Barley Breeding in Canada - A path forward from 2021

A Report Submitted to the Saskatchewan Barley Development Commission

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By

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Executive Summary

The Saskatchewan Barley Development Commission (SaskBarley) was established in 2013 with a mission: "To identify, develop and support research, market development, and extension initiatives that establish long term profitable and sustainable barley production for Saskatchewan producers". In its short existence, SaskBarley has become the largest levy collector on barley in Canada, and is playing a key leadership role in funding and coordinating variety development. While a number of successful research projects are already being undertaken by SaskBarley, sustainable funding for variety development is facing significant questions as the agriculture industry evolves in Canada.

During the Agriculture and Agri-food Canada (AAFC) value creation consultation (and variety development discussions as a whole), barley was considered from the same perspective as wheat. SaskBarley feels there are unique challenges facing barley variety development and advancement, and that these challenges have not been adequately analyzed throughout discussions of value creation or the future of variety development in Canada. One of these characteristic challenges is reluctance within the Canadian market to adopt new barley varieties with enhanced characteristics (Zmashenko et al., 2017). The recent failure of the AAFC led value creation consultations, the pilot project of the seed variety use agreements (SVUA) by the seed trade, and COVID-19 related federal deficit, all create uncertainty for barley variety development system that should be accounted for.

The uncertainty surrounding public and producer funded breeding programs in Canada also needs to be addressed for the long-term sustainability of the barley industry. Barley breeding in Western Canada has been facing capacity pressure for the past five years. Three barley breeding centers serve Western Canada: The Field Crop Development Centre (FCDC) in Lacombe, the Crop Development Centre (CDC) in Saskatoon, and the Agriculture and Agri-Food Canada (AAFC) station in Brandon. The AAFC has decreased from two breeders to one breeder (but has added a pathology position), the CDC operates with a shared breeding position between oats and barley, and the FCDC has two barley breeders. The FCDC activities have been hampered for the past four years by uncertainty within the Alberta government. The provincial government has very recently announced the programs at FCDC will be transferred to Olds College, with a small amount of funding to restructure research activities, and with additional funding coming from producer barley commissions and livestock producers. This has created significant uncertainty surrounding the future of that breeding program. In particular it is unclear how pre-breeding research will be funded.

SaskBarley's primary research goals are to increase profitability of barley production for producers through yield gains and agronomic efficiencies, varietal uptake, enhanced desirable market quality characteristics and specifications, and yield parity between malt and feed barley. This research attempts to answer questions on how to achieve these goals around variety development in Canada and build a long-term sustainable breeding model, while effectively accounting for the unique challenges of the barley sector.

It is within this setting the Saskatchewan Barley Development Commission has asked us to address four important questions related to investments in barley breeding in Western Canada:

1. Looking historically, what has been the rate of return to the producer and public investment in barley breeding since 1995 when check-off funded research began.
2. How much has the return to barley breeding been reduced by the slow adoption of new varieties by the malting industry?
3. How does Canada compare relative to its major competitors in terms of investment in barley breeding and R&D?
4. What are the future investment needs for barley investment in Canada?

The answers to these questions are summarised as follows:

1. The rate of the return to public and producer investments in barley breeding

While there is a long history of public barley breeding and research, we focus our research on the last 25 years, the period when producers have also contributed to the funding of public barley breeding activities through the WGRF and provincial levy funded commissions. In assessing the benefits and costs of these producer investments, we consider the investment cost since 1995 (two years after the WGRF was created) until 2019. For benefits we assume a ten-year gestation lag from breeding investment to new registered varieties. We consider only the benefits that are derived from varieties released from these funded breeding programs from January 1, 2005 to 2049 including their anticipated impact on future productivity growth. As a final step, we compare the present value of benefits and costs, assess the benefit/cost ratio and the internal rate of the return of the producer and public investments in barley breeding, and report the net present value of the investment.

