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Relative performance of Canadian spring wheat cultivars under organic and conventional field conditions

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Abstract Producing higher yields under organic conditions is generally hampered by weeds and lesser nutrient supply. In wheat certain adaptive traits like early season vigour, taller plants, and shorter life cycle have been reported to help plants compete with weeds and produce satisfactory yields. In this experiment we tested the hypothesis 'that early flowering and maturity conferred by insensitive vernalization alleles *Vrn-A1a* and/or *Vrn-B1* has a yield advantage under organic conditions' in Canadian spring wheat germplasm. We genotyped 32 cultivars for their vernalization gene composition (*Vrn-A1a, Vrn-B1 and Vrn-D1*) and studied these cultivars in organic and conventional management systems. We found 88 % of the cultivars possessed vernalization (*Vrn*) insensitive allele *Vrn-A1a* either alone or in combination with *Vrn-B1*. There were no differential affects between the cultivars having insensitive *Vrn* allele at either single locus (*Vrn-A1a*) or two (*Vrn-A1a, Vrn-B1*) under organic and conventional field conditions; except for days to maturity, where cultivars having only *Vrn-A1a* allele matured earlier. This earlier maturity did not translate to any yield advantage under organic field conditions. Overall, the cultivars grown under organic conditions were earlier flowering, lower yielding with lower test weight compared to the conventional management system. Significant cultivar × environment interactions were found for grain yield, grain protein content and grain fill rate. For grain protein content, cross-over interactions of the cultivars between the management systems were observed. Three cultivars (Marquis, Unity and Minnedosa) exhibited minimal comparative loss in grain yield and grain protein content under organic field conditions, and hence could potentially serve as parents for organic wheat breeding programs.

Keywords Spring wheat · Organic · Conventional · Vernalization

Abbreviations

CWRS	Canada western red spring
CWSWS	Canada western soft white spring

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CPS	Canada prairie spring
CWHWS	Canada western hard white spring
GFD	Grain fill duration
GFR	Grain fill rate
NIR	Near-infrared reflectance

Introduction

Crop production without the use of synthetic fertilizers and chemicals is called organic farming. The International Federation of Organic Agriculture Movements defines organic farming as "a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects". Extensive use of chemical inputs during the last century has raised numerous concerns over human and environmental health, and agricultural sustainability. Due to the fact that organic food production is safe and chemical-free, the demand for organic food has increased 4–5 times since 1990. Ever since, it has evolved as the most dynamic food industry, worth $59 billion globally with approximately 37.2 million ha area under certified organic cultivation worldwide (Paull and Hennig 2011). Canadian contribution towards organic food production is relatively small and approximately 0.7 million ha are organically managed and wheat is the number one Canadian organic crop grown on about 102, 434 ha (Agriculture and Agri-Food Canada 2009).

Organically managed lands differ substantially from their conventional counterparts for soil biodiversity, nitrogen level, soil moisture and retaining capacity, soil organic matter, weed intensity and types, and biotic and abiotic stresses (Hornick 1992; Gruber et al. 2000; Barberi 2002; Entz et al. 2001). This results in considerable differences in agronomic and quality traits of various crops grown and compared in organic and conventional management systems. Aside from environmental stress, cultivars exhibit significant genetic variation among each other to respond any biotic or abiotic stress (Romagosa and Fox 1993). Therefore, several studies reported inconsistencies in crop and/or cultivar performance from one location to other (Peterson et al. 1992; Sial et al. 2000).

In organic management systems, grain yields are generally low compared to conventional production systems (Poutala et al. 1993; Mason et al. 2007; Reid et al. 2009), while a great deal of confusion exists around the quality of the produce. In fact the nutritionally important quality micronutrients are affected by a number of factors related to soil, environment and management (Davis and Abbott 2006). Nelson et al. (2011) concluded that the quality of the organic produce varies from one location to other and should not be universalized. A number of studies suggest organic production to be superior and rich in their nutritional value (Nelson et al. 2011; Reid et al. 2009); however, there are studies reporting significant loss in grain protein content under organic conditions (Starling and Richards 1993; Ryan et al. 2004; Zorb et al. 2009). Mader et al. (2007) reported non-significant differences in nutritional value and baking quality in Eurpoean germplasm studied over 21 years.

Across the Canadian Prairies, the growing season or the number of frost free days are limited to 95–125 days in total. Earlier flowering and maturity are desirable traits to avoid yield and quality losses in this region. Under organic field conditions, earliness with better early season vigour is beneficial to compete for a limited nutrient supply. Mason et al. (2007) reported higher grain yield of the early maturing cultivars with better early season vigour under organic field conditions. Early maturity also confers adaptive advantage by avoiding abiotic stress conditions of early or late season frost, and hence, most Canadian spring wheat cultivars possess the most potent vernalization genes (Kamran et al. 2013). Iqbal et al. (2007) suggested that simultaneous selection for higher grain yield and early maturity is possible by identifying the certain *Vrn* gene combinations. In this context, it is important to study the how the different vernalization genes interact to induce early maturity without negatively affecting grain yield, and whether early maturity confers any yield advantage under organic field conditions.

