The competitive ability of 29 barley cultivars

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Abstract

Using competitive crops and cultivars can be an important integrated weed management (IWM) tool. Barley is considered a competitive crop, but cultivar competitiveness varies. There are two aspects of cultivar competitive ability; the ability to compete (AC) and the ability to withstand competition (AWC). A study was conducted to explore aspects of barley cultivar competitive ability with oats, and to examine the feasibility of ranking cultivars based on either, or both, AWC and AC. Field trials were undertaken in 2001 and 2002 to determine cultivar competitive ability for 29 barley cultivars commonly grown on the Canadian Prairies. Cultivars were selected from semi-dwarf and full height, hulled and hull-less, 2- and 6-row, and, feed and malt classes. Yield loss ranged from 6-79% while weed seed return ranged from 10-83% of gross yield. As a class, semi-dwarf and hull-less cultivars were less competitive than full height and hulled cultivars, respectively. However, considerable variation existed among within these classes, and an absolute relationship between class membership and competitive ability did not exist. Ranking barley cultivar competitive ability would make it a valuable IWM tool for farmers and extension personnel.

Introduction

Integrated weed management helps farmers manage rising herbicide costs, herbicide-resistant weeds and helps mitigate the social, health and environmental impacts of agriculture. Additionally, low-external-input (LEI) farming systems (Liebman and Davis 2000), such as organic and pesticide-free production systems, prohibit the use of herbicides for a specified time period. Using competitive crops and cultivars can be an important IWM tool, useful in both conventional and LEI farming systems.

Barley is the most competitive annual crop grown on the Canadian prairies (Todd 1989), and is considered globally to be competitive (Lemerle et al. 2001a). Barley cultivar competitiveness varies (Christensen 1995; Didon 2002; O'Donovan et al. 2000), but cultivar rankings are required to use cultivar competitive ability as an IWM tool. For farmers and extension personnel, competitive rankings would be useful for cultivar selection and recommendation.

There are two aspects of competitive ability. Ability to withstand competition (AWC) has been considered as the ability of the crop to withstand yield loss due to weed competition whereas ability to compete (AC) has been considered as the ability of the crop to suppress weeds

(Goldberg and Landa 1991). In varietal studies of competitive ability, both aspects need to be considered (Lemerle et al. 2001b), since these measures may not be strongly related..

Examination of cultivar competitive ability should incorporate sufficient cultivars and have broad representation of genetic and phenotypic classes. Lemerle et al. (2001b) suggested that as the number of cultivars declines, it becomes more likely that attributes observed to contribute to cultivar competitive ability may actually be chance associations. Previous research has noted that semi-dwarf and hull-less cultivars were generally less competitive than full height and hulled cultivars, respectively (O'Donovan et al. 2000). To be useful, both aspects of cultivar competitive ability should be consistent in over time and at different locations. In wheat cultivars, AC may be more consistent than AWC (Cousens and Mokhtari 1998). However, this has not been established for barley.

This research was undertaken to: 1) explore aspects of barley cultivar competitive ability (AWC and AC) with oats, and, 2) examine the feasibility of ranking cultivars based on either, or both, AWC and AC.

Materials and Methods

Screening trials were conducted in 2001 and 2002 to determine the range of barley competitive ability in western Canada. Barley cultivars were selected: 1) to represent barley classes based on seed rows (2- and 6-row), seed covering (hulled and hull-less), stature (full height and semi-dwarf) and end-use (feed and malt), 2) cultivars were grown on at least 5% of the acreage in its class in one or more of the Canadian prairie provinces in 1999, and, 3) to represent the range in competitive ability of barley cultivars. Certified, registered or breeder seed was available for 29 cultivars (Table 1).

A split-plot design, with 4 replicates, was used. Barley cultivars were the main plot. The subplots either had tame oat (*Avena sativa* L. cv. AC Assiniboia) seeded (weedy plots) or not (weed-free plots). Experimental plots (sub-plots) were 2m x 6m. All fields had clay loam soils and were previously under zero-till management.

