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’aventices [avoine (Avena sativa L.) et moutarde d’Inde (Brassica juncea L.)] ou d’adventices naturelles [folle avene (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]
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. The oat and oriental mustard cultivars were chosen 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 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 "Morgan" were included in each plot as control cultivars. Buctril M 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.
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 m² 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 m² 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 (Sinapis 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 oat grain 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 two-row barley cultivar “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...
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 under weed pressure. Nevertheless, it 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 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

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

| Fixed effects sources                  | EXP#1 df | EXP#2 df | EXP#3 df | EXP#4 KRF df | EXP#4 SRF df |
|----------------------------------------|----------|----------|----------|--------------|--------------|
| Cultivar                               | 18       | 35       | 47       | 7            | 7            |
| Weed treatment                         | 1        | 1        | 1        | 1            | 1            |
| Cultivar × weed treatment              | 35       | 35       | 47       | 7            | 7            |

**Grain yield (g m⁻²)**

| EXP#1 | EXP#2 | EXP#3 | EXP#4 KRF | EXP#4 SRF |
|-------|-------|-------|-----------|-----------|
| Cultivar effect                         | 18     | 35     | 47        | 7         | 7         |
| DSE   | 8.29**| 7.01***| 6.47***   |           |
| DPM   | 22.04***| 6.24***| 11.83***  |           |
| Plant height                            | 52.23***| 25.23***| 32.33***  |           |
| Tillers                                 | 4.74***| 6.08***|           |           |
| Spikes                                  | 4.01***| 4.7***  |           |           |
| LAI                                        | 4.56***|           |           |           |
| MTA                                        | 3.43***|           |           |           |
| Oat grain yield                          | 3.11***| 5.62***| 4.2***    |           |
| Mustard grain yield                      | 2.5***| 2.96***| 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;
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).

| Cultivar   | Market class | Wheat grain yield | Grain yield (g m⁻²) | 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 |
| PTS32      | 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 |

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).

| Cultivar       | Market class | Wheat grain yield | Mustard (g m⁻²) | Oat (g m⁻²) | Mustard reduction (%) | DSE (d) | DPM (d) | Plant height (cm) | Spikes (no. m⁻²) | Tillers (no. m⁻²) | HSD (0.05) |
|----------------|--------------|-------------------|----------------|-------------|----------------------|--------|--------|------------------|----------------|------------------|------------|
| Katepwa        | CWRS         | 417 208           | 50.2           | 55          | 94 89                | 586    | 496    | 52               | 201            | 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 Tabor       | 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.
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).

