

Wheat variety R&D investment and adoption in Western Canada

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Abstract

Wheat is a key agricultural product for Canada, the majority of which is grown in the Prairie Provinces and exported. While several new wheat varieties are registered each year, most of the wheat acreage in Western Canada is produced by a select number of new varieties. This study investigates the gap between recommended, registered, and commercially available varieties in Western Canada and estimates the R&D cost of non-adopted varieties. Results show a robust slate of commercially available new wheat varieties overall, as only 18% of proposed varieties did not receive registration and 7% of registered varieties were not adopted over the past 25 years. This translates to \$3.25–\$5.2 million in annual R&D funding invested in varieties that do not provide direct economic benefit to producers upon commercialization between 2000 and 2010 and \$7.5–\$12 million between 2011 and 2021. Non-adopted varieties may have value as parents in future crosses. In addition, Prairie-wide results reveal that varieties with higher yield and yield-enhancing traits such as disease resistance and lodging resistance are more widely grown. The current findings provide the best indicative data about the performance of wheat breeding programs and shed light on how Canada is performing with respect to research priorities and investments in varietal innovations. Limited and inconsistent varietal data across the Prairies and lack of transparent R&D costs on newly developed wheat varieties in Western Canada are among the challenges encountered in this research.

Key words: AAFC, durum wheat, innovation, plant breeding, red spring wheat, variety registration

1. Introduction

Canada has a lengthy global history of being a leading wheat producer and exporter. Wheat is Canada's largest seeded crop, grown mostly in the western Prairie Provinces of Alberta (AB), Saskatchewan (SK), and Manitoba (MB). In 2022, total wheat production reached 33.8 million tonnes (Statistics Canada 2023a), and wheat (including durum) production contributed \$11 billion in farm cash receipts to the Canadian economy (Statistics Canada 2023b). Canada ranks among the world's largest wheat exporters with 70% of its domestic production shipped to over 70 countries every year.¹ As such, well-funded wheat breeding research directed towards field-ready varieties is important to maintain Canada's global market position, to increase the value-added agricultural sector and to contribute to global food security.

With the growing world population and pressure on natural resource extraction and trade, there is continued importance on enhancing wheat productivity to respond to the growing wheat demands and to the changing climate. Thus, the need for substantive investments in research and development (R&D), particularly in support of new wheat varieties with improved traits to replace older varieties, is a priority for the agricultural industry. Over the years, increasing breed-

ing efforts have led to better adapted varieties and more diverse production of wheat classes to meet the challenges of the marketplace and the production concerns of wheat growers (McCallum and DePauw 2008). Yet, a yield gap remains between average yield and yield potential across the Canadian Prairies despite rising wheat yields over the last 20 years (Thomas and Graf 2014; Mangin et al. 2022). On the other hand, investment in wheat research—heavily dependent on government funding—and wheat acreage in Western Canada have been in a steady decline over time in favor of other crop kinds such as canola, soybeans, and corn that have become relatively more competitive as those crops enjoy strong intellectual property rights and thus allow firms to capture value on their investments (Veeman and Gray 2010; Fuglie et al. 2011; Galushko et al. 2020). Seeded acres of pulses, lentils, and peas have also increased over this time period. According to the Snapshot of Private Innovation Investment in Canada's Seed Sector, projected investments in 2022 were over \$94 million for canola, \$24 million for soybeans, \$19 million for corn, and \$22 million for wheat (Canadian Seed Trade Association 2018). The overall investment level in wheat plant breeding is low compared to other jurisdictions such as Australia and France. For instance, in 2015, Australia's expenditures of just over C\$100 million were 2.7 times the amount invested in Canada (JRG Consulting Group 2015). By 2019, the adoption

¹ <https://cerealscanada.ca/wheat>.

of end point royalties in Australia increased public sector investments in wheat breeding by just over 50%, meaning the current ratio between Australian and Canadian investments will be relatively unchanged (Zienkiewicz 2019). Shortage of resources available for investment is the most significant barrier to advance innovation as highlighted in the 2017–2022 Investment Survey conducted by the Canadian Seed Trade Association (2018).

In addition to those barriers, variety development is a lengthy process and includes four stages: (i) *pre-breeding*, which includes discovery, germplasm development, genomics, etc.; (ii) *breeding* of a number of generations of a crop kind; (iii) *variety finishing*, which refers to replication and registration; and (iv) *commercialization*, meaning the distribution and sale of a registered variety (JRG Consulting Group 2015). In a typical breeding program, wheat varieties take about a decade from first cross to recommendation for registration, followed by a 2- to 3-year period involving registration with the Canadian Food Inspection Agency (CFIA) and seed multiplication. This results in about a 12–13-year gap between the initial investment in R&D and new varieties being commercially available to farmers (Bolek-Callbeck and Gray 2022). Research grants provide budgeted amounts of funds on a yearly basis, rather than providing the entire grant amount at the start of the grant period. The attribution of costs during the first phase is difficult as inputs, including human capital, knowledge, and germplasm, are often considered to be sunk costs² (Smyth et al. 2014). On the other hand, delays between the research and commercialization phases associated with time requirements of the regulatory approval process decrease the returns on investments, and thus cause revenue losses (Smyth et al. 2014).

The commercialization of new wheat varieties varies across Canada. Breeders develop new wheat varieties knowing regional production will impact adoption. Winter wheat varieties are more conducive to Eastern Canada production due to the milder winters, while spring wheat varieties dominate Western Canada production due to the warmer, drier summer weather. This article focuses on wheat production across the Canadian Prairies.

Over 470 new wheat varieties are listed in the CFIA's database between 2000 and 2023, with just over half registered for use³ in the Prairies.⁴ Most of the registered wheat varieties for production on the Prairies are spring wheat (75%) followed by durum wheat (15%) and winter wheat (10%). While Canadian producers have several wheat classes and multiple varieties within each class to select from when deciding which varieties to adopt, wheat acreage in Western Canada is concentrated in a select few varieties. This means that not all wheat varieties that emerge from the R&D pipeline are successfully commercialized, as some registered varieties are never licensed and adopted by commercial

seed growers or farmers (Syme 2021). Research investigating the factors that contribute to commercialization failures is scarce. To our knowledge, only two empirical studies investigated this issue in Western Canada (Syme 2021; Lassoued and Smyth 2023). Both studies found that yield improvement is the leading factor determining whether a new variety will be successfully adopted followed by disease resistance and lodging resistance. Other non-yield genetic improvements required to improve yield and quality of wheat were also found critical for adoption. For instance, resistance to shattering and pre-harvest sprouting prevent wheat quality and quantity losses. High levels of protein are also important market characteristics (Scott et al. 2005; Syme 2021; Lassoued and Smyth 2023).

The gap between wheat varietal registration and varietal adoption might a priori suggest some lack of alignment between the needs of producers and the wheat research priorities. This raises the question about the efficiency of the R&D investments in Western Canadian wheat breeding programs. The objective of this paper is to estimate this inefficiency—that is, the “lost” research dollars that have been invested in the development of new wheat varieties, but are never successfully commercialized, therefore providing no public value or benefit at the time of commercialization. These varieties may provide value as parent varieties in future crosses within a breeding program, but at the time of unsuccessful commercialization, this future value cannot be calculated. To accomplish this objective, the number of varieties recommended for registration and those appearing in the growers' directories in the seed guides were first collected. Second, information on wheat varietal investments was gathered from available sources, allowing for R&D funding inefficiencies to be estimated.

Despite the lack of a comprehensive historical record tracking R&D spending on newly developed wheat varieties in Western Canada, the results of the article provide the public sector with the best indicative data (rough estimates) about the performance of wheat breeding programs. Current findings shed light on how Canada is performing with respect to research priorities and investments in varietal innovations.

2. Canadian varietal recommendation and registration

The objective of variety registration is to assess combinations of the agronomic, disease resistance, and end-use quality merit of potential new crop varieties. In the Seed Regulations,⁵ merit is defined as requiring new varieties to be equal or superior to reference or “check” varieties with regards to specific characteristics, which render the new variety beneficial for a particular purpose and in a specific region of Canada. Periodically, check varieties are updated to continually ensure that relevant comparisons are being made between existing varieties and new commercialized varieties. As the regulations do not detail those specific characteristics, it is the role of the Recommending Committee

² Refers to an investment already incurred that cannot be recovered.

³ Excluding spelt varieties and varieties with only interim regional registration in British Columbia.

⁴ Authors' calculation using the CFIA variety registration database: varieties of crop kinds registered in Canada: https://inspection.canada.ca/active/netapp/regvar/regvar_looke.aspx.

⁵ https://laws-lois.justice.gc.ca/eng/regulations/c.r.c.,_c._1400/FullText.html?wbdisable=true.

experts to do so. In concert with the Variety Registration Office (VRO) within the CFIA, Recommending Committees evaluate whether candidate crop varieties proposed for registration are at least equivalent to the “check” varieties. As such, these committees—existing for the majority of leading crop types—are an integral part of the Canadian variety registration system and serve to provide expertise and guidance to VRO. The latter does not register a variety unless it is recommended. New candidate varieties of many crop kinds are subject to testing based on crop-specific agronomic, quality, and/or disease resistance standards. All species, kinds, or types of crops requiring variety registration prior to being sold are listed in Schedule III of the Seeds Regulations.