The objectives of the study were: a) to study the differential behaviour of vernalization genes in days to flowering and maturity under organic and conventional management systems; b) if reduction in days to maturity due to insensitive *Vrn* genes confers grain a yield advantage under organic field conditions; c) to identify the genotypes/cultivars that are better suited to organic production.

Materials and methods

In this experiment we studied a set of 32 Canadian spring wheat cultivars in organic and conventional management systems. These cultivars were mostly released during the last ten years under the following four classes: Canada western red spring, Canada western soft white spring, Canada prairie spring and Canada western hard white spring. The four classes represent more than 96 % of the area under cultivation in Canadian prairies (Statistics Canada 2011).These cultivars were studied in 2010, 2011 and 2012 at the Edmonton Research Station (53°32′N, 113°32′W) University of Alberta, on conventional and organically managed fields located less than 1 km apart. The experiment was laid out in an alpha lattice design. Plot dimension at each site was 2 × 1.38 m with six rows. Data on days to flowering, days to anthesis and maturity, plant height, grain yield, test weight, and grain protein content were recorded. The organic field experiment in 2011 was overwhelmed with weeds and data were recorded for days to flowering, anthesis and maturity only. Days to flowering was recorded when 50 % of the spikes emerged out of the flag leaf. Days to anthesis was recorded when 50 % of the spikes in a plot exhibited protruded anthers. Days to maturity were recorded when 50 % of the peduncles had completely lost their green color. Grain protein content was estimated using a SpectraStar RTW apparatus by Unity Scientific by near infrared reflectance spectroscopy. Grain yield per plot was weighed and converted to yield on a t/ha dry basis. Grain fill duration (GFD) was estimated as the duration between anthesis and maturity, and grain fill rate (GFR) was estimated by dividing the total gain yield by total grain fill days.

The cultivars were genotyped for vernalization (*Vrn-A1a, Vrn-A1b, Vrn-B1, Vrn-D1)* genes. 7–10 day-old seedling leaf tissue was ground to extract DNA by standard CTAB protocol. Primer sequences for these *Vrn* genes were adopted from Yan et al. (2004) and Fu et al. (2005). PCRs were done in GeneAmp® 9700 PCR systems (Applied Biosystems). A total volume of 20 µL of the reaction mixture was used for PCR containing: a) 1–4 µL of template DNA about at a concentration of 25–100 ng/µL, b) 0.5 µL of each forward and reverse primers at 5 µM concentration, c) 10 µL of Extract-N-Amp™PCR ready mix (Sigma-Aldrich, Cat#E3004), and d) 5–8 µL sterile water to make total reaction volume to 20 µL. The PCR cycling conditions were followed exactly as described by Yan et al. (2004) and Fu et al. (2005). The PCR products were ran and visualized in a 3 % agarose gel.

The cultivar LSMEANS were estimated in PROC MIXED of SAS by keeping cultivar as the only fixed effect, and year, block nested in year, incomplete block nested in block and year as random effects in each environment. The LSMEANS were ranked from earliest to latest in term of time to flowering, anthesis, maturity and highest to lowest in terms of grain yield, grain protein content, test weight, GFD and GFR. To study the differential performance of the cultivars in the two environments (organic and conventional management systems), the data were analysed by using PROC MIXED in SAS by keeping the environment as a fixed effect while year, block nested in year, incomplete block nested in block and year as random effects. To identify the better performance of a cultivar in either of the environments, cultivar x environment interactions were calculated by modelling the cultivar, environment and cultivar × environment interaction as fixed effects. The identified significant interaction affects were further partitioned with a SLICE command in PROC MIXED for both cultivars and environments. To account for the number of comparisons, the alpha values were adjusted by BONFERRONI correction (Dunn 1961). The LSMEANS for the individual cultivar in each environment were estimated by keeping the cultivars as a fixed affect. The significance of difference between the conventional and organic management system was estimated by comparing it with the critical range estimate provided by the Rayan–Einot–Gabrial–Welsh test which adjusts the alpha value ‘experiment-wise’. The cultivars were also sub-grouped based on their *Vrn* gene composition and class, and were considered as a treatment. To retain enough statistical power and to avoid the genetic background noise of the cultivars from different classes, only CWRS cultivars were taken into consideration for ranking and comparison under organic field conditions. The differences between the cultivars with single insensitive allele (*Vrn-A1a*) or two (*Vrn-A1a, Vrn-B1*) were estimated only in the CWRS class. These treatments were

