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Competitive ability of western Canadian spring wheat cultivars in a model weed system

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Abstract

Economic and social pressures are spurring the study of alternate weed management strategies such as the development of competitive crop cultivars, capable of being used under an integrated management plan. The primary objective of this research was to determine whether western Canadian spring wheat (*Triticum* spp.) cultivars differ in their ability to compete against model weeds and whether those differences were expressed when challenged with wild weeds. A total of 71 wheat cultivars were grown in the absence or presence of simulated [cultivated oat (*Avena sativa* L.) and oriental mustard (*Brassica juncea* L.)] or natural [wild oat (*Avena fatua* L.)] weed competition conditions. Significant ($p = 0.01$) weed by cultivar interactions involving changes in yield cultivar rank were detected, indicating that the cultivars responded differently to competition. A small minority of cultivars such as Glenlea, CDC Rama, Genesis, AC Taber, AC Vista, Plenty, Napoleon, and BW652 had high-yield potential coupled with yield maintenance under weed pressure. The competitive ability advantage appeared to be associated with plant height or tillers per square meter as well as shorter vernalization requirement combined with photoperiod sensitivity. These outlier cultivar differences could be exploited in breeding new widely adapted varieties for scenarios where reduced herbicide weed control is desired, including situations where herbicide resistance limits chemical options. Cultivars with differing competitive ability under model weed conditions maintained their ranking when challenged by natural weed infestations. This suggests that selecting competitive spring wheat cultivars using a repeatable protocol based on model weeds is realistic.

Key words: western Canadian spring wheat, weed control strategies, competitive ability, model weed system, *Triticum aestivum* L

Résumé

Sous l'effet des contraintes économiques et sociales, on envisage de nouvelles méthodes pour combattre les mauvaises herbes, tel le développement de cultivars compétitifs, dont on pourrait se servir dans le cadre d'un programme de lutte intégrée. Les auteurs voulaient déterminer si la capacité de concurrencer les plantes servant de modèle aux adventices varie avec les cultivars de blé de printemps (*Triticum* spp.) utilisés dans l'Ouest canadien et si ces variations s'expriment toujours quand le blé doit concurrencer les adventices sauvages. À cette fin, ils ont cultivé 71 variétés de blé avec ou sans la concurrence de simulacres d'adventices [avoine (*Avena sativa* L.) et moutarde d'Inde (*Brassica juncea* L.)] ou d'adventices naturelles [folle avoine (*Avena fatua* L.)]. Les auteurs ont relevé des interactions sensibles ($p = 0,01$) entre les mauvaises herbes et la culture, notamment une modification dans le classement de la variété d'après son rendement, signe que les cultivars ne réagissent pas tous de la même façon à la concurrence des mauvaises herbes. Bien que peu nombreuses, les variétés comme Glenlea, CDC Rama, Genesis, AC Taber, AC Vista, Plenty, Napoleon et BW652 combinent un rendement potentiel élevé et la stabilité du rendement sous la pression engendrée par les adventices. Cet avantage semble lié à la hauteur du plant ou au nombre de talles par mètre carré, de même qu'à une vernalisation plus rapide, combinée à la sensibilité à la photopériode. Ces cultivars d'exception pourraient servir à créer de nouvelles variétés mieux adaptées quand on souhaite réduire l'usage des herbicides ou que la tolérance aux herbicides restreint les possibilités sur le plan chimique. Les cultivars dont la compétitivité diffère lors de la modélisation conservent leur place au classement quand on les teste avec une population naturelle d'adventices. On en déduit qu'il serait réaliste de sélectionner des variétés de blé de printemps compétitives en recourant à un protocole reproductible qui modélise les mauvaises herbes. [Traduit par la Rédaction]

Mots-clés : blé de printemps de l'Ouest canadien, méthodes de lutte contre les adventices, compétitivité, modélisation des mauvaises herbes, *Triticum aestivum* L.

Introduction

The concept of sustainable agriculture is, in part, based on reducing inputs. Herbicides are the primary method of weed control in spring wheat and represent a major investment for wheat producers. Three decades ago, herbicide use in western Canadian wheat production was estimated to cost roughly $150 million per annum while yield reductions due to uncontrolled weeds resulted in a further $200 to $1000 million in lost revenue annually (Ashford and Hunter 1986; Holm and Kirkland 1986). Currently, the cost of pesticides used in western Canadian agriculture is $2224 million, where herbicides accounted for 72.9% of agricultural sector pesticide sales (Health Canada 2018). In light of economic and social pressures and the buildup of herbicide-resistant weeds, there is a need for alternate weed control strategies. One of these strategies consists of raising the crop's level of competitiveness against weeds (Richards 1989). The increased interest in selecting highly competitive wheat genotypes has been reviewed in detail by Lemerle et al. (2001) and Mason and Spaner (2006).

Cultivars that are better suited for production in systems that do not use conventional weed control (e.g., organic crop production) or rely on an integrated weed management (IWM) approach are desirable. An IWM approach involves the use of diverse types of information and a variety of control tactics including the use of more competitive cultivars to develop strategies for subjecting weeds to multiple, temporally variable stresses (Liebman and Gallandt 1997; Hucl 1998). Concerted breeding efforts over the last 90 years to develop disease and insect resistant spring wheat cultivars have helped reduce input costs for producers in western Canada. A similar approach could be used for developing wheat cultivars better able to compete against weeds. Genotypic differences in the ability to suppress weeds have been reported in wheat (Challaiah et al. 1986; Richards 1989). Differences in competitive ability have been associated with early seedling vigor, height, tillering ability, leaf length and spread, ground cover, and nutrient uptake efficiency. Evidence suggests that high-yielding semidwarf cultivars of wheat are more susceptible to yield losses due to weed interference than standard height cultivars (Kirkland and Hunter 1991). Huel and Hucl (1996) reported a 40% difference in the competitive ability of morphologically diverse experimental spring wheat genotypes subjected to competition from model weeds.

Domesticated species are frequently used as model weeds instead of their wild counterparts (Huel and Hucl 1996). They are usually crop species that are related to wild weed species of interest, providing a genetically uniform, even-aged cohort, and assuring uniform spatial distribution and densities (Sanchez 2021). In contrast to weedy species that often exhibit low and unreliable germination rates and high rates of seed dormancy, domesticated model weeds exhibit high viability, rapid and uniform germination, and reliable establishment, improving the efficiency of experimental research (Smith et al. 2015).

The primary objective of this research was to determine whether spring wheat cultivars differ in their ability to compete against model weeds. Second, we wanted to examine whether the competitive ability rankings of cultivars obtained by using model weeds translate into cultivar differences when challenged with wild weeds.