| Cultivar       | Market class | Wheat grain yield | Grain yield ($m^{-2}$) | DSE (d) | DPM (d) | Plant height (cm) | Mustard | Oat |
|----------------|--------------|-------------------|------------------------|---------|---------|-------------------|---------|-----|
|                |              | control ($gm^{-2}$) | weedy ($gm^{-2}$) | reduction (%) |         |                  |         |
| AC Barrie      | CWRS         | 395               | 229                    | 42.0     | 55      | 94                | 94      | 59  |
| CDC Bounty     | CWRS         | 420               | 254                    | 39.4     | 54      | 100               | 97      | 44  |
| AC Cadillac    | CWRS         | 399               | 253                    | 36.7     | 54      | 98                | 97      | 49  |
| AC Elsa        | CWRS         | 400               | 210                    | 47.5     | 54      | 91                | 91      | 60  |
| Harvest        | CWRS         | 386               | 236                    | 38.8     | 52      | 89                | 88      | 54  |
| CDC Imagine    | CWRS         | 423               | 243                    | 42.7     | 55      | 92                | 97      | 51  |
| AC Intrepid    | CWRS         | 387               | 240                    | 38.1     | 52      | 90                | 90      | 41  |
| Journey        | CWRS         | 403               | 205                    | 49.2     | 56      | 93                | 94      | 55  |
| AC Abbey       | CWRS         | 367               | 188                    | 48.7     | 54      | 85                | 86      | 68  |
| Eatonia        | CWRS         | 351               | 204                    | 41.9     | 55      | 98                | 98      | 54  |
| Lillian        | CWRS         | 410               | 238                    | 41.8     | 56      | 93                | 92      | 55  |
| Lovitt         | CWRS         | 427               | 273                    | 36.1     | 54      | 97                | 93      | 42  |
| McKenzie       | CWRS         | 425               | 237                    | 44.4     | 52      | 96                | 94      | 52  |
| Prodigy        | CWRS         | 414               | 254                    | 38.7     | 55      | 97                | 95      | 48  |
| AC Splendor    | CWRS         | 368               | 215                    | 41.7     | 52      | 94                | 94      | 44  |
| AC Superb      | CWRS         | 407               | 245                    | 39.8     | 53      | 86                | 90      | 49  |
| CDC Teal       | CWRS         | 403               | 244                    | 39.3     | 54      | 93                | 92      | 47  |
| 5500HR         | CWRS         | 391               | 223                    | 42.9     | 54      | 93                | 92      | 56  |
| 5600HR         | CWRS         | 402               | 242                    | 39.9     | 55      | 100               | 98      | 47  |
| 5601HR         | CWRS         | 368               | 189                    | 48.7     | 56      | 100               | 98      | 63  |
| Roblin         | CWRS         | 343               | 207                    | 39.5     | 51      | 87                | 89      | 45  |
| Katepwa        | CWRS         | 377               | 217                    | 42.3     | 54      | 98                | 97      | 54  |
| Marquis        | CWRS         | 320               | 210                    | 34.3     | 58      | 106               | 105     | 49  |
| Red Fife       | CWRS         | 364               | 255                    | 30.0     | 58      | 114               | 111     | 41  |
| CDC Merlin     | CWRS         | 364               | 242                    | 33.6     | 54      | 99                | 100     | 42  |
| CDC Osler      | CWRS         | 413               | 226                    | 45.2     | 54      | 92                | 93      | 53  |
| CDC Go         | CWRS         | 424               | 264                    | 37.6     | 51      | 80                | 81      | 39  |
| CDC Alsask     | CWRS         | 411               | 258                    | 37.3     | 54      | 94                | 93      | 46  |
| PT 559         | CWRS         | 343               | 246                    | 28.3     | 52      | 93                | 94      | 36  |
| Snowbird       | CWHW         | 382               | 223                    | 41.6     | 53      | 92                | 90      | 54  |
| AC Crystal     | CPS          | 402               | 178                    | 55.8     | 59      | 84                | 85      | 74  |
| AC Foremost    | CPS          | 457               | 209                    | 54.3     | 55      | 76                | 79      | 75  |
### Table 4. (concluded).

| Cultivar        | Market class | Wheat grain yield | Grain yield (g m⁻²) | 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.
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 CWRSlines 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 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 $p = 0.01$. 

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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 | Plant height (cm) | Spikes | Wild oat |
|----------------|-------------------|-------------------|--------|----------|
|                | control (g m⁻²) | weedy (%) | reduction (cm) | control (%) | weedy (g m⁻²) | reduction (g m⁻²) | Biomass | Biomass* |
| KCRF           |                   |                   |        |          |            |                   |        |          |
| CDC Merlin     | 256               | 123               | 51.8   | 95       | 445        | 219               | 50.8   | 1062     |
| AC Minto       | 254               | 113               | 55.4   | 95       | 466        | 231               | 50.4   | 1123     |
| Katepwa        | 239               | 80                | 66.5   | 91       | 464        | 200               | 56.9   | 1201     |
| Columbus       | 256               | 100               | 60.8   | 95       | 436        | 196               | 55.0   | 1100     |
| Laura          | 310               | 130               | 58.2   | 89       | 298        | 121               | 59.4   | 1124     |
| Genesis        | 292               | 74                | 74.8   | 80       | 266        | 70                | 73.7   | 1429     |
| Oslo           | 209               | 66                | 68.2   | 67       | 397        | 199               | 49.8   | 1472     |
| Biggar         | 340               | 128               | 62.4   | 75       | 329        | 173               | 47.4   | 1180     |
| Average        | 270               | 102               | 62     | 86       | 387        | 176               | 55.4   | 1211     |
| HSD (0.05)     | 82w               | 94b               | 13     | 122      | 131        |                   | 352    | 392      |