Recommendation of new wheat, rye, and triticale varieties targeting Western Canadian Provinces for registration with the CFIA-VRO is the responsibility of the Prairie Recommending Committee for Wheat, Rye, and Triticale (PRCWRT), one of the independent Recommending Committees of the Prairie Grain Development Commission. This committee is composed of representatives from the three main value-chain stakeholder groups: variety/trait developers and assessors (e.g., plant breeders, pathologists, agronomists); producers (e.g., commodity group representatives, seed growers); and end-users (e.g., food and feed representatives, milling and baking industry representatives, grain handlers). The PRCWRT is made up of three evaluation teams: the agronomic evaluation team, disease evaluation team, and quality evaluation team. Each evaluation team is responsible for defining what constitutes merit, determining protocols for variety testing, and assessing merit in their respective areas of expertise. Assessments are made against the check varieties in terms of all the factors of evaluation. A candidate variety does not need to exceed the check varieties in all characteristics (yield, agronomic characteristics, disease tolerance, and end-use quality characteristics), but the entirety of traits of the candidate variety must at least be equal to the check variety, preferably exceeding it. Evaluation teams either endorse candidate varieties that exhibit traits meeting or exceeding those of check varieties or flag candidates exhibiting traits poorer than check varieties or that could potentially result in industry harm. Flagged candidate varieties require further assessment by the PRCWRT (PRCWRT 2021) and are subsequently voted on by a 23 member expert “Cultivar Voting Panel” that represents all sectors of the wheat value chain. Most varieties will exhibit both strengths and weaknesses relative to the check varieties; recommendations are based on the overall merit of the varieties under question as assessed by the PRCWRT voting members. A key feature of the standards is that they should not inhibit market access.

Between 2000 and 2023, 471 new wheat varieties⁶ were registered in the CFIA database: 11 of them were nationally registered, 445 regionally registered, 8 cancelled, 1 under contract regional registration, 1 interim regionally registered in the Western Provinces, 1 interim regionally registered in Ontario, and 4 interim regionally registered for production only in designated regions of British Columbia. Of the total vari-

eties registered between 2000 and 2023, 260 were registered for use in Western Canada.⁷

Canadian wheat varieties are grouped into classes based on growth habit (spring or winter) and end-use quality, under the authority of the Canadian Grain Commission (CGC). Ten wheat classes are recognized in Western Canada, while seven classes are recognized in Eastern Canada (Table 1). Canada Western Red Spring (CWRS) is the largest wheat class grown in Western Canada with 64% of Western Canadian exports, followed by Canada Western Amber Durum (CWAD) with 19%.⁸ Agriculture and Agri-Food Canada (AAFC) varieties account for the majority of insured acres for both CWRS and CWAD (CGC 2021).⁹

3. Wheat varietal development in Western Canada

Research and development into wheat crop genetics often requires a large capital investment and the use of research resources, including human capital, knowledge, germplasm, facilities (field, laboratory and greenhouse), land in diverse agri-ecological zones, and specialized research equipment as inputs to create a new and high-performing crop variety with commercially desirable attributes. Western Canadian wheat varietal development has been dominated by the public sector with the involvement of AAFC, which funds and conducts research to develop new wheat varieties (Table 2). The provinces of SK and MB fund varietal research. The province of AB had funded a small breeding program at Western Crop Innovations (WCI), formerly the Alberta Field Crop Development Center (FCDC), but this program was concluded several years ago and the last lines from this program are nearing the end of the variety development pipeline. The University of Saskatchewan (U of S)—through the Crop Development Centre (CDC), the University of Alberta (U of A), and the University of Manitoba (U of M) conduct wheat varietal research. The CDC receives producer funds from Western Grains Research Foundation (WGRF), provincial wheat commissions, and from private co-funders such as Bayer Crop Science, Cargill Ltd, FP Genetics, and Secan. Provincial commissions collect producer checkoff levies¹⁰ on wheat and barley grain sales annually and invest them into breeding research. The Canadian Wheat Research Coalition (CWRC) acts on behalf of, and in coordination with, the provincial commissions. Other organizations that fund and/or coordinate wheat varietal development include Alberta Innovates Bio Solutions (AI Bio)—works with partners to identify, coordinate, and fund research projects, Cereals Canada—provides leadership and support on behalf of the value chain to key initiatives (e.g.,

⁷ Excluding spelt varieties and those with interim regional registration in British Columbia only.

⁸ <https://cerealscanada.ca/cereal-grains/wheat>.

⁹ Variety data on the Canadian Grain Commission’s website are reported for insured acreage.

¹⁰ The Canadian Wheat Board collected a voluntary levy on wheat and barley sales from 1994 to 31 July 2017, and the funds were administered by the WGRF. Thereafter, provincial commissions collected the levies.

⁶ Seven spelt varieties were also registered during this period but are excluded from this analysis.

Table 1. Western Canadian wheat classes.

Wheat class	Characteristics/end use
Canada Western Red Spring (CWRS)	– Hard red spring wheat – Excellent milling and baking quality – Used for pan bread, alone or blended for hearth bread, steamed bread, noodles, flat bread, and pasta
Canada Western Amber Durum (CWAD)	– Durum wheat – High yield of semolina – Used for pasta and couscous
Canada Northern Hard Red (CNHR)	– Red spring wheat – Very good milling quality – Medium gluten strength – Used for flat breads, hearth breads, steamed breads, and noodles
Canada Prairie Spring Red (CPSR)	– Red spring wheat – Medium dough strength – Medium to strong gluten strength – Used for hearth breads, flat breads, steamed breads, and noodles
*Canada Prairie Spring White (CPSW)	– White spring wheat – Medium dough strength – Used for flat breads, noodles, and chapatis
*Canada Western Extra Strong (CWES)	– Hard red spring wheat – Extra strong gluten – Used for blending or in specialty products requiring high gluten strength
*Canada Western Hard White Spring (CWHWS)	– Hard white spring wheat – Excellent milling quality and flour colour – Used for breads and noodles
Canada Western Red Winter (CWRW)	– Hard red winter wheat – Excellent milling quality – Medium to strong gluten strength – Used for French breads, flat breads, steamed bread, and noodles
Canada Western Soft White Spring (CWSWS)	– Soft white spring wheat – Weak gluten strength – Low protein content – Used for cookies, cakes, pastries, flat breads, noodles, steamed breads, and chapatis
Canada Western Special Purpose (CWSP)	– Includes varieties that do not fit into the other wheat classes but provide value in identity preserved systems or niche market uses – May not be appropriate for milling due to high starch and low protein content – Typically high yielding varieties – Not required to meet strict quality requirements of other wheat classes – Mostly used for ethanol products or animal feed

Note: Source: authors' elaboration based on [CGC \(2019\)](#).
*Active breeding for CPSW, CWES, and CWHWS varieties has been discontinued.

market access, research), Genome Canada—a not-for-profit organization that invests and coordinates genomics research and innovation, Genome Prairie—supports research in SK and MB, Genome Alberta—supports research in Alberta, Agricultural Funding Consortium—provides joint funding from the Alberta government, WGRF, and AB Crop Industry Development Fund (ACIDF)—a private not-for-profit company owned by organizations in Alberta’s crop industry that managed investment initiatives ([JRG Consulting Group 2015](#)). With a new model of funding crop research by Alberta Agriculture and Forestry involving collaboration with the province’s crop commissions, ACIDF closed in 2018 ([Kienlen](#)

[2018](#)). In 2020, the Alberta government launched the Results Driven Agriculture Research initiative, focusing on funding and commercializing research that is results-oriented ([Alberta Government 2024](#)). Nearly three-quarters of all new wheat varieties in Western Canada are developed by AAFC Research Centers and the CDC with significant funding from farmer levies on wheat ([Table 3](#)). Other breeding institutions such as the U of A and the U of M are involved in developing field-ready cultivars as well as conducting discovery research to develop germplasm by selecting and improving traits in wheat lines that can eventually be bred into new varieties ([Scott et al. 2005](#)). Variety devel-

Table 2. Organizations involved in wheat variety development in Western Canada.

	Organization	Type	Role in variety development	Producer involvement
Federal Government	Agriculture and Agri- Food Canada*	Public	Funder and researcher	AAFC and producers jointly fund research
Provincial Governments	Government of AB/Field Crop Development Center*	Public	Funder and researcher	
	Government of SK*	Public	Funder	
	Government of MB	Public	Funder	
Universities	University of Alberta	Public	Researcher	Producers fund
	University of Saskatchewan—Crop Development Centre*	Public	Researcher	Producers fund
	University of Manitoba	Public	Researcher	Producers fund
Other organizations/ collaborators	Alberta Innovates Bio Solutions*	Public	Coordinator and funder	
	Cereals Canada*	Producer and private	Coordinator and influencer	Provincial Commissions Members
	Genome Canada and Genome Prairie (through Canadian Triticum Advancement Through Genomics)	Network	Funder	Co-funder
	Agricultural Funding Consortium	Consortium	Funder	Government of AB and producers jointly fund research
	AB Crop Industry Development Fund*	Funds from public, producer, and private	Funder	Governments and producers jointly fund research
	Western Crop Innovations ^a	Non-profit	Researcher	Government and producers jointly fund research
	Results Driven Agriculture Research	Non-profit	Funder	Government and producers jointly fund research
Major initiatives	National Wheat Improvement Program	Major initiative	Funded research network	Co-funder
	Canadian Wheat Alliance	Major initiative	Funded research network	Co-funder
	Canadian Triticum Advancement Through Genomics	Major initiative	Funded research network	Co-funder
	Canadian National Wheat Cluster	Major initiative	Funded research network	Co-funder

Note: Source: adapted from JRG Consulting Group (2015).