As shown in Figure 8 the expenditures on barley breeding have been fairly constant since 1995. When inflation adjusted to 2019 dollars, annual breeding expenditures have ranged between $2.3 to $3.5 million since 1995. Notably, these annual breeding investments are only about 0.14% of the gross crop value, which is lower than crops and far lower than industrial R&D investment rates of 3 to 5%.

We assume the stream of benefits created from post 1995 research investments are responsible for the genetic gain in varieties registered after 2004. As shown below, the impact is initially very small, but as the new varieties are adopted by producers and the performance of the new varieties increase over time, so does the impact on production. Figure 11 shows the weighted average yield index for Manitoba, Saskatchewan and Alberta based on the relative yields reported in the variety performance trials, and the seeded area of those varieties. As shown in the figure, by 2019 yields are about 7% higher in Saskatchewan and Alberta than they would be without the breeding investment, while Manitoba has seen a 12% increase.

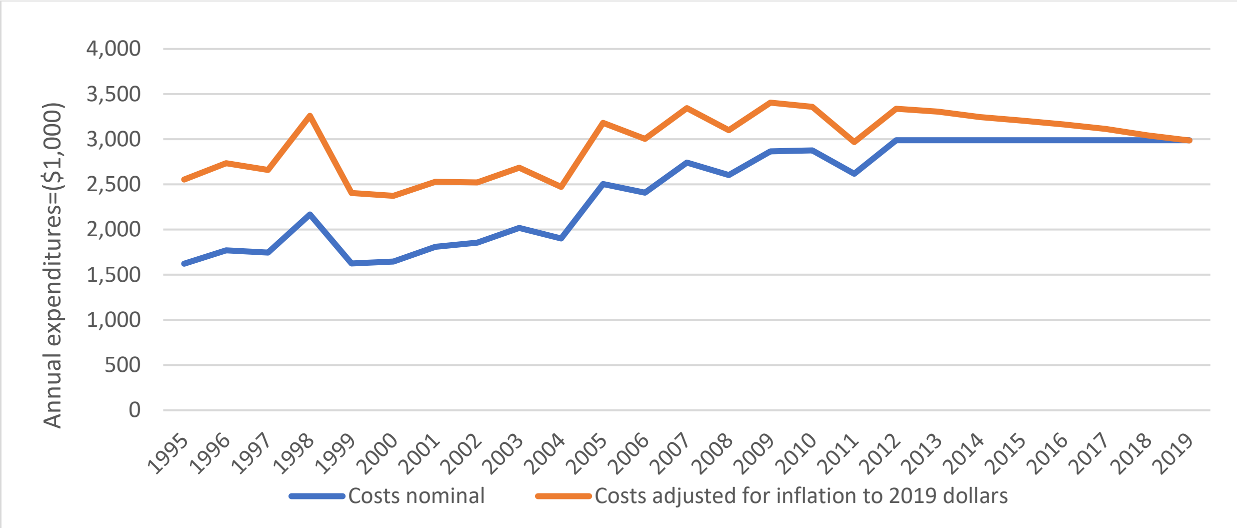

Figure 8: The nominal and inflation adjusted to 2019 expenditures on barley breeding in Canada
Source: Gray et al., 2012 and Feist and Barnes, 2020.