Table 1 Mean differences between the conventional and organic management system for days to flowering, anthesis, maturity, plant height (cm), grain yield (t ha^{-1}), test weight (kg hL^{-1}), grain protein content (%), grain fill days and grain fill rate for all the cultivars under study grown at Edmonton Research station during 2010, 2011 and 2012

Entry	Variety	YOR	Class	*Vrn-A1a*	*Vrn-B1*	*Vrn-D1*	Flowering (days)	Anthesis (days)	Maturity (days)	Height (cm)	Yield (t ha^{-1})	Test weight (kg hL^{-1})	Grain protein (%)	Grain fill duration	Grain fill rate
1	5700PR	2000	CPS[a]	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	0.0	0.6	3.3	−2.5	1.77	2.00	−1.87	3.7	40.6
2	5701PR	2001	CPS	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	1.2	1.5	6.5	−0.8	2.07	1.23	−1.87	6.4	36.7
3	5702PR	2010	CPS	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	0.6	1.7	−0.4	−5.2	1.42	0.75	−1.85	−1.6	47.5
4	Ac Vista	1996	CPS	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	0.9	0.4	2.7	−0.3	1.39	1.64	−1.11	3.0	33.1
5	Alvena	2007	CWRS[b]	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	1.3	1.5	2.1	0.8	1.60	3.6	0.66	1.6	47.6
6	Andrew	2000	CWSWS[c]	*vrn-A1*	*Vrn-B1*	*Vrn-D1*	1.4	2.2	2.6	−1.5	1.85	1.68	−2.13	1.3	48.2
7	Attila	–	CIMMYT	*vrn-A1*	*vrn-B1*	*Vrn-D1*	0.9	1.2	2.7	−1.2	0.54	2.9	−0.82	2.6	14.6
8	AC Barrie	1994	CWRS	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	0.5	0.9	−4.1	2.9	0.63	2.75	1.24	−2.9	33.8
9	Bhishaj	2002	CWSWS	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	1.5	2.0	3.8	0.1	1.17	−0.52	−1.99	3.3	28.9
10	Bounty	–	CWRS	*Vrn-A1a*	*Vrn-B1*	*vrn-D1*	1.0	1.2	1.1	0.0	1.26	2.88	0.34	1.2	44.9
11	CDC Go	2004	CWRS	*Vrn-A1a*	*Vrn-B1*	*vrn-D1*	−0.4	0.4	1.4	−2.2	1.03	3.43	−0.15	1.9	28.3
12	Fieldstar	2009	CWRS	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	1.4	2.7	5.4	−3.9	0.64	−0.38	1.05	3.5	19.5
13	Goodeve	2008	CWRS	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	1.1	2.4	0.8	1.9	1.24	2.62	−0.10	−1.0	46.1
14	Harvest	2002	CWRS	*Vrn-A1a*	*Vrn-B1*	*vrn-D1*	0.8	1.0	0.3	0.7	0.34	1.51	−0.09	0.8	16.6
15	Infinity	2006	CWRS	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	0.7	1.3	3.9	−2.4	0.14	0.46	1.10	3.9	3.4
16	Kane	2006	CWRS	*Vrn-A1a*	*Vrn-B1*	*vrn-D1*	0.1	0.6	−0.5	0.3	1.17	3.94	0.96	−0.4	37.0
17	Katepwa	1981	CWRS	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	−0.5	0.1	1.1	−0.6	1.11	3.62	1.59	1.9	36.0