In 2001 seed came from multiple sources and was treated with Charter. Barley cultivars and tame oats were sown simultaneously in seed rows to achieve a target density of 250 and 70 plants m^{-2}, respectively. The target density of 70 plants m^{-2} for tame oat was selected to achieve a 25% yield reduction. All plots were direct-seeded to a depth of 4cm using an air-seeder with narrow hoe type openers on 23cm row spacing. In 2002 when all barley seed came from a common source, seed treatment was not applied to either the crop or weed seed. Nitrogen fertilizer was applied at a rate of 78.4 kg ha^{-1} actual N as 46-0-0 in a mid-row band at seeding. Phosphorus was seed-placed at a rate of 22.4 kg actual P_20_5 ha^{-1} as 0-45-0.

Glyphosate was applied pre-seed as required. Weedy plots were treated with a broadleaf herbicide in-crop whereas weed-free plots were treated with a grassy and broadleaf herbicide. Foliar fungicide (Tilt 250E) was applied as per the label in all plots. Harvest was performed with a small plot combine and yield in weed-free plots was determined by weighing the sample from each plot after cleaning. In weedy plots, the dockage was determined by manually separating oat from barley seed and weighing the oat seed. Yield was calculated by subtracting dockage from the gross yield. A seed increase was undertaken in 2001 to provide a common seed source for 2002.

Cultivar AWC was calculated as: $$AWC=100-\%\ YL \qquad [1]$$
where YL is yield loss.

Cultivar AC was calculated as: AC = 100-% dockage [2]

All analyses were conducted in SAS. A separate ANOVA was conducted for each site-year and mean AWC and AC scores were separated using Fisher's protected LSD at _=0.05. Since barley is commonly classified and discussed by breeders and farmers in terms of phenotypic attributes (2- vs. 6-row, hulled vs. hull-less, full height vs. semi-dwarf) and end-use (malt vs. feed), orthogonal contrasts were performed on these phenotypic and end-use classes to determine if these classes varied in competitive ability. Simple correlation coefficients were calculated to examine the relationship of AWC with AWC and AC with AC.

Results and Discussion

Significant differences ($p \leq 0.0001$) in cultivar competitive ability occurred in all site-years for both AWC and AC. Values for AWC ranged from a minimum of 21 for Peregrine to a maximum of 94 for Virden, representing yield loss ranging from 6-79%. Values for AC ranged from a minimum of 17 for Falcon to a maximum of 90 for Virden. This represents a factor of approximately 5.3x separating the most from least weed suppressive cultivars. Since both AWC and AC have a theoretical minimum and maximum of zero and 100, respectively, barley cultivar competitive ability exhibited considerable range in these trials.

Cultivars differed substantially in competitive ranking both between and within site-years. For example, Kasota, Ranger, Excel and Metcalfe had consistently higher rankings for AWC and AC in 2001 compared to 2002 (Table 1). Harrington and B1602 had consistently higher rankings for AWC and AC in 2002 compared to 2001 (Table 1). Within a growing season, Stratus ranked 26th and 3rd for AWC at Sites 3 and 4, respectively. Stratus also ranked 5th and 4th at Sites 3 and 4, respectively for AC, as compared to 22nd at Sites 5 and 6 (Table 1).

Cultivars were categorized as highly-, poorly-, and intermediately-competitive. Since tame oats were seeded to achieve a target yield loss of 25%, cultivars having less than 25% yield loss and less than 25% of weed seed yield in weedy plots may be considered highly competitive (Figure 1). In addition to the cultivars Virden, Lacombe, Ranger, Robust, B1602 and Excel meeting these criteria, Metcalfe and Dolly were both ranked in the top 10 for both AWC and AC (Table 1) and were considered highly competitive. A clearly identifiable group of poorly-competitive cultivars (Figure 1) included Peregrine, Falcon, Thompson, Dawn and Kasota. These poorly-competitive cultivars were semi-dwarf, hull-less, or both. Cultivars not classed as poorly or highly competitive were considered intermediately competitive. Since poorly-competitive cultivars were semi-dwarf and hull-less, analysis of phenotypic and end-use classes was undertaken.

