Canadian spring hexaploid wheat (Triticum aestivum L.) cultivars exhibit broad adaptation to ultra-early wheat planting systems

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SHORT COMMUNICATION

Canadian spring hexaploid wheat (*Triticum aestivum* L.) cultivars exhibit broad adaptation to ultra-early wheat planting systems

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Abstract: Ultra-early wheat growing systems based on soil temperature triggers for planting instead of arbitrary calendar dates can increase grain yield and overall growing system stability of spring wheat (*Triticum aestivum* L.) on the northern Great Plains. We conducted field trials at three sites in western Canada from 2017 to 2019 to evaluate the suitability of Canadian spring hexaploid wheat cultivars and market classes for use within ultra-early spring wheat growing systems. All cultivars and classes exhibited improved grain yield stability (lower adjusted coefficient of variation values) and optimal grain yield when planted ultra-early at 2 °C soil temperature rather than delaying planting to 8 °C.

Key words: Wheat, grain, yield, stability, cultivar, ultra-early, climate, agronomy, planting.

Résumé : Les régimes de culture ultraprécoce du blé qui misent sur la température du sol plutôt qu'une date arbitraire inscrite au calendrier pour déclencher les semis peuvent augmenter le rendement grainier ainsi que la stabilité générale de la culture du blé de printemps (*Triticum aestivum* L.) dans les grandes plaines du Nord. De 2017 à 2019, les auteurs ont effectué des essais sur le terrain à trois endroits, dans l'Ouest canadien, en vue d'établir si les cultivars de blé de printemps hexaploïdes canadiens et les variétés marchandes pourraient servir à la culture ultraprécoce du blé. Les variétés et les classes illustrent toutes un rendement grainier plus stable (valeurs corrigées plus faibles du coefficient de variation) et donnent un rendement grainier optimal quand on les sème très tôt, soit à une température du sol de 2 °C plutôt que de 8 °C. [Traduit par la Rédaction]

Mots-clés : blé, grain, rendement, stabilité, cultivar, ultraprécoce, climat, agronomie, emblavures.

Introduction

Canada was the sixth largest global producer (32.3 MT) and third largest exporter (22.8 MT) of wheat (*Triticum aestivum* L.) in 2019 (FAOSTAT 2021). The average wheat grain yield in Canada has more than doubled from 1.5 Mg·ha^{-1} (1961–1970) to 3.2 Mg·ha^{-1} (2010–2019) as a result of improved genetics, agronomic management, synthetic fertilizer use, adoption of new technology and mechanization, and increased growing system efficiency (Beres et al. 2020; FAOSTAT 2021). Ultra-early seeding systems have been proposed as a new management approach to increase current grain yield; and enhance the resiliency of Canadian spring wheat growing systems against impending negative yield impacts of climate

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change (Collier et al. 2020; Collier et al. 2021). Wheat grain yield reduction on the northern Great Plains has been predicted in multiple studies, primarily as a result of reduced in-season precipitation and increased daily temperatures during the critical grain fill period (Kouadio et al. 2015; He et al. 2018; Qian et al. 2019; Collier et al. 2020). An early seeding strategy to avoid environmental stress during grain filling periods has been evaluated in the Australian grain belt and the United States Pacific Northwest (Kirkegaard et al. 2015; Hunt et al. 2018). Ultra-early wheat seeding systems for the northern Great Plains growing region are based on the use of soil temperatures to trigger planting, combined with optimized agronomic management, and are characterized by planting into soils at 2 °C–6 °C and maintaining optimal seeding rates of 400 seeds m^{-2}. Previously, we evaluated ultra-early wheat seeding systems using experimental cold tolerant spring wheat lines and one Canada Western Red Spring (CWRS) cultivar as a standard check (Collier et al. 2020). Wheat cultivar did not impact grain yield stability in this study; however, a broad evaluation of multiple Canadian spring wheat market classes and hexaploid spring wheat cultivars for adaptation to ultra-early spring wheat growing systems has not been completed to date. The purpose of the present study is to investigate grain yield and grain yield stability of multiple western Canadian spring wheat market classes and registered western Canadian hexaploid spring wheat cultivars planted in an ultra-early wheat seeding system on the northern Great Plains.

