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Allelopathic effects of camelina (*Camelina sativa*) and canola (*Brassica napus*) on wild oat, flax and radish

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ABSTRACT

Brassicacea members camelina (*Camelina sativa*) and canola (*Brassica napus*) were examined for allelopathic activity against wild oat (*Avena fatua*), flax (*Linum usitatissimum*), and radish (*Raphanus sativus*). This 4-part study investigated the effects of leaf washings, aqueous extracts, soil incorporated fresh plant residues and root exudates on seedling weight. The effects of aqueous extracts on germination were also quantified. Camelina and canola leaf washings increased radish seedling weight, while only canola increased flax weight. Where effects were observed, aqueous extracts of camelina and canola reduced the germination of wild oat, flax and radish. Wild oat and radish seedlings had reduced root weight and increased shoot weight in response to aqueous extracts. Incorporation of camelina or canola fresh plant residues into growth media increased radish weight, while only canola residues increased wild oat biomass. Canola root exudates decreased wild oat weight, but increased radish weight. Camelina exudates decreased flax weight. Aqueous extracts predominantly contained volatile sulfur containing compounds (methanethiol, dimethyl sulfide, dimethyl disulfide and dimethyl trisulfide) as potential allelochemicals. Further research will focus on confirming the allelopathic activity of candidate allelochemicals. Variable results between the different assays and the species investigated reflect the challenges of identifying a true allelopathic interaction between species and the need for rigorous and multi-part analyses, requiring subsequent confirmation in an ecological context.

Key words: Allelopathy, aqueous plant extract, *Avena fatua,* Brassicaceae, *Brassica napus*, camelina, *Camelina sativa*, canola, flax, leaf leachates, *Linum usitatissimum,*radish, *Raphanus sativus,* root exudates, wild oat

INTRODUCTION

Allelopathy denotes the stimulatory or inhibitory effects of chemicals released into the environment from one plant on the growth and development of another living organism (35). Selective breeding has been done to improve the allelopathic activity in some crops: rice, wheat and barley (5,6,24,25). Brassicaceae family plants are frequently cited as allelopathic (12,22,28-30,32) and include oilseed [canola (*Brassica napus* L.), camelina [*Camelina sativa* (L.) Crantz.], mustard (*Brassica rapa* L.)] and vegetable crops [broccoli (*Brassica oleracea* L.) and radish (*Raphanus sativus* L.)]. Glucosinolates, sulfur containing compounds characteristic of Brassicaceae members, have been attributed with allelopathic activity (31,33,42). Glucosinolates have limited biological activity, however

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their enzymatic degradation *via* thioglucoside glucohydrolase (EC 3.2.3.1) forms allelochemicals including isothiocyanates and nitriles (9).

Camelina is an European origin oilseed crop with renewed interest for its potential to serve as feedstock for biofuel production (14,23). Commonly called 'false flax', camelina is a known weed of flax crops, which may have afforded opportunity for crop-weed evolution (13,30). Currently, no herbicide is registered to control broadleaf weeds in camelina, thus limiting weed control options. *Camelina* spp. in flax (*Linum usitatissimum* L.) reduces the yields up to 80% in glasshouse experiments due to leaf-bound kolines (18). In contrast, subsequent research reported the stimulatory allelopathic effects of camelina leaf washings on flax growth due to the presence of phyllospheric bacteria *Enterobacter cloacae* (Jordan) Hormaeche (29,30). Results indicate the innate complexity of allelopathic interactions.

Canola may be utilized as green manure or as a cover crop to suppress weeds and maintain soil structure (8,19,42), however the significance of allelopathy in this activity has yet to be conclusively determined. Yasumoto *et al.* (43) conducted laboratory assays and reported auto-toxic effects of canola tissue, aqueous extracts and root exudates on seed germination and plant growth. Furthermore, they observed reduced sunflower (*Helianthus annuus* L.) growth in the field following canola cultivation and suggested root exudates were responsible. Likewise, Jafariehyazdi *et al.* (22) documented inhibition of sunflower germination and growth from the aqueous extracts of several *Brassica* ssp. including canola in laboratory assays. Further research is required to determine the mechanism of suppression observed in these studies.

