Resistance to cabbage seedpod weevil among selected Brassicaceae germplasm

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Abstract—Brassicaceae germplasm (*Brassica napus* L., *Brassica rapa* L., *Brassica juncea* (L.) Czern., *Brassica carinata* A. Braun, *Sinapis alba* L., *Camelina sativa* (L.) Crantz, *Crambe* species) with cultivar development potential for the prairies was evaluated for resistance to cabbage seedpod weevil (*Ceutorhynchus obstrictus* (Marsham) (Coleoptera: Curculionidae)) infestation under field conditions in southern Alberta from 2001 to 2005. Relative susceptibilities were as follows: *B. rapa* and *B. napus* > *B. juncea* = *B. carinata* > *S. alba*. Although some of the germplasm evaluated varied within species in terms of glucosinolate profile, erucic acid level, oil content, and plant height, none of these factors appeared to influence the degree of *C. obstrictus* damage. A subset of this germplasm was also evaluated in the greenhouse. Although the canola species *B. rapa* sustained the highest level of damage in the field tests, it was similar to other *Brassica* genotypes in the greenhouse. All lines of *S. alba* were virtually immune to weevil attack in both field and greenhouse tests, regardless of glucosinolate profile, suggesting that other factors confer resistance in this species. Synchrony of crop development with weevil activity in the field explains some of the variability in damage observed among genotypes and illustrates the importance of combining field and greenhouse studies when assessing resistance.

Résumé—Nous avons évalué dans des champs cultivés du sud de l'Alberta de 2001 à 2005 la résistance du germoplasme des Brassiceae (*Brassica napus* L., *Brassica rapa* L., *Brassica juncea* (L.) Czern., *Brassica carinata* A. Braun, *Sinapis alba* L., *Camelina sativa* (L.) Crantz et *Crambe* spp.) qui présentent un intérêt pour la formation de cultivars pour les Prairies résistants à l'infestation par le charançon de la silique du chou (*Ceutorhynchus obstrictus* (Marsham)(Coleoptera: Curculionidae)). Les vulnérabilités relatives sont dans l'ordre suivant: *B. rapa* et *B. napus* > *B. juncea* = *B. carinata* > *S. alba*. Bien qu'une partie du germoplasme varie au sein d'une même espèce en ce qui a trait au profil glucosinolate, à la concentration d'acide érucique, au contenu en huile et à la taille des plants, aucun de ces facteurs ne semble affecter les dommages causés par le charançon de la silique du chou. Nous avons aussi évalué un sous-ensemble de ce germoplasme en serre. Bien que l'espèce de canola, *B. rapa,* subisse le plus fort dommage dans les essais dans les champs, il est semblable aux autres génotypes en serre. Toutes les lignées de *S. alba* sont pratiquement à l'abri des attaques du charançon, quel

Received 12 October 2006. Accepted 1 May 2007.

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https://doi.org/10.4039/n06-083 Published online by Cambridge University Press

que soit leur profil glucosinolate, ce qui indique que ce sont d'autres facteurs qui expliquent la résistance chez cette espèce. Le synchronisme du développement de la culture et de l'activité du charançon dans les champs explique une partie de la variabilité des dommages observés chez les divers génotypes. Ces résultats montrent l'importance de combiner des études dans les champs et les serres lorsqu'on évalue la résistance.

[Traduit par la Rédaction]

Introduction

The cabbage seedpod weevil, *Ceutorhynchus obstrictus* (Marsham) (= *Ceutorhynchus assimilis* (Paykull)) (Coleoptera: Curculionidae), is a common pest of brassicaceous crops in its native Europe and throughout North America (Cárcamo *et al.* 2001). In the Canadian prairies, the weevil is established in southern Alberta and southwestern Saskatchewan (Dosdall *et al.* 2002), where insecticide spraying may be required to reduce economic losses in canola (*Brassica rapa* L. and *Brassica napus* L.) (Cárcamo *et al.* 2005). In southern Alberta, adults overwinter primarily in the leaf litter of caragana (*Caragana arborescens* Lam. (Fabaceae)) and other tree shelters (Ulmer and Dosdall 2006*a*), and disperse in spring to feed on early-flowering brassicaceous weeds. Adults later migrate to canola crops at the late-bud and flower stages, where they reproduce (Dosdall and Moisey 2004). Larvae consume three to six seeds inside a pod and the damage leads to significant yield loss when the proportion of pods infested surpasses 20% (Buntin 1999). Upon maturity, larvae chew a circular exit hole in the pod, drop to the soil, and pupate. In southern Alberta, new-generation adults start emerging as early as mid-July and feed on late-maturing canola pods into early September before flying to tree shelters as late as the end of October to overwinter.

Alternative management strategies have been investigated to reduce dependency on insecticides to manage *C. obstrictus*. Parasitoids are effective at reducing weevil populations in Europe (Murchie *et al.* 1997). In North America several species of natural enemies, many native, attack the weevil but have a negligible impact (Dosdall *et al.* 2006). Cultural control practices such as trap crops of early-flowering borders may allow insecticide use to be reduced (Cárcamo *et al.* 2007), but the non-feasibility of multiple seeding operations has hindered adoption of these strategies. Development of resistant cultivars would provide a practical and environmentally sustainable solution to managing *C. obstrictus*.