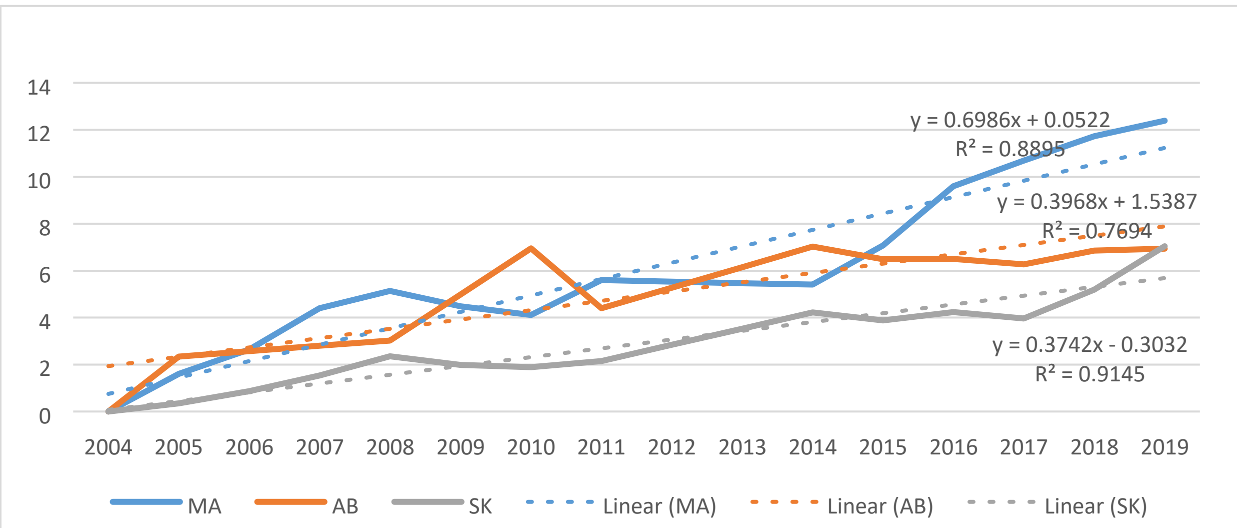

Figure 11: Percentage increase in weighted average yield index from 2004, in Saskatchewan, Manitoba and Alberta in years 2004-2019
Source: Author's calculations based on CPVT data and adopted acreage share data based on crop insurance data, which reports acreage insured by variety

The breeding and adoption of higher yielding barley varieties led to increased production and increased gross farm income. We also recognise that the impact of breeding effort from 1995 to 2019 will increase production for many years in the future as more producers adopt and continue to use the recently minted varieties. In Figure 12 we show the increase in barley production that can be reasonably attributed to the adoption of higher yielding barley varieties until 2029. After 2029 we assume these the related benefits depreciate at 5% per year until 2049.

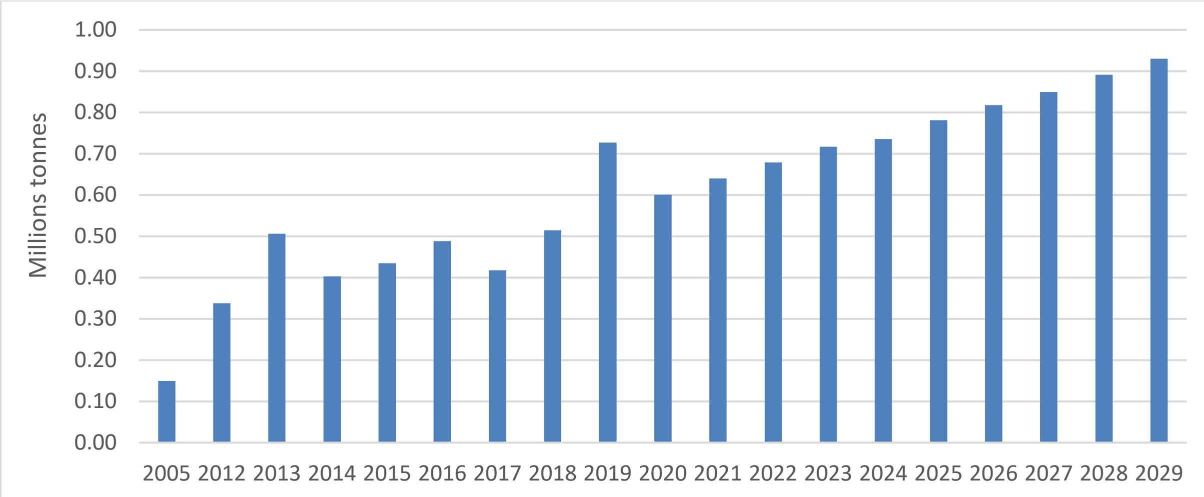

Figure 12: Change in total barley production in tonnes in Western Canada attributed to barley breeding investment.
Source Author's calculations based on data.