Laboratory experiments are an initial evaluation tool to identify a potentially allelopathic interaction. A four part laboratory and glasshouse experiment was designed to investigate the effects of camelina and canola: (i). Leaf washings, (ii). Aqueous plant extracts, (iii). Soil incorporated fresh plant residues and (iv). Root exudates. The effects were evaluated on 3- recipient plant species: (i). Wild oat [abundant weed in Canadian prairies (39)], (ii). Flax [crop species historically associated with camelina] and (iii). Radish [Brassicaceae species]. Identification of allelopathic activity may help in the development of cultivars with enhanced allelopathic activity and development of integrated weed management systems. This research aimed to: (i). Observe the allelopathic potential of camelina and canola, (ii). Compare the results from four distinct assays commonly used in allelopathic studies and (iii). Determine if the observed effects were species specific.

MATERIALS AND METHODS

Camelina (cultivar 'Calena'), canola (variety 72-55 Roundup Ready®), flax (cultivar 'Bethune'), radish (cultivar 'Cherry Belle') and wild oat seeds harvested from wild plants near Edmonton, Alberta, Canada, were used for these assays. Camelina and canola aqueous extracts were prepared from plants grown in the field (without chemical controls), in 2011 at Ellerslie Research Station, Alberta, Canada. Field grown plants at the stem elongation to early flowering growth stages were dug up with spades, rinsed with water, and transported to the lab. Plants were then partitioned into roots and shoots to prepare aqueous extracts. The remaining assays were done with camelina and canola

grown from seed in glasshouse conditions. All glasshouse propagated plants for assays were grown in 15 cm pots in soil-less potting medium (Sunshine Mix 4, Sun Gro Hort) and fertilized bi-weekly using 24-8-16 all-purpose plant food (Scotts Miracle-Gro).

Leaf washings

Camelina and canola were tied into 76.0 g shoot bundles, cut stems were sealed with Parafilm® (Pechiney Plastic Company) and bundles were agitated at 135 rpm for 10 min in 1.0 L distilled water. Washings were stored in dark at 4 ˚C. Fifty pre-germinated recipient plants seeds (wild oat, flax or radish) were placed in individual acrylic germination boxes [16 cm x 24 cm x 4 cm] (Hoffman Manufacturing, Inc.) between two sheets of non-toxic white filter paper (15 x 23 cm; No. 601 Whatman #1 equivalent, Hoffman Manufacturing, Inc.) and saturated with 25 mL of appropriate washing. An additional 5 mL was added on day 6 to avoid desiccation. For each recipient species, there were 3 treatments: (i). Camelina leaf washings, (ii). Canola leaf washings, and (iii). Distilled water. Seeds were placed in an Adaptis A1000 (Conviron Ltd., USA) growth chamber [23°C, 16 h light/8 h dark cycles] for 10 days, thereafter the root and shoot fresh weight of each of the seedlings were recorded. Samples were dried at 65°C for 96 h and dry weights were recorded. Experimental design was complete randomized block with three replications.

Aqueous extracts

Camelina and canola root and shoot aqueous extracts were prepared by homogenization of 150 g fresh material and 300 mL distilled water for 2 min in a Waring® blender, filtered through cheesecloth and stored in dark at 4°C. pH was recorded for each extract (data not shown). Fifty recipient seeds (wild oat, flax or radish) were placed in individual acrylic germination boxes [16 cm x 24 cm x 4 cm] between two sheets of non-toxic white filter paper (15 x 23 cm No. 601 Whatman #1 equivalent, Hoffman Manufacturing, Inc.) saturated with 25 mL extract. An additional aliquot of 5 mL extract was added on day 6 to avoid desiccation. Each recipient species received one of 5-extracts: (i). Camelina shoot, (ii). Camelina root, (iii). Canola shoot, (iv). Canola root and (v). Distilled water. Boxes were placed in an Adaptis A1000 (Conviron Ltd., USA) growth chamber [23°C, 16 h light/8 h dark cycles]. The number of germinated seeds was counted daily for 12 days thereafter individual seedling's root and shoot fresh weights were recorded. Germination rate was calculated as under:

$$\text{Germination rate} = N_1/D_1 + N_2/D_2 \ldots\ldots + N_i/D_i$$

Where, *Ni*: Number of seeds that germinated in days *i* (*Di*) (22).