*Involved in both wheat and barley varietal development.

^aThe WCI has taken over the role of Alberta's FCDC.

operators have the opportunity to apply for Plant Breeders' Rights (PBR), which, if granted based on meeting specific requirements, provide intellectual property protection for their varieties. The protected varieties are then licensed to pedigreed seed growers who must remit seed royalties. The royalty income collected on AAFC varieties flows to general revenues of the Government of Canada and is not directly used to support breeding programs (JRG Consulting Group 2015). Private seed companies such as Syngenta Canada¹¹ (with 25 varieties) have registered wheat varieties for use in the Prairies.

The CWRC has core breeding agreements in place with public breeding institutions to provide stability support to Western Canadian breeding programs. The most recent agreements commit \$22.6 million¹² to AAFC from 2020 to 2025, \$9.6 million to the U of S CDC from 2020 to 2024, and \$3.5 million and \$2 million to the U of M and U of A, respectively, from 2020 to 2026 (Canadian Wheat Research Coalition 2022). Between 1995 and 2020, the present value of total varietal R&D

expenditures is \$685 million, with \$314.6 million of these investments being producer-funded (Bolek-Callbeck and Gray 2022). Based on a recent study at the U of S, farmers in Western Canada now receive \$33 in benefits from every \$1 contributed towards wheat breeding programs (Bolek-Callbeck and Gray 2022), an improvement from the approximately \$20 return per \$1 investment as of 2012 (Gray et al. 2012).

4. Methodology

4.1. Varietal data collection

Data for this study were collected from multiple regional sources over the last 24 years (2000–2023). The list of wheat varieties supported for registration by the PRCWRT was collected from the PRCWRT's website.¹³ All classes of Western Canadian wheat and durum were included in the analysis, with the exception of hulled wheat varieties, such as spelt, which were excluded due to low production levels. The list of varieties available for purchase from commercial seed growers in the Prairie Provinces for each year under study

¹¹ Syngenta Canada ceased all wheat variety development in Canada in 2019.

¹² All figures are expressed in Canadian dollars.

¹³ https://www.pgdc.ca/committees_wrt_pd.html.

Table 3. Developers of wheat varieties registered for use in Western Canada: 2000–2023.

Developer	No. of varieties	%
Agriculture and Agri-Food Canada*	131	50.4
University of Saskatchewan CDC*	58	22.3
Syngenta Canada Inc.†	25	10.1
University Of Alberta*	15	5.8
Limagrain Cereal Research Canada†	6	2.3
North Dakota State University*	5	2.0
AgriPro & United Grain Growers†	4	1.6
KWS (United Kingdom)†	3	1.2
AgriPro & Agricore United†	2	0.8
University of Minnesota*	2	0.8
Wiersum Plant Breeding†	2	0.8
FCDC, Alberta Agriculture and Forestry*	1	0.4
Hyland Seeds†	1	0.4
Semican International†	1	0.4
Saskatchewan Wheat Pool†	1	0.4
University of Manitoba*	1	0.4
University of Saskatchewan CDC & Saskatchewan Wheat Pool‡	1	0.4
Western Feed Grain Development Coop Ltd.†	1	0.4
Total	260	100

Note: Source: authors’ calculations using the CFIA variety registration database.
 *Public breeding program.
 †Private breeding program.
 ‡Public–private partnership program.

was created using the directory of crop varieties available through seed growers in each provincial seed guide. This directory lists the pedigreed seed crops that successfully received, or were in the process of receiving, seed crop certification by the Canadian Seed Growers’ Association each year and indicates which varieties will be commercially available to farmers from seed growers within each of the Prairie Provinces for the upcoming year. While the directories were used in this analysis to represent variety availability, it is important to note that they do not include varieties commercially available from sources other than Prairie seed growers.

Due to limited historical record of seed guide publications, the years of available seed guides and directories of commercial seed growers’ guides varied among the Prairie Provinces. Manitoba seed guide data and grower directories from 2001 to 2011 were obtained through personal communication with Manitoba Agriculture personnel and 2012–2023 data were obtained from publicly available seed guide publications on the Seed Manitoba website.¹⁴ Saskatchewan seed guide data and grower directories from 2002 to 2014 were obtained through personal communication with the Saskatchewan Seed Growers Association (SSGA) and data from 2015 to 2023 were obtained from publicly available seed guide publications on the SSGA website.¹⁵ Alberta seed guide data were available from 2011 to 2023 from the Alberta Seed Guide website and from 2000–2002 to 2004–2006

from the Government of Alberta website,¹⁶ but grower directories were only available from 2011 to 2023 and were obtained from publicly available seed guide publications on the Alberta Seed Guide website.¹⁷ Varietal registration data were gathered from the CFIA database of crop varieties registered in Canada (CFIA 2022). Data on the top varieties seeded, by acreage, in each province were collected from the list of insured commercial acres on the CGC’s website for each respective year from 2008 to 2023 (CGC 2021) and from Canadian Wheat Board (CWB) survey data from 2000 to 2007.¹⁸

To evaluate the impact of yield on adoption of newly developed wheat varieties, yield data were collected from the results of the AB, SK, and MB regional variety trials (RVTs) included in the seed guides. On the Prairies, CWRS and CWAD varieties made up 90% of wheat acreage in 2021 (CGC 2021), and therefore, the evaluation of yield data was limited to these two classes. As growing conditions vary regionally, yield data differ among varieties in each of the three Prairie RVTs and between production zones that are defined in Saskatchewan variety guides. Yield data for each variety were collected from the most recent RVT results available for each of the three provinces. All yields were presented as a percent (yield index) of a check variety. Yield index is the relative yield performance of each new variety relative to a check variety of wheat. For instance, a new variety with a yield index

¹⁴ <https://www.seedmb.ca>.
¹⁵ <https://saskseed.ca/seed-guides>.

¹⁶ <https://open.alberta.ca/publications/varieties-of-cereal-and-oilseed-crops-for-alberta>.
¹⁷ <https://www.seed.ab.ca>.
¹⁸ Obtained through personal communication with Dr. Pierre Hucl, U of S wheat breeder.

of 110 means that it was 10% higher yielding than the check variety in randomized plot yield trials.

Saskatchewan seed guides used AC Barrie as the check variety for CWRS varieties in RVTs from 2001 to 2014 and Carberry from 2015 to 2021 before switching to AAC Brandon in 2022. For CWAD varieties, Kyle was the check variety in RVTs from 2001 to 2006, AC Avonlea from 2007 to 2008, and Strongfield from 2009 to 2023. Alberta seed guides used Katepwa from 2000 to 2002, AC Barrie from 2004 to 2006, and from 2011 to 2018,¹⁹ Carberry from 2019 to 2021, and AAC Brandon in 2022 to 2023 for CWRS varieties. For CWAD varieties, Alberta seed guides used Kyle from 2000 to 2006 and Strongfield from 2011 to 2023. For the Manitoba RVT results, in which yield data were listed as bushel/acre (bu/ac) rather than as a percent of the check, yield comparisons were completed manually by calculating the percent difference in the yield between the check variety and the other CWRS varieties. Comparable yield data were not available for varieties that did not receive registration with the CFIA and therefore were omitted from the dataset. Average yield data for varieties that were tested in only one or two of the Prairie Provinces, but not across all three provinces, were calculated using results from only the RVTs where the variety was tested.

4.2. Wheat variety development expenditures in Western Canada

A comprehensive and complete record tracking all flows of R&D funds supporting wheat variety development expenditures in Western Canada is lacking. Some agency grant projects are publicly available for instance on Genome Canada and WGRF websites. Those funding commitments cover a number of years (i.e., 2–5 years). It makes more sense to assess the efficiency of those expenditures over a period of time rather than a point of time considering the timeframe to develop a new variety. Anecdotal information suggests that wheat breeders themselves do not know exactly how much they spent on an annual basis as they usually have ongoing various multi-year programs. A few rough estimates are published in a few reports.