When all cultivars were considered, AWC generally differed among phenotypic and end-use classes (Table 2). The exception was for the 2- versus 6-row comparison for AWC. When row phenology was considered alone, 6-row cultivars were both the most and least competitive cultivars, whereas 2-row cultivars tended to be intermediately competitive. Semi-dwarf cultivars were less competitive than full height cultivars. Hull-less cultivars were less competitive than hulled cultivars (Figure 1). As with row phenology, feed cultivars were observed to be both the most and least competitive cultivars. When less competitive semi-dwarf and hull-less cultivars were removed, the probability that no difference occurred between: 1) hulled and hull-less classes was reduced, 2) 2- and 6-row classes varied by site-year, and, 3) feed and malt classes was substantially reduced for AWC (Table 2).

Table 1. Rank, and Variance of Rank (Var), for Ability to Withstand Competition (AWC) and Ability to Compete (AC) for Barley Cultivars. Data are Ordered by Rank of AC.

Cultivar	Code[b]	AWC								AC							
		2001		2002						2001		2002					
		1[a]	2	3	4	5	6	Rank	Var	1	2	3	4	5	6	Rank	Var
Virden	6FYF	1	1	1	1	1	1	1	0.0	1	1	2	1	1	1	1	0.2
Lacombe	6FYF	3	5	11	4	5	2	2	10.0	2	2	9	4	6	3	2	7.5
Ranger	6FYF	16	20	1	8	7	3	3	55.0	7	7	1	4	2	2	2	7.0
Robust	6FYM	12	13	7	12	1	13	7	23.1	4	4	5	3	4	5	4	0.6
B1602	6FYM	2	2	20	17	13	13	8	57.4	3	2	9	8	7	6	5	7.8
Excel	6FYM	12	22	4	4	5	16	8	55.9	12	8	2	2	3	9	5	18.0
Metcalfe	2FYM	9	13	7	10	3	4	3	14.3	9	20	4	4	4	4	7	41.5
Dolly	2FYF	5	5	19	4	11	20	8	53.1	5	5	5	9	10	12	8	9.5
Stratus	2FYM	14	10	26	3	20	24	17	77.8	5	6	5	4	22	22	9	77.5
Bedford	6FYF	7	13	20	10	23	11	13	38.4	9	9	15	9	13	12	10	6.6
Phoenix	2FNF	5	18	6	8	16	8	8	29.8	14	23	12	9	9	7	11	33.5
Oxbow	2FYM	9	20	7	12	10	23	13	41.9	14	19	5	12	8	14	11	24.4
Stander	6FYM	17	24	10	25	23	20	23	31.8	13	12	9	15	16	14	13	6.2
Manley	2FYM	17	4	3	4	9	7	3	27.5	19	9	12	18	13	20	14	19.8
Bacon	6FNF	8	8	12	19	16	20	13	28.2	9	13	12	16	22	14	14	19.5
Hawkeye	6FNF	20	11	14	17	22	13	18	18.2	22	15	15	12	21	10	14	23.0
Candle	2FNF	11	13	5	2	8	10	3	16.6	20	24	15	14	10	14	17	25.0
Harrington	2FYM	4	2	14	16	16	18	8	47.1	7	9	20	22	16	18	17	36.7
Kendall	2FYM	22	11	17	20	21	18	20	15.8	20	15	21	18	16	18	19	5.2
McGwire	2FNF	24	13	20	20	11	11	20	30.7	23	20	24	16	10	10	19	38.6
Earl	6SYF	20	23	17	25	23	28	25	14.7	17	20	15	20	13	25	19	18.3
Stein	2FYM	19	19	26	15	4	8	13	64.6	16	13	22	24	16	22	22	19.4
Condor	2FNF	25	24	12	14	13	6	19	54.7	26	25	19	20	16	20	23	14.4
Gainer	2FNF	25	9	20	23	26	4	20	83.8	23	18	22	23	25	8	23	39.0
Kasota	6SYF	14	5	28	28	16	25	24	85.5	17	15	28	28	26	26	25	33.5
Dawn	2FNF	27	26	20	22	13	16	26	30.3	27	27	25	26	24	24	26	1.9
Thompson	2SYF	22	27	14	23	28	27	27	27.5	25	26	27	25	28	27	26	1.5
Falcon	6SNF	29	28	20	27	26	26	28	10.0	29	29	26	27	27	27	28	1.5
Peregrine	6SNF	28	29	29	29	29	29	29	0.2	28	28	29	28	29	29	29	0.3
Mean									36.0								18.5