Converting yield increases into producer benefits required three additional considerations. We applied standardized adoption curves to estimate the future increase in the producer yield that will be realized as current higher yielding varieties are initially adopted by producers and then depreciate. Second, we applied a 10-year rolling average of barley price to estimate the economic value of the additional production going forward. Third, we also considered the modest impact additional production had on prices as we calculated the benefits to producers. Incorporating these three effects allowed us to reasonably anticipate the annual stream of benefits for the 25 years of producer and public breeding investments.

The final step in a benefit - cost analysis is to calculate the present value of benefits and costs so they can be compared. Applying a 5% discount factor to reflect the producers' cost of borrowed money (or real interest rate) increases the value of past expenditures and decreases the value of future benefits to recognize the time value of money. Adding up the annual present values allow us to compare the total present value of total expenditures to date to the present value of total benefits created. A final adjustment is made to reflect the fact that given the supply and demand conditions, barley buyers pay a small portion of check off costs because of higher prices, while 95% of the check off cost are borne by producers.

Figure 14 shows the discounted streams of producer costs and producer benefits of barley breeding over time. By assumption, between 1995 and 2004, producers incurred the breeding costs (shown in red) without benefits. Beginning in 2005 new barley varieties developed as a result of analyzed investment were released and were adopted by producers. These benefits increased over time as producers adopted even higher yielding varieties. By 2019 the higher yielding varieties were increasing the gross margin of barley producers by $60.4 million dollars, relative to what it would have been without the 25 years of producer breeding investment. This large annual benefit (shown in green) is 40 times higher than the breeding costs incurred by producers in 2019. The benefits extend well beyond 2019 reflecting the fact that if breeding programs were closed today, barley producers would continue to benefit from the current varieties for many years into the future.

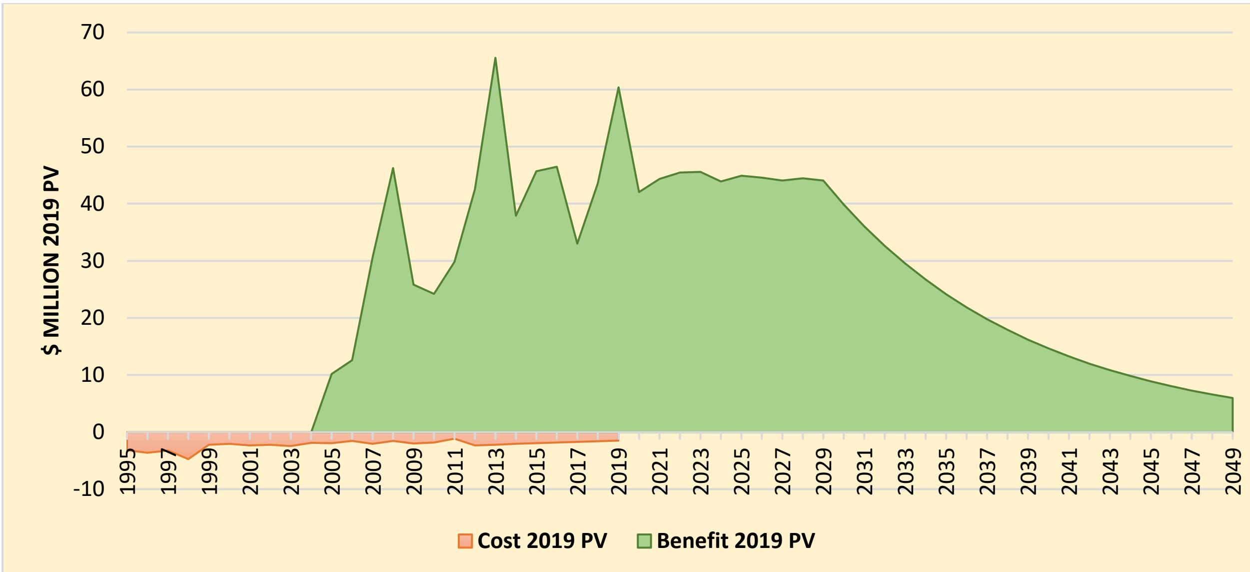

Figure 14: Benefits and Costs of the producer investments in Western Canadian barley breeding from 1995 to 2019

