	df	F	P	df	F	P	df	F	P
Year	1	25.22	< 0.0001	1	9.66	0.0020	1	0.10	0.7566
Variety†	1	4.55	0.0336	1	4.23	0.0403	1	132.13	< 0.0001
Day‡	2	14.21	< 0.0001	3	0.00	1.0000	3	0.01	0.9994
Variety*day	2	4.98	0.0074	3	0.14	0.9341	3	0.01	0.9994
Injury	3	1.35	0.2576	3	5.55	0.0010	3	1.51	0.2104
Variety*injury	3	0.94	0.4216	3	7.96	< 0.0001	3	6.18	0.0004
Day*injury	6	1.55	0.1624	9	0.02	1.0000	9	0.01	1.0000
Variety*day*injury	6	2.01	0.0634	9	0.02	1.0000	9	0.01	1.0000
Injury type‡‡	1	21.37	< 0.0001	1	115.79	< 0.0001	1	84.85	< 0.0001
Variety*injury type	1	1.45	0.2301	1	0.37	0.5428	1	19.36	< 0.0001
Day*injury type	2	3.86	0.0220	3	0.00	0.9999	3	0.01	0.9994
Variety*day*injury type	2	14.24	< 0.0001	3	0.15	0.9283	3	0.01	0.9994
Injury*injury type	3	0.54	0.6572	3	2.29	0.0779	3	4.80	0.0027
Variety*injury*injury type	3	0.49	0.6875	3	2.60	0.0515	3	7.01	0.0001
Day*injury*injury type	6	2.90	0.0090	9	0.02	1.0000	9	0.01	1.0000
Variety*day*injury*injury type	6	2.77	0.0120	9	0.02	1.0000	9	0.01	1.0000
Error	335			446			446		

† Hybrid 357 RR and open-pollinated variety, Raider RR.
‡ Growth period after injury for growth rate, days after feeding injury for seed yield and % oil of seed.
‡‡ Simulated and *P. cruciferae* feeding injury.

Table 2. Percent relative compensatory growth rate response to different levels of simulated and *P. cruciferae* feeding injury to two varieties of seedling canola

	2003						2004					
	Plant growth period after injury (d)											
	7-14		14-21		21-28		7-14		14-21		21-28	
Injury (%)	Actual	Simulated	Actual	Simulated	Actual	Simulated	Actual	Simulated	Actual	Simulated	Actual	Simulated
	% Relative compensatory growth rate†											
	357 RR											
10	97.3 b	101.5 a	102.6 a	94.8 b*	100.1 a	104.1 a	99.3 b	102.9 a	98.7 a	99.8 a	98.8 a	100.9 a
30	100.3 a	102.1 a	100.6 a	96.8 b	99.6 b	103.2 a	99.3 a	100.3 a	97.9 a	100.5 a	98.2 b	101.4 a
50	101.0 a	102.9 a	99.1 a	94.3 b*	97.7 b*	103.2 a	97.7 a	98.4 a	97.7 a	99.3 a	98.7 b	103.0 a*
70	104.8 a*	102.1 a	102.1 a	96.1 b	94.0 b*	103.1 a	93.9 a*	97.1 a	98.5 a	96.9 a*	98.3 b	103.9 a*
	Raider RR											
10	101.0 a	101.2 a	86.3 b*	101.2 a	114.8 a*	101.4 b	96.3 b	101.0 a	98.8 b	101.6 a	100.3 a	102.3 a
30	99.1 a	101.9 a	101.4 a	101.6 a	102.5 a	102.9 a	95.2 a*	99.7 a	100.2 a	100.4 a	102.3 a	99.7 b
50	100.8 a	104.2 a	105.0 a	100.7 a	99.2 b	105.0 a*	93.4 b*	102.0 a	99.3 a	103.1 a	101.4 a	102.8 a
70	108.2 a	102.0 a	103.4 a	99.6 a	101.5 a	104.3 a*	83.5 b*	97.8 a	92.0 b*	101.7 a	99.2 a	102.0 a

† Relative compensatory growth rate (% of control) values less than 100% represent damage; 100% represents no damage; and values greater than 100% represent compensation. Means within a row for each injury pair and growth period followed by the same letter are not significantly different at $P < 0.05$ (LSD).

* Means within a column for each injury type within a growth period are significantly different from the control (100%) at $P < 0.05$ (LSD).

