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Evaluating the Competitive Ability of Semileafless Field Pea Cultivars

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The inclusion of competitive crop cultivars in crop rotations is an important integrated weed management (IWM) tool. However, competitiveness is often not considered a priority for breeding or cultivar selection by growers. Field pea (*Pisum sativum* L.) is often considered a poor competitor with weeds, but it is not known whether competitiveness varies among semileafless cultivars. The objectives of this study were to determine if semileafless field pea cultivars vary in their ability to compete and/or withstand competition, as well as to identify aboveground trait(s) that may be associated with increased competitive ability. Field experiments were conducted in 2012 and 2013 at three locations in western Canada. Fourteen semileafless field pea cultivars were included in the study representing four different market classes. Cultivars were grown either in the presence or absence of model weeds (wheat and canola), and competitive ability of the cultivars was determined based on their ability to withstand competition (AWC) and their ability to compete (AC). Crop yield, weed biomass and weed fecundity varied among sites but not years. Cultivars exhibited inconsistent differences in competitive ability, although cv. Reward consistently exhibited the lowest AC and AWC. None of the traits measured in this study correlated highly with competitive ability. However, the highest-yielding cultivars generally were those that had the highest AC, whereas cultivars that ranked highest for AWC were associated with lower weed fecundity. Ranking the competitive ability of field pea cultivars could be an important IWM tool for growers and agronomists.

Nomenclature: Field pea, *Pisum sativum* L.
Key words: Competition, competitive ability, cultivars, semileafless pea, weeds, yield loss.

Field pea is often considered a poor competitor with weeds because of slow seedling growth, short stature, and slow canopy closure (Saskatchewan Pulse Growers 2011). Previous weed surveys in Alberta, Canada, reported 67% of field pea fields suffered yield losses because of weeds, compared with only 40% of canola (*Brassica napus* L.) fields and 27% of barley (*Hordeum vulgare* L.) fields (Harker 2001). Numerous studies have estimated field pea yield losses due to weed competition and have found it to range between 27 and 85% (Lemerle et al. 2006; McDonald 2003; Spies et al. 2011; Townley-Smith and Wright 1994). Excellent weed control is critical to field pea production, but is often difficult to achieve (Townley-Smith and Wright 1994; Harker 2001). Collectively, cultural weed suppression techniques facilitate IWM and could reduce weed interference in field pea crops (Grevsen 2003).

Competitive crop cultivars are an important component of crop rotations, and are also an important component of integrated weed management (Lemerle et al. 2001). Competitive cultivars represent a potentially attractive weed management option because growers do not incur any additional costs by sowing them (Andrew et al. 2015). Moreover, they can reduce the seed return of weeds through an improved ability to suppress neighbours (competitive effect), or they can exhibit less crop yield loss due to an enhanced ability to tolerate neighbors (competitive response) (Goldberg and Landa 1991; Jordan 1993). In crop production, this can be expressed as the ability to withstand competition (AWC, competitive response) or the ability to compete (AC, competitive effect) (Watson et al. 2006). When examining the competitive ability among crop cultivars, both aspects need to be considered (Jordan 1993; Lemerle et al. 1996; Watson et al. 2006) as differential cultivar responses to weed competition could arise if some cultivars have peak resource demands at times when weed resource use is low (Watson et al. 2006).

Enhancing crop competitive ability is crucial for weed management (Lindquist and Mortensen 1998; Mohler 2001; Zerner et al. 2008). Aboveground traits such as plant height, vigorous early growth, number of tillers, leaf area, and seed size are recognized as key traits influencing crop competitive ability (Dingkuhn et al. 1999; Froud-Williams

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1997; Gaudet and Keddy 1988; Lemerle et al. 1996; Lindquist et al. 1998; Willenborg et al. 2005). However, several belowground traits can also influence competitive ability, including seminal root development, root biomass, root architecture, and root size (Dunbabin 2007; Gaudet and Keddy 1988; Pavlychenko and Harrington 1974; Rubio et al. 2003). Identifying which traits are most associated with competitive ability could help plant breeders to develop more competitive field pea cultivars. This information could also be used to derive AC and AWC values, allowing for the creation of cultivar rankings based on competitive ability that may be used to guide cultivar selection by growers and agronomists.