Materials and Methods

We conducted the present study at three sites in western Canada in 2017 and 2018, and one site in 2019 resulting in seven total site-years (Table 1). The experiment was seeded as a factorial randomized complete block design with four blocks. Treatment combinations consisted of two seeding dates and twelve wheat cultivars (Table 2). Wheat cultivars were selected based on a combination of the significance of the seeded area of the cultivar within its wheat class in 2016, and the widest genetic variation available within commercial Canadian cultivars for vernalization, photoperiod and height genes (Kamran et al. 2013; Canadian Grain Commission 2021; Statistics Canada 2021). Soil temperatures were determined, and seeding was triggered as previously reported (Collier et al. 2021, 2020). To identify spring wheat lines and classes with increased sensitivity to ultra-early seeding, a sowing density of 200 viable seeds m^{-2}, known to be sub-optimal in ultra-early wheat seeding systems, was used (Collier et al. 2021). Seeding equipment and operations, nutrient and pest management and data collection was completed as reported by Collier et al. (2021).

Statistical analyses were completed using the MIXED procedure of SAS (Version 9.4, Cary, NC, USA) and followed the procedure of Collier et al. (2021), with the exception that the combined ANOVA was completed with site-year, replication, soil temperature trigger and cultivar as variables in the CLASS statement (SAS Institute 2018).

An LSMESTIMATE statement for grain yield with soil temperature trigger × cultivar as a fixed effect was used to compare the grain yield of each cultivar when seeded at either 2 °C or 8 °C soil temperature.

A biplot grouping methodology using mean grain yield on the vertical axis and adjusted coefficient of variation (aCV) on the horizontal axis, as originally described by Francis and Kannenberg (1978) and modified by Doring and Reckling (2018), was used to explore system stability and variability of grain yield with multiple wheat cultivars and wheat classes. We categorized data on the biplots into four groups/quadrants divided by the mean aCV and the mean grain yield of the growing system: (Group I) high mean grain yield and low variability, (Group II) high mean grain yield and high variability, (Group III) low mean grain yield and high variability, and (Group IV) low mean grain yield and low variability.

Results

Environmental conditions

Planting was earlier, and all sites experienced more cold stress after seeding in 2017 than in 2018 or 2019. The earliest planting was in Lethbridge, AB on March 20 of 2017. The Scott, SK site was planted on 31 Mar. and the Edmonton, AB site was planted on 7 Apr. of 2017. Prolonged snow cover in 2018 resulted in all locations planting between 23 Apr. and 27 Apr.; in 2019, the first planting date at the Lethbridge site was 2 Apr. After initial plantings, each site-year experienced multiple nights of ambient air temperatures below freezing. In 2017, the Scott site experienced the harshest conditions of the study, with 27 nights of ambient air temperatures below freezing after planting; the lowest temperature observed was −9.4 °C. The Lethbridge and Edmonton sites recorded 17 and 14 nights, respectively, of ambient air temperatures below freezing after planting in 2017, with temperatures as low as −7.6 °C and −6.1 °C, respectively.

Accumulated precipitation fell below the 30-yr average for all seven site-years. The Lethbridge site received the least precipitation in 2017 and 2019, which was 66% and 67% of the 30-yr average respectively, and the Scott site received the least precipitation in 2018, (70% of the 30-yr average). Initial planting dates, environmental information and additional climatic, and site-specific information is included in Table 1.

Grain yield, grain quality, and plant establishment

Planting trigger did not have a significant effect on grain protein content, grain test weight, thousand kernel weight, grain yield or plant establishment. There

Table 1. Post-seeding air temperature extremes and cumulative freezing events recorded at each location × year.