Previous studies aimed at investigating germplasm of oilseed brassicaceous crops for resistance to C. obstrictus have identified considerable variation in susceptibility among genotypes. In general, varieties of canola and brown mustard (*Brassica* species) are highly to moderately susceptible to attack (Brown *et al.* 1999; McCaffrey *et al.* 1999; Kalischuk and Dosdall 2004); however, white mustard (*Sinapis alba* L.), black mustard, *Brassica nigra* (L.) W.D.J. Koch, and *Crambe abyssinica* Hochst. ex R.E. Fries. are sources of weevil resistance that could be exploited in breeding programs (Brown *et al.* 1999; McCaffrey *et al.* 1999; Kalischuk and Dosdall 2004). Glucosinolates found in brassicaceous crops are important secondary plant compounds that provide cues to insect specialists and repel generalists (Renwick 2002). For example, it has been suggested that in *S. alba*, sinalbin (*p*-hydroxybenzyl) confers resistance to C. obstrictus (McCaffrey *et al.* 1999). Intergeneric hybrids, developed by crossing *S. alba* with *B. napus* and then backcrossing progeny to the *B. napus* parent, are potential sources of resistance to the weevil (Brown *et al.* 1997; McCaffrey *et al.* 1999; Kalischuk and Dosdall 2004), but to date, a resistant commercial cultivar remains to be registered. The objective of this study was to investigate additional germplasm of Brassicaceae for resistance to *C. obstrictus*. Although several researchers have identified resistance to *C. obstrictus* attack in *S. alba* (Doucette 1947; Dmoch 1965; Harmon and McCaffrey 1997; Brown *et al.* 1999; McCaffrey *et al.* 1999; Kalischuk and Dosdall 2004), no previous studies have investigated a broad range of *S. alba* germplasm for its susceptibility to this pest, including newly developed genotypes with altered seed glucosinolate profiles that make these lines near to canola quality. Moreover, potential resistance sources in some Brassicaceae species, like *Camelina sativa* (L.) Crantz and *Crambe*

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hispanica L., have not been tested and could serve as additional resistance sources in breeding programs.

Materials and methods

The study was conducted from 2001 to 2005 on the research farm of Agriculture and Agri-Food Canada 6 km east of Lethbridge, Alberta (49°42.525′N, 112°45.505′W), and in 2001 and 2002 on irrigation sites near Lethbridge (2001: 49°37′N, 112°39′W; 2002: 49°46′N, 112°58′W) maintained by the Canola Council of Canada. The sites were located in the Moist Mixed Grassland Ecoregion on dark brown chernozemic soils with semiarid conditions (annual precipitation 350–450 mm) and mean annual temperature around 5 °C.

Thirty-six genotypes of Brassicaceae germplasm were tested during the 5 year study, with most lines evaluated for at least 2 years in the field (Table 1). The species tested (with the number of entries in parentheses) were as follows: *S. alba* (11), *Brassica carinata* A. Braun (8), *Brassica juncea* (L.) Czern. (6), *B. rapa* (5), *B. napus* (2), *Crambe hispanica* L. *hispanica* (1), *Crambe hispanica glabrata* (DC.) (1), *C. abyssinica* (1), and *C. sativa* L. (1).

Between 10 and 20 genotypes were planted each year (Table 1) following a randomized complete block design with four replicates. From 2001 to 2003 the focus of the test was on current and historical genotypes (mostly registered cultivars; Tables 2 and 3), whereas in 2004 and 2005 the focus was on experimental germplasm (Table 4). Each plot consisted of four 3 m long rows (20–23 cm apart) of one genotype separated by a 1 m space planted to a cereal cover crop. All genotypes were planted on the same day between late April and early May each year at the rate of 100 seeds per row. Ethalfluralin (1100 g active ingredient/ha) was soil-incorporated prior to seeding to control graminaceous weeds. Although seeds were coated with a standard commercial mixture of fungicide and insecticide to prevent flea beetle damage, in some years foliar insecticides were applied to control flea beetles and grasshoppers during the seedling stage. The plots were irrigated as needed every year.

A greenhouse no-choice test was also conducted from October 2001 to January 2002 to complement field testing of the 10 genotypes (Table 1) planted in the summer of 2001. For this test, seedlings were transplanted to 8 L pots containing a Cornell mix soil-less medium and later thinned to one plant per pot and caged at the early-flower stage. Cages were constructed using 14 gauge wire frame to support a fine mesh (70/2.5 cm Bioquip Product 7250C, Bioquip Products, 2321 Gladwick Street, Rancho Dominguez, California, 90220, United States of America) around each of the pots. Weevils were obtained from a laboratory culture established from adults collected near Lethbridge in December 2000 and used in other overwintering laboratory studies. Two male and two female weevils were added during the early-flower stage to five replicate plants per genotype arranged in a completely randomized block design. However, damage to plants from aphids and powdery mildew reduced the replicatesn to two to four for some genotypes.