Typically, crop species differ in their ability to compete for resources (Loomis and Connor 1992) and in many cases, there is also variation in competitive ability among cultivars of the same crop species (Tepe et al. 2005; Watson et al. 2006; Willenborg et al. 2005). This may not be the case for field pea, however. Semileafless field pea cultivars, which occupy most of the field pea acreage across the Northern Great Plains region, are preferentially grown over leafy field pea cultivars even though they are less competitive with weeds (Harker et al. 2008; Semere and Froud-Williams 2001). Leaf area typically is a key component of a competitive crop stand because of its relationship with light capture (Loomis and Conner 1992; Radosevich et al. 2007). Semileafless field pea cultivars have a modified leaf structure wherein leaflets are replaced by tendrils and therefore they lack true leaves. On the other hand, leafy cultivars possess a leaf structure that consists of stipules, petioles, leaflets, and tendrils, all of which contribute to improved competitive ability because of increased light interception (Harker et al. 2008; Spies et al. 2011; Wall et al. 1991).

Current breeding efforts in field pea are focused on breeding for smaller seed size to reduce seed costs, despite the importance of seed size in suppressing weed interference (Willenborg et al. 2005; Xue and Stougaard 2002). Consequently, it is possible that the competitive ability of field pea may have been depressed concomitantly as plant breeders selected for small seed size. It is also plausible that variation in traits that confer competitive ability may be negligible between cultivars because of the genetic similarity between cultivars. It is important, therefore, to understand if differences in competitive ability exist among field pea cultivars and if so, to identify the traits that are conferring these differences. The objectives of this study were to determine if semileafless field pea cultivars vary in their ability to compete and withstand competition, as well as to identify aboveground trait(s) that may be associated with increased competitive ability.

Materials and Methods

Experimental Design and Location. Field experiments were conducted in 2012 and 2013 at three locations; the Kernen Crop Research Farm (52.13°N and 106.53°W) near Saskatoon, SK; the Goodale Research Farm (52.15°N and 106.53°W) near Floral, SK; and the St. Albert Research Station (53.68°N and 113.61°W) near St. Albert, AB. The Kernen site was lost to flooding in 2012 and will not be discussed further. Both Saskatchewan sites were located on a Dark Brown Chernozemic (Typic Boroll) clay soil with a pH and soil organic matter content ranging between 6.4 to 6.6 and 2.1 to 2.8%, respectively. The Alberta site was located on an Orthic Black Chernozemic (Udic Boroll) clay–loam soil with a pH of 6.6 to 7.4 and soil organic matter content varying from 10 to 10.7%. All plots were established on wheat or barley stubble.

The experiment was designed as a split-block with four replicates per treatment. Main blocks consisted of weedy and weed-free treatments, whereas subplots were comprised of 14 semileafless field pea cultivars from four different market classes (green, yellow, dun, forage) (Table 1). This resulted in 28 experimental units (treatments) in each replicate, with a subplot (field pea cultivar) size of 2 by 7 m. Subplots were arranged in a randomized complete block design within each main block. The weedy half of each block was sown with imidazolinone-resistant spring wheat (cv. CDC Imagine) and canola (cv. 45H73) at target densities ranging between 20 and 25 plants m^{-2} for each species. The imidazolinone-resistant crops were used as model weeds, enabling the removal of all other weeds and providing uniform weed densities across the experiment. Seeding rates of the model weeds were adjusted based on germination tests and an assumed mortality of 20% for wheat and 50% for canola. Model weeds were sown at a depth of 2 cm by cross seeding them over the appropriate main plot immediately after the peas were sown.

The plot area at all sites received an application of 900 g ae ha^{-1} of glyphosate before or immediately after sowing to control emerged weeds. Field pea seed was treated before sowing with a seed treatment containing 15.59% carbathiin and 13.25% thiram at a rate of 300 ml 100 kg^{-1} of seed. Field peas were sown at a depth of 5 cm and at a target plant density of 75 plants m^{-2}. The Saskatchewan sites were sown

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Table 1. Cultivars and their classification based on vine length and seed size. Adapted from the Alberta Seed Industry Partnership (2010) and Saskatchewan Ministry of Agriculture (2012).