HSD (0.05) 82w 94b

| SRF            | Wheat grain yield | Wheat | Spikes | Wild oat |
|----------------|-------------------|-------|--------|----------|
|                | 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               | 72     | 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—vernization 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 \( Rht-B1b \); \( vrn-A1 \); \( Vrn-B1 \); \( vrn-D1 \); and \( Ppd-D1a \) (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

Supplementary data are available with the article at https://doi.org/10.1139/CJPS-2021-0257.

References

Andrew, I.K.S., Storkey, J., and Sparkes, D.L. 2015. A review of the potential for competitive cereal cultivars as a tool in integrated weed management. Weed Res. 55: 239–248. doi:10.1111/wre.12137 PMID: 27478257.
Ashford, R., and Hunter, J.H. 1986. Annual grass weeds and their control in wheat in western Canada. In: A.E. Slinkard and D.B. Fowler (eds.), Wheat production in Canada - a review, 367–373. University of Saskatchewan, Saskatoon.
Beres, B.L., Harker, K.N., Clayton, G.W., Bremer, E., Blackshaw, R.E., and Graf, R.J. 2010. Weed-competitive ability of spring and winter cereals in the northern great plains. Weed Technol. 24: 108–116. doi:10.1614/WT-D-09-00036.1.
Canada Statistics. 2018. Farm operating expenses and depreciation (x 1000). doi:10.25318/3210004901-eng.
Challaiah, R.E., Burnside, O.C., Wicks, G.A., and Johnson, V.A. 1986. Competition between winter wheat (Triticum aestivum) cultivars and downy brome (Bromus tectorum). Weed Sci. 34: 689–693. doi:10.1017/S0043174500006792.
Health Canada. 2018. Pest control products sales report for 2018. Ottawa, ON: Health Canada 2018.
Holm, F.A., and Kirkland, K.J. 1986. Annual broadleafed weed control in wheat in western Canada. In: A.E. Slinkard and D.B. Fowler (eds.), Wheat production in Canada - a review, 375–390. University of Saskatchewan, Saskatoon.
Hucl, P. 1998. Response to weed management of four spring wheat genotypes differing in competitive ability. Can. J. Plant Sci. 78: 171–173. doi:10.4141/P97-029.
Huel, D.G., and Hucl, P. 1996. Genotypic variation for competitive ability in spring wheat. Plant Breed. 115: 325–329. doi:10.1111/j.1439-0523.1996.tb00927.x.
Kirkland, K.J., and Hucl, P. 1991: Competitiveness of canada prairie spring wheats with wild oat (Avena fatua L.). Can. J. Plant Sci. 71: 1089–1092. doi:10.4141/cjs91-151.
Lermerle, D., Gill, G.S., Murphy, C.E., Walker, S.R., Cousens, R.D., Mokhtari, S., et al. 2001. Genetic improvement and agronomy for enhanced wheat competitiveness with weeds. Aust. J. Agric. Res. 52: 527–548. doi:10.1071/AR00056.
LICON Inc. 1992. LAI-2000 Plant Canopy Analyzer Operating Manual. LICOR Inc., Lincoln, Nebraska, U.S.A.
Lieberman, M., and Gallandt, E. 1997. Many little hammers: ecological management of crop-weed interactions. In: L. Jackson, (ed). Ecology in agriculture. Academic Press, San Diego, pp. 291–343.
Lozada, D.N., Carter, A.H., and Mason, R.E. 2021. Unlocking the yield potential of wheat: influence of major growth habit and adaptation genes. Crop Breed. Genet. Genom. 3(2): e210004.
Mason, H., Goonewardene and, L. and Spaner, D. 2007a. Competitive traits and the stability of wheat cultivars in differing natural weed environments on the northern canadian prairies. J. Agric. Sci. 146: 21–33. doi:10.1017/S0021859607007319.
Mason, H., Navabi, A., Frick, B., O’Donovan, J., and Spaner, D. 2007b. Cultivar and seeding rate effects on the competitive ability of spring cereals grown under organic production in northern canada. Agron. J. 99: 1199–1207. doi:10.2134/agronj2006.0262.
Mason, H.E., and Spaner, D. 2006. Competitive ability of wheat in conventional and organic management systems: a review of the literature. Can. J. Plant Sci. 86: 333–343. doi:10.4141/P05-051.
Matus-Cadiz, M.A., Pozniak, C.J., and Hucl, P.J. 2008. Puroindoline allele diversity in Canadian and northern US hard red spring wheat varieties differing in kernel hardness. Can. J. Plant Sci. 88: 873–883. doi:10.4141/CJPS07168.