Expenditures on public wheat variety development are estimated to be between \$25 and \$30 million per year, with just under half of these costs producer-funded (Bolek-Callbeck and Gray 2022). According to Tom Steve, past general manager of the Alberta Wheat Commission, investment in wheat research in Canada is estimated between \$30 and \$32 million a year (Pratt 2014). Similarly, Dr. DePauw, an internationally recognized plant breeder and former research scientist for AAFC,²⁰ estimated that about \$30 million is allocated to wheat variety development every year, with AAFC being the largest contributor with \$14 million, followed by the National Research Council with \$13 million for the 10 years it was involved in discovery wheat research. The rest is producer contribution (DePauw 2014, as cited in; JRG Consulting

Group 2015). Those estimates are prior to accounting for any provincial government spending or private investment. Based on information compiled by the JRG Consulting Group (2015), expenditures on variety development added up to \$46.1 million with \$33.7 public contribution (government and universities), and equal contribution of \$6.2 million by each of the private and producer funds in 2013–2014. According to the Bolek-Callbeck and Gray (2022) study commissioned by the Saskatchewan Wheat Development Commission aimed at estimating the benefits and costs of producer total annual R&D investments in wheat varietal development in Western Canada, the present value of total R&D investments (including both public and producer funding) averaged \$27 million between 1995 and 2020, with the lowest value of \$18.53 million in 2013 and the highest value of \$34.46 million in 1998.

Given the lack of complete and accurate wheat variety R&D expenditures, scenarios were conducted using estimates found in the literature and mentioned above. The current analysis is of an ex-post nature, undertaken after investments were made with a view to appraising the inefficiency of R&D investments, or the funds spent developing varieties that are not successfully commercialized. Based on the estimates reported above, we considered the following scenarios assuming minimum and maximum (nominal) values of total annual R&D investment to prevent under- and overestimation: \$25, \$30, \$35, and \$40 million.

5. Result analysis and discussion

5.1. Wheat varieties recommended, registered, and appearing in Prairie grower directories

Between 2000 and 2021, there were 294 wheat varieties recommended for registration by the PRCWRT (Fig. 1).²¹ Of the 294 varieties, 244 (83%) were registered for sale in Canada with the CFIA by the end of 2023, four of which received interim registration for British Columbia only.²² The remaining 50 (17%) varieties did not receive registration or had not yet received registration. Of the 240 varieties that successfully received registration with the CFIA for production in the Prairie region, 222 appeared in the directories of commercial seed growers in one of the three Prairie seed guides, indicating a robust slate of varieties commercially available for planting and thus representing a potential commercialization rate of 93%. Only 18 (7%)²³ varieties that received registration with the CFIA for planting on the Prairies made no appearance in the Prairie directories of crop varieties available from seed growers by 2023. A similar number of new varieties appeared in the Alberta and Saskatchewan seed guides, while the number of new varieties appearing in the Manitoba seed guides was approximately 30% lower.

Once wheat varieties are recommended for registration by the PRCWRT, the time period between registration and being commercially available from a Prairie seed grower is

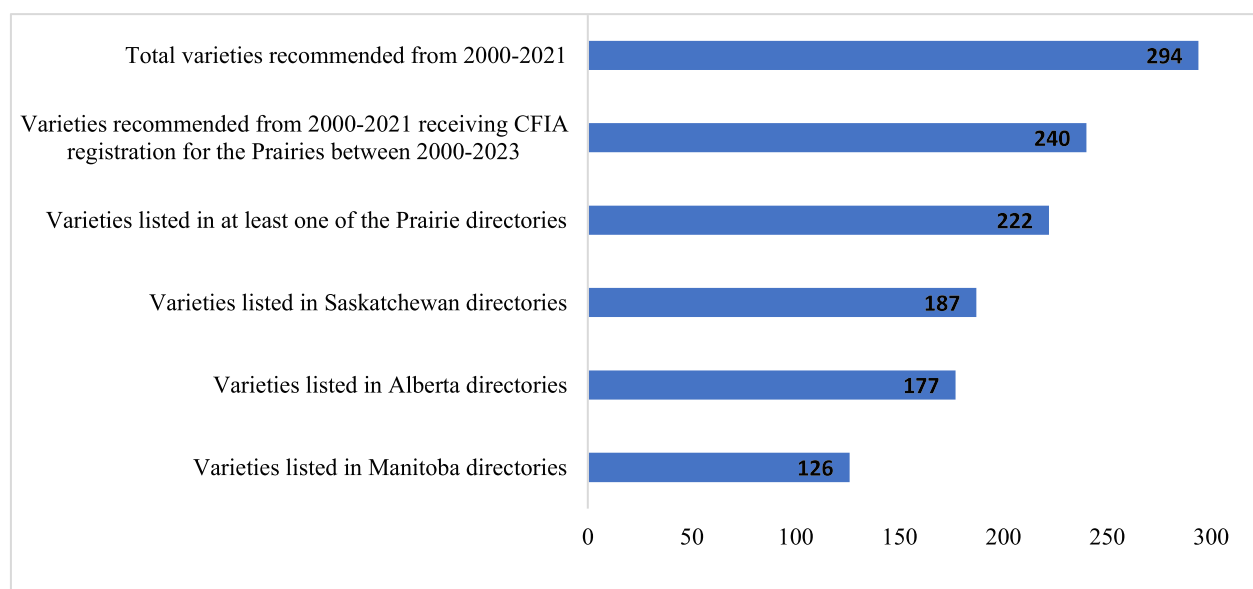
¹⁹ RVT data were not available from Alberta seed guides from 2003 to 2007–2010.

²⁰ <http://www.borlaugtrainingfoundation.org/blog/2020/6/1/meet-the-board-ron-depauw>, https://esask.uregina.ca/entry/de_pauw_ronald_1944.jsp.

²¹ Excluding spelt varieties.

²² For the remainder of the analysis, the four varieties with interim registration for British Columbia only are excluded.

²³ Percents of varieties do not add up to 100% due to rounding.

Fig. 1. Wheat varieties recommended for Prairie registration and available for sale from commercial Prairie seed growers.

quite short. The average length of time until registration is granted was estimated to be approximately 0.7 years. Similarly, the average number of years from recommendation to the variety's first appearance in one of the Prairie seed grower directories was found to be 1.9 years. The relatively quick turnaround from recommendation to a variety being commercially available for planting suggests that the commercialization portion of the variety development pipeline is efficiently transferring innovations in the wheat seed industry to farmers for production.

5.2. Top produced varieties

To gauge the speed and extent of the adoption of newly registered wheat varieties, the top 10 varieties of CWRS and CWAD produced each year in the Prairie Provinces up to the end of 2023 was compared to the list of varieties recommended for registration (Figs. 2 and 3).²⁴ Between the crop years of 2000 and 2023, a total of 66 different CWRS varieties composed the top 10 seeded varieties from each year. Twenty-one of these varieties were recommended for registration prior to 2000, 24 were recommended between 2000 and 2010, and 21 were recommended between 2011 and 2021. Of the 129 CWRS varieties recommended for registration between the years of 2000 and 2021, a total of 45 (35%) were produced on significant acreage in at least one of the Prairie Provinces. Of the remaining 84 varieties recommended for registration, 22 were never registered, leaving 62 registered varieties that were never produced on significant acreage. Based on seeded acreage data from the CGC and the CWB surveys, in Alberta, the top 10 CWRS varieties produced in any given year between 2000 and 2023 composed between 82% and

86% of total CWRS acreage, in Saskatchewan, they composed between 59% and 90% of acreage, and in Manitoba, 82% and 98%. Between the 10-year period of 2000 and 2010, 43 CWRS varieties were recommended for registration, with 24 (56%) being produced on significant Prairie acreage. In comparison, 86 CWRS varieties were recommended for registration between 2011 and 2021, with only 21 (24%) of these varieties seeing significant production. This contrast in the number of varieties seeing significant adoption between the two time periods can partly be attributed to the length of time these varieties have been available. Across the Prairies, the average age of the top 10 CWRS varieties planted each year between 2000 and 2023 was 8.4 years, which provides an indication of the lag period between the most successful varieties being recommended for registration and seeing significant production.²⁵ Between the three Prairie Provinces, the average age of the most produced varieties was 7.7 in Manitoba, 8.2 in Saskatchewan, and 9.2 in Alberta. The lag period seen in varietal adoption indicates that the most recent varieties may still see significant production in the future as older varieties are replaced. Comparing the two 11-year periods under study, the average age of the top CWRS varieties produced across the Prairies from 2000 to 2010 was 8.8, decreasing to 8 years from 2011 to 2021. The decrease in the average age of the top produced varieties suggests that with greater choice, producers may be more willing to adopt newer varieties.

Durum wheat (CWAD) is commonly grown in Saskatchewan and Alberta, where 80% and 20% of Canada's durum production is located, respectively. Less than 1% of Canada's durum is produced in Manitoba (Statistics Canada 2023a). The analysis for CWAD production was only conducted for the provinces of Alberta and Saskatchewan. Between 2000 and 2023, 32 different varieties composed

²⁴ Due to the relatively fewer durum varieties available to farmers compared to CWRS varieties, some years between 2000 and 2021 saw fewer than 10 CWAD varieties significantly produced in terms of insured acreage.

²⁵ The average age of each variety was calculated using the year the variety was recommended for registration.

Fig. 2. Canada Western Red Spring (CWRS) varieties recommended for registration between 2000 and 2021 with sufficient seeded acres to be included in top 10 varieties planted on the Prairies between 2000 and 2023.