a Site number.
b Codes are: 2,6 = rows; S,F = semi-dwarf, full height; Y,N = hull – Yes, No; M,F = Malt,Feed

Individual cultivars did not always reflect the classes they occurred in. For example, Earl was the most competitive semi-dwarf (Figure 1), and in some site-years was intermediately competitive. Kasota, another semi-dwarf cultivar, ranked highly for AWC in 2001, particularly at Site 2 (Table 1). Furthermore, height alone did not necessarily confer a competitive advantage. For example, Ranger, a full-height shorter-stature cultivar, was highly competitive in 2002. By contrast, the hull-less cultivar Hawkeye was the tallest, but among the least competitive of the full height cultivars (Figure 1). Phoenix was another tall, hull-less cultivar, (Figure 1) was nearly categorized as highly-competitive since its overall rank was 8th in AWC and 11th in AC (Table 1).

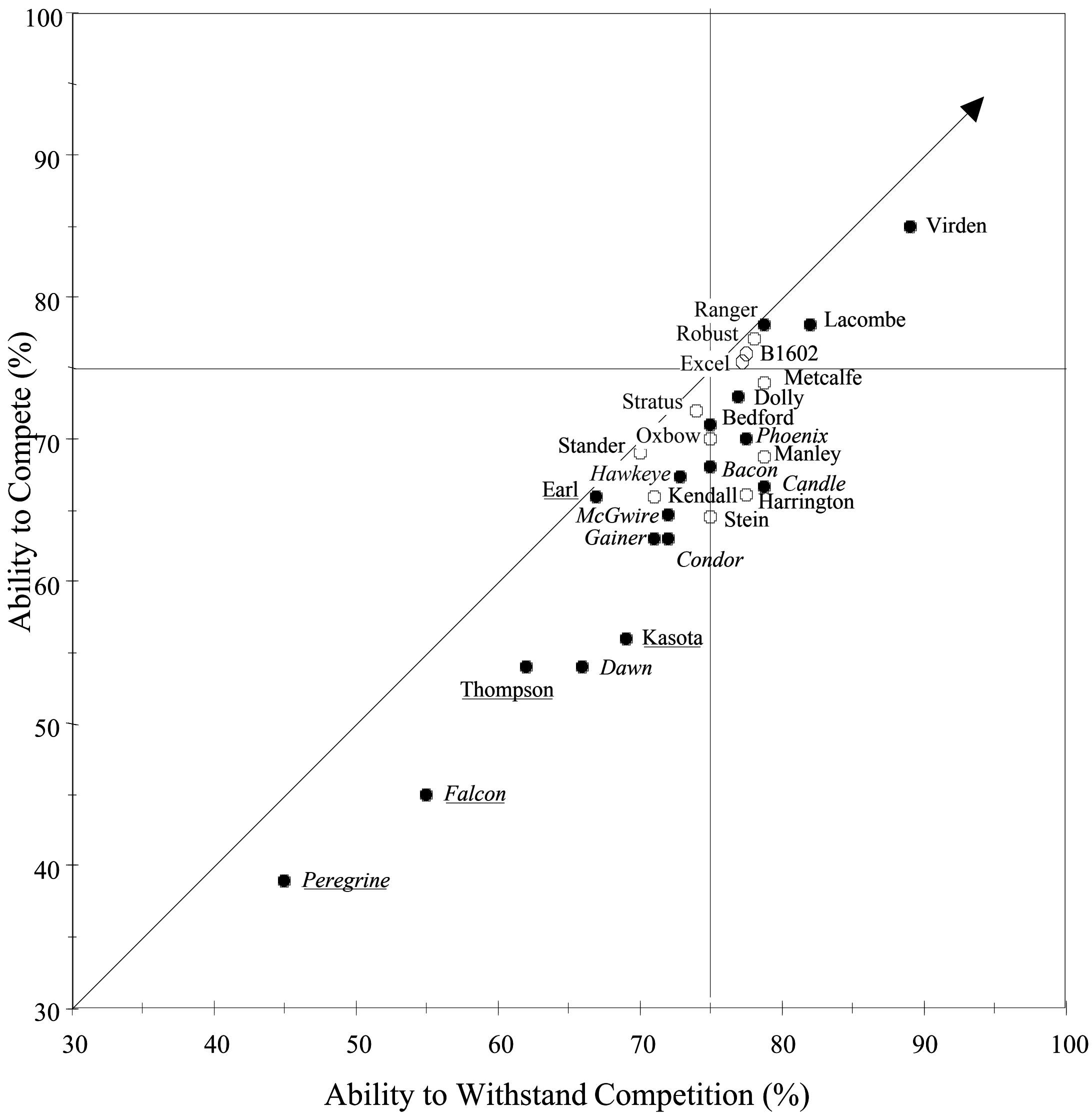

Figure 1. Scatterplot of ability to compete (AC) versus ability to withstand competition (AWC). Data are averaged across all site-years. The arrow points in the direction of increasing competitive ability. Dashed lines represent: 1) on the abscissa (AWC), 25% yield loss, and, 2) on the ordinate (AC), 25% weed seed yield by weight in the weedy sample. Malt cultivars are denoted by open circles, semi-dwarf cultivars are underlined, and hull-less cultivars are in *italics*.

The relationship of AWC with AWC, and AC with AC was often statistically significant, but not substantive (Table 3). When either or both of the semi-dwarf and hull-less cultivars were removed from the analysis, no mean correlation coefficient exceeded 0.5. As each of these classes of cultivars were removed, correlation coefficients generally either declined or remained constant (Table 3). Correlation coefficients for AC