Table 3. Yield compensatory growth in response to different levels of simulated and *P. cruciferae* injury to two varieties of seedling canola

	2003				2004			
	Seed yield		% Oil of seed		Seed yield		% Oil of seed	
Injury (%)	Actual	Simulated	Actual	Simulated	Actual	Simulated	Actual	Simulated
	% Compensatory growth†							
	357 RR							
10	95.3 a	128.8 b*	98.3 b*	106.5 a*	74.8 b*	98.3 a	99.7 b	101.0 a
30	70.7 b*	89.8 a	94.1 b*	102.9 a*	83.6 b*	113.7 a*	99.4 b	102.7 a*
50	89.9 a	75.8 b*	99.0 b	102.1 a	94.0 b	117.8 a*	99.0 a	100.3 a
70	108.1 a	117.1 a*	96.5 b*	106.2 a*	88.8 b	139.9 a*	99.3 b	102.0 a*
	Raider RR							
10	82.6 b*	95.7 a	91.4 b*	98.0 a*	92.2 b	115.7 a*	91.3 b*	97.4 a*
30	82.8 b*	96.2 a	97.5 a	96.0 a*	83.1 b*	120.4 a*	96.9 a	97.4 a*
50	83.0 b*	111.5 a*	96.2 a	97.5 a*	89.9 b	114.7 a*	96.9 a	97.8 a*
70	87.6 a	83.0 a*	98.1 a	96.6 a*	68.7 b*	136.6 a*	95.8 a*	98.2 a*

† Compensatory growth (% of control) values less than 100% represent damage; 100% represents no damage; and values greater than 100% represent compensation. Means within a row for each injury pair and yield parameter followed by the same letter are not significantly different at $P < 0.05$ (LSD).

* Means within a column for each injury type and yield parameter are significantly different from the control (100%) at $P < 0.05$ (LSD).

$P = 0.0198$; $F = 11.08$; df = 1, 6; $P = 0.0158$; $F = 15.00$; df = 1, 6; $P = 0.0082$; $F = 22.07$; df = 1, 6; $P = 0.0033$).

Raider RR plants generally compensated with growth in response to actual or simulated beetle injury in 2003 (Table 2). There was no significant difference in growth rate at all levels of simulated versus insect injury at 7-14 d after seedling injury. At 14-21 d after injury, growth rates were significantly different for only 10% seedling injury, with responses being 86.3% for *P. cruciferae* and 101.2% for simulated injury ($F = 76.43$; df = 1, 6; $P = 0.0001$). During the 21-28 d growth period, growth rate responses were significant for 10% injury ($F = 8.96$; df = 1, 6; $P = 0.0242$) and 50% ($F = 25.45$; df = 1, 6; $P = 0.0023$) and growth responses were greater at 10% injury.

Growth rates by Raider RR plants in 2004 were generally less in response to *P. cruciferae* injury than following simulated injury at 7-28 d after 10-70% seedling injury (Table 2). These responses were significant at 7-14 d for 10, 50 and 70% seedling injury ($F = 6.31$; df = 1, 6; $P = 0.0458$; $F = 23.77$; df = 1, 6; $P = 0.0028$; $F = 231.64$; df = 1, 6; $P < 0.0001$), 14-21 d after 10 and 70% injury ($F = 8.35$; df = 1, 6; $P = 0.0277$; $F = 85.89$; df = 1, 6; $P < 0.0001$) and at 21-28 d after 30% seedling injury ($F = 8.01$; df = 1, 6; $P = 0.0300$).

Canola yield in response to *P. cruciferae* feeding injury. Seed yield was reduced following actual and simulated insect injury to 357 RR plants in 2003 (Table 3). Significant differences in injury type occurred when seedlings were injured at the 10, 30 and 50% levels ($F = 5.57$; df = 1, 30; $P = 0.0250$; $F = 5.29$; df = 1, 30; $P = 0.0285$; $F = 5.33$; df = 1, 30; $P = 0.0281$). Percent oil by 357 RR plants was lowered in response to actual *P. cruciferae* feeding (Table 3). Significantly lower responses of 94.1-99.0% for actual compared with compensatory responses for simulated injury occurred at all injury levels ($F = 37.16$; df = 1, 30; $P < 0.0001$; $F = 44.18$; df = 1, 30; $P < 0.0001$; $F = 9.97$; df =1, 30; $P = 0.0039$; $F = 489.57$; df = 1, 30; $P < 0.0001$).

In 2004, seed yield production of 357 RR plants was significantly lowered (Table 3). Responses were 74.8-94.0% for *P. cruciferae* injury compared with 98.3-139.9% responses for simulated injury at 10-70% seedling injury ($F = 20.35$; df = 1, 30; $P < 0.0001$; $F = 20.48$; df = 1, 30; $P < 0.0001$; $F = 11.67$; df = 1, 30; $P = 0.0018$; $F = 24.15$; df = 1, 30; $P < 0.0001$). Percent oil production was significantly lowered in *P. cruciferae*-damaged plants with responses of 99.3-99.7%, and compensated in responses to simulated injury at 10, 30 and 70% seedling injury ($F = 5.52$; df = 1, 30; $P = 0.0255$; $F = 12.46$; df = 1, 30; $P = 0.0014$; $F = 8.84$; df = 1, 30; $P = 0.0058$) (Table 3).