Table 1 continued

Entry	Variety	YOR	Class	*Vrn-A1a*	*Vrn-B1*	*Vrn-D1*	Flowering (days)	Anthesis (days)	Maturity (days)	Height (cm)	Yield (t ha^{-1})	Test weight (kg hL^{-1})	Grain protein (%)	Grain fill duration	Grain fill rate
18	Lillian	2004	CWRS	*Vrn-A1a*	*Vrn-B1*	*vrn-D1*	1.5	1.5	3.2	2.6	2.05	1.74	0.51	2.5	56.2
19	Lovit	2003	CWRS	*Vrn-A1a*	*Vrn-B1*	*vrn-D1*	1.3	1.5	2.7	−0.6	0.96	1.42	0.73	2.0	32.7
20	Marquis	1910	CWRS	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	2.4	2.9	5.4	3.2	−0.41	2.25	−0.40	4.0	−6.3
21	Minnedosa	2008	GP	*Vrn-A1a*	*Vrn-B1*	*vrn-D1*	1.6	2.1	3.1	−1.1	0.53	0.79	−0.34	1.8	12.5
22	Osler	2003	CWRS	*Vrn-A1a*	*Vrn-B1*	*vrn-D1*	0.2	1.0	2.7	2.1	2.01	3.64	0.89	2.9	53.2
23	Park	1963	CWRS	*Vrn-A1a*	*Vrn-B1*	*vrn-D1*	0.3	0.9	5.6	6.3	0.29	2.70	0.67	5.8	6.6
24	Sadash	2008	CWSWS	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	3.3	4.1	6.7	−0.4	1.91	0.76	−0.73	4.2	41.8
25	Snowwhite 475	2004	CWHWS[d]	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	0.7	2.6	2.1	−2.8	1.40	1.66	0.05	0.8	35.3
26	Snowwhite 476	2004	CWHWS	*vrn-A1*	*Vrn-B1*	*vrn-D1*	2.9	3.3	2.4	−1.8	1.09	1.14	0.14	0.6	31.6
27	Somerset	2005	CWRS	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	2.2	2.1	1.0	5.1	1.07	3.52	0.49	0.6	33.5
28	Stettler	2008	CWRS	*Vrn-A1a*	*Vrn-B1*	*vrn-D1*	0.1	0.2	1.0	0.0	1.11	4.66	1.47	2.2	30.6
29	Superb	2001	CWRS	*Vrn-A1a*	*Vrn-B1*	*vrn-D1*	−0.6	0.2	−3.7	3.4	0.61	3.10	−1.12	−2.6	27.9
30	CDC Teal	1991	CWRS	*Vrn-A1a*	*vrn-B1*	*vrn-D1*	0.5	0.9	0.1	2.2	0.95	3.37	0.76	0.3	35.4
31	Unity	2009	CWRS	*Vrn-A1a*	*Vrn-B1*	*vrn-D1*	−0.4	1.4	2.8	3.6	0.32	1.17	−0.28	2.0	14.5
32	Waskada	2008	CWRS	*Vrn-A1a*	*Vrn-B1*	*vrn-D1*	1.0	1.5	0.1	−1.2	1.32	1.89	0.39	−0.2	42.4
–	–	–	–	Mean $_{(Conventional)}$			56.4	59.5	102.9	94.5	5.30	76.00	10.50	43.4	121.2
–	–	–	–	S.E $_{(Mean)}$			0.17	0.10	0.50	0.50	0.11	0.15	0.09	0.49	2.17
–	–	–	–	Mean $_{(Organic)}$			55.5	58.0	100.8	94.3	4.20	73.50	10.60	41.7	89.7
–	–	–	–	S.E $_{(Mean)}$			0.20	0.20	0.80	0.50	0.13	0.40	0.35	0.97	2.29

Table 1 continued

Entry	Variety	YOR	Class	*Vrn-A1a*	*Vrn-B1*	*Vrn-D1*	Flowering (days)	Anthesis (days)	Maturity (days)	Height (cm)	Yield (t ha^{-1})	Test weight (kg hL^{-1})	Grain protein (%)	Grain fill duration	Grain fill rate
–	–	–	–	Prob > F			<0.0001	<0.0001	0.119	0.78	<0.0001	<0.0001	0.87	0.0008	0.018

Grain fill duration = Days to maturity − days to anthesis

Grain fill rate = (Total grain yield)/(Grain fill duration)

[a] Canadian prairie spring

[b] Canada western red spring

[c] Canada western soft white spring

[d] Canada western hard white spring

considered a fixed effect to compare organic and conventional environments.

Results

Most of the cultivars under study possessed insensitive vernalization alleles at two of the *Vrn-1* loci: 28 of 32 cultivars possessed insensitive *Vrn* allele *Vrn-A1a* either alone (*Vrn-A1a-vrn-b1-vrn-D1* 50 % or 16 cultivars) or in combination with *Vrn-B1* (*Vrn-A1a-Vrn-b1-vrn-D1* 38 % or 12 cultivars) (Table 1). The harvest from the organic plots were weighed with and without weed seeds. Overall, the weed seed contributed 16 to 43 % of the total harvested yield during 2010 and 2012 (Data not shown). All the traits under study except days to maturity, plant height and grain protein content differed statistically between organic and conventional management in overall analysis of variance (Table 1). Generally, the cultivars under organic conditions were earlier flowering, lower yielding with a lower test weight compared to the conventional management system (Table 1). This trend was similar in sub-groups of cultivars belonging to CWRS class having either one or two insensitive alleles at *Vrn-1* locus (*Vrn-A1a-vrn-B1-vrn-D1 or Vrn-A1a-Vrn-B1-vrn-D1*) (Table 2). The only exception was the cultivars with single insensitive *Vrn* allele matured earlier under organic environment compared to the cultivars having two insensitive vernalization alleles (*Vrn-A1a* and *Vrn-B1*) (Table 2). However, this reduction in days to maturity failed to translate into higher grain yields under organic field conditions.