Samples were dried at 65°C for 96 h and weighed. Experimental was done in complete randomized block with three replications, blocked in time, donor species was main effect and root vs. shoot was the sub-effect.

Chemical analysis of aqueous extracts

Fifteen mL aliquots of camelina and canola shoot and root aqueous extracts were added in 20 mL glass containers, sealed with a rubber septum cork and allowed 30 min equilibration time. The volatile organic compounds (VOCs) in extracts were analyzed by

headspace sampling (10-µL Hamilton company injection syringe) and subsequent injection into a gas chromatography mass spectrometry (GC/MS). Agilent 6890N Network GC system with 5975 C VL MSD was employed. A HP-5MS non polar fused silica capillary column (30 m x 0.25 mm, 0.25 µm film thickness) was used under the following conditions: oven temperature program from 30°C (2 min) to 270°C at 15°C/min and the final temperature kept for 2 min; injector temperature, 270°C; helium carrier gas, split flow rate 35.1 mL/min, total flow rate 38.7 mL/min; the volume of injected sample was ~10-µL; split injection technique; ionization energy 70 eV, in the electronic ionization mode; ion source temperature 230°C; scan mass range of m/z 35-350 and interface temperature 280°C. Identification of the chemical constituents was realised by comparing their mass spectra with those gathered in the NIST library database

Incorporated fresh residues

Glasshouse grown camelina and canola root and shoot biomass was chopped into ~1 cm fragments, mixed with soil-less media and divided evenly between 24 pots. An additional 12 pots were filled with media only. To separate the effects on germination, 6 pre-germinated seedlings of each recipient plant were planted in 12 pots (4 control, 4 camelina residues, 4 canola residues) and after 2-weeks, seedlings were thinned to 4 seedlings per pot. Five weeks after planting, individual radish plant height, fresh shoot and root weight were recorded. Samples were dried at 65°C for 96 h for dry weight recording. Experimental design was complete randomized block with three replications.

Root exudates

Glasshouse grown camelina and canola were removed from the pots at stem elongation to early flowering stage. The media was hand sieved to remove all root fragments, bulked and redistributed into clean pots and control pots were filled with new media. To separate the effects on germination, 6 pre-germinated seedlings of each recipient plant were planted in 12 pots (4 control, 4 camelina residues, 4 canola residues) and after 2-weeks, seedlings were thinned to 4 seedlings per pot. Five weeks after planting, individual radish plant height, fresh shoot and root weight were recorded. Samples were dried at 65°C for 96 h for dry weight recording. Experimental design was complete randomized block with three replications.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using a mixed model (PROC MIXED) in SAS (36). Prior to ANOVA the data was reviewed to ensure residuals met the assumptions for normality and homogeneity of variance. All data did not differ significantly from normal population with exception of ‘effects of incorporated fresh residues’ and ‘effects of root exudates’ which were square root transformed. The data was analyzed with a mixed model as a one-way ANOVA where block (replicate) was considered random. Least squared means generated by the model with Bonferroni adjusted alpha values and means separation were carried out using PDMIX800 (37). Mean values within a column followed by the same letter are not significantly different ($p > 0.05$).

RESULTS AND DISCUSSION

Leaf washings

The camelina and canola leaf washings tended to increase the seedling fresh weight of recipient plants, where an effect was observed (Table 1, Figure 1A). Wild oat fresh weight was not affected by leaf washings ($p > 0.05$). Flax root and shoot fresh weight increased in response to canola ($p < 0.05$), but not to camelina ($p > 0.05$). Camelina and canola leaf washings increased root and shoot fresh weight in radish ($p \leq 0.001$). In summary, the leaf washings of canola increased seedling fresh weight in radish and flax, while camelina leaf washings stimulated only the radish. Due to the small sizes of seedlings at harvest for this assay, the majority of dry weights were negligible (<0.000) and could not be used in statistical analyses.