Location	Latitude/ Longitude	Agroecological region	Soil zone, Texture	Soil organic matter(%)	pH	Average yearly precipitation* (mm)	Year	Actual precipitation (mm)	Earliest seeding date**	Number of days with air temperature below 0°C after initial seeding date	Lowest air temperature recorded after seeding (°C)
Edmonton, Alberta	53°33′N 113°29′W	Parkland	Black, Loam	9.5	5.9	446	2017	416	7 Apr.	14	−6.1
							2018	391	27 Apr.	1	−1.2
Lethbridge, Alberta	49°41′N 112°50′W	Western Prairies	Dark brown, Clay loam	4.6	8.0	380	2017	249	20 Mar.	17	−7.6
							2018	284	23 Apr.	2	−1.2
							2019	253	2 Apr.	16	−6.9
Scott, Saskatchewan	52°21′N 108°49′W	Western Prairies	Dark brown, Clay loam	2.9	6.0	366	2017	300	31 Mar.	27	−9.4
							2018	257	24 Apr.	5	−3.1

Note: *1981–2010 average yearly precipitation accumulation. **Based on 2 °C soil temperature trigger date.

was no negative impact of ultra-early seeding on grain quality or grain yield (Table 2).

Wheat cultivars and classes varied ($P < 0.001$) for all grain yield, grain quality, and plant establishment variables (Table 2). In general, the CWRS and Canada Prairie Spring Red (CPSR) cultivars displayed the greatest grain protein concentration and lower grain yield, and the Canada Western Soft White Spring (CWSWS), Canada Western Special Purpose (CWSP) and cold tolerant (CT) experimental lines accumulated lower grain protein content and greater grain yield. Potential differential performance of a cultivar planted at 2 °C soil temperature versus at 8 °C soil temperature may have been masked by the lack of a significant planting soil temperature × cultivar interaction. This was further confirmed by performing an LSMEstimate within the PROC MIXED procedure of SAS which did not detect yield differences between the ultra-early 2 °C and 8 °C soil temperature planting time (Table 2). Analysis of plant establishment data indicated no difference within cultivars in the number of live plants between ultra-early and conventional planting timing with the exception of CDC Plentiful (CWRS), which displayed a greater number of viable plants at the ultra-early planting time (data not shown).

Wheat class and grain yield stability

To visualize the effect of planting date, wheat cultivar and wheat class on grain yield and growing system stability, a modified biplot grouping methodology was employed. The original methodology of Francis and Kannenberg (1978) was modified to include an adjusted coefficient of variation (aCV) in the place of a traditional coefficient of variation as described by Doring and Reckling (2018). The use of an aCV negates the dependence of system stability on the magnitude of the realized grain yield. Biplot A in Fig. 1 illustrates the stability of each cultivar when planted ultra-early into 2 °C soil and when planted into soil at 8 °C. All points related to the 8 °C soil temperature planting trigger are located right of the mean aCV value and are located in Groups II and III of the biplot; which are defined by lower grain yield stability than the data points in Groups I and IV. All of the cultivars planted ultra-early are represented on the left side of the mean aCV value, in Groups I and IV. This indicates the greatest grain yield stability occurred when the cultivars in this study were planted at an ultra-early timing triggered by 2 °C soil temperatures despite the harsh environmental conditions experienced after planting. Biplot B presents the same data points grouped by Canadian wheat market class rather than by specific cultivar. The CWSWS and CWSP cultivars had the greatest grain yield, while CPSR and CWRS cultivars had relatively lower grain yield. Relative grain yield between wheat classes was consistent regardless of planting time. All wheat classes performed similarly in response to ultra-early planting, with similar grain yields relative to planting at 8 °C, but exhibited improved grain

Table 2. Least square means for grain yield, grain quality parameters, and plant counts for multiple western Canada wheat cultivars/classes planted ultra-early.