Of the 22 CWRS cultivars, three out of the top six earliest maturing cultivars were among the lowest yielding (Lillian, Osler, and Alvena ranks: 21, 22 and 18); whereas, two out of the six latest maturing cultivars were higher yielding cultivars ranked as six and five (AC Barrie and Superb) (Table 3). These results suggest that there is no clear evidence to conclude whether earlier flowering and/or maturity have conferred any yield advantage. Rather, a strong positive correlation was found between grain yield and days to flowering and maturity (Table 6). These results also suggested that significant cultivar × environment interaction is more likely to impact the grain yield, rather than the maturity times. Cultivar × environment interaction effects were found significant for grain yield, grain protein content and GFR (Table 4).

The estimates of sliced LSMEANS of the cultivars and environment for the traits were ranked according to the minimum and maximum differences between organic and conventional environments (Table 1). Maximum differences between organic and conventional conditions for days to flowering, anthesis and maturity were observed in Sadash and Superb. Sadash has the maximum acceleration under organic conditions by 3.3, 4.1 and 6.7 days in flowering, anthesis and maturity, while Superb had the maximum delay of 0.6 and 3.7 days in flowering and maturity (Table 1, 5). A low negative correlation between plant height and grain yield was found in organic and non-significant positive correlation was found under conventional conditions (Table 6).

Marquis, the oldest studied cultivar, had higher yield and protein content under organic conditions than conventional. This was the only exception, as all other cultivars had lower yield under organic conditions. The minimum grain yield losses under organic conditions were incurred by Infinity (0.14 t ha^{-1}) while the maximum losses were noted in 5701PR (2.07 t ha^{-1}) (Table 1, 5). In terms of grain protein content, cross-over interaction among the cultivars and environments occurred: 15 of 32 cultivars studied exhibited higher grain protein content under organic conditions while 17 cultivars had higher grain protein under conventional conditions (Table 1, 5). The top six cultivars with higher grain protein (>1.85 %) under organic conditions were: Andrew, Bhishaj, 5700PR, 5701PR, and 5702PR (Table 1, 5), however, all of these cultivars except 5702PR incurred maximum grain yield losses under organic field conditions (Table 1). The cultivars like Fieldstar, Infinity, AC Barrie, Stettler, and Katepwa had significant loss of grain protein (>1.05 %) under organic grown conditions (Table 5). The trend for loss in grain filling rate was quite similar to the trend in grain yield. The cultivar Infinity had almost no difference (3.38) in GFR while cultivar Lillian had substantially low (56.2) GFR under organic conditions (Table 1).

Cultivars grown under organic field conditions generally flowered earlier as compared to conventional conditions. As the nutrient supply under organic conditions is limiting, the cultivars under organic field conditions produced 21 % less grain yield on an average; however, the cultivars Marquis, Infinity, Park, Unity, Harvest and Minnedosa had comparable grain yields in both management systems (Table 5).

Discussion and conclusion

We report the following four main results of this study: a) most of the cultivars studied possessed insensitive *Vrn* alleles: *Vrn-A1a* either alone or in combination with *Vrn-B1* b) cultivars having single insensitive *Vrn* alleles, i.e. *Vrn-A1a* induced earlier maturity under organic conditions compared to *Vrn-A1a* and *Vrn-B1* in combination; however, this accelerated maturity did not confer any yield advantage; c) cultivars grown under organic management system were earlier flowering, lower

Table 2 Differences in effects of vernalization genes in organic and conventional management systems for CWRS cultivars in the study, grown at Edmonton Research station during 2010, 2011 and 2012

	Lines with *Vrn-A1a*			Lines with *Vrn-A1a* and *Vrn-B1*		
	Conventional	Organic	Pr > F	Conventional	Organic	Pr > F
Flowering (days)	56.3 ± 0.3[a]	55.2 ± 0.4	0.0018	55.8 ± 0.3	55.3 ± 0.3	0.0834
Anthesis (days)	59.4 ± 0.2	57.8 ± 0.4	<0.0001	58.9 ± 0.2	57.9 ± 0.3	0.0002
Maturity (days)	100.7 ± 0.8	102.0 ± 1.2	0.1339	101.2 ± 0.8	103.5 ± 1.1	0.0073
Height (cm)	97.8 ± 1.1	97.0 ± 0.9	0.4701	94.9 ± 0.7	94.2 ± 0.7	0.5259
Yield (t ha^{-1})	5.03 ± 0.2	4.04 ± 0.3	<0.0001	5.08 ± 0.2	3.99 ± 0.2	<0.0001
Test weight (kg hL^{-1})	76.5 ± 0.3	72.6 ± 1.7	0.001	77.6 ± 0.2	73.9 ± 0.4	<0.0001
Protein content (%)	10.94 ± 0.2	10.61 ± 0.3	0.2669	10.64 ± 0.1	10.56 ± 0.2	0.7447
Grain fill duration	41.25 ± 0.8	43.41 ± 0.9	0.0186	42.4 ± 0.8	44.8 ± 0.9	0.0022
Grain filling rate	123.3 ± 4.7	89.6 ± 5.2	<0.0001	120.8 ± 3.5	85.7 ± 3.3	<0.0001