Materials and methods

Four experiments were conducted to quantify the competitive ability of western Canadian spring wheat cultivars (*Triticum aestivum* L.) against weeds. In the first three experiments, the competitive ability was tested using cultivated oat (*Avena sativa* L.) and oriental mustard (*Brassica juncea* L.) as model weeds, while in the fourth experiment wheat cultivars were challenged with wild oat (*Avena fatua* L.) that was indigenous to the soil seed bank. Model weeds were sown slightly shallower to avoid mixing by the seeder and perpendicular to wheat rows. The nonweedy plots were driven over with the seeder in the ground to provide equal soil packing and disturbance for both, weedy and nonweedy treatments. All experiments were established on fallow land.

In Experiment#1, 17 spring wheat and two barley (*Hordeum vulgare* L.) cultivars were evaluated over a 4-year period (1991–1994) at the University of Saskatchewan's Seed Farm (SF), on a Bradwell clay loam soil (Table S1). Barley has long been recognized to be more competitive than wheat (Pavlychenko and Harrington 1934); hence, it was included in the experiment as control. Field trials were sown in replicated plots on the 17th, 5th, 7th, and 12th of May in 1991, 1992, 1993, and 1994, respectively. Each plot consisted of five rows spaced 0.2 m apart and 3.6 m long, with a target wheat seeding rate of 250 seeds m^{-2}. Fertilizer (11–51-0) was drilled in with the wheat seed at a rate of approximately 50 kg ha^{-1}. The oat and oriental mustard cultivars "Morgan" and "Cutlass", respectively, were cross-seeded over half of each replication plot (randomly assigned), using a seeding rate of 40 seeds m^{-2} (1991) and 80 seeds m^{-2} (1992, 1993, and 1994). The herbicide Buctril M (Bayer Crop Science Inc., Calgary, AB, Canada) was applied perpendicular to each replication (block) to eliminate weeds, primarily redroot pigweed (*Amaranthus retroflexus*), from the control (nonweedy) half of each plot when the wheat reached the four-leaf stage. The herbicide solution was applied using an application rate of 100 L ha^{-1} with 560 g a.i. ha^{-1} (280 g a.i. ha^{-1} bromoxynil + 280 g a.i. ha^{-1} 2-methyl-4-chlorophenoxyacetic acid (MCPA), respectively). Monocot weeds were present at trace levels in the research fields used for this experiment and the two subsequent ones.

In Experiment#2, 28 spring wheat, five durum (*Triticum turgidum* var. *durum* L.) and one spring spelt (*T. aestivum* spelta group) cultivars were evaluated along with two barley cultivars at SF, Saskatchewan, during 1995 and 1996 (Table S1). Field trials were sown in replicated plots on 6 and 10 May, respectively. The oat and oriental mustard cultivars "Waldern" and "Cutlass" were used as model weeds. Instead of cross-seeding across each 3.6 m long plot, back-to-back weedy versus nonweedy 3.6 m-length plots were seeded within a replication and the weeds seeded across one of the blocks, using a seeding rate of 48 seeds m^{-2}. The position of the weedy versus nonweedy blocks was randomized within replications (i.e., front versus back), but cultivars were stripped across weedy versus nonweedy treatments. Fertilization and weed control (nonweedy blocks) practices were carried out in the same way as described for Experiment#1.

In Experiment#3, 40 spring wheat, five durum and one spring spelt cultivars were evaluated along with a single triticale (x Triticosecale Wittmack.) and a single barley cultivar in each of 3 years (2004–2006) at the Kernen Crop Research Farm (KCRF), Saskatchewan, on a Sutherland clay loam soil (Table S1). Field trials were sown on 25, 26, and 23 May of 2004, 2005, and 2006, respectively, using a wheat seeding rate of 300 seeds m^{-2}. As in Experiment#2, the oat and oriental mustard cultivars "Waldern" and "Cutlass" were used as model weeds but using a seeding rate of 55 seeds m^{-2} for each of the weed species. Fertilization and weed control (nonweedy blocks) practices were carried out in the same way as described in the two previous experiments.

In Experiment#4, eight spring wheat cultivars were evaluated at two sites, KCRF and Agriculture and Agri-Food Canada's Scott Research Farm (SRF) at Scott, Saskatchewan in 1995 and 1996 (Table S1). Cultivars were sown on 4 and 17 May 1995 and 24 May 1996 at the KCRF and SRF, respectively. The plot size was 4 m × 6 m (1995) or 2 m × 6 m (1996) at the SRF and 4.5 m × 6 m at the KCRF with 0.20 m (SRF) and 0.18 m (KCRF) spacing between rows and a seeding rate of 250 seeds m^{-2}. The herbicides Horizon (clodinafop-propargyl (240 g/L)) (Syngenta Canada, Guelph, ON, Canada) and Buctril M were used at both sites to eliminate weeds (wild oat, redroot pigweed, and green foxtail (*Setaria viridis* L.) from half of each replication (nonweedy blocks) with a dose of 56 and 560 g a.i. ha^{-1} (280 g a.i. ha^{-1} bromoxynil + 280 g a.i. ha^{-1} MCPA), respectively. One glyphosate application prior to crop emergence was used at the KCRF in 1995 to curb an excessively high (>1000 plants m^{-2}) wild oat indigenous to the seed bank. Fertilizer (11–52-0) was drilled in with the wheat seed at a rate of approximately 40 kg ha^{-1}. The plant introduction (PI) numbers and (or) cultivar descriptions of materials used in this study have been cited elsewhere (Matus-Cadiz et al. 2008; McCallum and DePauw 2008).