	Protein (%)	Test weight (Kg·hL^{-1})	Thousand kernel weight (g)	Plant count (plants 6m·row^{-1})	Grain yield (Mg·ha^{-1})		
Planting trigger							
2 °C Soil temperature	12.8	80.3	32.8	214	4.01		
8 °C Soil temperature	12.6	80.7	32.4	203	3.79		
F Test	NS	NS	NS	NS	NS		
$LSD_{0.05}$							
Cultivar (Class)					Grain yield (Mg·ha^{-1})	Grain yield at 2 °C soil temperature trigger[a]	Grain yield at 8 °C soil temperature trigger[a]
5700PR (CPSR)	14.3	81.6	36.4	206	3.59	3.67	3.51
AC Andrew (CWSWS)	11.3	79.4	33.5	204	4.20	4.37	4.03
Conquer (CPSR[b])	13.9	80.8	36.6	214	3.79	3.88	3.71
AC Foremost (CPSR[b])	13.3	80.1	38.0	192	3.61	3.63	3.58
LQ1282A (CT)	10.9	81.1	28.4	200	4.28	4.47	4.09
LQ1299A (CT)	11.8	79.5	30.3	205	3.92	4.07	3.77
LQ1315A (CT)	11.7	80.3	31.1	197	4.00	4.19	3.82
Pasteur (CWSP)	12.2	81.6	33.4	218	4.35	4.50	4.19
CDC Plentiful (CWRS)	14.0	80.4	39.8	228	3.63	3.76	3.51
AC Sadash (CWSWS)	10.8	80.2	33.5	207	4.27	4.40	4.15
CDC Stanley (CWRS)	13.9	79.2	28.6	221	3.52	3.49	3.55
AC Stettler (CWRS)	14.1	81.7	31.8	216	3.61	3.67	3.54
F Test	*	*	*	*	*	—	—
$LSD_{0.05}$	0.5	0.6	0.9	12	0.22	—	—

Note: Yield and grain quality parameters do not include data from Lethbridge in 2018 due to plot damage, plant counts include data from all seven locations. *Significant at $P < 0.001$; NS, not significant; $LSD_{0.05}$, least significant difference at $P < 0.05$. Abbreviations: CPSR, Canada Prairie Spring Red; CWSWS, Canada Western Soft White Spring; CT, cold tolerant; CWSP, Canada Western Special Purpose; CWRS, Canada Western Red Spring.

[a]There was no difference in grain yield at 2 °C and 8 °C soil temperature planting triggers for any individual cultivar ($P < 0.05$).

[b]Moved to the Canada Northern Hard Red (CNHR) class after 2016.

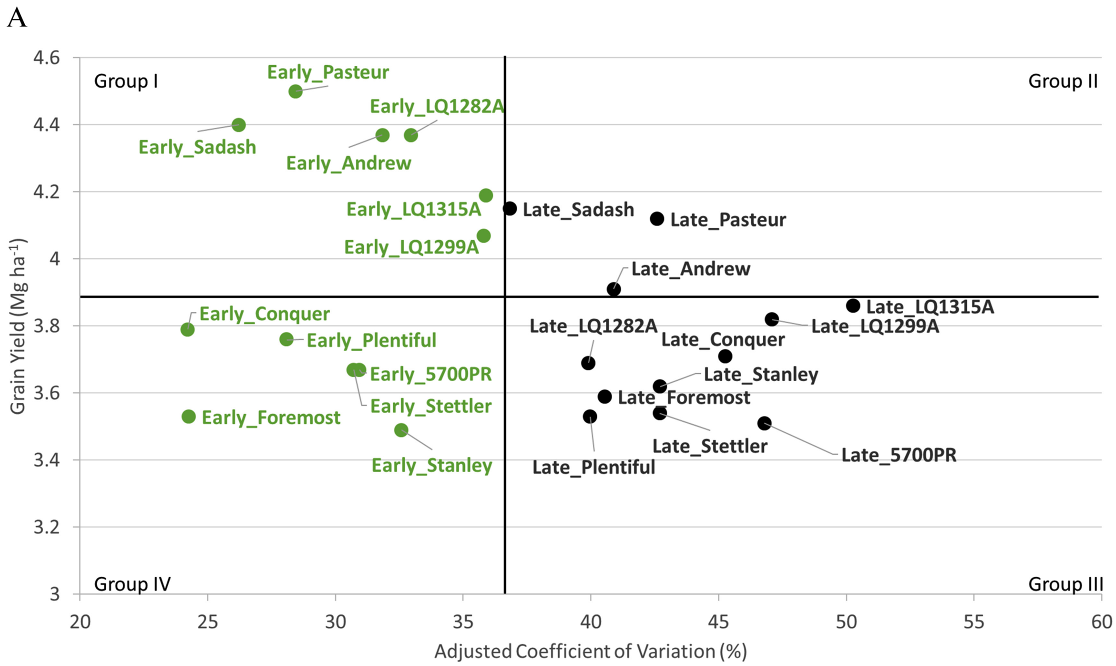
yield stability and thus, improved growing system stability when planted in 2 °C soil.