For the greenhouse test, all pods on each plant were counted and examined for exit holes. For the field test in 2001 and 2002 at the Canola Council of Canada site, 20 plants were selected randomly from each plot at the end of the growing season, the pods on each plant were counted, and the pods were examined for weevil exit holes. For the remaining tests, 10 plants were selected randomly and total pods and weevil exit holes on the main, middle, and bottom branches were counted, as recommended by Cárcamo *et al.* (2004). In 2001, plants at the Agriculture and Agri-Food Canada site were severely damaged by flea beetles, grasshoppers, and drought, and in most cases only the primary raceme developed pods that could be counted. In the late summer of 2005, above-average rainfall prolonged pod ripening and larval development, therefore the first replicate block was assessed by dissecting all the pods to include immature larvae. For the remaining replicates the varieties with senesced plants were assessed first. From 2003 to 2005, plant growth stage was recorded near the peak of weevil activity and in the last 2 years, weevils were monitored at the site by using sticky cards and sweeping the perimeter border of canola. Weevil damage on each plant was assessed from weevil emergence, *i.e.*, the number of exit holesper 100 pods, and analyzed using one-way ANOVA with Tukey's HSD range test to separate means ($P < 0.05$). In cases where variances were heterogeneous, data were rank-transformed prior to one-way ANOVA (Conover and Iman 1981). Statistical analyses were performed using Statistix™ for Windows (Analytical Software 2000).

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https://doi.org/10.4039/n06-083 Published online by Cambridge University Press

https://doi.org/10.4039/n06-083 Published online by Cambridge University Press

Table 1. Brassicaceae genotypes evaluated for resistance to the cabbage seedpod weevil, *Ceutorhynchus obstrictus*, in southern Alberta from 2001 to 2005.

Species* and genotype	Genotype features	Level of flowering at peak *C. obstrictus* abundance†	Site years
Brassica carinata (8)			
S67	High levels of allyl glucosinolate	Very low	2002, 2003
S71	High levels of allyl glucosinolate	Very low	2002, 2003
98-7605	Breeding for early maturity; brown-seeded	High	2004, 2005
98-7606	Early maturing decreasing height	High	2004, 2005
99-7702	Early maturing; decreasing height	High	2004, 2005
99-7705	Breeding for early maturity; yellow-seeded	High	2004, 2005
04-203	Early maturing; decreased height	High	2004, 2005
04-204	Early maturing; decreased height	High	2004, 2005
Brassica juncea (6)			
'AC Vulcan'	High allyl glucosinolate levels	Moderate	2001, 2001‡, 2002, 2002‡, 2003
'Arid'	Canola-quality mustard; trace of allyl glucosinolate, <30 µm hydroxybutenyl glucosinolate, no erucic acid, no HOBE	Moderate	2003, 2004, 2005
'Commercial Brown'	Similar glucosinolate profile to 'AC Vulcan'	High	2001, 2001‡, 2002, 2002‡, 2003
J90-4253	Low glucosinolate, 0% erucic acid	Moderate	2001, 2001‡, 2002, 2002‡, 2003
VR03.9 5902-HT1	High glucosinolate, high erucic acid content, high oil content	High	2004, 2005
VR03.9 5933-HT1	High glucosinolate content, high erucic acid content, high oil content	High	2004, 2005
Brassica napus (2)			
'AC Excel'	Industry-standard canola variety; no HOBE	Low	2001, 2001‡, 2002, 2002‡, 2003
'Q2'	Alberta industry standard canola variety	High	2005
Brassica rapa (5)			
'AC Echo'	Rapeseed; high glucosinolate and erucic acid levels	Low	2004, 2005
'AC Parkland'	Canola quality; reduced glucosinolate and erucic acid levels	High	2005
'AC Sunbeam'	Canola quality; bred for resistance to cabbage root maggot	Moderate	2001, 2001‡, 2002, 2002‡, 2003, 2004, 2005
'ACS-C7'	Canola quality; bred for moderate resistance to blackleg	Moderate	2002, 2003, 2004, 2005
02-8165	Reduced glucosinolate and erucic acid levels; selected for early maturity	Moderate	2004, 2005
Camelina sativa (1)			
SRS 933 (JS00-1003)	New oilseed crop	Moderate	2002, 2003

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Table 1 (*concluded*).

Species* and genotype	Genotype features	Level of flowering at peak *C. obstrictus* abundance†	Site years
Crambe abyssinica (1)			
SRS 2705 (JS01-821)	High hydroxybutenyl glucosinolate levels	Very low	2002, 2003
Crambe hispanica glabrata (1)			
SRS 2848 (JS01-925)	Moderate hydroxybutenyl levels, some allyl glucosinolate	Very low	2002, 2003
Crambe hispanica hispanica (1)			
SRS 2726 (JS01-933)	High hydroxybutenyl glucosinolate levels	Low	2002, 2003
Sinapis alba (11)			
'AC Base'	Industry-standard condiment (hot) mustard; high hydroxybenzyl glucosinolate (HOBE) levels	Moderate	2001, 2001‡, 2002, 2002‡, 2003, 2004, 2005
'AC Pennant'	High HOBE levels	Moderate	2005
'Andante'	High HOBE levels, high mucilage levels	High	2005
FMK 2002HS1	Reduced HOBE levels; start of canola-quality lines	High	2004
FMK 2002HS2	Reduced HOBE levels; start of canola-quality lines	Moderate	2004
JS03-540	Low HOBE levels, high erucic acid levels	Moderate	2005
JS03-541	Low HOBE levels, low erucic acid levels	Moderate	2005
LGS SA 93-0860	Low HOBE levels, high erucic acid levels	High	2001, 2001‡, 2002, 2002‡, 2003
'Ochre'	High HOBE levels	High	2001, 2001‡, 2002, 2002‡, 2003
SRS 2764	High HOBE levels, dwarf line	High	2001, 2001‡, 2002, 2002‡, 2003
'Svalof' line	High HOBE levels, high erucic acid content, high-oil line	Moderate	2001, 2001‡, 2002, 2002‡, 2003

*The number in parentheses is the number of genotypes tested.
†Proportion of plants flowering: high, 75%–99%; moderate, 50%–74%; low, 25%–49%; very low, <25%.
‡Study site at a Canola Council of Canada demonstration farm.