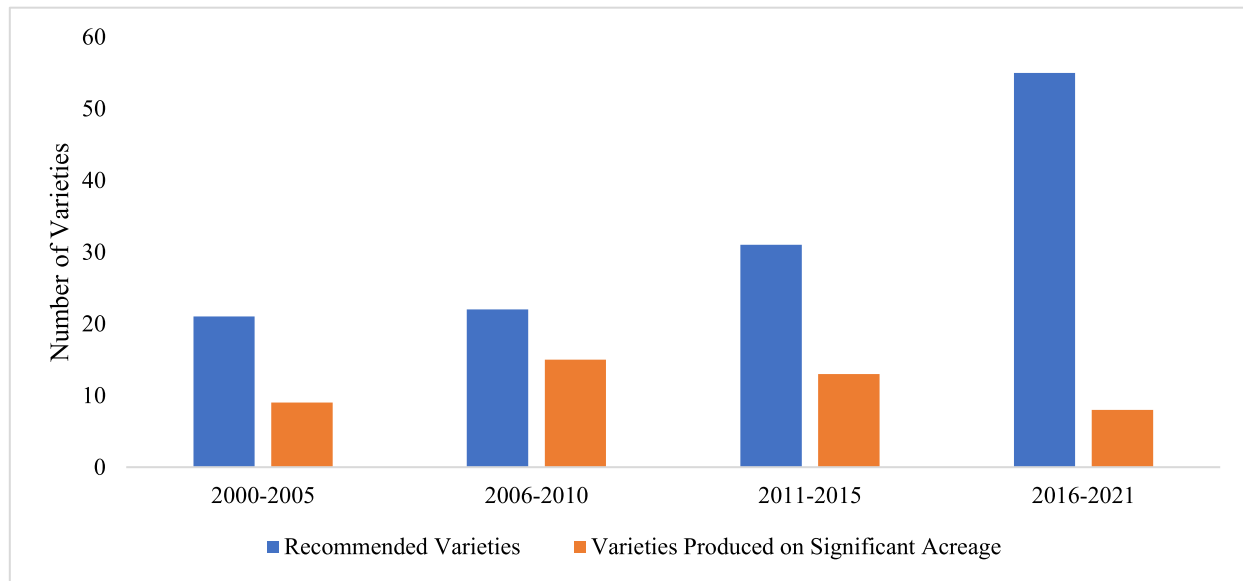
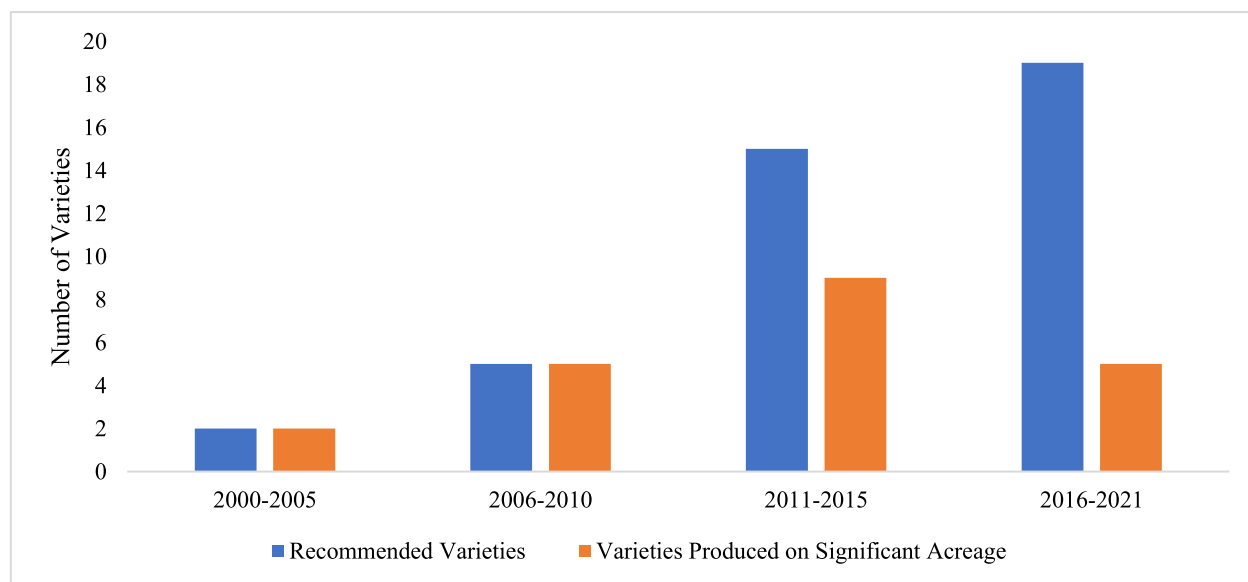


Fig. 3. Canada Western Amber Durum (CWAD) varieties recommended for registration between 2000 and 2021 with sufficient seeded acres to be included in top 10 varieties planted on the Prairies between 2000 and 2023.



the top seeded varieties each year (Table 4).²⁶ Of the 41 CWAD varieties recommended for registration between 2000 and 2021, 21 (51%) were produced on significant acreage across the Prairies. Excluding the eight CWAD varieties that never received registration, there remain 12 varieties recommended for registration that have not been produced on significant acreage. The top CWAD varieties between 2000 and 2023 composed between 91% and 100% of total CWAD

acreage in Alberta and 88%–100% of total CWAD acreage in Saskatchewan.

In the first 11 years under study (2000–2011), only seven CWAD varieties were recommended for registration. All of these varieties received registration and became one of the top 10 varieties produced on the Prairies in the following years. Between 2011 and 2021, 34 CWAD varieties were recommended for registration, with 14 (41%) of them seeing significant production following registration. The average age of the top CWAD varieties produced each year was 11.5 in Saskatchewan and 11.2 in Alberta. Comparing the age of top varieties produced on the Prairies between the 11-year time periods under study, the average age of top CWAD vari-

²⁶ Due to the smaller acreage of CWAD varieties and the limited number of varietal options compared to CWRs, some years saw fewer than 10 CWAD varieties produced on significant acreage in Saskatchewan or Alberta.

Table 4. Canada Western Red Spring (CWRS) and Canada Western Amber Durum (CWAD) varieties recommended for registration between the years of 2000 and 2021 and produced on significant acreage between 2000 and 2023.

	Alberta	Saskatchewan	Manitoba
CWRS varieties	AAC Brandon*	AAC Alida*	AAC Brandon*
	AAC Connery*	AAC Brandon*	AAC Cameron*
	AAC Elie*	AAC Cameron*	AAC Elie*
	AAC Hockley*	AAC Elie*	AAC Hockley*
	AAC Leroy*	AAC Hodge*	AAC Hodge*
	AAC Redberry*	AAC Leroy*	AAC Leroy*
	AAC Redwater*	AAC Redberry*	AAC Redberry*
	AAC Viewfield*	AAC Starbuck*	AAC Redwater*
	AAC Wheatland*	AAC Viewfield*	AAC Starbuck*
	Carberry*	AAC Wheatland*	AAC Tisdale*
	CDC Abound†	Carberry*	AAC Viewfield*
	CDC Alsask†	Cardale*	AAC Wheatland*
	CDC Go†	CDC Abound†	Bolles§
	CDC Imagine†	CDC Go†	Carberry*
	CDC Landmark†	CDC Hughes*	Cardale*
	CDC Plentiful†	CDC Imagine†	CDC Go†
	CDC Stanley†	CDC Landmark†	CDC Landmark†
	CDC Utmost†	CDC Plentiful†	CDC Plentiful†
	Harvest*	CDC Stanley†	CDC Stanley†
	Lillian*	CDC Titanium†	Glenn‡
	Muchmore*	CDC Utmost†	Harvest*
	Shaw*	Glenn‡	Infinity*
	Stettler*	Goodeve*	Kane*
	Superb*	Harvest*	Muchmore*
	Unity*	Infinity*	Superb*
		Lillian*	Vesper*
		Shaw*	WR859 CL
		Superb*	Waskada*
		Unity*	5601HR
		Vesper*	5602HR
			5603HR
			5605HR CL
CWAD varieties	AAC Congress*	AAC Congress*	
	AAC Grainland*	AAC Grainland*	
	AAC Goldnet*	AAC Marchwell*	
	AAC Raymore*	AAC Raymore*	
	AAC Spitfire*	AAC Spitfire*	
	AAC Stronghold* Brigade*	AAC Stronghold* Brigade†	
	CDC Alloy†	CDC Alloy†	
	CDC Dynamic†	CDC Credence†	
	CDC Fortitude†	CDC Defy†	
	CDC Precision†	CDC Dynamic†	
	CDC Verona †	CDC Fortitude†	
	CDC Vivid†	CDC Precision†	
	Commander*	CDC Verona†	
	Enterprise*	Commander*	
	Eurostar*	Enterprise*	
	Strongfield*	Eurostar*	
	Transcend*	Strongfield*	
		Transcend*	

*Developed by AAFC Research Centres.

†Developed by U of S CDC.

‡Developed by North Dakota State University.

§Developed by University of Minnesota.

||Developed by Syngenta Canada.

eties produced from 2000 to 2010 was 12.8 years, decreasing to 10.2 from 2011 to 2021, providing further evidence that greater choice may increase the willingness of producers to adopt new varieties.