		Vine length		Seed size	
Cultivar	Market class	cm	Classification	g/1,000	Classification
CDC Mozart	Yellow	61	Short	241	Large
CDC Meadow	Yellow	76	Tall	221	Medium
Cutlass	Yellow	68	Medium	233	Medium
Reward	Yellow	76	Tall	248	Large
SW Midas	Yellow	66	Medium	213	Small
CDC Centennial	Yellow	61	Short	259	Large
CDC Patrick	Green	79	Tall	201	Small
Camry	Green	57	Short	258	Large
Cooper	Green	71	Medium	280	Large
CDC Sage	Green	71	Medium	199	Small
CDC Striker	Green	66	Medium	244	Medium
Stratus	Green	55	Short	260	Large
CDC Dakota	Dun	85	Tall	205	Small
CDC Leroy	Forage	95	Tall	150	Small

with a small plot drill with the use of disk openers on a row spacing of 23 cm, whereas the Alberta sites were sown with a small plot drill with hoe openers on 20-cm row spacing. Soil at both sites was inoculated with granular *Rhizobium leguminosarum* (4.6 kg ha^{-1}), and monoammonium phosphate fertilizer was applied with the seed at rates based on soil test recommendations. In-crop weed control was achieved by applying a premix formulation of imazamox + imazethapyr (1 : 1) with Merge® adjuvant at 43 g ai ha^{-1} and 0.5% v/v, respectively, across the entire plot area at the four- to six-node stage of crop growth. Any weeds remaining after the in-crop herbicide application were removed by hand. Plots at both sites received fungicide and insecticide applications as necessary.

Vine length was measured as the distance from the soil surface to the top of the apical meristem for five randomly selected, flowering plants in each plot. Leaf-area index (LAI) was also determined at flowering by selecting plants in a 0.125 m^{-2} area, removing the leaves from these plants and scanning them with a leaf-area meter. In 2013, the petioles and tendrils were also included in this measurement. Field pea and model weed aboveground biomass was determined by cutting all aboveground plant material at the soil surface from two, 0.25-m^{-2} areas in each plot. The crop and model weeds were then separated, placed in individual paper bags, dried at 80°C for 72 h and weighed.

Plots at the Alberta site were harvested using hand sickles to cut a 1.5-m^{-2} quadrat in each plot. Samples were placed into cloth bags, dried at 80°C for 96 h and threshed in a stationary threshing machine. In 2012, the St. Albert site received hail damage just prior to harvest and consequently, a 0.25-m^{-2} quadrat from each plot was vacuumed from the soil surface and weighed to account for any potential harvest losses. Plots at the Saskatchewan sites were desiccated with diquat (420 g ai ha^{-1}) and subsequently harvested with a small plot combine that threshed a 6.58-m^{-2} area from each plot. Seed at all sites was dried to a constant moisture of 16%, weighed, and cleaned with a dockage tester to obtain a clean yield and also, to separate the model weed seed from the crop. Thousand-seed weight (TSW) was obtained for each plot by counting 250 seeds, weighing them and multiplying by a factor of four. With the use of the yield and dockage data, ability to withstand competition (AWC) was calculated as

$$AWC = 100^{*}\left(Y_{wp}/Y_{wfp}\right) \qquad [1]$$

where Y_{wp} is the field pea yield from the weedy plot and Y_{wfp} is the field pea yield from the weed-free plots. Ability to compete (AC) was calculated as

$$AC = 100 - \%\ dockage \qquad [2]$$

where percent dockage represents % the percentage of pseudo weed seed (canola and wheat) in each field pea sample. The AWC value measures crop tolerance to weed interference, and AC measures the crop's ability to reduce weed seed production (Watson et al. 2006).