The assessed phenotypic traits and experiments in which they were examined are summarized in Table S2. Days to spike emergence (DSE) were recorded as the number of days from planting until 50% of the spikes in each plot had completely emerged above the flag leaves (Zadoks' Growth Stage 58; Zadoks et al. 1974); days to physiological maturity (DPM) were recorded as the number of days from planting until 50% of the peduncles in each plot had turned yellow (Zadoks' Growth Stage 92); plant height was recorded as the average of three values for each plot measured in centimeter from the soil surface to the tip of the spike excluding awns. The seedling establishment of model weeds and crop cultivars was determined for one 0.41 m^{-2} quadrat per plot when the wheat reached the two-leaf stage. The location of the quadrat was marked, and tiller and spike counts were taken in the same area when wheat reached the flag leaf and physiological maturity stages, respectively. Leaf area index (LAI) and mean leaf tip angle (MTA) were measured in the weed-free control plots using a LI-COR LAI-2000 Plant Canopy Analyzer (LI-COR, Lincoln, NE, USA) (Welles and Norman 1991). The LAI-2000 measures the attenuation of diffuse sky radiation at five zenith angles simultaneously with an optical sensor and calculates LAI and MTA as a measure of how the leaves are oriented (LICOR 1992). Measurements made above and below the canopy are used to determine canopy light interception, from which the LAI and MTA of the foliage are then computed using a mathematical inversion of a model for radiation transfer in vegetation canopies (Perry et al. 1988). Wild oat and wheat biomass samples were collected in 0.5 m^{-2} quadrats when the wheat reached the physiological maturity stage and are expressed on a fresh weight basis. At maturity, the central portion (1.2 m) of each plot was harvested by running a plot combine perpendicularly down each field block to remove the area where the weedy and nonweedy treatments intersected. The remaining portions of each plot (weedy and nonweedy) were measured (1.0–1.1 m in length). Grain samples were run over a 26-hole riddle and a 5/64 round sieve in a Carter-Day dockage tester (Model C-XT2, Simon-Day Ltd., Winnipeg, MB). The air flow was set to remove a maximum amount of chaff without removing any mustard seed. The wild oat was separated by the riddle, with the wheat going through the riddle and the wild oat going over the top. The riddle did not remove all the wild oat seed; therefore, we had to estimate the remaining oat in the sample. We did this by taking a 200 g subsample for each plot, separating the wild oat manually, and calculating the percentage of wild oat in the 200 g sample and applying that percentage to the whole sample. The wild mustard (*Sinapsis arvensis L.*) and other weed seeds were then separated by the 5/64 round sieve.

A randomized complete block design in a strip plot arrangement was used for experiments 1, 2, and 3, while a split plot design was used for experiment#4. In the first three experiments, the main plot (horizontal stripping) was assigned to weed treatments (presence versus absence) and the subplot to cultivars, while in experiment#4 the main plot was the weed treatments (weedy and nonweedy blocks) and the subplot to cultivars. The number of replications was r = 4 (Experiments 1 and 4 SRF), r = 6 (Experiments 2, 3, and 4 KCRF). For Experiments 1, 2, and 3, the measurements on the wheat cultivars, other than grain yield, were carried out on the nonweedy (control) treatment only. Data were analyzed using PROC MIXED (SAS Institute, Cary, NC; version 9.3) with weed treatment and cultivars considered fixed effects and years and replications considered random effects. The method of Cornelius et al. (1992) was used to test for significant ($p = 0.05$) changes in genotype rank between weed-free and weedy conditions. Main effects are presented for traits in which cultivar × weed treatment interactions were not significant at $p = 0.05$. Correlation coefficients were tested for homogeneity at the 0.05 probability level prior to pooling across years within experiments.

Results

Model weed densities averaged 24, 34, and 49 mustard seedlings m^{-2} and 64, 36, and 56 oat seedlings m^{-2} for experiments 1, 2, and 3, respectively. The crop densities averaged 185, 187, and 250 seedlings m^{-2} for the three experiments. The seedling establishment of model weeds and crop cultivars did not show significant differences between cultivars (data not presented).

For Experiment#1, analysis of variance (ANOVA) detected a significant ($p = 0.01$) cultivar × weed treatment interaction for wheat grain yield (Table 1), indicating that the cultivars responded differently to competition. Averaged over the 17 wheat and two barley cultivars, yields were reduced by 37% in the presence of model weeds. Of the spring wheat cultivars evaluated, "Roblin" and "CDC Merlin" (Canadian Western Red Spring (CWRS) market class) experienced the smallest yield reductions from tame oat and mustard competition, while the semidwarf Canadian Prairie Spring (CPS) cultivars "Oslo" and "Biggar" experienced the largest reductions (Table 2). The spread in yield reduction between the most and least competitive wheat cultivars was approximately 14%. The two-row barley cultivar "Harrington" experienced a 25% yield reduction, while the six-row cultivar "Brier" experienced a 31% yield reduction. Thus, the most competitive wheat cultivars were similar to the six-row barley cultivar in terms of yield reduction. Roblin experienced the smallest yield reduction due to competition but was the third-lowest yielding cultivar under nonweedy conditions (Table 2). The cultivars differed significantly in terms of agronomic traits (DSE, DPM, plant height, tiller and spike number, LAI and MTA) and in the amount of mustard and oat grain produced in their presence (Table 2). Although wheat cultivars switched rank for grain yield between the nonweedy and weedy treatments, these changes in rank were not statistically significant ($p = 0.05$) based on the test proposed by Cornelius et al. (1992). Of the 17 wheat cultivars evaluated, only the cultivars Genesis (CPS), Glenlea (Canadian Western Extra Strong (CWES)), and the University of Saskatchewan experimental CWRS line BW652 were in the top quartile for grain yield under both nonweedy and weedy conditions. The University of Saskatchewan experimental CWRS line PT532 along with the cultivar CDC Merlin were intermediate for yield potential and competitive ability. The cultivars CDC Merlin and Glenlea resulted in the lowest oat grain yields (Table 2) and did not differ significantly from either barley cultivar. The cultivars Oslo and "Park" allowed the largest production of oat (Table 2). Mustard grain yields were low but differed between barley and wheat (Table 2).

Similar to experiment#1, a significant cultivar × weed treatment interaction for wheat yield (Table 1) was observed in Experiment#2. Wheat and barley grain yields were reduced by 49%, averaged over 2 years when comparing weedy and weed-free treatments. As was observed in the previous experiment, the two-row barley cultivar Harrington suffered the smallest yield reduction (22%). Of the wheat cultivars, Park and "Marquis" suffered the smallest yield reductions (35%) under competition but were among the lowest yielding under weed-free conditions (Table 3). The least competitive CWRS wheat cultivars were "AC Domain" and "CDC Teal". Except for AC Taber, the rest of CPS wheat cultivars were all relatively poor competitors. Biggar and "AC Foremost", both semidwarf varieties, suffered the biggest yield reductions (71 and 61%, respectively). Cultivars differed significantly ($p < 0.001$) in terms of agronomic traits and in the amount of mustard and oat grain produced in their presence. Wheat cultivars switched rank for grain yield between the nonweedy and weedy treatments, and some of these changes in rank were statistically significant (Table 3). Of the 47 significant cross-over interactions, 45 involved CPS cultivars, of which 23 were attributed to the cultivar Biggar. A majority of the rank switches between the nonweedy and weedy treatments were between the CWRS and CPS cultivars. Of the 34 wheat cultivars evaluated, only Glenlea (CWES), AC Taber (CPS), and the CWAD cultivar Plenty were in the top quartile for yield under both nonweedy and weedy conditions (Table 3). The CWAD cultivar "Medora" was intermediate for yield potential and competitive ability. The spelt wheat cultivar CDC Nexon produced the lowest mustard and oat grain yields and did not differ significantly from the two barley cultivars in that respect. The cultivars Park, Marquis, and Glenlea had below-average mustard and oat grain yields and did not differ significantly from the six-row barley cultivar Brier (Table 3).