Seed yield responses by Raider RR, in 2003, were significantly lowered for insect than for simulated injury at 10-50% injury ($F = 4.92$; df = 1, 30; $P = 0.0343$; $F = 6.06$; df = 1, 29; $P = 0.0200$; $F = 6.06$; df = 1, 30; $P < 0.0001$) (Table 3). Responses of Raider RR for percent oil were lowered following actual and simulated *P. cruciferae* injury (Table 3). Significant differences between injury types occurred for only 10% seedling injury ($F = 5.67$; df = 1, 30; $P = 0.0239$).

In 2004, similar to 357 RR, Raider RR plants seed yield were reduced for all levels of *P. cruciferae* feeding, but increased for all levels of simulated beetle injury (Table 3). Differences in responses between injury types were significant at all levels of injury ($F = 23.49$; df = 1, 30; $P < 0.0001$; $F = 171.92$; df = 1, 30; $P < 0.0001$; $F = 31.34$; df = 1, 30; $P < 0.0001$; $F = 151.37$; df = 1, 30; $P < 0.0001$). Although percent oil responses of plants in relation to injury were lowered, the only detectable difference was at 10% injury (Table 3). Plants that sustained actual *P. cruciferae* injury were significantly low in percent oil content than those that received simulated feeding injury ($F = 7.95$; df = 1, 30; $P = 0.0084$).

Discussion

In this study, plant growth responses to *P. cruciferae* damage and simulated injury were compared across progressive injury levels for an open-pollinated and a hybrid canola cultivar. The hybrid (357 RR) generally showed a greater increase in growth rate in response to simulated than actual crucifer flea beetle feeding injury. In 2003, 357 RR had an initial higher growth rate response to all levels of simulated beetle injury than injury by *P. cruciferae*. Hybrid 357 RR also showed a greater recovery in plant growth rate to simulated compared with insect injury. In 2004, growth rates for 357 RR were reduced and similar in response to either simulated or insect injury across all injury levels through 21 d after injury. At 21-28 d after occurrence of injury, 357 RR was only able to show a recovery response to simulated injury. Growth rates for Raider RR in 2003 were generally compensatory for *P. cruciferae* and simulated injury with similar growth responses between both injury types. In 2004, Raider RR growth rate was not affected by up to 70% simulated injury. In response to *P. cruciferae* injury, growth rate for Raider RR was initially reduced followed by a recovery response of compensation. Regardless of injury levels, the effect of injury on canola growth rate appeared to be less when canola seedlings were artificially injured compared with actual insect injury. These findings correspond well with the suggestion by Gavloski and Lamb (2000b) that artificial injury has a lesser effect on canola growth than that from *P. cruciferae*. Brandt and Lamb (1994) also observed that *B. napus* was least tolerant to *P. cruciferae* feeding injury among *Brassica* species they tested.

Seed yield was generally reduced by actual insect injury for both varieties and years. The reduced seed yield shows that canola did not fully recover from actual feeding injury (Gavloski and Lamb 2000b). In 2003, significant differences in seed yield responses for both varieties were observed at 10-50% seedling injury when both injury types were compared. Percent grain oil content in 357 RR was reduced following *P. cruciferae* feeding and similar or greater for simulated injury than actual-damaged plants in both years. Percent oil for both injury types in Raider RR plants was reduced with reductions generally being greater for actual *P. cruciferae* feeding than simulated injury in both years.

Results from these studies showed that canola growth generally differs among injury types and that actual *P. cruciferae* feeding injury led to measurable damage, whereas simulated injury resulted in plant compensation at most injury levels. This study indicates that simulated beetle injury levels via the method tested do not adequately mimic *P. cruciferae* feeding, corroborating observations by Nowatzki and Weiss (1997). Moreover, according to Capinera and Roltsch (1980), Talekar and Lee (1988) and Gavloski and Lamb (2000c), simulated insect injury may not have the same effects on plant growth as actual insect feeding. They suggest that artificial methods may increase net photosynthesis (Capinera and Roltsch 1980, Talekar and Lee 1988) resulting in compensatory growth. Gavloski and Lamb (2000c) observed that crucifer plants have low compensatory abilities due to highly dispersed feeding on the cotyledons and defoliation of the apical meristem by *P. cruciferae*. It seems that a factor which may be salivary in origin associated with flea beetle feeding disrupts the wound response of canola seedlings under severe defoliation. This affects the plant depending on the level of defoliation (Capinera and Roltsch 1980). Plant growth and seed yield in response to seedling injury in this study show that actual *P. cruciferae* feeding injury was more detrimental to canola than simulated injury. Therefore, until an appropriate technique is found, mechanical injury cannot be relied on to substitute for *P. cruciferae* feeding injury.

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