Statistical Analysis. Residuals were tested to ensure that they met the assumptions of ANOVA. PROC UNIVARIATE was used to assess normality, whereas Levene's test was used to confirm the homogeneity of error variances. Where residuals did not conform

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Table 2. P values for field pea vine length, leaf-area index (LAI), petiole and tendril area (PTA), crop and model weed biomass, and crop and model weed seed production from three and two site years in Saskatchewan (SK) and Alberta (AB), respectively in 2012 and 2013.

Source	Vine length		Leaf area index		Petiole and leaf tendril area[a]		Crop biomass		Weed biomass		Crop yield		Model weed seed yield	
	SK	AB	SK	AB	SK	AB	SK	AB	SK	AB	SK	AB	SK	AB
	cm				cm^2		kg ha^{-1}							
Cultivar (CU)	< 0.001	< 0.001	0.022	0.977	0.034	0.149	0.001	0.125	0.173	0.279	0.001	0.154	0.029	0.277
Competition (CO)	0.965	0.862	0.247	0.146	0.096	0.199	0.019	0.561	NA[b]	NA	0.071	0.241	NA	NA
CU by CO	0.613	0.968	0.685	0.745	0.917	0.857	0.663	0.116	NA	NA	0.089	0.177	NA	NA
Year (Y)	0.246	0.361	0.216	0.234	0.369	NA	0.199	0.401	0.309	0.369	0.278	0.227	0.365	0.372
Y by CU	0.015	0.096	0.075	0.06	0.441	NA	0.451	0.424	0.232	0.241	0.061	0.301	0.451	0.068
Y by CO	0.100	0.167	0.126	0.195	0.259	NA	0.223	0.163	NA	NA	0.149	0.163	NA	NA
Y by CO by CU	0.222	0.152	0.323	0.237	0.222	NA	0.216	0.209	NA	NA	0.235	0.316	NA	NA

[a] Data are from 2013 only.
[b] Abbreviation: NA, not applicable.

to the assumptions of ANOVA, data were $\log_{10}$ transformed (petiole and tendril area at SK sites). All transformed data were backtransformed prior to presentation. Analysis of variance (ANOVA) was performed using the PROC MIXED procedure of SAS (SAS Institute 2011). Semi-leafless field pea cultivars and the competition treatment (presence/absence of weeds) were considered fixed effects in the statistical model, whereas random effects consisted of block nested within sites, years, and the combinations of sites and years by fixed effects interactions. Random effects were examined using the COVTEST option of PROC MIXED to determine if the sites and years could be combined. Because of significant site-by-treatment interactions, data were pooled across years within each province. Means separation was performed with the use of a Fisher's Protected LSD test at $P < 0.05$. Correlations were performed using the Spearman method of PROC CORR to assess the relationships between aboveground traits. Single degree of freedom contrasts were calculated using ESTIMATE statements in SAS to compare means among market classes (green vs. yellow) of semileafless field pea cultivars.

Results and Discussion

Competitive Traits. Leaf-area index (LAI) and vine length were significantly different among cultivars at the SK sites, but LAI did not differ at the AB sites (Table 2). Camry, Reward, Cutlass, and CDC Dakota exhibited a lower LAI than CDC Meadow and CDC Striker (Table 3). The difference between the cultivar with the greatest LAI (CDC Striker) and least LAI (Camry) was 38%. CDC Dakota and CDC Sage also had longer vine lengths than CDC Centennial, CDC Mozart, Stratus, and Camry (data not shown). Significant differences in petiole and tendril area were also observed between cultivars at the SK sites (Table 2), where the difference between the cultivar with the greatest (CDC Dakota) and least (Stratus) petiole and tendril area was 58% (Table 3).

Field pea shoot biomass was reduced (37%) in the presence of weeds at SK, although no effect of weed competition was detected at AB (Table 2). CDC Striker produced more shoot biomass than all other cultivars except CDC Dakota and CDC Sage (Table 3). Collectively, these three cultivars produced greater shoot biomass than most of the other cultivars, regardless of weed competition. The high shoot biomass production observed for CDC Striker may be due, in part, to a very high LAI (Table 3). Similarly, large differences in seed yield were observed for field pea at the SK sites, irrespective of weed competition (Table 2). For example, CDC Dakota (4598 kg ha-1) produced 48% more seed yield than Reward (3,107 kg ha-1), the highest- and lowest-yielding cultivars, respectively (Table 3). Interestingly, CDC Dakota, which had a low LAI compared to other cultivars, was the highest-yielding cultivar in both years at the SK sites. No significant differences in crop yield were observed between cultivar and weed competition, or their interaction at the AB sites (Table 2).