A significant cultivar × weed treatment interaction for grain yield (Table 1) was observed in Experiment#3. Wheat and barley grain yields were reduced, on average, by 42% over the course of 3 years (Table 4). The two-row barley cultivar "CDC Kendall" replaced Harrington as a control. As was observed in the previous experiments, the two-row barley cultivars suffered the smallest yield reduction (23%). The University of Saskatchewan experimental bread wheat line PT559 and the heritage cultivar "Red Fife" suffered the smallest yield reductions under competition but were among the lowest for yield under nonweedy conditions (Table 4). The least competitive CWRS wheat cultivars were "Journey", "AC Abbey", and "5601HR". AC Crystal and AC Foremost experienced yield reductions of 56% and 54%, respectively. The semidwarf durum cultivar "AC Navigator" was also amongst the poorest competitors. The cereal cultivars differed significantly ($p = 0.05$) in terms of agronomic traits and in the amount of mustard and oat grain produced in their presence. Wheat cultivars switched rank for grain yield between the nonweedy and weedy treatments, and some of these changes in rank were statistically significant. Of the significant pairwise changes in cultivar rank, 39 involved CPS cultivars and 32 involved CWAD cultivars. AC Navigator accounted for 23 of the 86 rank changes. Of the 46 wheat cultivars, the cultivars CDC Rama (CWES), Napoleon (CWAD), AC Vista (CPS), and AC Andrew were in the top quartile for yield under both nonweedy and weedy conditions. The CWRS cultivars "Lovitt" and "CDC Go", the CWES cultivar "CDC Walrus" and the spring spelt cultivar "CDC Zorba" were intermediate for yield potential, but they exhibited good competitive ability against model weeds. CDC Zorba allowed the least oat grain production and did not differ significantly from the two-row barley cultivar CDC Kendall. In addition, the CWES cultivars CDC Rama and CDC Walrus, the CWRS cultivars PT559, AC Intrepid, AC Cadillac, Prodigy, 5600HR, Marquis and Red

Table 1. Fixed-effect *F* tests for wheat yield, wheat agronomic traits, and weed grain yield and biomass for four experiments.

	EXP#1		EXP#2		EXP#3		EXP#4 KCRF		EXP#4 SRF
Fixed effects sources	Grain yield (g m^{-2})								
	df	*F* value	df	*F* value	df	*F* value	df	*F* value	*F* value
Cultivar	18	6.92***	35	5.47***	47	7.68***	7	7.84**	1.2 NS
Weed treatment	1	28.08**	1	11.74 NS	1	73.36*	1	22.07 NS	49.65***
Cultivar × weed treatment	18	3.35***	35	4.05***	47	7.93***	7	4.15*	2.81*
	EXP#4 KCRF						EXP#4 SRF		
	Plant height (cm)			Spikes (No. m^{-2})		Wheat biomass (g m^{-2})			Spikes (No. m^{-2})
	df	*F* value		*F* value		*F* value			*F* value
Cultivar	7	12.74**		6.31**		1.51 NS			16.18***
Weed treatment	1	6.84 NS		19.45 NS		3.35 NS			1.5 NS
Cultivar × weed treatment	7	0.47 NS		1.39 NS		0.68 NS			1.9 NS
	EXP#1		EXP#2		EXP#3		EXP#4 KCRF		EXP#4 SRF
Cultivar effect	df	*F* value	df	*F* value	df	*F* value	df	*F* value	*F* value
DSE	18	8.29***	35	7.01***	47	6.47***			
DPM	18	22.04***	35	6.24***	47	11.83***			
Plant height	18	52.23***	35	25.23***	47	32.33***			
Tillers	18	4.74***	35	6.08***					
Spikes	18	4.01***	35	4.7***					
LAI	18	4.56***							
MTA	18	3.43***							
Oat grain yield	18	3.11***	35	5.62***	47	4.2***			
Mustard grain yield	18	2.5***	35	2.96***	47	9.04***			
Wild oat biomass							7	4.59*	1.28 NS
Wild oat panicles							7		1.21

Note: EXP, experiment; KCRF, Kernen Crop Research Farm; SRF, Scott Research Farm; NS, not significant; DSE, days to spike emergence; DPM, days to physiological maturity; LAI, leaf area index; MTA, mean leaf tip angle. See Materials and Methods section for descriptions of Experiments#1, 2, 3, and 4. *, **, *** Significant at $p = 0.05$, $p = 0.01$, and $p = 0.001$, respectively;

Fife, together with Napoleon (CWAD) also did not differ significantly from the barley control in terms of oat grain yield (Table 4). The triticale cultivar Sandro had the highest yield under nonweedy conditions, while it ranked second under weed pressure. However, it exhibited moderate competitive ability against model weeds, with 42.7% yield reductions and intermediate mustard and oat grain yields.

Wheat grain yield reduction was positively correlated with oat and mustard seed yield (Table 5). Crop height was negatively correlated ($p < 0$ .01) with wheat yield reduction in two of the three model weed experiments. DSE and physiological maturity were weakly or not correlated with wheat yield reduction. Wheat LAI and MTA were not associated with wheat grain yield reduction. Tiller and spike production were significantly correlated with wheat grain yield reduction only in experiment#1 (Table 5).

Uncontrolled wild oat growth reduced wheat yields by an average of 62% in the trial grown at the KCRF over 2 years (Table 6). The eight spring wheat cultivars differed significantly in their ability to compete with wild oat. The most competitive cultivar, CDC Merlin, suffered a 52% reduction compared with 75% for the least competitive cultivar, Genesis. The cultivars AC Minto and Laura showed intermediate levels of yield reduction while Katepwa, Columbus, Biggar, and Oslo showed higher levels. A significant ($p = 0.05$) cultivar × weed treatment (sprayed versus unsprayed) interaction was detected for wheat grain yield, indicating that the cultivars did not respond uniformly to interspecific competition. This interaction is also manifested by the significant cultivar differences for wild oat biomass (Table 6). The cultivars Genesis and Oslo allowed significantly higher weed biomass production. Interspecific competition reduced wheat spike number m^{-2} by 56% (averaged over years) and increased wheat plant height by 7%. In both cases, the cultivar × weed treatment interaction was not statistically significant. Three cases of significant ($p < 0.05$) cross-over interactions for grain yield were detected. These were for the cultivar Genesis with CDC Merlin, AC Minto, and Columbus.