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Table 2. Numbers of *Ceutorhynchus obstrictus* exit holes per 100 pods for different genotypes of *Brassica carinata*, *B. juncea*, *B. napus*, *B. rapa*, and *Sinapis alba* planted in the first site, a field near Lethbridge, Alberta (2001, 2002, and 2003) and a second site 10 km east of Lethbridge (2001 and 2002).

	2001		2002		2003
Species and genotype	First site	Second site	First site	Second site	First site
Brassica carinata					
S67			4.8±1.6*cde*		0.9±0.3*bcdef*
S71			5.3±0.6*bcd*		1.4±0.3*abcde*
Brassica juncea					
'AC Vulcan'	6.6±3.3*abc*	41.0±8.5*ab*	6.3±0.7*abcd*	6.7±1.0*ab*	1.9±0.7*abcd*
'Arid'					1.5±0.3*abcd*
'Commercial Brown'	12.6±4.0*a*	26.4±1.5*bc*	9.4±2.0*abc*	8.1±1.3*ab*	1.4±0.4*abcde*
J 90-4253	6.1±1.6*ab*	26.9±7.6*abc*	2.1±0.8*defg*	3.4±0.6*bc*	1.3±0.2*abcde*
Brassica napus					
'AC Excel'	1.0±0.5*abc*	44.9±2.0*ab*	3.6±0.9*cdef*	10.4±2.2*a*	2.7±0.8*abc*
Brassica rapa					
'AC Sunbeam'		70.7±4.7*a*	17.7±1.9*ab*	27.0±3.8*a*	6.2±0.8*a*
ACS-C7			18.9±3.2*a*		4.3±0.9*ab*
Camelina sativa			0.03±0.02*ij*		0*g*
Crambe abyssinica			0.009±0.009*ij*		1.9±1.7*cdef*
Crambe hispanica glabrata			0*j*		0*g*
Crambe hispanica hispanica			0.01±0.01*ij*		0.1±0.1*fg*
Sinapis alba					
'AC Base'	0*c*	1.0±0.4*d*	0.02±0.02*ij*	0.1±0.1*d*	0.1±0.06*defg*
LGS SA 93–0860	1.5±0.9*abc*	3.1±1.3*cd*	0.5±0.2*efgh*	0.6±0.3*cd*	0.2±0.08*defg*
'Ochre'	0*c*	0.9±0.1 *d*	0.1±0.04*ghi*	0.1±0.02*d*	0.1±0.1*efg*
SRS 2764	1.1±0.4 *abc*	1.5±0.2*cd*	0.2±0.05*fgh*	0.04±0.03*d*	0.04±0.01*fg*
'Svalof'	1.0±0.6*bc*	0.8±0.2*d*	0.08±0.04*hij*	0.1±0.08*d*	0.2±0.07*efg*

Note: Values are given as the mean ± standard error. For each year, means in a column followed by the same letter do not differ ($P > 0.05$) using Tukey's HSD test.

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Table 3. Number of pods per plant, total exit holes per plant, percentage of pods infested, and emergence of larvae (number of exit holes per 100 pods), from a greenhouse study to assess resistance of *Brassica* and *Sinapis* genotypes to *Ceutorhynchus obstrictus*.

			Exit holes				
Species and genotype	*N*	No. of pods/plant*	No.*	Range	% of pods infested*	No. of holes/100 pods*	Plant biomass (g)*
Brassica juncea							
'AC Vulcan'	5	473±100	104±89	0–458	18±15	27±23	40±2
'Commercial Brown'	4	390±146	102±88	0–365	31±20	38±24	42±6
J90-4253	4	487±101	189±133	0–566	33±19	41±24	39±4
B. napus							
'AC Excel'	3	373±71	43±40	1–123	10±9	13±12	52±3
B. rapa							
'AC Sunbeam'	2	130±54	14±10	4–25	9±4	9±4	26±5
Sinapis alba							
'AC Base'	3	61±31	0±0	0.0	0±0	0±0	65±2
LGS SA 93-0860	5	193±38	3±2	0–12	2±2	2±2	70±6
'Ochre'	4	50±19	0±0	0.0	0±0	0±0	72±5
SRS 2764	5	319±214	7±6	0–31	1±1	1±1	60±9
'Svalof'	4	16±8	0±0	0.0	0±0	0±0	85±7

Note: Two male and two female weevils were introduced to caged plants at the early flower stage.
*Values are given as the mean ± standard error.

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Table 4. Numbers of Ceutorhynchus obstrictus exit holes per 100 pods for different genotypes of *Brassica carinata*, *B. juncea*, *B. napus*, *B. rapa*, and *Sinapis alba* in 2004 and 2005.