were higher than for AWC. More pair-wise correlation coefficients were statistically (Table 3) and substantively (Watson 2004) significant for AC than for AWC. Correlation coefficients were often higher for 6-row than 2-row, hulled than hull-less, feed than malt and semi-dwarf than full height classes (Table 3).

The competitive ranking of AC was generally less variable than that of AWC (Table 1). Among highly-competitive cultivars, only Excel, Metcalfe and Dolly had one ranking outside the top 10 (Table 1) for AC. By contrast, most cultivars had more than one ranking not in the top 10 for AWC. When considering poorly-competitive cultivars, only Kasota escaped having all ranking for both AWC and AC in the bottom 10. While highly- and poorly-competitive cultivars tended to have fewer substantial differences in ranking, intermediately competitive cultivars tended to have many substantial differences in competitive ranking. Manley, Candle, Harrington and Stein all had substantially better rankings for AWC than AC. By contrast, Stratus and Stander had substantially better ranking for AC than AWC (Table 1).

Table 2. Contrasts (p-values) for Values of Ability to Withstand Competition (AWC) With All, Cultivars, Then Semi-dwarf, Then Hull-less Cultivars Removed.

Site (year)	All Cultivars				Semi-dwarf cultivars excluded			Semi-dwarf and hull-less cultivars excluded	
	Stature[1]	Hull[2]	Rows[3]	Use[4]	Hull	Rows	Use	Rows	Use
Site 1 (2001)	<0.0001	<0.0001	ns	<0.0001	<0.0001	<0.0001	ns	0.0006	0.0154
Site 2 (2001)	<0.0001	<0.0001	ns	<0.0001	0.0131	ns	ns	0.0350	ns
Site 3 (2002)	<0.0001	0.0068	ns	0.0580	ns	0.0426	ns	0.0881	0.0043
Site 4 (2002)	<0.0001	<0.0001	0.0015	0.0012	0.0063	ns	ns	0.0429	ns
Site 5 (2002)	<0.0001	0.0013	ns	0.0027	0.0121	ns	ns	ns	ns
Site 6 (2002)	<0.0001	ns	0.0443	ns	ns	ns	0.0225	ns	ns