McCallum, B.D., and DePauw, R.M. 2008. A review of wheat cultivars grown in the Canadian prairies. Can. J. Plant Sci. 88: 649–677. doi:10.4141/CJPS07159.

Murphy, K.M., Dawson, J.C., and Jones, S.S. 2007. Relationship among phenotypic growth traits, yield and weed suppression in spring wheat landraces and modern cultivars. Field Crops Res. 105: 107–115. doi:10.1016/j.fcr.2007.08.004.

Pavlychenko, T.K., and Harrington, J.B. 1934. Competitive efficiency of weeds and cereal crops. Can. J. Res. 10: 77–94. doi:10.1139/cjr34-006.

Pecetti, L., Marcotrigiano, A.R., Russi, L., Romani, M., and Annicchiarico, P. 2019. Adaptation of field pea varieties to organic farming across different environments of Italy. Crop Pasture Sci. 70: 327–333. doi:10.1071/CP18216.

Perry, S.G., Fraser, A.B., Thomsonand, D.W., and Norman, J.M. 1988. Indirect sensing of plant canopy structure with simple radiation measurements. Agric. For. Meteorol. 42: 255–278. doi:10.1016/0168-1923(88)90082-2.

Richards, M.C., 1989. Crop competitiveness as an aid to weed control. In Proceedings of the Brighton Crop Protection Conference-Weeds November 1989, 573–578. Brighton, England.

Sanchez, J.J. 2021. Evaluating methods for research in physical weed control and farm asset tracking. Electronic Theses and Dissertations. 3422. https://digitalcommons.library.umaine.edu/etd/3422.

Smith, R.G., Atwood, L.W., Pollnac, F.W., and Warren, N.D. 2015. Cover-crop species as distinct biotic filters in weed community assembly. Weed Sci. 63: 282–295. doi:10.1614/WS-D-14-00071.1.

Snape, J.W., Butterworth, K., Whitechurch, E., and Worland, A.J. 2001. Waiting for fine times: genetics of flowering time in wheat. Euphytica, 119: 185–190. doi:10.1023/A:1017594422176.

Stelmakh, A.F. 1993. Genetic effect of vrn genes on heading date and agronomic traits in bread wheat. Euphytica, 65: 53–60. doi:10.1007/BF00022199.

Welles, J.M., and Norman, J.M., 1991: Instrument for indirect measurement of canopy architecture. Agron. J. 83: 818–825. doi:10.2134/agronj1991.00021962008300050009x.

Zadoks, J.C., Chang, T.T., and Konzak, C.F. 1974. A decimal code for the growth stages of cereals. Weed Res. 14: 415–421. doi:10.1111/j.1365-3180.1974.tb01084.x.

Zhang, J., Dell, B., Biddulph, B., Khan, N., Xu, Y. Luo, H., et al. 2014. Vernalization gene combination to maximize grain yield in bread wheat [Tricicum aestivum L.] in diverse environments. Euphytica, 198(3): 439–454. doi:10.1007/s10681-014-1120-6.