In the 1995 trial, later flushes of wild oat produced biomass after the control plots had been treated with herbicide (Table 6). The cultivars Laura, CDC Merlin, and AC Minto allowed a quarter to a half as much wild oat late biomass production as did the cultivar Oslo. This growth represents wild oat plants that would have emerged when the wheat canopy was well established. In experiment#1, we demonstrated that CDC Merlin and AC Minto had a higher leaf area per unit ground area (LAI) at spike emergence, than other spring wheat cultivars. This appears to confer a competitive advantage to these two

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Table 2. Least-square means for grain yield and agronomic traits of 17 spring wheat and two barley cultivars, and their effect on mustard and oat grain yield at the University of Saskatchewan's SF, Saskatchewan, averaged over 4 years (1991–1994).

		Wheat grain yield										Grain yield ($g\ m^{-2}$)	
Cultivar	Market class	control ($g\ m^{-2}$)	weedy ($g\ m^{-2}$)	reduction (%)	DSE (d)	DPM (d)	Plant height (cm)	Tillers (no. m^{-2})	Spikes (No. m^{-2})	LAI	MTA	Mustard	Oat
Katepwa	CWRS	406	259	36.3	57	97	104	678	512	4.0	56	7	181
Columbus	CWRS	401	234	41.6	60	100	111	718	477	4.2	52	8	180
Laura	CWRS	428	254	40.7	58	100	103	633	444	3.4	58	8	206
CDC Makwa	CWRS	410	249	39.3	57	97	107	691	512	4.0	55	9	175
Pasqua	CWRS	403	246	39.0	58	97	102	771	540	4.1	54	6	190
Roblin	CWRS	390	272	30.4	54	94	94	614	451	3.5	57	6	166
CDC Teal	CWRS	429	254	40.7	57	96	97	707	518	3.9	57	7	174
AC Minto	CWRS	380	230	39.5	60	98	109	689	515	4.2	53	9	195
CDC Merlin	CWRS	414	278	32.8	58	99	109	752	505	4.3	50	10	152
Park	CWRS	344	198	42.3	55	96	100	549	440	3.3	54	11	229
BW652	CWRS	460	292	36.6	57	98	90	627	475	3.8	57	9	181
PT532	CWRS	421	279	33.7	54	95	87	707	544	3.6	57	6	194
Glenlea	CWES	460	293	36.3	60	101	110	538	354	4.0	54	8	160
Genesis	CPS	492	302	38.7	62	102	104	650	360	4.2	55	6	185
Oslo	CPS	452	252	44.3	55	99	79	529	407	3.1	59	10	240
Biggar	CPS	514	291	43.4	61	102	84	628	396	3.6	59	8	216
Cutler	CPS	420	256	39.0	55	96	83	613	417	3.4	57	8	188
Harrington	Barley	491	371	24.5	58	91	80	788	606	4.6	54	3	136
Brier	Barley	611	422	31.0	56	91	89	588	364	5.0	49	3	165
Average		438	275	37.4	57	97	97	656	465	3.9	55	7	185
HSD (0.05)		98w	116b		4.5	7.5	15	190	167	1.7	10	10	71

Note: DSE, days to spike emergence; DPM, days to physiological maturity; LAI, leaf area index; MTA, mean leaf tip angle; w, within column comparisons; b, between column comparisons; CWRS, Canadian Western Red Spring; CPS, Canadian Prairie Spring; CWES, Canadian Western Extra Strong.

Table 3. Least-square means for grain yield and agronomic traits of 34 wheat and two barley cultivars, and their effect on mustard and oat grain yield at the University of Saskatchewan's SF, Saskatchewan, averaged over 2 years (1995 and 1996).

		Wheat grain yield								Grain yield (g m^{-2})	
Culitvar	Market class	control (g m^{-2})	weedy (g m^{-2})	reduction (%)	DSE (d)	DPM (d)	Plant height (cm)	Tillers (no. m^{-2})	Spikes (no. m^{-2})	Mustard	Oat
Katepwa	CWRS	417	208	50.2	55	94	89	586	496	52	201
AC Barrie	CWRS	442	229	48.2	56	96	87	612	489	46	197
Columbus	CWRS	407	237	41.7	58	100	96	610	473	39	177
AC Cora	CWRS	422	206	51.2	56	95	91	607	514	50	203
AC Domain	CWRS	418	178	57.5	53	96	84	524	478	58	228
AC Eatonia	CWRS	384	187	51.4	57	97	91	532	480	53	215
Invader	CWRS	443	218	50.7	58	99	87	598	505	52	205
Laura	CWRS	449	219	51.1	57	99	91	527	427	47	195
CDC Makwa	CWRS	434	219	49.7	56	94	92	635	573	47	195
CDC Merlin	CWRS	423	239	43.5	56	96	96	602	455	40	174
AC Michael	CWRS	419	215	48.5	57	97	90	595	496	44	190
AC Minto	CWRS	438	239	45.4	57	96	97	630	550	47	173
Pasqua	CWRS	422	216	48.8	56	95	88	561	476	44	208
Roblin	CWRS	403	196	51.4	52	96	77	470	461	50	219
CDC Teal	CWRS	446	207	53.6	56	98	83	558	484	47	207
AC Majestic	CWRS	427	207	51.5	58	97	89	635	525	52	214
Biggar	CPS	523	151	71.1	56	102	72	418	347	73	257
Cutler	CPS	453	198	56.3	51	95	72	482	422	48	200
Genesis	CPS	553	222	59.8	58	99	92	509	384	51	229
AC Karma	CPS	517	222	57.1	54	100	76	509	451	56	221
AC Taber	CPS	529	244	53.9	56	102	77	510	415	48	216
AC Foremost	CPS	522	203	61.2	53	102	70	524	453	54	233
Oslo	CPS	494	213	56.8	51	97	69	447	429	53	225
Glenlea	CWES	491	279	43.2	57	98	95	442	390	33	173
Wildcat	CWES	461	244	47.0	51	96	76	422	436	42	179
Park	CWRS	412	267	35.2	52	95	87	584	481	38	151
Marquis	CWRS	366	237	35.3	59	100	103	603	494	35	154
Grandin	HRS	460	219	52.4	54	99	81	524	443	46	217
Kyle	CWAD	443	211	52.4	58	100	96	425	385	50	216
Medora	CWAD	481	281	41.6	54	99	89	357	348	38	169
AC Melita	CWAD	460	233	49.4	54	98	90	379	341	44	208
Plenty	CWAD	511	294	42.5	56	102	94	423	404	36	171
Sceptre	CWAD	471	260	44.7	55	99	79	389	363	47	165
CDC Nexon	Spelt	418	261	37.5	64	103	119	538	347	29	126
Harrington	Barley	578	451	22.0	57	93	65	774	593	15	99
Brier	Barley	663	432	34.9	55	92	70	492	390	27	137
Average		461	237	48.6	56	98	86	529	450	45	193
HSD (0.05)		110w	148b		6.3	8.0	25	236	173	24	74

Note: DSE, days to spike emergence; DPM, days to physiological maturity; w, within column comparisons; b, between column comparisons; CWRS, Canadian Western Red Spring; CPS, Canadian Prairie Spring; CWES, Canadian Western Extra Strong; HRS, Hard Red Spring.