[a] Standard error of the mean

Table 3 LSMEANS for the CWRS cultivars in organic management system and their relative ranks for days to flowering, anthesis, maturity, plant height (cm), grain yield (t ha^{-1}), test weight (kg hL^{-1}), grain protein content (%), grain fill days and grain fill rate for the cultivars grown at Edmonton Research station during 2010, 2011 and 2012

Variety	Flowering (days)	Rank	Anthesis (days)	Rank	Maturity (days)	Rank	Yield (t ha^{-1})	Rank	Test weight (kg hL^{-1})	Rank	Grain protein (%)	Rank	Grain fill duration	Rank	Grain fill rate	Rank
Park	53.2	1	56.1	2	94.0	1	4.05	11	73.9	11	10.40	12	36.8	22	98.4	6
Lovit	55.1	10	58.1	14	96.7	2	3.72	16	74.6	8	10.12	14	37.8	19	84.7	15
Lillian	56.7	21	59.0	21	97.0	3	3.34	21	73.4	15	11.02	4	37.2	21	82.2	17
Osler	55.6	15	58.3	16	97.3	4	3.13	22	72.7	19	10.32	13	37.8	18	76.7	21
Alvena	55.1	11	57.9	11	97.5	5	3.72	18	73.7	22	10.66	7	38.7	16	84.9	14
Marquis	55.5	13	57.5	9	97.6	6	4.29	7	75.4	3	11.57	1	38.7	15	100.6	5
Unity	54.7	6	56.8	5	97.7	7	4.62	3	76.1	2	10.84	6	40.3	13	104.6	3
Infinity	56.4	19	58.9	20	97.8	8	4.76	2	74.5	9	9.70	19	37.7	20	117.5	1
Fieldstar	53.5	2	56.1	1	97.9	9	4.29	8	76.7	1	9.87	18	41.0	9	93.0	7
Goodeve	54.8	7	57.0	7	98.5	10	4.16	9	73.8	12	11.02	5	40.8	10	90.4	8
Bounty	55.8	17	58.8	18	98.5	11	3.90	12	75.1	4	10.63	9	38.5	17	88.9	9
Harvest	54.0	5	56.4	3	98.6	12	4.55	4	75.0	6	10.63	10	40.7	11	102.7	4
Katepwa	55.7	16	58.2	15	99.8	13	3.48	20	72.7	18	9.60	22	40.7	12	77.6	20
Minnedosa	55.2	12	57.4	8	99.8	14	4.88	1	74.8	7	10.44	11	41.6	7	110.7	2
Somerset	56.2	18	58.8	19	100.0	15	3.72	17	72.4	21	11.12	3	39.5	14	85.9	13
CDC Teal	55.0	8	57.5	10	100.0	16	3.85	14	73.6	14	10.05	16	41.3	8	82.7	16
Kane	55.0	9	57.9	12	101.6	17	3.69	19	73.7	13	9.68	21	43.2	5	77.9	19
CDC Go	53.7	4	56.8	6	101.7	18	3.89	13	73.3	16	11.23	2	43.8	3	78.8	18
Waskada	53.6	3	56.6	4	102.2	19	3.75	15	75.0	5	10.09	15	44.3	2	71.7	22
Stettler	56.9	22	59.2	22	102.9	20	4.15	10	73.1	17	9.69	20	42.3	6	86.3	12
Barrie	55.5	14	58.0	13	103.8	21	4.31	6	74.4	10	9.95	17	43.7	4	88.5	10
Superb	56.6	20	58.6	17	105.7	22	4.49	5	72.5	20	10.65	8	45.8	1	87.6	11

Note: The cultivars are ranked based on the days to maturity from earliest to latest maturing

Table 4 ANOVA table of the probability of F-tests for cultivar, environment (Organic and conventional) and the interaction between cultivar and environment for the experiment grown at Edmonton Research station during 2010, 2011 and 2012

	Cultivar	Envt.	Cultivar × Envt.
Flowering (days)	<0.0001	<0.0001	0.3081
Anthesis (days)	<0.0001	<0.0001	0.1879
Maturity (days)	<0.0001	0.0616	0.7295
Height (cm)	<0.0001	0.7793	0.9922
Yield (t ha^{-1})	<0.0001	<0.0001	0.0008
Test weight (kg hL^{-1})	0.0742	<0.0001	0.1455
Protein content (%)	<0.0009	0.6967	<0.0001
Grain fill duration	<0.0001	<0.0010	0.8534
Grain filling rate	0.0042	<0.0001	0.0100

yielding and had lower test weight compared to the conventional management system d) significant cultivar x environment interactions were noted for grain yield, grain protein content and GFR.