1 full height vs. semi-dwarf
2 hulled versus hull-less
3 2-row versus 6-row
4 feed versus malt

Table 3. Average of Simple Correlation Coefficients of AWC With AWC and AC With AC. The Number of Significant Occurrences Out of 15 is in Parentheses. Semi-dwarf and Hull-less Classes Were Successively Removed From the Analysis.

Cultivar class	All cultivars		Semi-dwarf cultivars excluded		Semi-dwarf and hull-less cultivars excluded	
	AWC	AC	AWC	AC	AWC	AC
All cultivars	0.4326 (15)	0.6329 (15)	0.2016 (7)	0.4603 (15)	0.2002 (6)	0.4301 (13)
2-row	0.2103 (5)	0.3679 (12)	0.1388 (3)	0.2734 (6)	0.0900 (0)	0.1517 (2)
6-row	0.5626 (15)	0.7424 (15)	0.2450 (5)	0.4568 (13)	0.2696 (6)	0.4247 (11)
Full height	0.2016 (7)	0.4603 (15)	-	-	-	-
Semi-dwarf	0.3735 (4)	0.4650 (7)	-	-	-	-
Hull-less	0.5111 (14)	0.6303 (15)	0.1180 (2)	0.2629 (8)	-	-
Hulled	0.2994 (11)	0.5706 (15)	0.2002 (6)	0.4301 (13)	-	-
Feed	0.5010 (15)	0.6790 (15)	0.2695 (6)	0.5581 (15)	0.2852 (2)	0.4962 (10)
Malt	0.0875 (2)	0.2803 (6)	0.0875 (2)	0.2803 (6)	0.0875 (2)	0.2803 (6)

Most research reporting barley cultivar competitive ability has employed fewer than 10 cultivars (Christensen 1995; Didon 2000; O'Donovan et al. 2000). These studies generally have used cultivars with moderate to high AWC. A factor of approximately 2.5x has been reported (Christensen 1995; O'Donovan et al. 2000) from least to most competitive in terms of weed suppression ability, but this can vary when nutrients are plentiful or withheld (Konesky et al. 1989). Excluding poorly-competitive cultivars, values for AWC and AC reported in our research are similar to those reported elsewhere.

Most previous research has not explicitly considered differences in phenotypic and genotypic classes of barley cultivars, but has supported the proposition that semi-dwarf (O'Donovan et al. 2000) and shorter-stature cultivars (Lanning et al. 1997) are less competitive than taller cultivars. O'Donovan et al. (2000), examined the competitive ability of a group of barley cultivars including full height, semi-dwarf, hulled, and hull-less ones. They included three hull-less cultivars and found that two of three were poor competitors. As in our study, Phoenix was relatively competitive. The poor competitive ability of hull-less cultivars has been attributed to poor emergence, possibly resulting from hull-less cultivars' greater susceptibility to loss of seed vigour due to vulnerability to mechanical damage and subsequent invasion by fungi than hulled cultivars (O'Donovan et al. 2000).

Highly competitive cultivars need to be competitive at multiple locations in multiple years to be reliably recommended. Cousens and Mokhtari (1998) and Lemerle et al. (2001a) found that few wheat cultivars were consistently more competitive than others. Consequently, making reliable recommendations to farmers was difficult given the considerable environmental component. Results from our study suggests that AC for poorly- and highly-competitive barley cultivars was more consistent over time than intermediately-competitive ones. While AWC was less stable, barley cultivars can reliably be classed as highly-, intermediately, and poorly-competitive.

Consistency of cultivar competitive ability can be affected by a number of factors. Crop seed vigour is affected by the growing conditions under which the mother plant matures (Andersson and Milberg 1998), differences in harvest practices (Bourgeois et al. 1996) and seedlot differences (Morrison et al. 1991). In our study, Ranger was notable for its differential AWC based on seed source differences between 2001 and 2002. Consequently, research into cultivar competitive ability should be undertaken with seed grown at a common location and harvested with the same equipment, to reduce confounding of cultivar competitive ability due to genotypic and environmental variability.