Table 1. Effects of camelina and canola leaf washings on wild oat, flax, and radish seedling root and shoot fresh weight

Leaf Washings	Wild oat	Flax	Radish
		Root fresh weight (mg/plant)	
Control	42ab	28a	49a
Canola leaf washings	46a	34b	81b
Camelina leaf washings	37b	31ab	69c
		Shoot fresh weight (mg/plant)	
Control	36a	9a	24a
Canola leaf washings	36a	13b	30b
Camelina leaf washings	34a	10a	33c

Mean values within a column followed by the same letter are not significantly different ($p > 0.05$). For results that differed significantly from the control, the % difference is presented.

Leaves are the main source of allelopathic inhibitors and the focus of many allelopathic investigations (35). Lovett *et al.* (28-30) reported positive effects of camelina leaf washings on flax growth. We observed no significant increase in flax root or shoot weight in response to camelina leaf washings. Wild oat was unaffected, while radish fresh weights were consistently increased compared to the control. Canola leaf washings increased fresh weighs in both flax and radish by 17-44% relative to controls. Lovett *et al.* (30) attributed the stimulation of flax growth to the presence of native camelina phyllospheric bacteria, *E. cloacae,* which metabolized the glucosinolate benzyl-isothiocyanate to benzylamine (an allelochemical stimulatory at low concentrations). Glucosinolate content in camelina seed ranges from 18.7 to 36.2 μmol g^{-1}(38), much lower than canola seed (39.94 to 53.01 μmol g^{-1}) (42); however, gluosinolate content in leaf tissue or washings is not known. Future research may identify, quantify and compare levels of benzylamine, or potential allelochemicals, in camelina and canola leaf washings.

Aqueous extracts

Aqueous extracts suppressed the seed germination of recipient plants ($p < 0.001$) (Table 2). However, the effects of canola root and shoot extracts on flax and wild oat seed germination were not significant ($p > 0.05$) over controls. Canola extracts were less inhibitory to seed germination than camelina extracts. With the exception of camelina

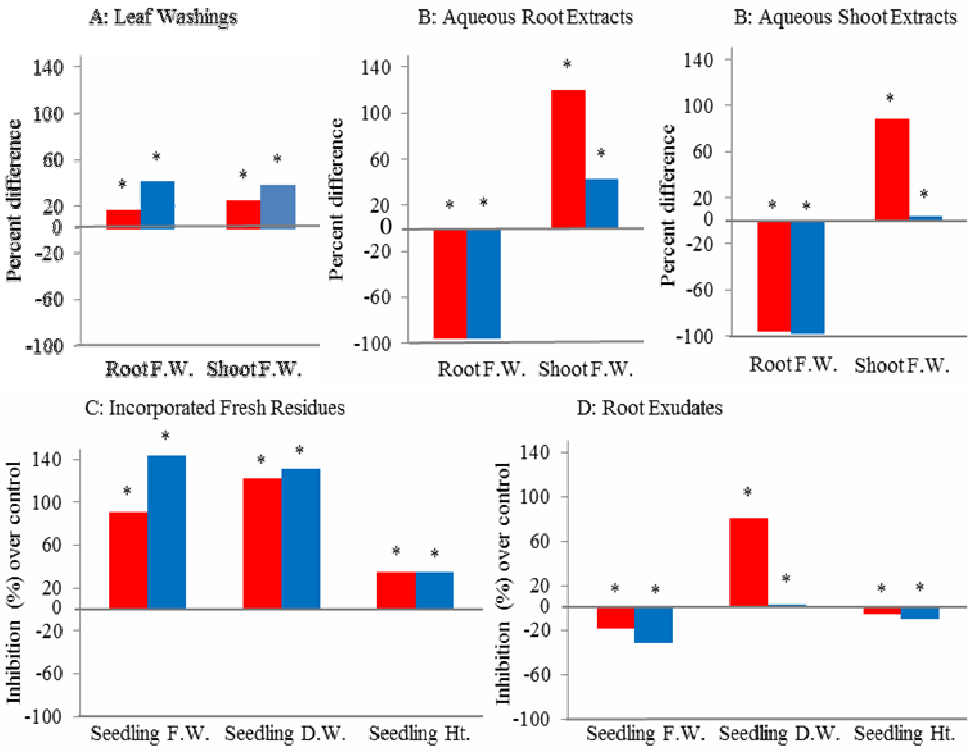

Figure 1. Percentage stimulation or inhibition observed in radish in response to canola and camelina leaf washings, aqueous extracts, soil incorporated residues, and root extracts. The effect of canola (red bars) and camelina (blue bars) leaf washings (A), aqueous root and shoot extracts (B), soil incorporated plant residues (C), and root extracts (D) on radish fresh weight (F.W.), dry weight (D.W.), and height (Ht.) are displayed as the percentage stimulation or inhibition observed compared to the control. Values that demonstrated a statistically significant difference from the control values are indicated with a *.