With only 7% of registered wheat varieties not making an appearance in the Prairie seed grower directories, our results indicate potential high commercialization rates of newly developed varieties. However, the relatively insignificant acreage planted to most of these varieties suggests that there is still room for improvement in the varietal development pipeline. As discussed above, only 35% and 51% of CWRS and CWAD varieties, respectively, recommended for registration since 2000 were being planted on the majority of acreage of these crops. When surveying Western Canadian wheat producers, Galushko et al. (2020) found that while 80% of respondents review the published seed guides—as relevant/unbiased sources of information about new varieties—yearly, only 6% of them introduce a new wheat variety every year and 20% adopt a new variety every second year. The results suggest more critical selection of new crop varieties to be advanced within the crop breeding or commercialization pipeline could help improve the efficiency of research dollar use.

5.3. Yield of recommended wheat varieties

Yield, disease resistance, and lodging resistance are the most considered agronomic factors when making varietal adoption decisions (Syme 2021; Lassoued and Smyth 2023). This is not surprising as pedigreed seed growers and commercial producers are mainly paid for yield (bu/ac), which is key for their business profitability and investment viability. Due to the importance of yield improvements for varietal adoption decisions, it is helpful to compare the yields of varieties that have been adopted on a large scale with those varieties that have not been adopted to the same extent to determine how much yield must improve to impact adoption rates.

Due to the change in check varieties used in RVT data tables, the yields of the older varieties cannot easily be compared to those of more recently released varieties. For CWRS varieties recommended for registration between 2000 and 2010, yield indices were presented as a percent of the check variety AC Barrie. For varieties recommended for registration after 2010, yields were presented as a percent of the check variety Carberry. Check varieties changed to ACC Brandon in 2022 Alberta and Saskatchewan seed guides. Comparable yield data for the majority of varieties recommended for registration from 2020 to 2021 were not available from RVT trials prior to 2022, when the check variety changed to AAC Brandon. Varieties without comparable yield data available were excluded from the analysis. For CWAD varieties, comparable yield indices presented as a percent of the check variety were available for all varieties recommended from 2000 to 2021. However, as all seven CWAD varieties recommended prior to 2012 have seen significant production, the comparison of yields was only conducted on varieties recommended for registration since 2012. For all varieties, the most recent comparable yield data were used in the analysis. In Saskatchewan, the yield data were broken into four distinct cropping zones

based on the location of the RVT. For the analysis below, the average yield index across these cropping zones was used.

Based on results from the Prairie RVTs, average yields of CWRS varieties recommended for registration between 2000 and 2010 that were among the top 10 annually produced varieties up to and including the 2023 crop year were between 2% and 6% higher than the average yields of the varieties that were not adopted to the same extent (Fig. 4).²⁷ For varieties recommended for registration between 2011 and 2021, average yields of top produced varieties were between 1% and 4% higher than the remaining varieties. This result indicates that the most popular CWRS varieties typically had yield as a primary consideration in their adoption.

When comparing yields of the top produced CWAD varieties with the remaining varieties, only those recommended from 2012 onward were examined, as all varieties recommended prior to 2012 were adopted on significant acreage (Fig. 5). In Saskatchewan, there was only a 1% increase in average yields seen in the varieties among the top 10 produced compared to varieties not produced to the same extent. In Alberta, average yields of newly recommended varieties included in the top 10 produced were 4% lower than varieties not produced to the same extent. However, the CWAD varieties most recently recommended for registration between 2018 and 2020 produced average yields that were 3% higher than the average yield of all CWAD varieties recommended between 2012 and 2021. The varieties most recently recommended for registration may be in the infancy stages of their commercial adoption and in future years adoption levels of these higher yielding varieties may increase.

These results suggest that, in general, the highest yielding varieties are being adopted to the greatest extent, which is consistent with the findings of recent empirical studies by Syme (2021) and Lassoued and Smyth (2023). Certainly, other traits are important for producers, such as improved disease resistance or lodging resistance, but yield is a primary consideration in adoption decisions. Therefore, when making selection decisions in the breeding and recommendation stages, a greater emphasis should be placed on advancing varieties that exhibit improved yield potential combined with important disease resistance and lodging resistance traits. The varieties in the top 10 have a suite of the desired traits combined with high grain yield, although this may vary depending on regionalized disease pressures. AAC Brandon was the number one CWRS variety from 2016 to 2021. Producers chose to grow AAC Brandon not only due to its grain yield but also because it has wide adaptation and resistance to rusts and *Fusarium* head blight on a strong semi-dwarf straw stature. An example of yield not being the determining factor in adoption rates is the comparison between CWRS varieties Carberry and Shaw, both of which were registered in 2009. While Shaw was 13% higher yielding in Saskatchewan trials, it reached max-

²⁷ While only CWRS and CWAD varieties recommended for registration up to 2021 are included in the analysis, the evaluation of the top produced varieties is extended to the 2023 crop year to include adoption of the most recent varieties, as adoption typically occurs 1–3 years after recommendation

Fig. 4. Comparison of average yields between top produced Canada Western Red Spring (CWRS) varieties between 2000 and 2023 and remaining varieties recommended for registration between 2000 and 2021. Notes: (1) Yield indices for varieties recommended between 2000 and 2010 are presented as percent of AAC Barrie and varieties recommended between 2011 and 2021 are presented as percent of Carberry. (2) Comparable yield data were not available for the majority of varieties recommended for registration from 2020 to 2021 because these varieties were not included in regional variety trials (RVTs) prior to 2022 when the check variety changed to AAC Brandon.

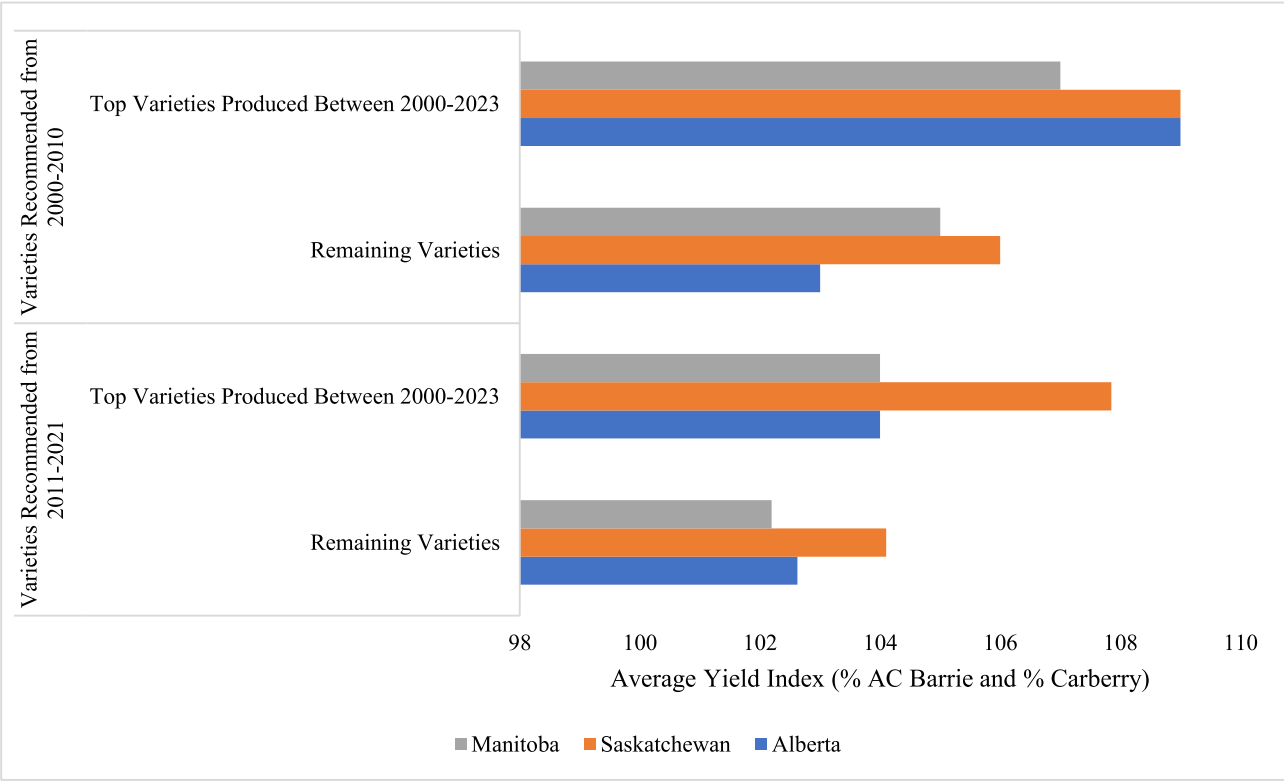
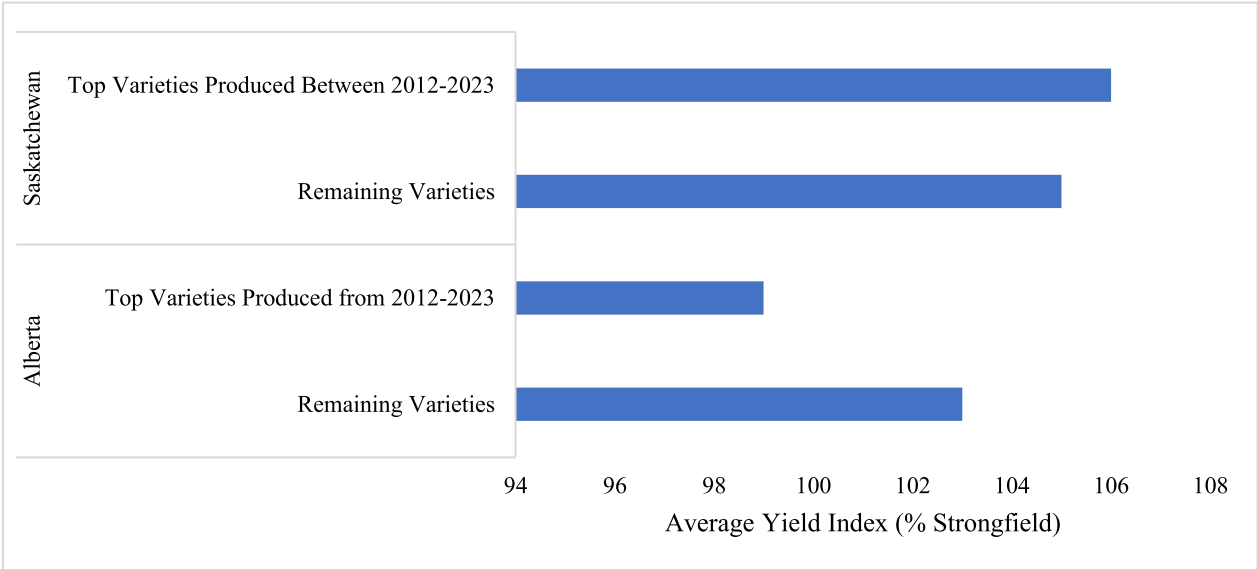