Species and genotype	2004	2005
Brassica carinata		
98-7605	33.1±4.0*de*	19.2±4.08*bcd*
98-7606	34.1±2.6*de*	22.2±5.7*bcd*
99-7702	30.9±3.3*def*	15.3±4.0*bcde*
99-7705	33.9±3.6*cd*	23.9±4.2*abcd*
04-203	32.8±4.2*de*	21.4±4.4*bcd*
04-204	36.9±1.9*bcd*	19.9±2.9*bcd*
Brassica juncea		
'Arid'	17.9±2.0*fg*	11.9±0.2*def*
VR03.9 5902-HT1	20.8±0.3*efg*	11.1±1.2*def*
VR03.9 5933-HT1	31.9±2.9*def*	12.8±3.2*cdef*
Brassica napus		
Q2		20.9±6.5*bcd*
Brassica rapa		
'AC Echo'	58.3±6.0*abc*	32.4±5.5*abc*
'AC Parkland'		38.6±4.4*ab*
'AC Sunbeam'	89.1±4.1*a*	56.5±6.9*a*
ACS-C7	69.7±2.7*ab*	37.5±7.4*ab*
02–8165	60.5±6.5*ab*	33.9±4.2*ab*
Sinapis alba		
'AC Base'	0.2±0.09*g*	0.2±0.06*ef*
'AC Pennant'		0.03±0.03*f*
'Andante'		0.09±0.06*ef*
FMK 2002HS1	0.6±0.3*g*	
FMK 2002HS2	0.4±0.2*g*	
JS03-540	0.2±0.1*g*	0.07±0.07*f*
JS03-541	0.3±0.08*g*	0.05±0.03*f*

Note: Values are given as the mean ± standard error. For each year, means in a column followed by the same letter do not differ ($P > 0.05$) using Tukey's Studentized range test.

Results

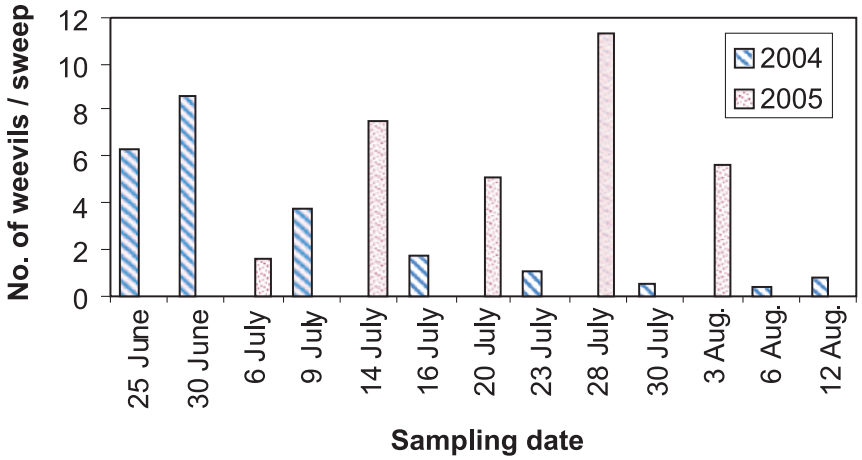
Weevil abundance and resultant crop damage varied from 2001 to 2005. Drought and hot weather in 2001 caused rapid pod ripening and likely prevented many larvae from reaching maturity (Dosdall and Moisey 2004). Hence, in 2002 most of the susceptible lines had fewer than 20 exit holes per 100 pods (Table 2), which is considered to be below the economic threshold in Georgia, United States of America (Buntin 1999). By 2004, however, damage levels had reached 90 exit holes per 100 pods. Adult weevil activity peaks in late June to early July in the region (Dosdall and Moisey 2004). For example, in 2004, when damage levels were highest, there was a peak of nine weevils per 45° sweep on 30 June in the canola bordering the trial site (Fig. 1). In 2005, extremely high precipitation in June (272 mm) probably influenced weevil phenology and plant development, so that a first peak of activity of overwintered weevils (eight per 45° sweep) occurred on 14 July and a second peak on 28 July, representing overwintered and pre-overwintering weevils (non-reproductive new generation; Fig. 1).

Sinapis alba germplasm was highly resistant to weevil damage but there was some variability in the degree of weevil feeding on the different genotypes. The number of exit holes per 100 pods in field tests (Tables 2 and 4) and in the greenhouse evaluation (Table 3) was lower than one for most lines except LGS SA93-0860 and SRS 2764, which had two and one weevils emerging in the greenhouse, respectively. In the field, both lines had plants with one to three weevils emerging per 100 pods (Table 2).

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Fig. 1. Abundance of cabbage seedpod weevils (*Ceutorhynchus obstrictus*) per 45° sweep at the canola border of the study site near Lethbridge used to evaluate resistance of Brassicaceae genotypes to this insect.



During years of high weevil abundance, field damage in *B. juncea* genotypes averaged 12–41 holes per 100 pods; these levels were intermediate between the little-damaged *S. alba* and the most-damaged *B. rapa* (Tables 2–4). Because of heterogeneity in the variances of several genotypes, ANOVAs on ranked data did not always distinguish these different genotypes. Within *B. juncea*, the experimental line J90-4253 had less damage than one of the commercial cultivars ('AC Vulcan', 'Commercial Brown') at one field site in 2002. In the greenhouse, however, J90-4253 had the highest average damage of the 10 genotypes, at 41 exit holes per 100 pods, and a record number of 566 larvae produced from a single plant, showing a large reproductive potential of over 200 progeny per female weevil (Table 3).