Source Author's calculations as described in the report

The summary indicators for the Benefit Cost analysis are reported in Table 3. In the Base Case, which is our best estimate of the returns, the total producer investments in barley breeding have a 2019 present value of $52.3 million. In return, producers have seen the release and adoption of new varieties generating yield induced benefits with a present value of $1,360 million. The calculated B/C ratio is 26.0 to 1, with an internal rate of return of 32% per year. The Net Present Value of producers' breeding investment exceeds $1.31 billion dollars.

These results indicate that producer funded barley breeding has been an outstanding long-run investment. A B/C ratio of 26 to 1 implies that even after accounting for long research lags, adoption lags, and the time value of money, each dollar of investment on average returned $26 of benefits. The internal rate of return of 32.0 % per year suggest this is equivalent to earning 32% annual return (plus inflation) on an investment account. The additional breeding resources created by check-offs to date have increased western Canadian barley producer gross margins by $1.36 billion dollars. The returns on the sum of producer and public breeding investments, which includes a portion of downstream benefits, is $3.4 billion.

Scenario B, in Table 3, recognises that finding a complete total of all public expenditures on barley breeding is difficult. In this Scenario we assume the actual public breeding expendituures are 35% higher than those reported by Cereals Canada, Feist and Barnes (2020). As such, Scenario B estimates should be considered a conservative a lower bounds to the returns to barley breeding investments.

Table 3: The Estimated Benefits and Costs of Producer and Public Investments barley breeding 1995 to 2019

Scenario		Costs 2019 Present Value *($ Million)*	Benefits 2019 Present Value *($ Million)*	Benefit/Cost Ratio	Internal Rate of Return	2019 Net Present Value *($ Million)*
Scenario A: The Base case	**Producer**	52.3	1,360	26.0	32.0%	1,308
	Total	137.6	3,580	26.0	32.0%	3,442
Scenario B: 35% Increase in Cost	**Producer**	52.3	1,020	19.3	28.9%	968
	Total	185.8	3,580	19.3	28.9%	3,394
Scenario C: Top yielding malting varieties immediately adopted	**Producer**	52.3	2,584	49.4	45.9%	2,532
	Total	137.6	6,803	49.4	45.9%	6,665
Scenario D: 4- year adoption of Copeland and Synergy	**Producer**	52.3	2,364	44.5	40.2%	2,312
	Total	137.6	6,122	44.5	40.2%	5,985

Source; Author's calculations

2. How much has the return to barley breeding been reduced by the slow adoption of new varieties by the malting industry?

The widespread adoption of new malting barley varieties occurs very slowly. This is understandable but very different that most markets where the new technology is adopted quickly. After repeated success, maltsters and brewers grow to trust the performance of an existing variety. As this trust grows it becomes increasingly difficult to market new varieties, even if they have superior agronomic, yield, and/or quality characteristics. As a result of this *lock-in*, many good varieties are passed over, and the general rate of adoption of higher yielding varieties is slower.

Like Marquis wheat, the Harrington barley variety registered in 1983 became a symbol of Canadian malting barley and dominated malting barley sales for 20 years. AC Metcalf registered in 1997 took over from Harrington as the most grown variety in 2002, - 5 years after its induction. CDC Copeland over took AC Metcalfe and became the lead variety in 2017- 15 years after its introduction in 2002. AC Synergy, released in 2015 is currently increasing in adoption and may be the next leader. As outlined in the report, other varieties with even higher yields were passed over during these four decades of malting barley development.