shoot extract, aqueous extracts did not significantly decrease overall germination in radish. However, while overall germination was not affected, germination of radish seeds was delayed as evidenced by a significant decrease in the germination rate (data not shown). The ability to delay weed germination in agriculture may allow the crop to gain a competitive advantage over weeds by allowing crops to become established in advance of weed growth. The effects of plant extracts on seedling fresh weight were variable (Table 2, Figure 1B). Due to low seed germination of wild oat and flax, the ability to interpret the effects of camelina and canola extracts on fresh weight was limited. No significant differences ($p > 0.05$) were observed in flax shoot fresh weight. In radish, root fresh weight decreased, but the shoot fresh weight increased. While canola shoot extract had no effect on seed germination in wild oat, it decreased the root fresh weight but increased the shoot fresh weight. Due to small sizes of seedlings at harvest for this assay, the majority of dry weights were negligible (<0.000) and could not be used in statistical analyses.

Table 2. Effects of camelina and canola aqueous root and shoot extracts on wild oat, flax, and radish seed germination and seedling root and shoot fresh weight

Aqueous extracts	Wild oat	Flax	Radish
		Germination (%)	
Control	56.7a	70.7a	96.6a
Canola root	6.0b	44.7ab	76.7a
Canola shoot	23.3ab	50.7ab	74.0a
Camelina root	1.3b	11.3b	86.0a
Camelina shoot	15.3ab	12.7b	59.3b
		Root fresh weight (mg/plant)	
Control	20a	10	276a
Canola root	*	*	12b
Canola shoot	7b	*	12b
Camelina root	*	n/a	4c
Camelina shoot	*	*	2c
		Shoot fresh weight (mg/plant)	
Control	16a	20a	51a
Canola root	18ab	17a	112b
Canola shoot	29b	21a	96b
Camelina root	*	n/a	73c
Camelina shoot	12a	8a	53a

[n/a] Data failed to converge due to lack of germinated seedlings. * Least squared estimates were unable to be generated due to highly non-normal data points. Mean values within a column followed by the same letter are not significantly different ($p > 0.05$). For results that differed significantly from the control, the % difference is presented.

The suppression of germination by camelina and canola extracts observed in this study agrees with previous research. Evenari (12) reported that glucosinolate containing mustard (Brassicaceae) oils are strong germination inhibitors. Aqueous seed extracts of *Brassica juncea* (L.) Czern. significantly reduced the germination of alfalfa (*Medicago sativa* L.), radish and turnip (*Brassica rapa* var. *rapa* L.) (17). Similarly, aqueous seed extracts of *Brassica nigra* L. reduced wheat (*Triticum aestivum* L.) germination (12) and allyl isothiocyante liberated from macerated *B. nigra* leaves inhibited the germination of *Bromus rigidus* (Roth) seeds (3). Germination inhibition *via* allelochemicals is due to lipid mobilization (2) and low levels of isothiocyanates (glucosinolate break-down product) induces secondary dormancy (32). The use of plant extracts to elicit allelopathic responses is not reflective of plant activity in nature (20). The identification of active compounds present in extracts with the ability to suppress seed germination or seedling growth is still of interest as it may support alternative weed control methods.

Chemical analysis of aqueous extracts

The analysis of VOCs from aqueous extracts confirmed the major presence of numerous sulfur containing compounds (including ethanethiol, dimethyl sulfide, dimethyl disulfide and dimethyl trisulfide) (Table 3). In all samples analyzed, dimethyl disulfide was major sulfur based compound. Similar compounds are reported in the root emissions of *Brassica nigra* plants (10). Other significant chemicals in camelina shoot extract were: thanolamine, 3-pentanone, 3-hexen-1-ol and tetrahydrofuran. While canola shoot extract

contained the 4, dimethyl 1,2- pentadiene and 2,2- dimethoxypropane. Carbamic acid was also detected in canola root and shoot extracts. Carbamic acid is intermediate during the decomposition of carbamate esters, possibly present in extracts. Carbamates have well known allelopathic effects (16).