Fig. 5. Comparison of average yields between top produced Canada Western Amber Durum (CWAD) varieties between 2012 and 2023 and remaining varieties recommended for registration between 2012 and 2021.



imum acreage of 3.9% of all CWRS acres in 2014, likely because of its susceptibility to FHB and tall stature. Carberry became the most widely grown variety across Western Canada

in 2014 at 11.4% of acreage largely due to its robust disease resistance and strong semi-dwarf stature combined with acceptable yield.

Table 5. Estimated total annual wheat varietal investment into varieties that do not provide economic value to farmers at the time of commercialization (million \$).

	R&D investment	Investment into recommended varieties that were not registered	Investment into registered varieties that were not adopted	Total spending on unsuccessful varieties
2000–2010	25	2.5	0.75	3.25
	30	3	0.9	3.9
	35	3.5	1.05	4.55
	40	4	1.2	5.2
2011–2021	25	5.5	2	7.5
	30	6.6	2.4	9
	35	7.7	2.8	10.5
	40	8.8	3.2	12

5.4. Estimated investment inefficiency of wheat varietal R&D

As advanced earlier in the analysis, among the 294 varieties that were recommended for registration by the PRCWRT, 240 (82%) received registration for the production in the Prairies and 222 (76%) were commercially available from Prairie seed growers. This means that 76% of the R&D funds resulted in varieties that provided direct economic value to Prairie farmers at the time of their commercialization. However, significant differences were seen in the number of developed and commercialized varieties in the two decades under study. Between 2000 and 2010, 87 wheat varieties were recommended for registration, of which 78 (90%) received registration. Of the varieties that received registration, 76 (97%) were listed as commercially available from seed growers in Prairie grower directories. In comparison, 207 wheat varieties were recommended for registration between 2011 and 2021, 162 (78%) of which received registration for production in the Prairie Provinces.²⁸ Of the 162 varieties registered for Prairie production, 146 (90%) appeared in Prairie grower directories. This comparison indicates that between 2000 and 2010, only 3% of registered varieties had no direct economic benefit to producers upon exiting the variety development pipeline, while between 2011 and 2010, 10% of registered varieties provided Prairie producers no direct economic benefits upon exiting the development pipeline.

It is important to note that varieties that did not receive registration and commercialized varieties that were not adopted, or not adopted at a significant level, may provide economic value to producers as parent varieties in future crosses, contributing to development of potentially superior varieties. The future value of these varieties as building blocks in development of new varieties, although not known upon unsuccessful commercialization of these varieties, is important to breeders and producers alike. However, due to the inability to quantify the probability value of the varieties created by future crosses involving these unsuccessful varieties, the current analysis is concentrated on the direct value provided to producers by the varieties upon exiting the variety development pipeline. In addition, data are not publicly

available on varieties that are not put forward for recommendation by the breeder or that do not receive recommendation for registration by the PRCWRT.

It must also be considered that making the decision not to submit varieties for recommendation at the end of the variety development process would not significantly decrease the sunk costs of this investment, as the majority of R&D funds would already have been spent on variety development. If a variety reaches the end of the development pipeline, it would typically proceed with recommendation, registration, and potential commercialization to provide farmers with more varietal choice as opposed to abandoning the variety. Thus, while more stringent evaluation may help to improve R&D efficiencies near the start of the R&D pipeline while costs can still be saved, abandoning varieties near the commercialization stage may not result in improved investment efficiency.

As displayed in Table 5, when the total varietal wheat spending ranges between \$25 and \$40 million in a year (nominal value), this translates to \$550–880 million over the 22-year period of study (2000–2021), assuming varietal spending remained consistent over the 22 years. For the first 11 years under study, this translates to an estimated \$290 000–\$460 000 annually spent per wheat variety recommended for registration. For the period of 2011–2021, this translates to an estimated \$120 000–\$190 000 annually spent per variety recommended for registration. Having 10% of new varieties not being registered and an additional 3% of registered varieties not being adopted between 2000 and 2010 means that 13% of the investment to develop new wheat varieties had no direct economic benefit to Prairie wheat producers upon commercialization. This results in the annual investment into wheat varieties not providing producers with direct benefits at the time of commercialization to range between \$3.25 and \$5.2 million for the first 11 years under study. Between 2011 and 2021, 22% of investments resulted in varieties that did not receive registration for the Prairies and an additional 8% in varieties that were registered but not adopted. This translates to between \$7.5 and \$12 million spent annually developing varieties that did not provide direct benefits to producers upon commercialization between the last 11 years under study. These results indicate that despite the increase in the number of varieties commercialized between 2011 and 2021

²⁸ Excluding the four varieties registered for production only in British Columbia.

Table 6. Estimated annual Canada Western Red Spring (CWRS) varietal investment into varieties that do not provide economic value to farmers at the time of commercialization (million \$).

	R&D investment	Investment into recommended varieties that were not registered	Investment into registered varieties that were not adopted	Total spending on unsuccessful varieties
2000–2010	12.25	1.47	0.25	1.72
	14.7	1.76	0.29	2.06
	17.15	2.06	0.34	2.4
	19.6	2.35	0.39	2.74
2011–2021	10.5	2.1	0.32	2.42
	12.6	2.52	0.38	2.9
	14.7	2.94	0.44	3.38
	16.8	3.36	0.5	3.86

Table 7. Estimated annual Canada Western Amber Durum (CWAD) varietal investment into varieties that do not provide economic value to farmers at the time of commercialization (million \$).

	R&D Investment	Investment into recommended varieties that were not registered	Investment into registered varieties that were not adopted	Total spending on unsuccessful varieties
2011–2021	4.0	0.96	0	0.96
	4.8	1.15	0	1.15
	5.6	1.34	0	1.34
	6.4	1.54	0	1.54

compared to the previous 11 years, the percentage of successfully commercialized varieties is lower.

From a plant breeder's standpoint, however, it is important to consider that more varieties registered at a lower cost per variety indicates greater efficiency within the breeding programs. Having more varieties to choose from allows farmers to tailor their variety choices to their specific production conditions and agronomic practices, although their variety choice may not be one of the top 10 varieties planted. Even varieties that are not adopted on a large scale are important to those who grow them, as each variety has a unique combination of traits that make it the best choice for a particular farm, soil type, or growing region.

Between 2000 and 2010, 49% of all wheat varieties recommended for registration by the PRCWRT were CWRS varieties and between 2011 and 2021, 42%. Assuming the funding directed to CWRS variety development translates to the proportion of CWRS varieties compared to total wheat varieties developed, this translates to \$12.25–\$19.6 million invested into development of CWRS varieties from 2000 to 2010 and \$10.5–\$16.8 million from 2011 to 2021 (Table 6).

Of the 43 CWRS varieties recommended for registration from 2000 to 2010, 12% were not registered and a further 2% were registered but not adopted. This translates to a total of \$1.72–\$2.74 million spent annually on developing CWRS varieties that did not provide direct economic benefits to producers at the time of commercialization. In the subsequent 11-year period, 86 CWRS varieties were recommended for registration, with 20% not receiving registration and 3% of registered varieties not seeing adoption, resulting in an estimated annual investment into unsuccessful varieties of \$2.42–\$3.86 million.