In 2004 and 2005, plants of *B. carinata* genotypes grown under high weevil pressure were consistently damaged at intermediate levels (20–35 exit holes per 100 pods), with some lines showing higher levels of damage than the *B. juncea* 'Arid' and VR03.9 5902-HT1 lines in 2004 (Table 4). In 2002 and 2003, under low weevil pressure, plants of the two *B. carinata* genotypes tested, S71 and S67, did not differ from those of *B. juncea* (Table 2).

In field tests, the weevil damage sustained by the two species of canola varied considerably (Tables 2–4). *Brassica napus* ('AC Excel' and 'Q2') plants had similar emergence (20–40 exit holes per 100 pods) to the *B. carinata* or *B. juncea* lines, which, in some site-years, had significantly less damage than *B. rapa* (*e.g.*, 2002 and 2003 in Table 2; Tukey's HSD test after ANOVAs on ranked data, $P < 0.05$). In all field tests, *B. rapa* consistently exhibited the highest level of damage of all genotypes; in 2004, for example, emergence was close to 90 for the 'AC Sunbeam' line (Table 4). In the greenhouse study, this trend was reversed, as the two canola species had similar damage and fewer exit holes per plant than the *B. juncea* genotypes (Table 3).

The results of the *Camelina* species and *Crambe* species assessments were inconclusive. Although, in general, few or no exit holes were found in these cultivars (Table 4), in most cases the plants grew poorly and pod production occurred too late for weevil infestation. In 2003, one *C. abyssinica* plant had 19 exit holes.

Discussion

Our study confirmed previous reports of resistance to *C. obstrictus* in *S. alba*. Most tested genotypes of this species had fewer than one weevil exit hole per 100 pods, and, in the greenhouse, the cultivars 'AC Base', 'Ochre', and 'Svalof' had no exit holes when weevils were confined on caged plants. These results are similar to those reported by Brown *et al.* (1999), McCaffrey *et al.* (1999), Kalischuk and Dosdall (2004), and Ulmer and Dosdall (2006*b*). The three cultivars tested have high levels of hydroxybenzyl glucosinolate (HOBE), typical of "hot" yellow mustards. HOBE may be implicated in resistance of *S. alba* to crucifer-feeding flea beetles, *Phyllotreta* Chevrolat spp. (Coleoptera: Chrysomelidae) (J.S., unpublished data); it is thus reasonable to

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infer that it may also be involved in resistance of *S. alba* to C. obstrictus (McCaffrey *et al.* 1999). However, both of the *S. alba* lines JS03-541 and JS03-540 contained no HOBE. The fact that virtually no weevils were produced on those two lines, or on the FMK 2002HS parental lines with HOBE levels intermediate between them and the condiment yellow mustard cultivars ('AC Base', 'AC Pennant', and 'Andante'), suggests that traits other than glucosinolate content conferred resistance in this germplasm. Furthermore, the presence or absence of mucilage ('Andante') or erucic acid (JS03-541) or high oil content ('Svalof') in the seed, and even plant height (SRS 2764) appeared to play no role in the resistance to *C. obstrictus* observed in *S. alba*. Similarly, Ulmer and Dosdall (2006*b*) assessed the role of the glucosinolate profile on the oviposition and development of *C. obstrictus* in determining susceptibility in selected brassicaceous crops, including *S. alba*. They concluded that factors other than glucosinolate content (at detectable levels) confer the known antixenosis to *C. obstrictus* observed in *S. alba*.

In contrast to *S. alba*, all of the eight *B. carinata* genotypes tested suffered substantial weevil damage, though less than that observed in *B. rapa*. These results conflict with the field reports by Dosdall *et al.* (2004) but agree with a later study showing high susceptibility of *B. carinata* (Ulmer and Dosdall 2006*b*). Under field-plot conditions, the later crop maturation of *B. carinata* relative to surrounding susceptible hosts may allow it to escape some weevil damage (Ulmer and Dosdall 2006*b*), a conclusion with which we concur. This emphasizes the need to combine greenhouse and field studies to assess the relative resistance of germplasm to insect attack.

Results from small-plot experiments comparing levels of insect damage to various genotypes planted in close proximity need to be interpreted with caution. In this study, *B. rapa* was consistently damaged at higher levels than *B. napus*. Yet in southern Alberta, *B. napus* planted early in large monocultures requires insecticide spraying to prevent yield losses (Cárcamo *et al.* 2005). Growth stage partially influenced the level of weevil damage incurred by the various genotypes in the field. *Brassica rapa*, which flowers 1 week earlier, is more attractive than *B. napus* because female weevils require a pollen and nectar meal before producing eggs (Dmoch 1965). In addition, Kalischuk and Dosdall (2004), using experimental arenas, demonstrated that weevils have a preference for *B. rapa* pods over those of other Brassicaceae. The differential flowering time among canola species can be exploited to manage *C. obstrictus* populations using *B. rapa* as trap crops bordering fields of *B. napus* (Cárcamo *et al.* 2007). A similar pattern of higher incidence of lygus bugs in the earlier flowering *B. rapa* was noted by Butts and Lamb (1991).