Model weed seed yield differed between cultivars at the SK sites, but was not affected by cultivars at the AB sites (Table 2). Model weed seed yield varied widely among field pea cultivars, as cv. Reward exhibited 70% higher (1,196 kg ha^{-1}) weed seed production compared with CDC Dakota (700 kg ha^{-1}) (Table 3). Model weed seed production was greatest in the cultivars CDC Mozart, SW Midas, Camry, and Stratus. Model weed biomass was not affected by field pea cultivars (Table 2).

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Table 3. Effect of pea cultivar on leaf area index, pea and leaf tendril area, crop biomass, crop seed yield and model weed seed yield from 3 Saskatchewan sites in 2012 and 2013. Similar letters indicate no significant difference based on $LSD_{0.05}$.

Cultivar	Leaf area index	Pea and leaf tendril area[a]	Shoot biomass	Crop seed yield	Model weed seed yield
		cm^2	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
CDC Mozart	2.23 bcde	819.4 bcd	5,788 bcd	3,467 ef	990 abc
CDC Meadow	2.59 ab	843.3 bcd	5,866 bcd	4,250 abc	776 cd
Cutlass	2.00 cde	872.6 bcd	5,290 de	3,751 cde	941 bcd
Reward	1.84 de	905.5 abcd	4,761 e	3,107 f	1,196 a
SW Midas	2.07 bcde	825.8 cd	5,878 bcd	3,874 bcde	993 abc
CDC Centennial	2.29 bcd	1,154.5 ab	6,117 bc	3,834 cde	892 cd
CDC Patrick	2.44 abc	1,167.3 abc	5,836 bcd	4,409 ab	859 cd
Camry	1.75 e	835.8 bcd	5,407 cde	3,455 ef	998 abc
Cooper	2.45 abc	1,237.9 a	5,420 cde	4,120 abcd	840 cd
CDC Sage	2.25 bcde	957.2 abcd	6,333 ab	3,615 def	949 abcd
CDC Striker	2.82 a	1,072.3 abcd	7,134 a	3,887 bcde	860 cd
Stratus	2.17 bcde	796.5 d	5,166 de	3,386 ef	1,163 ab
CDC Leroy	2.12 bcde	847.8 bcd	5,167 de	4,217 abc	907 cd
CDC Dakota	2.03 cde	1,260.1 a	6,559 ab	4,598 a	700 d
$LSD_{0.05}$	0.52	303.6	812	545	250

[a] Data are from 2013 only.

Our results showed that field pea competitive traits varied between sites, but were consistent across years. This may be because of variations in soil properties and environmental conditions between the AB and SK sites. For example, soil organic-matter content at AB was approximately three- to five-fold greater than SK sites; precipitation events also differed at the sites throughout the growing season. These differences could have led to greater expression of traits at some sites, as cultivars may respond differently to various climatic conditions (Cousens and Mokhtari 1998). Nevertheless, similar trends in data across sites and the ability to combine the data across years suggests that field pea competitive traits are generally consistent across cultivars regardless of site or environmental properties. This is important because variations across locations can result in a lack of congruence in identifying traits responsible for competitive ability (Andrew et al. 2015; Cousens and Mokhtari 1998).

Results from this study indicated that competition from model weeds did not significantly reduce field pea yield when compared to the pea monoculture. We suspect that this may be an artifact of the statistical design, in which weed competition was the main plot in a split-block design. With only one degree of freedom for comparing the effect of competition, there may not have been sufficient statistical power to detect significant differences. Indeed, previous research has shown that field pea is usually sensitive to weed densities. Wall et al. (1991) noted that a wild mustard density of 20 plants m^{-2} reduced field pea yield by as much as 35%. Field pea yield losses of up to 26% were reported in a canola–wheat mixture of 50 plants m^{-2} (Spies et al. 2011). Although we targeted the same density as Spies et al. (2011), actual model weed densities in this study were approximately 65 to 85% of those targeted. Thus, it is possible that results of this study were influenced by lower than anticipated model weed densities.