Table 3. Relative quantities of the volatile organic compounds detected by headspace GC/MS of aqueous extracts of camelina & canola samples shoots and roots

Compound identified	Relative content			
	Camelina		Canola	
	Root	Shoot	Root	Shoot
Dimethyl disulfide	XXX	XXX	XXX	XXX
Dimethyl sulfide	X	X		XX
Methanethiol	X			XX
Dimethyl trisulfide		X		
Methyl disulfide		X		
3-Pentanone		X		
Trichloromethane		X	X	
Tetra hydrofuran		X	X	X
3-Hexen-1-ol		XX		
Carbamic acid			X	XX
4,4, Dimethyl 1,2- pentadiene				XX
2,2- Dimethoxypropane	X			
Ethanolamine	X	X		

^{XXX} Predominant content with > 80% of detected VOCs. ^{XX} Content greater than 5% of detected VOCs. ^{X} content < 5% of detected VOCs

This study focused on identifying the volatile compounds in extracts identifiable by GC/MS. Additional research will focus on identification of potential non-volatile hydrophilic allelochemicals (including glucosinolates and other phenolic compounds) using high performance liquid chromatography with mass spectrometry. Volatile organic compounds due to their facile permeability in soil, may play a major role in allelopathic activity. The presence and activity of these chemicals must be confirmed in an ecological context to identify them as allelopathic in nature.

Incorporated fresh residues

Significant increases in seedling weight and height were observed in some instances in wild oat and consistently in radish, but no effect was observed in flax, in response to incorporation of fresh residues of camelina and canola (Table 4, Figure 1C). The incorporation of canola fresh residues increased wild oat dry weight ($p \leq 0.01$), but not fresh weight or height. Camelina fresh residues increased wild oat height, but had no effect on fresh or dry weight. Canola and camelina residues significantly increased ($p > 0.05$) the radish height (35%), and fresh and dry weights (91-143%) than control. However, the seedling weight and height of flax was not significantly affected ($p > 0.05$).

Table 4. Effects of camelina and canola incorporated fresh residues on wild oat, flax, and radish seedling weight and height

Incorporated fresh plant residues	Wild oat	Flax	Radish
		Seedling fresh weight (mg/plant)	
Control	707a	637a	413a
Canola fresh residues	1145a	558a	787b
Camelina fresh residues	943a	608a	1004b
		Seedling dry weight (mg/plant)	
Control	145a	129a	77a
Canola fresh residues	240b	120a	171b
Camelina fresh residues	187ab	121a	178b
		Seedling height (cm)	
Control	35.1a	23.1a	7.7a
Canola fresh residues	39.3ab	23.1a	10.4b
Camelina fresh residues	40.9b	21.9a	10.4b

Mean values within a column followed by the same letter are not significantly different ($p > 0.05$). For results that differed significantly from the control, the % difference is presented.

Brassica spp. crops have potential for green manuring in an integrated crop management strategy (8,9,26). A green manure crop is planted in fall to prevent soil erosion and improve soil moisture retention. Brassica green manuring efficacy is due to the presence of the glucosinolate degradation volatile product isothiocyanates (15,32,33,41) with allelopathic potential. After incorporation of turnip-rape mulch, the amount of isothiocyanates remaining in soil after 24 h declined by >90% (32). The cause and effect relationship between such observations and potential allelopathic activity must be interpreted with caution.

The incorporation of crop residues in soil influences the mineralization processes, improves soil productivity and affects the functional diversity of soil microbial community (4,11). In contrast, spring-incorporated canola residues reduced weed biomass up to 96% in potato (*Solanum tuberosum* L.) fields (8) and up to 49% in soybean (*Glycine max* L.) crop (26). Although the reduced weed biomass is attributed to secondary metabolites (1), the mechanism is not known. Reductions in weed biomass reported in many studies (8,26,27,40) may be due to their reduced or delayed seed germination, as these variables were not eliminated in these experimental designs. We used pre-germinated recipient plant seedlings to determine the allelopathic effects on seedling growth and biomass accumulation in wild oat, flax and radish and found that soil incorporated canola and camelina residues demonstrated effects on wild oat and radish, but had no effect on flax.