The *Vrn* gene screening results of the cultivars under study reveals that most of the cultivars possessed insensitive vernalization alleles at either one or two loci (*Vrn-A1a* and *Vrn-B1*). These results are in line with previous findings in older Canadian spring wheat cultivars (Kamran et al. 2013). Mason et al. (2007) proposed a hypothesis that earlier flowering and maturity can help the plants outcompete weeds and produce better yields in organic systems. Based on this hypothesis, we studied modern Canadian germplasm to determine whether any of the particular *Vrn* genes or gene combinations governing flowering and maturity are better suited for organic conditions. Based on the germplasm studied in this experiment, the proposed hypothesis does not stand true; the insensitive allele *Vrn-A1a* conferred earlier maturity compared to the two *Vrn* alleles *Vrn-A1a* and *Vrn-B1,* but this acceleration cannot be clearly attributed to any yield advantage. The earliest maturing cultivar ‘Park’ (94 days to maturity) ranked 11 followed by Lovit (96.7 days to maturity) at 16th position (Table 3). A strong positive correlation was also found between days to flowering and/or maturity and grain yield (Table 6); which also suggests that grain yield increases with longer growth duration and delayed maturity. Apparently cultivar × environment interaction is responsible for higher grain yield under organic field conditions rather than the delay in days to maturity or *Vrn* gene combination. Kirk et al. (2012) found significant effects of the environments (both

Table 5 Relative ranking of the cultivars based on the differences between the conventional and organic management systems for grain yield (t ha^{-1}), grain protein content (%) for all the cultivars grown at Edmonton Research station during 2010, 2011 and 2012

Rank	Cultivar	Yield (t ha^{-1})			Cultivar	Protein content (%)		
		Conv[a]	Org[b]	Diff[c]		Conv	Org	Diff
1	Marquis	3.88	4.29	−0.41	Harvest	10.53	10.63	−0.09
2	Infinity	4.91	4.76	0.14	Goodeve	10.92	11.02	−0.10
3	Park	4.33	4.05	0.29	CDC Go	11.09	11.23	−0.15
4	Unity	4.94	4.62	0.32	Unity	10.55	10.84	−0.28
5	Harvest	4.88	4.55	0.34	Minnedosa	10.09	10.44	−0.34
6	Minnedosa	5.41	4.88	0.53	Marquis	11.17	11.57	−0.40
27	5700PR	5.90	4.12	1.77	Kane	10.64	9.68	0.96
28	Andrew	6.88	5.03	1.85	Fieldstar	10.92	9.87	1.05
29	Sadash	6.85	4.94	1.91	Infinity	10.80	9.70	1.10
30	Osler	5.14	3.13	2.01	AC Barrie	11.19	9.95	1.24
31	Lillian	5.39	3.34	2.05	Stettler	11.15	9.69	1.47
32	5701PR	5.71	3.64	2.07	Katepwa	11.19	9.60	1.59
–	LSD $_{(0.05)}$	0.11	0.17	–	–	0.14	0.23	–

[a] Conventional

[b] Organic

[c] Difference

Table 6 Pearson correlation co-efficient for the conventional and organic management system for days to flowering, anthesis, maturity, plant height (cm), grain yield (t ha^{-1}), test weight (kg hL^{-1}), grain protein content (%), grain fill days and grain fill rate for the CWRS cultivars only

	Flowering (days)	Anthesis (days)	Maturity (days)	Height (cm)	Yield (t ha^{-1})	Test weight (kg hL^{-1})	Protein content (%)	Grain fill duration	Grain filling rate
Flowering (days)	1	**0.85**	**0.78**	**0.06**	**0.42**	**−0.41**	**−0.01**	**−0.22**	**0.54**
		<0.0001	0.001	0.4232	<0.0001	<0.0001	0.9158	0.0023	<0.0001
Anthesis (days)	**0.94**	1	**0.15**	**0.10**	**0.40**	**−0.34**	**0.08**	**−0.11**	**0.47**
	<0.0001		0.0293	0.1655	<0.0001	<0.0001	0.342	0.1363	<0.0001
Maturity (days)	**0.73**	**0.72**	1	**0.19**	**0.43**	**0.31**	**0.45**	**0.97**	**−0.09**
	<0.0001	<0.0001		0.0051	<0.0001	0.0003	<0.0001	<0.0001	0.1957
Height (cm)	**−0.16**	**−0.20**	**−0.23**	1	**0.07**	**0.47**	**0.47**	**0.17**	**0.03**
	0.03	0.01	0.01		0.30	<0.0001	<0.0001	0.01	0.67
Yield (t ha^{-1})	**0.66**	**0.58**	**0.79**	**−0.20**	1	**0.42**	**0.33**	**0.32**	**0.84**
	<0.0001	<0.0001	<0.0001	0.02		<0.0001	0.00	<0.0001	<0.0001
Test weight (kg hL^{-1})	**0.20**	**0.16**	**0.19**	**0.01**	**0.21**	1	**0.26**	**0.38**	**0.19**
	0.02	0.07	0.03	0.89	0.02		0.00	<0.0001	0.03
Protein content (%)	**−0.69**	**−0.67**	**−0.78**	**0.30**	**−0.76**	**−0.15**	1	**0.43**	**0.01**
	<0.0001	<0.0001	<0.0001	0.00	<0.0001	0.10		<0.0001	0.87
Grain fill duration	**0.56**	**0.52**	**0.97**	**−0.21**	**0.76**	**0.17**	**−0.72**	1	**−0.22**
	<0.0001	<0.0001	<0.0001	0.02	<0.0001	0.05	<0.0001		0.00
Grain filling rate	**0.59**	**0.50**	**0.52**	**−0.13**	**0.92**	**0.19**	**−0.63**	**0.46**	1
	<0.0001	<0.0001	<0.0001	0.12	<0.0001	0.03	<0.0001	<0.0001	