Competitive Indices. Ability to withstand competition (AWC) differed among cultivars at SK but not at AB. CDC Centennial, CDC Mozart, CDC Patrick, CDC Sage, and CDC Striker exhibited greater AWC values than most of the other cultivars, indicating that they were better able to withstand the presence of competitors (Table 4). Values for AWC ranged from 91 to 62, representing a yield loss of 9 to 38% and a factor of approximately 1.5X, separating the most-able from the least-able cultivar to withstand competition.

Differences in AC were only detected among cultivars at SK. CDC Dakota, CDC Patrick, CDC Meadow, and Cooper were the strongest at suppressing model weed seed production, while Stratus and Reward were the weakest, with the remaining cultivars intermediate to these (Table 4). AC values ranged from 86 to 69 (14 to 31% seed return) for CDC Dakota and Reward, respectively, which indicates that CDC Dakota was 25% more weed-seed suppressive than Reward. Although values did not differ significantly at the AB sites, Sage and CDC Striker also exhibited a high AWC, whereas CDC Dakota exhibited a high AC value (Table 4).

Taken together, these data show that SW Midas, Camry, Stratus, and Reward consistently ranked among the lowest for both AWC and AC (Table 4;

Table 4. Mean values for ability to withstand competition (AWC) and ability to compete (AC) for field pea cultivars grown in Saskatchewan (SK) and Alberta (AB) in 2012 and 2013.

	SK				AB		Mean	
Cultivar	AWC Value	Rank	AC Value	Rank	AWC Value	AC Value	AWC Value	AC Value
CDC Dakota	73	7	86	1	87	97	80	92
CDC Patrick	81	3	83	2	66	95	74	89
CDC Meadow	72	8	83	3	80	96	76	90
Cooper	71	10	82	4	64	92	68	87
CDC Centennial	91	1	82	5	75	94	83	88
CDC Striker	76	5	81	6	95	98	86	90
CDC Leroy	71	9	81	7	66	95	69	88
Cutlass	75	6	80	8	63	94	69	87
CDC Sage	78	4	79	9	96	97	87	88
CDC Mozart	88	2	78	10	57	96	73	87
SW Midas	69	13	77	11	63	95	66	86
Camry	69	12	75	12	63	93	66	84
Stratus	71	11	73	13	83	92	77	83
Reward	62	14	69	14	57	93	60	81
Mean	75		79		73	95	74	87
LSD (0.05)	15		5		NS[a]	NS		

[a] Abbreviation: NS, not significant.

Figure 1A). In fact, Reward was clearly the least competitive of the cultivars studied, exhibiting the lowest AWC and AC values of all cultivars across nearly all sites and years (Figure 1). CDC Centennial and CDC Patrick consistently ranked among the most competitive of the cultivars included in this study, exhibiting high AWC and AC values (Table 4; Figure 1). The observed differences in competitive ability were not due to market class, as single degree of freedom contrasts did not detect significant differences in AWC ($P = 0.532$) or AC ($P = 0.427$) values between yellow and green seed coat colors. Likewise, differences also were not due to associations with specific traits, as none of the correlations between crop yield, weed seed production or other competitive traits were strong in magnitude (> 0.7; Fox et al. 1997), despite being statistically significant (Table 4). This may be an indication that competitive ability cannot be attributed to a single trait in field pea, as has been acknowledged in other crops (Lemerle et al. 1996; Mennan and Zandstra 2005; Watson et al. 2006). It is also possible, however, that the traits most important to field pea competitive ability were not measured in this study, and that competition belowground is more important to cultivar competitive ability than are aboveground traits.