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Table 4. Least-square means for grain yield and agronomic traits of 46 wheat, one triticale and one barley cultivar, and their effect on mustard and oat grain yield at the KCRF, Saskatchewan, averaged over 3 years (2004–2006).

		Wheat grain yield						Grain yield (g m^{-2})	
Culitvar	Market class	control (g m^{-2})	weedy (g m^{-2})	reduction (%)	DSE (d)	DPM (d)	Plant height (cm)	Mustard	Oat
AC Barrie	CWRS	395	229	42.0	55	94	94	59	121
CDC Bounty	CWRS	420	254	39.4	54	100	97	44	105
AC Cadillac	CWRS	399	253	36.7	54	98	97	49	101
AC Elsa	CWRS	400	210	47.5	54	91	91	60	118
Harvest	CWRS	386	236	38.8	52	89	88	54	116
CDC Imagine	CWRS	423	243	42.7	55	92	97	51	115
AC Intrepid	CWRS	387	240	38.1	52	90	90	41	99
Journey	CWRS	403	205	49.2	56	93	94	55	134
AC Abbey	CWRS	367	188	48.7	54	85	86	68	134
Eatonia	CWRS	351	204	41.9	55	98	98	54	117
Lillian	CWRS	410	238	41.8	56	93	92	55	109
Lovitt	CWRS	427	273	36.1	54	97	93	42	105
McKenzie	CWRS	425	237	44.4	52	96	94	52	122
Prodigy	CWRS	414	254	38.7	55	97	95	48	94
AC Splendor	CWRS	368	215	41.7	52	94	94	44	110
AC Superb	CWRS	407	245	39.8	53	86	90	49	112
CDC Teal	CWRS	403	244	39.3	54	93	92	47	107
5500HR	CWRS	391	223	42.9	54	93	92	56	127
5600HR	CWRS	402	242	39.9	55	100	98	47	99
5601HR	CWRS	368	189	48.7	56	100	98	63	121
Roblin	CWRS	343	207	39.5	51	87	89	45	109
Katepwa	CWRS	377	217	42.3	54	98	97	54	121
Marquis	CWRS	320	210	34.3	58	106	105	49	103
Red Fife	CWRS	364	255	30.0	58	114	111	41	100
CDC Merlin	CWRS	364	242	33.6	54	99	100	42	107
CDC Osler	CWRS	413	226	45.2	54	92	93	53	122
CDC Go	CWRS	424	264	37.6	51	80	81	39	107
CDC Alsask	CWRS	411	258	37.3	54	94	93	46	106
PT 559	CWRS	343	246	28.3	52	93	94	36	97
Snowbird	CWHW	382	223	41.6	53	92	90	54	119
AC Crystal	CPS	402	178	55.8	59	84	85	74	143
AC Foremost	CPS	457	209	54.3	55	76	79	75	152

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Table 4. (*concluded*).

		Wheat grain yield						Grain yield (g m^{-2})	
Culitvar	Market class	control (g m^{-2})	weedy (g m^{-2})	reduction (%)	DSE (d)	DPM (d)	Plant height (cm)	Mustard	Oat
AC Taber	CPS	445	224	49.7	58	84	85	59	136
5700PR	CPS	422	202	52.0	54	78	79	61	151
5701PR	CPS	429	240	44.2	55	78	79	64	134
AC Vista	CPS	481	265	44.9	53	83	85	47	119
AC Andrew	CWSWS	540	298	44.8	56	84	83	55	123
Glenlea	CWES	387	241	37.7	57	103	100	50	105
CDC Rama	CWES	435	286	34.3	54	103	101	37	91
CDC Walrus	CWES	427	266	37.6	56	97	97	46	99
Kyle	CWAD	445	239	46.4	57	108	107	48	118
AC Avonlea	CWAD	447	226	49.5	53	90	89	55	108
AC Morse	CWAD	470	242	48.4	53	86	87	54	126
Napoleon	CWAD	483	258	46.5	55	93	91	53	102
AC Navigator	CWAD	472	211	55.2	55	81	82	63	145
CDC Zorba	Spelt	431	267	38.0	61	119	115	37	86
Sandro	Triticale	548	314	42.7	54	99	99	51	144
CDC Kendall	Barley	477	370	22.5	58	71	72	23	81
Average		414	240	41.9	55	93	92	51	115
HSD (0.05)		82w	98b		3.4	8.9	15	31	47

Note: DSE, days to spike emergence; DPM, days to physiological maturity; w, within column comparisons; b, between column comparisons; CWRS, Canadian Western Red Spring; CWHW, Canada Western Hard White; CPS, Canadian Prairie Spring; CWES, Canadian Western Extra Strong; CWSWS, Canadian Western Soft White Spring; CWAD, Canadian Western Amber Durham.

Table 5. Correlation between % wheat grain yield reduction versus wheat agronomic traits and weed grain yields.

	EXP#1	EXP#2	EXP#3
Weedy wheat grain yield	– 0.75**	– 0.69**	– 0.62**
DSE	0.24 NS	– 0.19 NS	0.12 NS
DPM	0.24 NS	0.08 NS	0.39**
Plant height	– 0.10 NS	– 0.62**	– 0.54**
Tillers	– 0.36**	– 0.12 NS	
Spikes	– 0.27**	– 0.10 NS	
LAI	– 0.19 NS		
MTA	– 0.05 NS		
Oat grain yield	0.39**	0.79**	0.77**
Mustard grain yield	0.72**	0.90**	0.75**

Note: EXP, experiment; see Materials and Methods section for descriptions of Experiments#1, 2, and 3. DSE, days to spike emergence; DPM, days to physiological maturity; LAI, leaf area index; MTA, mean leaf tip angle; NS, not significant. **Significant at $p = 0.01$.

cultivars. Laura, however, had a low LAI, suggesting that some other plant characteristic confers a competitive advantage to this cultivar.