Brassica juncea cultivars flowered at nearly the same time as *B. rapa* but consistently suffered about 50% less weevil damage under field conditions. The canola-quality *B. juncea* 'Arid', with reduced levels of hydroxybutenyl glucosinolate and virtually no allyl or HOBE, had among the lowest levels of damage among all the *Brassica* mustards tested in the field, including *B. carinata*. However, in the greenhouse study a parental line with the same glucosinolate profile but slightly reduced vigour, J90-4253, had levels of damage that were similar to or higher than those in the two other *B. juncea* cultivars. Furthermore, low levels of HOBE in the tissues of LGS 93-0860 did not increase weevil damage compared with SRS 2764, and damage in both lines was low.

The contradiction between field and greenhouse data suggests that under shaded cage conditions in the greenhouse, 'Arid' could lose some of its partial resistance to the weevils. Alternatively, if the weevils have no choice, they may cause greater damage; this hypothesis can be tested easily with commercial fields of this cultivar in areas with high weevil populations. The low level of damage observed in *B. rapa* in the greenhouse was unexpected given the consistently high level of damage observed in the field and in past studies (Kalischuk and Dosdall 2004). Interactions between plant vigour and disease may have made the plants less attractive to the weevils in the greenhouse.

Crambe L. species and *Camelina* Crantz species exhibit resistance to several cruciferfeeding insect specialists (Anderson *et al.* 1992; Palaniswamy *et al.* 1998). Because they appear to be poorly adapted to the growing conditions in southern Alberta, their use as a source of resistance to *C. obstrictus* could not be adequately assessed in this investigation. Very few plants were established per plot in 2002 and 2003, and their pod production was delayed past the middle of July, so weevils active at the time may have been past their peak reproductive period. No exit holes were observed for

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C. h. glabrata in either year and only 1 hole in several thousand pods (1 pod = 1 large seed) for *C. h. hispanica* and *C. sativa*. For *C. abyssinica*, however, 1–2 holes per 100 pods were noted in 2003. This result suggests that larvae can complete their development in a single seed, contrary to speculations by Dmoch (1965) and Kalischuk and Dosdall (2004). As implied by these authors, however, the weevil may not reach reproductive status if fitness is compromised by the poor resource quality of these hosts. A trial that synchronizes pod development in *Camelina* species and *Crambe* species with weevil oviposition could elucidate whether these species possess any resistance to *C. obstrictus*.

In conclusion, our study demonstrated that the relative susceptibilities of the Brassicaceae germplasm that was tested were as follows: *B. rapa* and *B. napus* > *B. juncea* = *B. carinata* > *S. alba*. The *Camelina* species and *Crambe* species appeared to be resistant, but the lack of synchrony between their pod production and weevil reproduction may explain the lack of damage. Greenhouse studies need to be combined with field tests to confirm apparent resistance in late-maturing germplasm. Our study showed that breeding efforts to develop specialty Brassicaceae did not influence susceptibilities tos *C. obstrictus*. Elucidating the factors that impart resistance to *C. obstrictus* in Brassicaceae remains a challenge to the advancement of host-plant resistance against this pest.

Acknowledgements

We gratefully acknowledge G. Rakow, K. Falk, F. Katepa-Mupondwa, V. Ripley, R. Gugel (all with the Saskatoon Research Centre (SRC) of Agriculture and Agri-Food Canada) and C. Franke (Saskatchewan Wheat Pool) for providing seed and advice on the attributes of the genotypes tested in this project, and R. Weiss (SRC), R. Dyck, T. Larson, C. Klima, B. Lounds, N. Schmolds, and K. Coles (Lethbridge Research Centre), and N.T. Cowle and P. Conway (Alberta Agriculture, Food and Rural Development) for technical support. Funding was provided primarily by the Abase program of Agriculture and Agri-Food Canada, the Alberta Agricultural Research Institute, and the Alberta Canola Producers Commission.

References

Analytical Software. 2000. Statistix™. Version 7. User's manual. Analytical Software, Tallahassee, Florida. ISBN 10881789-05-5.

Anderson, M.C., Peng, C., and Weiss, M.J. 1992. Crambe, *Crambe abyssinica* Hochst., as a flea beetle resistant crop (Coleoptera: Chrysomelidae). Journal of Economic Entomology, **85**: 594–600.

Brown, J., Brown, A.P., Davis, J.B., and Erickson, D.A. 1997. Intergeneric hybridization between *Sinapis alba* and *Brassica napus*. Euphytica, **93**: 163–168.

Brown, J., McCaffrey, J.P., Harmon, B.L., Davis, J.B., Brown, A.P., and Erickson, D.A. 1999. Effect of late season insect infestation on yield, yield components and oil quality of *Brassica napus*, *B. rapa*, *B. juncea* and *Sinapis alba* in the Pacific Northwest region of the United States. Journal of Agricultural Science, **132**: 281–288.

Buntin, G.D. 1999. Damage loss assessment and control of the cabbage seedpod weevil (Coleoptera: Curculionidae) in winter canola using insecticides. Journal of Economic Entomology, **92**: 220–227.