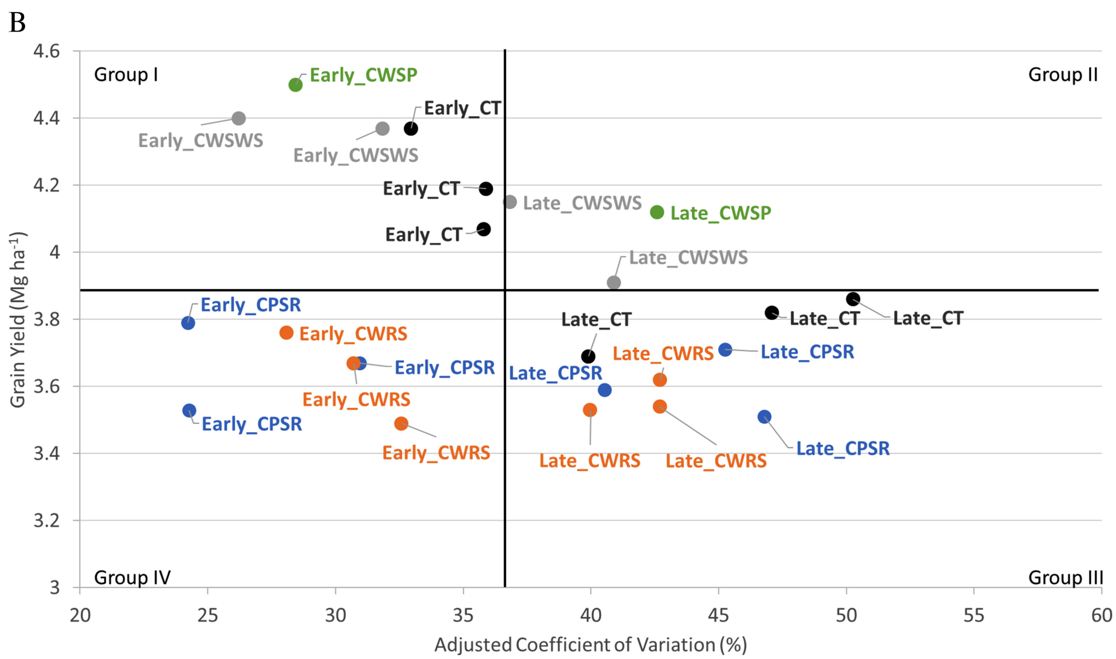
Discussion

We have reported that planting wheat ultra-early based on soil temperature on the northern Great Plains of western Canada not only maintained grain yield, but can also lead to increased grain yield over delayed planting (Collier et al. 2021, 2020). These previous studies reported that specially developed cold tolerant spring wheat lines were not required to successfully plant wheat ultra-early; however, these studies only evaluated one cultivar from the CWRS wheat class. Here, we evaluated nine wheat cultivars from four Canadian wheat market classes, as well as three cold tolerant lines. In all cases, when wheat cultivars were planted earlier (2 °C soil temperatures in the top 5 cm of soil) the growing system stability was superior to the same cultivars planted later at 8 °C soil temperatures. Collier et al. (2021) evaluated manipulations to agronomic management of ultra-early wheat seeding systems to increase grain yield and growing system stability, and reported that using optimal seeding rates (400 seeds m^{-2}) was a critical agronomic management strategy to maintain or increase grain yield and growing system stability in an ultra-early wheat seeding system. In the present study, a sub-optimal seeding rate (200 seeds m^{-2}) was used to identify wheat cultivars or classes susceptible to decreases in grain yield or growing system stability as a result of ultra-early seeding. The lack of a negative response in grain yield and growing system stability when planted ultra-early at sub-optimal seeding rates indicates that broad adaptation to ultra-early seeding systems exists within a majority of Canadian wheat germplasm and commercially available cultivars representing dominant market classes in western Canada.