Wild oat competition at the Scott site reduced wheat yields by an average of 26% (Table 6) and spike numbers by approximately 27% (Table 6). Thus, on average, interspecific competition at the SRF was half as intense as in the KCRF experiment. Averaged over years, cultivar × weed treatment interaction was statistically significant for wheat grain yield (Table 1). The cultivars differed by as much as 22% in grain yield under weedy conditions and 21% under weed-free conditions. Columbus and Katepwa suffered the least yield reduction while Genesis and Oslo suffered the largest reductions (Table 6). A single statistically significant cross-over interaction was detected (Genesis versus Columbus). Wheat biomass, wild oat biomass, and wild oat panicles m^{-2} did not differ statistically among cultivars (Table 6). Averaged over years, the trend was for lower wild oat biomass production in Katepwa and Columbus plots versus higher wild oat biomass in the Genesis and Oslo plots. A similar trend was observed for wild oat panicle production.

Discussion

In the present study, spring wheat genotypes differed significantly in their ability to maintain yield in the presence of competing species and to reduce oat and mustard grain yield. Furthermore, we detected significant cross-over interactions (changes in cultivar rank) for wheat grain yield under weed-free versus weedy conditions. Thus, a cultivar's grain yield under weed-free conditions was not necessarily a good predictor of crop yield reduction due to competition. Of the wheat traits measured, crop height appeared to have the greatest impact on competitive ability. The shortest wheat genotypes tended to suffer the largest yield reductions and allowed the most weed growth. This is in agreement with earlier reports in the literature (Mason and Spaner 2006). Semidwarf cultivars in the CPS class tended to suffer the highest yield reductions due to model weed pressure and allowed higher model weed grain yields. A similar trend was observed in the durum wheat cultivars, where AC Navigator, a semidwarf, showed the largest yield reductions relative to other durum wheat cultivars evaluated. These observations are consistent with those of Kirkland and Hunter (1991), who concluded that semidwarf cultivars of wheat are more susceptible to yield losses due to weed interference than standard height cultivars.

On average, about 10% of the wheat cultivars evaluated over the course of the three experiments with model weeds were in the top quartile for grain yield under both weed-free and weedy conditions. This group included the CWES cultivars Glenlea and CDC Rama, the CPS cultivars Genesis, AC Taber, and AC Vista, the CWAD cultivars Plenty and Napoleon, the CWSWS cultivar AC Andrew and the experimental CWRS lines BW652, which combined high grain yield potential with the highest yields under weed pressure. Three of these (Glenlea, CDC Rama, and Plenty) have larger seeds and were in the top quartile for plant height. The larger seed may provide a competitive advantage earlier in crop development and the taller plant stature may benefit these cultivars later in the season. Greater competitive ability from larger seeds has been associated with higher relative growth rate in early growing stages (Pecetti et al. 2019). While plant height has been largely related to light competition, its importance depending on the relative weed height and growth habit throughout the growth stages of the crop (Andrew et al. 2015). Cultivars such as AC Taber, AC Vista, and AC Andrew were in the lower quartile for plant height, suggesting that there are other characteristics that confer a competitive advantage to these cultivars. The wheat cultivars that experienced the smallest yield reductions due to competition from model weeds (Roblin, CDC Merlin, Park, Marquis, PT559, and Red Fife) were amongst the lowest yielding in the absence of weeds. Thus, the smaller yield reductions experienced by these cultivars were, in part, an artifact of their lower yield potential and inability to respond to higher environmental resources.

The results for the early-maturing cultivars Roblin and Park were not consistent across experiments. In the first experiment (1991–1994), Park allowed significantly higher mustard

Table 6. Least-square means for grain yield and agronomic traits of eight wheat cultivars, and their effect on wild oat at the KCRF and Agriculture and Agri-Food's SRF, Saskatchewan, averaged over 2 years (1995 and 1996).

	Wheat grain yield				Spikes			Wild oat	
KCRF	control (g m^{-2})	weedy (%)	reduction (cm)	Plant height (cm)	control (%)	weedy (g m^{-2})	reduction (g m^{-2})	Biomass	Biomass*
CDC Merlin	256	123	51.8	95	445	219	50.8	1062	132
AC Minto	254	113	55.4	95	466	231	50.4	1123	117
Katepwa	239	80	66.5	91	464	200	56.9	1201	155
Columbus	256	100	60.8	95	436	196	55.0	1100	92
Laura	310	130	58.2	89	298	121	59.4	1124	60
Genesis	292	74	74.8	80	266	70	73.7	1429	182
Oslo	209	66	68.2	67	397	199	49.8	1472	254
Biggar	340	128	62.4	75	329	173	47.4	1180	138
Average	270	102	62	86	387	176	55.4	1211	141
HSD (0.05)	82w	94b		13	122	131		352	392
	Wheat grain yield			Wheat		Spikes		Wild oat	
SRF	Control (g m^{-2})	Weedy (%)	Reduction (g m^{-2})	Biomass (no. m^{-2})	Control **(%)**	Weedy (g m^{-2})	Reduction (No. m–2)	Biomass	Panicles
CDC Merlin	281	210	25.0	1000	331	248	25.1	237	134
AC Minto	266	189	28.8	982	340	248	27.1	217	86
Katepwa	258	202	21.7	985	407	289	29.0	118	83
Columbus	285	234	17.8	1137	350	271	22.6	166	86
Laura	284	218	23.1	1083	369	257	30.3	242	140
Genesis	317	208	34.3	1165	230	191	16.9	370	129
Oslo	281	195	30.6	799	320	192	40.0	406	187
Biggar	324	238	26.6	1024	271	213	21.4	194	124
Average	287	212	26.0	1022	327	238	26.6	244	121
HSD (0.05)	31w	72b		NS	107	103		NS	NS

Note: KCRF, Kernen Crop Research Farm; SRF, Scott Research Farm; NS, not significant; w, within column comparisons; b, between column comparisons.
∗1995 wild oat later flush biomass.

and oat production and suffered a greater yield reduction than cultivars such as Roblin and CDC Merlin. In the second experiment (1995–1996), however, Park suffered smaller yield reductions and allowed less oat production than Roblin and CDC Merlin. In the third experiment (2004–2006), Roblin was similar to CDC Merlin in terms of yield reduction and oat grain production. The reasons for these contrasting results may be due to different weather conditions experienced by the cultivar throughout the experiments and phenotypic plasticity of different traits. Average oat yields for the first two experiments differed by less than 5% but mustard grain yields were six times higher in the second experiment. The average mustard yields were similar for the second and third experiments, but the oat yields were 60% lower in the third experiment. This raises the question of whether the differing growth habits of mustard and oat influence yield reduction of phenologically diverse wheat cultivars differentially.