The results of this study demonstrate that competitive differences exist between semileafless field pea cultivars, although the differences were small in magnitude. Based on AC and AWC values, our data show that CDC Dakota, CDC Centennial, CDC Patrick, and CDC Meadow ranked among the best for model weed seed suppression, although they did not consistently exhibit the greatest AWC values. Growers would be well advised to choose any of these cultivars if competition from weeds was expected to be substantial. On the other hand, Camry, Stratus, and Reward were consistently less competitive than most other cultivars (Table 4; Figure 1) and these cultivars should not be recommended if weed competition is expected. If growers select any of these

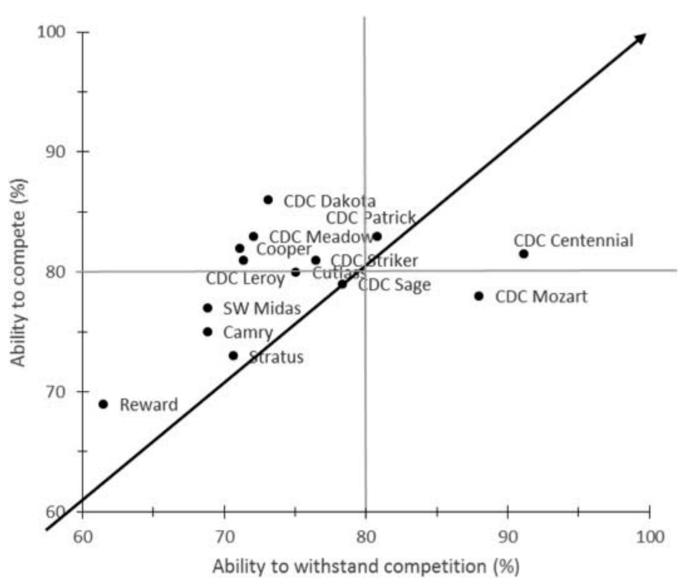

Figure 1. Scatterplot of ability to compete (AC) versus ability to withstand competition (AWC). Data are averaged across all site-years in Saskatchewan. The arrow points in the direction of increasing competitive ability. Gray lines represent (1) on the *x* axis (AWC), 20% yield loss and (2) on the *y* axis (AC), 20% model weed seed yield.

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Table 5. Spearman's correlation coefficients and *P* values for leaf-area index, petiole and tendril area, vine length, crop biomass, weed biomass, crop thousand seed weight, crop yield, weed seed yield, ability to withstand competition (AWC), and ability to compete (AC) at Saskatchewan and Alberta in 2012 and 2013.[a]

	Leaf area index	Petiole and tendril area	Vine length	Shoot biomass	Weed biomass	1000 seed weight	Crop yield	Weed seed yield	AWC
		cm^2	cm	kg ha^{-1}	kg ha^{-1}	g	kg ha^{-1}	kg ha^{-1}	
	Saskatchewan								
Leaf area index	1								
Petiole and tendril area	0.74***	1							
Vine length	0.41***	0.22*	1						
Crop biomass	0.32***	0.36**	0.21***	1					
Weed biomass	−0.36***	−0.10 NS	−0.37***	−0.38***	1				
1000 seed weight	−0.18**	0.09 NS	−0.59***	−0.10 NS	0.28**	1			
Crop yield	0.41***	0.48***	0.34***	0.41***	−0.50***	−0.13*	1		
Weed seed yield	−0.33***	−0.01 NS	−0.47***	−0.52***	0.76***	0.045***	−0.51***	1	
AWC	0.40***	0.25 NS	0.35***	0.32***	−0.51***	−0.16*	0.60***	−0.54***	1
AC	0.44***	0.23 NS	0.54***	0.48***	−0.76***	−0.43***	0.70***	−0.94***	0.62***
	Alberta								
Leaf area index	1								
Petiole and tendril area	0.69***	1							
Vine length	0.06 NS	−0.01 NS	1						
Crop biomass	0.04 NS	0.22*	−0.32***	1					
Weed biomass	0.02 NS	−0.06 NS	0.52***	−0.76***	1				
1000 seed weight	−0.09 NS	0.11 NS	−0.05 NS	−0.10 NS	0.19 NS	1			
Crop yield	0.16*	0.31**	−0.08 NS	0.54***	−0.54***	0.22***	1		
Weed seed yield	0.11 NS	−0.10 NS	0.29**	−0.57***	0.52***	0.34***	−0.46***	1	
AWC	−0.13NS	0.14 NS	−0.41***	0.69***	−0.61***	−0.16NS	0.75*	−0.56***	1
AC	−0.01NS	0.04 NS	0.26**	0.11 NS	−0.15 NS	−0.23*	0.25**	−0.69***	0.15NS

[a] NS indicates not significant.
* Significant at the 0.05 probability levels.
** Significant at the 0.01 probability levels.
*** Significant at the 0.001 probability levels.