Butts, R.A., and Lamb, R.J. 1991. Seasonal abundance of three *Lygus* species (Heteroptera: Miridae) in oilseed rape and alfalfa in Alberta. Journal of Economic Entomology, **84**: 450–456.

Cárcamo, H.A., Dosdall, L., Dolinski, M., Olfert, O., and Byers, J.R. 2001. The cabbage seedpod weevil (*Ceutorhynchus obstrictus* [Marsham]) — a review. Journal of the Entomological Society of British Columbia, **98**: 201–210.

Cárcamo, H.A., Entz, T., and Blackshaw, R.E. 2004. Sub-sampling canola plants (*Brassica napus* L) to estimate cabbage seedpod weevil (*Ceutorhynchus obstrictus* Marsham) damage. Journal of Entomological Science, **39**: 122–124.

Cárcamo, H.A., Dosdall, L.M., Johnson, D., and Olfert, O. 2005. Evaluation of foliar and seed-coated insecticides for control of the cabbage seedpod weevil (Coleoptera: Curculionidae) in canola. The Canadian Entomologist, **137**: 476–487.

Cárcamo, H.A., Dunn, R., Dosdall, L.M., and Olfert, O. 2007. Managing cabbage seedpod weevil in canola using a trap crop — a commercial scale study in western Canada. Crop Protection, **26**: 1325–1334.

Conover, W.J., and Iman, R.L. 1981. Rank transformations as a bridge between parametric and nonparametric statistics. American Statistician, **35**: 124–129.

Dmoch, J. 1965. The dynamics of a population of the cabbage seedpod weevil (*Ceutorhynchus assimilis* Payk.) and the development of winter rape. Part I. Ekologiya Polska Seria A, **13**: 249–287.

Dosdall, L.M., and Moisey, D.W. 2004. Developmental biology of the cabbage seedpod weevil,

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https://doi.org/10.4039/n06-083 Published online by Cambridge University Press

Ceutorhynchus obstrictus (Coleoptera: Curculionidae), in spring canola, *Brassica napus*, in western Canada. Annals of the Entomological Society of America, **97**: 458–465.

Dosdall, L.M., Weiss, R.M., Olfert, O., and Cárcamo, H.A. 2002. Temporal and geographical distribution patterns of cabbage seedpod weevil (Coleoptera: Curculionidae) in canola. The Canadian Entomologist, **134**: 403–418.

Dosdall, L.M., Moisey, D.W., Cárcamo, H.A., and Otani, J. 2004. Integrated management of the cabbage seedpod weevil and overwintering biology of canola pests. Technical report, University of Alberta, Edmonton, Alberta.

Dosdall, L.M., Ulmer, B.J., Gibson, G.A.P., and Cárcamo, H.A. 2006. The spatio-temporal distribution dynamics of the cabbage seedpod weevil, *Ceutorhynchus obstrictus* (Marsham) (Coleoptera: Curculionidae), and its larval ectoparasitoids in canola in western Canada. Biocontrol Science and Technology, **16**: 987–1006.

Doucette, C.F. 1947. Host plants of the cabbage seedpod weevil. Journal of Economic Entomology, **40**: 838–840.

Harmon, B.L., and McCaffrey, J.P. 1997. Laboratory bioassay to assess *Brassica* spp. germplasm for resistance to the cabbage seedpod weevil (Coleoptera: Curculionidae). Journal of Economic Entomology, **90**: 1392–1399.

Kalischuk, A.R., and Dosdall, L.M. 2004. Susceptibilities of seven Brassicaceae species to infestation by the cabbage seedpod weevil (Coleoptera: Curculionidae). The Canadian Entomologist, **136**: 265–276.

McCaffrey, J.P., Harmon, B.L., Brown, J., Brown, A.P., and Davis, J.B. 1999. Assessment of *Sinapis alba*, *Brassica napus* and *S. alba* × *B. napus* hybrids for resistance to cabbage seedpod weevil, *Ceutorhynchus assimilis* (Coleoptera: Curculionidae). Journal of Agricultural Science, **132**: 289–295.

Murchie, A.K., Williams, I.H., and Alford, D.V. 1997. Effects of commercial insecticide treatments to winter oilseed rape on parasitism of *Ceutorhynchus assimilis* Paykull (Coleoptera: Curculionidae) by *Trichomalus perfectus* (Walker) (Hymenoptera: Pteromalidae). Crop Protection, **16**: 199–202.

Palaniswamy, P., Lamb, R.J., and Bodnaryk, R.P. 1998. Resistance to the flea beetle *Phyllotreta cruciferae* (Coleopetra: Chrysomelidae) in false flax *Camelina sativa* (Brassicaceae). The Canadian Entomologist, **130**: 235–240.

Renwick, J.A. 2002. The chemical world of crucivores: lures, treats and traps. Entomologia Experimentalis et Applicata, **104**: 34–42.

Ulmer, B.J., and Dosdall, L.M. 2006*a*. Spring emergence biology of the cabbage seedpod weevil (Coleoptera: Curculionidae). Annals of the Entomological Society of America, **99**: 64–69.

Ulmer, B.J., and Dosdall, L.M. 2006*b*. Glucosinolate profile and oviposition behaviour in relation to the susceptibilities of various Brassicaceae to the cabbage seedpod weevil. Entomologia Experimentalis et Applicata, **121**(3): 203–213.

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