All seven CWAD varieties that were recommended for registration between 2000 and 2010 were registered, commercialized, and adopted. Therefore, the analysis of investment inefficiencies in CWAD variety development and commercialization is limited to the most recent 11 years under study, 2011–2021. During this period, 16% of wheat varieties recommended for registration by the PRCWRT were CWAD varieties, resulting in an estimated annual R&D investment into CWAD variety development of \$4–\$6.4 million. Of the 34 CWAD varieties that were recommended for registration from 2011 to 2021, 8 (24%) did not receive registration. All 26 of the varieties that received registration went on to be successfully commercialized and adopted. The total R&D funds spent annually on CWAD varieties between 2011 and 2021 that did not provide direct economic benefit to producers upon exiting the variety development pipeline is estimated at \$0.96–\$1.54 million (Table 7).

While approximately one-quarter of total varieties recommended for registration during the 22 years under study failed to provide a direct economic benefit to Prairie wheat producers at the time of their commercialization, there remains the possibility that these varieties may still potentially yield biological or genetic value. Even though these varieties were not commercially adopted, they may possess genetic value in terms of other traits of value for new varieties, such as improved disease resistance or drought tolerance for use as a parent of new varieties. Long-term germplasm preservation of these economically unsuccessful varieties will be important to better enable future research should there be potential traits of value. One example of the potential future value of unsuccessfully commercialized varieties is the parentage of AAC Brandon, one of the most important CWRS varieties in Prairie history. AAC Brandon is derived from the

CWRS varieties Superb, CDC Osler, and ND744, of which only Superb and CDC Osler were registered and only Superb was adopted on significant acreage on the Prairies. Thus, only one out of three parent varieties were successfully commercialized. However, the contribution of traits from all three parent varieties resulting in the development of AAC Brandon highlights the future potential of varieties that fail to succeed at the commercialization phase and the importance of these “near genetic misses” to wheat breeding programs. It is important to note that this future value can only be observed in hindsight, as it is entirely possible that unapproved varieties that are used to develop new varieties may similarly be unsuccessful and not adopted on significant acreage, if they are successfully approved.

One factor that plays a role in the licensing of new varieties is the small national seed market. The limited number of seed companies means that if they currently have varieties that are meeting the needs of their farmer clients and a new variety offers marginal gains in valued traits, there is a limited chance of the variety being licensed. To offset this, public developers could consider publicly releasing unlicensed varieties with no royalty requirements. This may incentivize the seed market to consider licensing what would otherwise be an unlicensed variety.

One recently enacted change in revenue collection for crop variety developers is the introduction of the Variety Use Agreement (VUA).²⁹ This Agreement is structured to collect a trailing royalty on farm-saved seed that would be used for seeding purposes in subsequent crop years. In 2020, the VUA pilot program for the 2020 growing season was announced by the Canadian Seed Trade Association and the Canadian Plant Technology Agency (Alberta Seed Guide 2020), after over a decade of discussions and consultations relating to the need for increased investment and support for crop variety development, including a series of consultation meetings held by AAFC in 2018 (Government of Canada 2024). The objective is that this will further increase the amount of wheat variety R&D funding available given the common practice of bin running seed, which will now create a consistent royalty stream for breeders. The Canadian VUA system is comparable to the current royalty collection programs on farm saved seed in the United Kingdom (UK) and Germany, in which royalties for farm saved seeds represent approximately half of certified seed royalty levels (Hervouet and Lemarié 2024; Galushko et al. 2020). The provision to enact a trailing royalty was enabled by the adoption of UPOV 91 in 2015. Currently it is optional for developers to choose to protect their varieties using the VUA, and the majority of varieties are still not included in the system. There are a number of potential reasons why the VUA has seen little uptake since its introduction, including the lack of AAFC participation as well as the lack of consensus on value creation models across the Canadian agricultural industry (AAFC 2024).

As public funding supporting wheat varietal development has been declining over the last couple of decades and royalties to plant breeders have been low, there is a need for an alternative research funding model to ensure additional

revenue to advance breeding efforts. One solution is to attract more private investment to keep Canadian wheat varieties competitive; such is the case for higher value crops, including canola. Both declining profitability and acreage are the two major barriers for private investment in wheat breeding (McIntosh 2018). In the case of Western Canada, about 20% of wheat planted provides royalties. With new crop revenue models, it is expected that developers can capture much higher returns. For instance, in France, 85% of returns go to the PBR holder and the remaining 15% supports public breeding programs (Cross 2015). As such, more public-private partnership is anticipated to grow in Western Canadian wheat breeding in the future. There is evidence that this approach is working, for instance, in the Australian wheat model based on endpoint royalties, or in the UK or German markets where trailing-royalty systems are in place, and thus Canada has the advantage to learn from these international experiences. Stronger property rights—key incentives for private players—are a policy tool that can be used to improve the funding in Western Canadian wheat breeding and advance varietal innovations. Greater utilization of public-private research partnerships may potentially contribute to increasing the efficiency of new variety adoption. Public-private partnerships (P3s) offer the potential to reduce development costs, spread the risk of commercialization, and facilitate higher adoption, especially in instances when the P3 is transparently designed, where both parties agree to the outcomes and processes required to reach agreed outcomes, and that are well managed (Smyth et al. 2021).

6. Conclusion

Results of this analysis indicate that the downstream segments of the wheat variety development pipeline are working effectively to get newly developed varieties commercially available for farmers. Within the last couple of decades, over 80% of varieties that were recommended for registration by the PRCWRT received CFIA registration, and of these registered varieties, just over 90% became commercially available for purchase from Prairie seed growers. Despite the plethora of new wheat varieties approved for commercialization, only a handful of newly developed CWRS and CWAD varieties, and specifically those with high yield potential and a full suite of traits, including robust disease resistance and strong semi-dwarf stature, dominate the majority of acreage seeded to these crops. Commercialization of new wheat varieties could be made more efficient by decreasing the number of varieties that advance beyond each breeding stage and the recommendation process through more stringent evaluation criteria. However, more stringent evaluation may be more effective nearer to the start of the variety development pipeline, while sunk costs can still be managed, as opposed to near the end of the pipeline when the majority of costs have already been spent on varietal development and cannot be recovered by abandoning varieties. Given that yield increases combined with a robust slate of other advantageous traits are the main reason for adopting new varieties, greater rigor applied in the development of

²⁹ For full details see <https://seeds-canada.ca/variety-use-agreement/>.

new varieties that removes lines with minimal or marginal yield increases would improve adoption rates.

With the lack of competitive private sector wheat varieties released, wheat—the largest field crop in Canada—has remained heavily dependant on public breeding programs supplemented by collecting producer checkoffs. Based on data gathered in this analysis, the annual investment in wheat varietal development was estimated to range between \$25 and \$40 million (nominal value). With 10% of varieties recommended for registration not receiving registration with the CFIA and a further 3% of registered varieties between 2000 and 2010 not appearing in the Prairie grower directories, R&D spending on varieties that do not provide direct economic value to producers at the time of exiting the R&D pipeline is estimated between \$3.25 and \$5.2 million annually for the first 11 years under study. Between 2011 and 2021, 22% of recommended varieties did not receive registration and a further 8% of registered varieties did not appear in the Prairie grower directories, resulting in an estimated investment into varieties that do not provide economic value upon exiting the R&D pipeline of \$7.5–\$12 million annually in the last 11 years of the study. Varieties that are not registered or adopted by producers have potential to contribute value to the agriculture industry as parents of new varieties. However, the inability to speculate on the success of these varieties in future crosses prevents quantification of these future benefits at the time of these varieties exiting the variety development pipeline. Limited available investment data, the unavailability of data on developed varieties that are not put forward or do not receive recommendation for registration, as well as the difficulty of placing a value on the potential of unsuccessfully commercialized varieties as future crosses, impedes the ability to obtain more accurate estimates of the inefficiency of Western Canadian wheat breeding programs.

In addition to the lack of a complete record tracking R&D investment in wheat research, the current analysis is also limited by the accessibility to historical provincial seed grower directories. Without consistent available data across the three Prairie Provinces, it is challenging to conduct a Prairie-wide analysis of the state of the wheat variety commercialization and adoption systems. Furthermore, the lack of consistency in data reporting across the provincial seed guides, especially with regards to RVT data and check varieties, hampered the ability to conduct cross-provincial analyses across the whole time period. Improved coordination among the provincial seed associations would help to alleviate these constraints in the future.

New breeding technologies may be able to contribute to more rapid development of higher yielding varieties with enhanced disease, lodging, and other essential traits, which will contribute to increased adoption rates of these varieties. In 2023, the [CFIA and Health Canada \(2023\)](#) announced that new genomic breeding technologies, such as genome editing like CRISPR, would be viewed as the equivalence of existing varieties, provided there is no foreign DNA in the commercialized variety, and would not be subject to additional risk assessment, with the Feeds Division within the CFIA affirming this in 2024 ([CFIA 2024](#)). Confirmation that genome editing technologies will not trigger additional and expensive regu-

latory oversight may enable greater use of genome editing technology application to the development of new varieties. Application of these more precise breeding technologies may enable higher successful adoption.

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Data availability

Data generated or analyzed during this study are not available due to the nature of this research as is required by University of Saskatchewan data protection policy.

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Competing interests

The authors declare there are no competing interests.

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