Note: Values above diagonal are conventional and below are organic data coefficients

Negative sign means a negative correlation and no sign means positive correlation

The values in bold represent the correlation coefficient and the values in normal font represent corresponding *p* values

organic and conventional) on grain yield and protein content; and reported higher grain yield of the lines selected in organic environments. Another possible reason for this discrepancy could be due to the QTL responsible for accelerated GFR (Nass and Reisser 1975). GFR is a relatively less explored area of research, and is reported to play a significant role in determining wheat grain yield (Yang and Zhang 2006). Wang et al. (2009) detected 17 QTL explaining 7.2–20.8 % of the total phenotypic variation in GFR in a Chinese winter population. Kirigwi et al. (2007) also reported a QTL affecting the GFR on chromosome 4A. Therefore, a differential genetic background of the cultivars under study might have contributed towards a significant cultivar × environment interaction for grain yield. A strong positive correlation between GFR and grain yield found in this study (Table 6) further justifies the differential behaviour of the cultivar under stress conditions. A low negative correlation between the grain yield and plant height found in organic conditions also suggest that the taller CWRS cultivars do not necessarily better compete with weeds for light interception. However, these results are not in agreement with Mason et al. (2007) and Wolfe et al. (2008). Similarly, a strong negative correlation between grain protein content and GFD in organic conditions was found, and a moderate to low positive correlation between the same traits was found in conventional management systems (Table 6).

The significant cultivar × environment interaction for grain yield found in this study suggests that some cultivars can tolerate nutrient, weed and disease pressure better than other cultivars. Overall, the cultivars exhibited significant interaction with the organic and conventional management systems for grain yield, grain protein content and GFR.

Cultivar interaction with environment for grain protein content was interesting, as some of the cultivars had higher grain protein content under organic conditions and some had higher grain protein content under conventional conditions. Some cultivars produced similar grain protein under both organic and conventional management systems (Table 5). As all the cultivars are flowering and maturing within the available growing time in Canadian Prairies, cultivars better suited to organic condition were selected based on minimum grain yield and grain protein losses. Selecting the top six cultivars (20 %) that had minimum grain yield and grain protein losses among the systems resulted in three common cultivars (Table 5). These three cultivars viz. Marquis, Unity and Minnedosa had comparable yield and grain protein contents in both production systems. Marquis, the oldest cultivar in the study, had higher yield and better protein content under organic conditions. Marquis was bred in early 20th century, and the selection was practiced under organic conditions. The other two cultivars that had minimum grain yield and grain protein losses under organic conditions, were released recently (Minnedosa 2008 and Unity 2009); and defy the particular hypothesis that older cultivars are better suited to organic breeding (Table 4). In a micronutrient analysis of five Canadian spring wheat cultivars released during 1910 to 2000 Nelson et al. (2011) found no particular trend in cultivar performance in relation to their year of release.

Better performance of certain cultivars under organic field conditions has been reported previously (Mason et al. 2007). Nass et al. (2003) reported significantly higher grain yield by AC Barrie under organic conditions compared to check AC Walton, which generally outcompeted AC Barrie for grain yields under conventional conditions. Kitchen et al. (2003) found higher grain yields in organic conditions at 3 of the 14 paired sites; and found significant cultivar × environment interaction for grain yield. Carr et al. (2006) reported cultivar x environment interactions for grain yield, grain protein content and test weights in fifteen spring wheat cultivars of northern Great Plains. Murphy et al. (2007) reported different genotypic ranks between the organic and conventional management systems. Przystalski et al. (2008) reported cross-over interaction of the cultivars between the management systems and suggested trait and stress oriented breeding for organic crop production.

Overall, we found significant interaction of the cultivars with management system; therefore, breeding for organic production should be conducted on organically managed lands. When grown under organic field conditions the earlier flowering cultivars generally produced lower grain yields and had lower test weights. Three cultivars: Marquis, Minnedosa, Harvest and Unity had minimum losses under organic conditions and can potentially serve as parents for organic breeding.

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