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poorly competitive cultivars for production, cultivar mixtures represent a potential option to improve their ability to compete with weeds (Darras et al. 2015).

We found that there was often little relationship between AC and AWC, and cultivars that were ranked highly for one metric frequently ranked poorly for the other. Consequently, it is difficult to identify a single cultivar that was clearly and consistently better able to tolerate and withstand competition. This is consistent with previous research by Harker et al. (2008) and Spies et al. (2011), who reported that the highest-yielding field pea cultivars under weed competition were not necessarily the highest yielding cultivars under weed-free conditions. However, conclusions drawn by Harker et al. (2008) and Spies et al. (2011) were based on comparisons between semi-leafless and leafy field pea cultivars. The current study is the first to include only semileafless cultivars and to document differences in competitive ability. These findings are relevant to growers on the Northern Great Plains, who almost exclusively grow semileafless cultivars.

The lack of varietal consistency observed in this study for AC and AWC values may not be surprising given that correlations between AC and AWC were not significant at the AB sites, and were low and only moderately significant at the SK sites. While the reasons for this remain unclear, it could mean that AC and AWC are driven by different mechanisms. Because AC and AWC are surrogates for competitive effect and response, our data suggest that competitive response and effect are not "two sides of the same coin" as purported by Wang et al. (2010), and should indeed be considered separate entities as contended by Andrew et al. (2015). This concurs with other studies, many of which have also reported that different mechanisms may be responsible for competitive response and competitive effect (Goldberg and Landa 1991; Keddy et al. 1994; Lamb et al. 2007; Miller and Werner 1987). Competitive response could be a function of aboveground mechanisms such as those demonstrated by Afifi and Swanton (2011), who noted that low-red to far-red light ratios reflected from neighboring weeds influenced the light quality intercepted by maize plants. In contrast, competitive effect may be more highly influenced by root volume or other traits related to stress resistance or resource acquisition (Wang et al. 2010).

Strong correlations in this study were detected between AC and weed seed production (−0.69 at AB, −0.94 at SK; $P < 0.001$), as well as between AWC and field pea crop yield (0.75 at AB, 0.60 at SK; $P < 0.001$) (Table 5). This is not surprising, considering that a high AC value should be indicative of a variety that smothers weeds and thus minimizes weed growth. Likewise, cultivars with a high AWC should withstand competition and thus produce higher yields even in the presence of weeds. Such strong correlations show that AC and AWC are good metrics for determining field pea competitive ability and can be used by breeders as selection criteria to improve competitive ability. Published cultivar rankings would require breeders to include competitive ability in variety trials and in seed guides to help growers to select competitive cultivars. As suggested by Watson et al. (2006), publishing AWC and AC rankings separately would be beneficial in various production systems. AWC would be suitable in a conventional (high input) production system, as crop yield is important and the use of herbicides and other agronomic practices helps to minimize the impact of competition from weeds and to reduce weed seed return. In organic (low input) crop production systems, where minimizing weed seed return can be as important as crop yield, AC would be a critical metric for competitive cultivars.

In conclusion, semileafless field pea cultivars assessed in this study exhibited variation in competitive ability; however, competitive differences were only observed at the SK sites. CDC Dakota, CDC Patrick, and CDC Meadow were the top cultivars in their ability to compete (AC), while CDC Centennial, CDC Mozart, and CDC Patrick exhibited a high ability to withstand competition (AWC). Reward consistently ranked lowest for both metrics. None of the aboveground traits measured in this study were strongly correlated with the competitive metrics, implying that multiple traits are working in conjunction or other mechanisms not measured in the current study must underlie competitive ability in field pea.

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