A number of cultivars with intermediate to higher yield potential coupled with improved yield maintenance under weed pressure were identified. The CWRS cultivars Lovitt and CDC Go, the CWES cultivars CDC Rama and CDC Walrus, the CWAD cultivar Medora, and the spelt cultivar Zorba fit that category. With the exception of CDC Go, these cultivars are intermediate to tall for plant height. CDC Go appears to be an outlier in that it was one of the shortest-strawed cultivars in the experiment in which it was evaluated yet was effective in maintaining grain yield and suppressing model weed grain yield. Wheat growth habits are largely governed by three genetic systems—vernalization response, photoperiod sensitivity, and reduced height genes—that act together to determine the genotype basic adaptation for a particular environmental condition (Snape et al. 2001). The semidwarf cultivars, CDC Go and AC Superb, both carriers of the *Rht-B1b*; *Vrn-A1a*; *Vrn-B1*; *vrn-D1*; and *Ppd-D1b* combination, suffered the smallest yield reductions (37.6 and 39.8%, respectively) under weed pressure. Cultivars with *Rht-B1b*; *vrn-A1*; *Vrn-B1*; *vrn-D1*; *Ppd-D1a* (AC Andrew) or *Rht-D1b*, *Vrn-A1a*; *vrn-B1*, *vrn-D1*, and *Ppd-D1a* (5700PR, 5701PR, and AC Vista) combinations exhibited intermediate grain yield reductions (ranging from 44.2 to 52%), while those cultivars carrying the *Rht-D1b*; *vrn-A1*; *Vrn-B1*; *vrn-D1*; *Ppd-D1a* combination (AC Crystal, AC Taber, and AC Foremost) experienced the greatest grain yield reductions (ranging from 50 to 56%). These results suggest that cultivars carrying the *Rht-B1b* semidwarf gene combined with the double dominant *Vrn* genotype (*Vrn-A1a*; *Vrn-B1*) and photoperiod sensitivity (*Ppd-D1b*) have a plant type or growth pattern that differs from other short-strawed cultivars, allowing them to better maintain the grain yield under model weed pressure. Genotypes carrying double-dominant *Vrn* alleles combined with the *Ppd-D1b* photoperiod allele have been reported to have higher grain yield under both stressed and normal conditions (Stelmakh 1993; Zhang et al. 2014; Lozada et al. 2021). Thus, a shorter vernalization requirement combined with photoperiod sensitivity may play an important role for both adaptation and improved yield potential.

Mason et al. (2007a, b) evaluated ten spring wheat cultivars in central Alberta and reported that the cultivars Park, Marquis, and McKenzie resulted in less weed biomass (−6% to −43%) at crop maturity than the cultivars Katepwa and CDC Go. In experiment#3 of the current study, CDC Go and Marquis allowed below-average model weed grain yields, while McKenzie and Katepwa allowed above-average yields of mustard and oat grain. The differing results between the current study and that of Mason and Spaner (2007a, b) could be a result of cultivar adaptation, or the use of nonshattering model weeds compared with wild weeds that would have shattered prior to crop harvest-readiness.

In the study by Mason et al. (2007a), the cultivar Park was lower yielding relative to Katepwa, CDC Go, and McKenzie in all but the lower-yielding environments. For example, Park out-yielded CDC Go, Katepwa, and McKenzie in environments with mean yields of 400, 1000, and 1400 kg ha^{-1} or less, respectively, while the mean yield for the study was 3000 kg ha^{-1}. Mason et al. (2007a) interpreted the low regression coefficient ($b = 0.84$) for Park grain yield on environmental yield potential to be evidence of yield stability and thus desirable for low-input production systems. Producers, historically, favor cultivars with medium-to-high yield potential coupled with a moderate response ($b \geq 1.0$) to environmental yield potential (i.e., intermediate stability), which may explain why production of the earlier maturing cultivar Park was restricted to the short growing season areas of Alberta. Murphy et al. (2007) evaluated 63 spring wheat cultivars over a 3-year period under low soil fertility, low yield potential (average grain yield 1300 kg ha^{-1}) conditions with and without mechanical weed control. There was five times less weed biomass in the five cultivars with the greatest weed suppression compared with the five least suppressive cultivars, which were similar in grain yield. Triticale has been found to compete well with both monocot and dicot weeds when tall winter varieties were planted (Beres et al. 2010). In our study, the cultivar Sandro was in the top quartile for plant height; however, it only exhibited moderate competitive ability.

Huel and Hucl (1996) speculated that the use of crop plants as model weeds may complicate the extrapolation of competitive ability to commercial production systems. In the current study, we found that cultivars with differing levels of competitive ability under controlled conditions maintained their ranking when challenged by natural weed infestations. This suggests that breeding competitive spring wheat cultivars using a repeatable protocol based on model weeds is realistic; however, factors such as growth habits, relative weed height, canopy structure, etc. should be carefully considered when extrapolating results as they could change the dynamics of the competition.

Although a small minority, cultivars exhibiting the desired combination of high-yield potential and ability to limit weed growth were identified. These outlier cultivar differences could be exploited in situations where alternate or reduced herbicide weed control strategies are desired. For example, the use of competitive spring wheat cultivars in conjunction with short-term residual action herbicides could provide a longer weed suppressive period. They also represent a valuable resource possible to be use in situations where herbicide resistance limits chemical options. Finally, the positive association found between competitive ability against weed species and some morphological and developmental traits could be explored in the development of future widely adapted varieties.

Conclusions

During the course of this study, we evaluated 71 spring wheat cultivars representing the major market classes grown in western Canada. None of the wheat cultivars approached the two-row barley control in terms of yield maintenance in the presence of model weeds. A number of wheat cultivars approached the six-row barley control in yield maintenance and lower oat yields but those cultivars were generally of a lower yield potential. Nine of the 71 cultivars evaluated (Glenlea, Genesis, BW652, AC Taber, Napoleon, AC Vista, CDC Rama, and Plenty) had the desired combination of high-yield potential, yield maintenance, and suppression of model weed yields in at least one of the four experiments. This competitive advantage appeared to be associated with higher plant height or tillers per square meter as well as shorter vernalization requirement combined with photoperiod sensitivity. In conclusion, this research demonstrated that repeatable differences in competitive ability can be detected in commercially grown western Canadian spring wheat cultivars. Cultivars that were able to suppress model weed grain yields and maintain their own yields also were able to better suppress wild oat than less competitive cultivars.

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Supplementary material

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