Barley cultivar competitive ability has a substantial range and can be an important IWM tool. It can be used in conjunction with other IWM tools such as yield loss thresholds and reduced herbicide rates. Farmer adoption of cultivar competitive ability requires rankings for AWC and AC be made available in variety seed guides in the same way yield and disease ratings currently are. Published ranking would require breeders to incorporate competitive ability into variety trials. Different ranking bases may be important in different production systems. For example, AWC may be more suitable for conventional production systems, where herbicides are used, than for organic systems. While yield loss is incurred as a result of low AWC, high seed return (low AC) need not occur since herbicide application can reduce weed numbers, and therefore, weed seed yield. In organic, and other low-external-input systems, some yield loss may be acceptable, but minimizing seed return is also an important objective.

Literature Cited

Andersson, L. and P. Milberg. 1998. Variation in seed dormancy among mother plants, populations and years of seed collection. Seed Sci. Res. 8:29-38.

Bourgeois, L, J. Moes, and E. H. Stobbe. 1996. Impact of threshing on hard red spring wheat seed vigour. Can. J. Plant Sci. 76:215-221.

Christensen, S. 1995. Weed suppression ability of spring barley varieties. Weed Res. 35:241-247.

Cousens, R. D. and S. Mokhtari. 1998. Seasonal and site variability in the tolerance of wheat cultivars to interference from *Lolium rigidum*. Weed Res. 38:301-307.

Didon, U. M. E. 2002. Variation between cultivars in early response to weed competition. J. Agron. Crop Sci. 188:176-184.

Goldberg, D. E., and K. Landa. 1991. Competitive effect and response: hierarchies and correlated traits in the early stages of competition. Ecol. 79:1013-1030.

Konesky, D. W., M. Y. Siddiqi and A. D. M. Glass. 1989. Wild oat and barley interactions: varietal differences in competitiveness in relation to phosphorus supply. Can. J. Bot. 67:3366-3371.

Lanning, S. P., L. E. Talbert, J. M. Martin, T. K. Blake and P. L. Bruckner. 1997. Genotype of wheat and barley affects light penetration and wild oat growth. Agron. J. 89:100-103.

Lemerle, D., B. Verbeck, and B. Orchard. 2001a. Ranking the ability of wheat varieties to compete with *Lolium rigidum*. Weed Res. 41:197-209.

Lemerle, D., G. S. Gill, C. E. Murphy, S. R. Walker, R. D. Cousens, S. Mokhtari, S. J. Peltzer, R. Coleman, and D. J. Luckett. 2001b. Genetic improvement and agronomy for enhanced weed competitiveness with weeds. Aust. J. Agric. Res. 52:527-548.

Liebman, M., and A. S. Davis. 2000. Integration of soil, crop and weed management in low-external-input farming systems. Weed Res. 40:27-47.

Morrison, I. N., K. M. Nawolsky, M. H. Entz, and A. E. Smith. 1991. Differences among certified wheat seedlots in response to trifluralin. Agron. J. 83: 119-123.

O'Donovan, J. T., K. N. Harker, G. W. Clayton, and L. M. Hall. 2000. Wild oat (*Avena fatua*) interference in barley (*Hordeum vulgare*) is influenced by barley variety and seeding rate. Weed Technol. 14:624-629.

Todd, B. G. 1989. Weed control in barley. Pages 43-48 i*n* Proceedings of the Prairie Barley Symposium. Slinkard, A.E., B.G. Rossnagel and F.A. Holm (Eds.). Crop Development Centre: Saskatoon.

Watson P.R. 2004. The contribution of attributes in the seed, seedling, and mature plant phases to barley (*Hordeum vulgare*) cultivar competitiveness against weeds. Ph.D. Thesis. University of Manitoba, Winnipeg, Manitoba, Canada.