This work corroborates the results of previous studies and supports the expansion of current ultra-early wheat growing system recommendations to include additional wheat classes in western Canada. Spring wheat from Canadian wheat market classes including, but not

Fig. 1. Biplots summarizing grain yield means versus adjusted coefficient of variation (aCV) for each wheat cultivar planted at each soil temperature (A), and for each Canadian wheat market class planted at each soil temperature (B). Abbreviations are as follows: (I) The first word represents the soil temperature at planting (early = 2 °C soil temperature, late = 8 °C soil temperature). (II) The second word denotes the wheat cultivar in Biplot A (See Table 2 for full wheat cultivar names), or the functional class of the wheat cultivar in Biplot B (CWRS, Canada Western Red Spring; CPSR, Canada Prairie Spring Red; CWSWS, Canada Western Soft White Spring; CWSP, Canada Western Special Purpose; CT, cold tolerant). The use of colour serves to group data points by soil temperature at planting (Biplot A), and by wheat functional class (Biplot B). Biplot group definitions: (Group I) high mean grain yield and low variability; (Group II) high mean grain yield and high variability; (Group III) low mean grain yield and high variability; (Group IV) low mean grain yield and low variability.





limited to, CWRS, CWSWS, CPSR, CWSP and Canada Northern Hard Red (CNHR) can successfully be planted in ultra-early wheat growing systems. The impacts of a changing climate including fewer precipitation events and increased daily temperatures may disproportionately affect higher-yielding, lower protein wheat cultivars such as CWSWS and CWSP class cultivars that require longer grain-filling periods and longer growing seasons. Shifting planting to earlier in the season and optimizing agronomic management within an ultra-early wheat growing system acts as an avoidance mechanism to negate, or reduce, future grain yield losses resulting from climate change. In such a scenario, a shift to ultra-early seeding may serve as a mitigation strategy to maintain current grain yield potential and achieve further yield gap closure on the northern Great Plains.

Conclusions

Canadian hexaploid spring wheat cultivars exhibited broad suitability for use in ultra-early wheat growing systems. The most successful ultra-early wheat growing systems will incorporate commercial Canadian hexaploid spring wheat cultivars, planted at optimal seeding densities of not less than 400 seeds m^{-2}, when soil temperatures of 2 °C–6 °C in the top 5 cm of the soil surface are first observed. Ultra-early growing systems incorporating these management tactics will lead to increased grain yield and grain yield stability relative to current conventional wheat growing practices and increase the resiliency of wheat growing systems on the northern great plains.

Competing Interests

The authors declare there are no competing interests.

Author Contributions

Mr. Collier, Senior Corresponding Author — co-developed and conceptualized the hypotheses and field experiments. Used project for partial fulfilment of PhD thesis requirements at the University of Alberta. Analyzed data and prepared manuscript. Participated in meetings and presented findings at conferences, field days and grower meetings.

Dr. Beres, Co-Investigator/Corresponding Author — co-developed and conceptualized the hypotheses and field experiments. Identified and recruited Collaborators, PhD student, and led workshops to finalize proposal. Participated in meetings and presented findings at conferences, field days and grower meetings. Co-supervises Mr. Graham Collier.

Dr. Graf, Co-Investigator — developed cold-tolerant lines used for field experiments. Reviewed and edited manuscript.

Ms. Gampe, Co-Investigator — site collaborator at Scott, SK Research Farm. Reviewed and edited manuscript.

Dr. Spaner, Principal Investigator — responsible for the field experimentation at the Edmonton sites. Co-Supervisor of Mr. Graham Collier. Reviewed and edited manuscript and mentored manuscript preparation and statistical analyses.

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