Root exudates

Root exudates had no effect on seedlings heights for wild oat, flax or radish (Table 5, Figure 1D). Seedling weights were generally unaffected. Canola root exudates decreased ($p > 0.05$) the fresh weight of wild oat, but had no effect on flax or radish fresh weight. In contrast, camelina root exudates significantly decreased flax fresh weight ($p = 0.0477$), but had no effect on wild oat or radish.

Table 5. Effects of camelina and canola root exudates on wild oat, flax, and radish seedling weight and height

Root exudates	Wild oat	Flax	Radish
		Seedling fresh weight (mg/plant)	
Control	652a	136a	679a
Canola root exudates	237b	66ab	550a
Camelina root exudates	431ab	23b	458a
		Seedling dry weight (mg/plant)	
Control	237a	10a	86a
Canola root exudates	104a	83ab	156b
Camelina root exudates	17a	63b	89a
		Seedling height (cm)	
Control	46.1a	12.5a	4.9a
Canola root exudates	43.9a	10.3a	4.6a
Camelina root exudates	43.4a	10.2a	4.4a

Mean values within a column followed by the same letter are not significantly different ($p > 0.05$). For results that differed significantly from the control, the % difference is presented.

Root exudates are products of living roots, where no leaf washings, volatiles or residues from the above ground biomass are present (35), However, the isolation of root exudates and observation of their effects is difficult. Roots contain less allelochemicals than leaves and root allelochemicals are less potent and present in smaller amounts (35). Additionally, the amount of exudates present can be dependent on external factors including photoperiod and temperature (34), yet certain phenolics exuded from roots may be inhibitory or stimulatory depending on the concentration (7). The rhizosphere is the site of greatest activity within the soil matrix and therefore, represents the largest fraction of root exudates (7). Rhizospheric soil is $\leq$ 2 mm from the root surface (7), hence, we examined the effects of both rhizospheric and non-rhizospheric media in this allelopathic study. Yasumoto *et al.* (43) observed a reduction in yield and quality of crops following canola cultivation that they attributed to the presence of juvenile volunteer canola seedlings root exudations. Although the observed reduction in crop yield and quality may be associated with the presence of allelochemicals, additional variables may have contributed to these observations. For instance, while competition for nitrogen uptake was eliminated as a potential confounding factor in this study, other soil nutrients were not considered. The effects of root exudates are difficult to isolate from subtle changes in soil quality that may significantly impact the growth of subsequent crops.

CONCLUSIONS

The results of this preliminary assessment of allelopathic potential of camelina and canola suggested that further research is warranted to determine if allelopathic activity exists in an ecological context. Laboratory assays serve as a useful initial screening method to identify potential allelopathy, but are not sufficient to confirm the existence of allelopathy in a natural context. The results of the 4 -assays used to identify potential allelopathy in camelina and canola demonstrated variability. Leaf washings increased the seedling fresh weights. The aqueous plant extracts suppressed germination and root

weights, but shoot weights were increased. Where effects were observed, soil incorporated plant residues increased the height and weight of recipient species, while root exudates decreased the recipient fresh weight. We determined the effects of camelina and canola on 3 -recipient species [weed (wild oat), crop (flax) and brassicacea species (radish)]. This study showed the species-specific potential of allelopathic interactions. For example, leaf washings of canola increased the seedling fresh weight in radish and flax, but camelina leaf washings stimulated only radish fresh weight and neither canola nor camelina influenced the wild oat. The observed variability between the 3 -recipient species and in results of 4 -different assays emphasizes the challenges associated with unambiguously identifying allelopathic activity. Future experimentation will focus on the isolation and comparison of specific allelochemicals from leaf leachates, aqueous extracts, root exudates, and decomposing residues; and evaluation of the allelopathic activity of these chemicals in laboratory and field experiments.

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