To answer the question of how the slower rate of malting barley adoption has impacted the producer return on investment, we consider two counter-factual situations to the adoption patterns that occurred. In Scenario C, we estimate the return to breeding if malt barley producers always grew only the highest yielding registered malting barley variety each year. Recognising unrealistic assumption with respect to malting quality, this is an extreme upper bound of what could be possible. In Scenario D we simulate the adoption of the eventually dominant CDC Copeland and AC Synergy within 4 years of their release, which might be attainable in a very integrated supply chain. The results of Scenario C and D are reported in Table 3. We simulate the producer benefits in these two counterfactuals, relative to the 2004 yield baseline.

Not surprisingly, faster adoption would substantially increase the return to barley breeding. As reported in Table 3, Scenario C, in the most optimistic scenario where the highest yielding varieties are grown, the B/C increase 49.4 to 1 and the IRR to 45.9% per year. As also reported in Table 3, in the more conservative counterfactual scenario D, where the industry aggressively adopts CDC Copeland and then AC Synergy, the B/C is 44.5 to 1 and the IRR to 40.2% per year.

3.Where does Canada sit relative to its major competitors in terms of investment in barley breeding and R&D?

Canadian producers are participating in competitive global markets for both feed and malting barley. The majority of global barley production takes place in Russia, Germany, France, and Ukraine. The next largest barley producers are Australia, Canada, Spain, Turkey, the United Kingdom, and the United States of America (FAO, 2021).

Canada is also a large barley exporter and faces the most direct competition from France and Australia, which as can be observed in Figure 23, are the largest barley exporters. In viewing the future, it is important to consider how Canada compares to these rivals both in terms of research investment and the genetic gain.

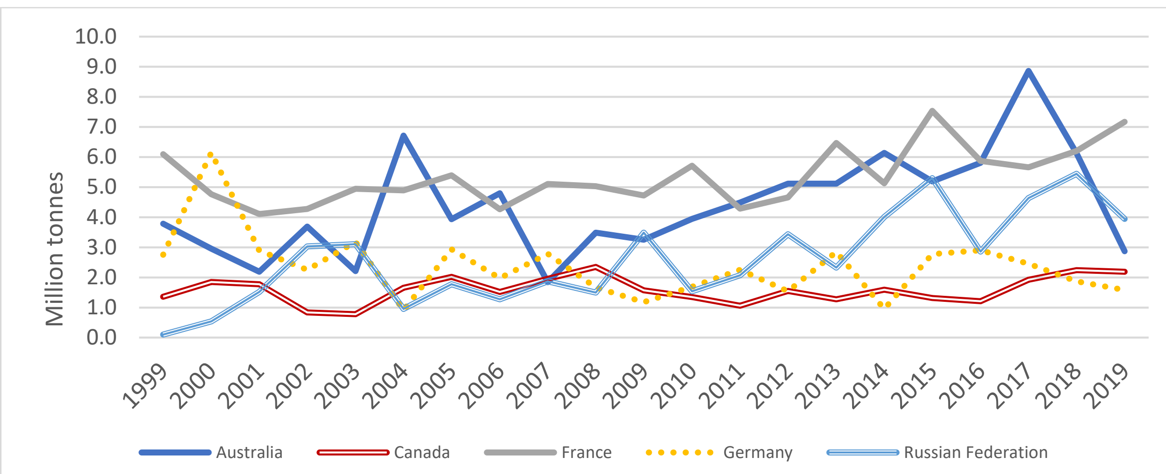

Figure 23: Barley exports from Australia, Canada, France, Germany, Russian Federation in years 1999-2019.
Source FAOSTATS 2021

As shown in Figure 22 the average yield of barley in France, and Germany is higher than the average barley yield in Australia, and Russia. The average barley's yield in Canada is between those groups of countries and closer to lower yielding countries.

Australia spends about $24 million (Australian dollars) on barley breeding, which is almost 8 times more than Canada does. While Australian barley yields are lower than average barley yield in Canada, Australian barley has a very good reputation and Australia is known for high quality and purity of its barley. Australia will continue to be an important competitor. The average barley production in Australia over the last 5 years was 9.8 million tonnes and has an increasing trend. The estimated trend line based on data from years 1998-2018 indicates that Australian barley production has been increasing by about 200,000 tonnes per year for the last 20 years.

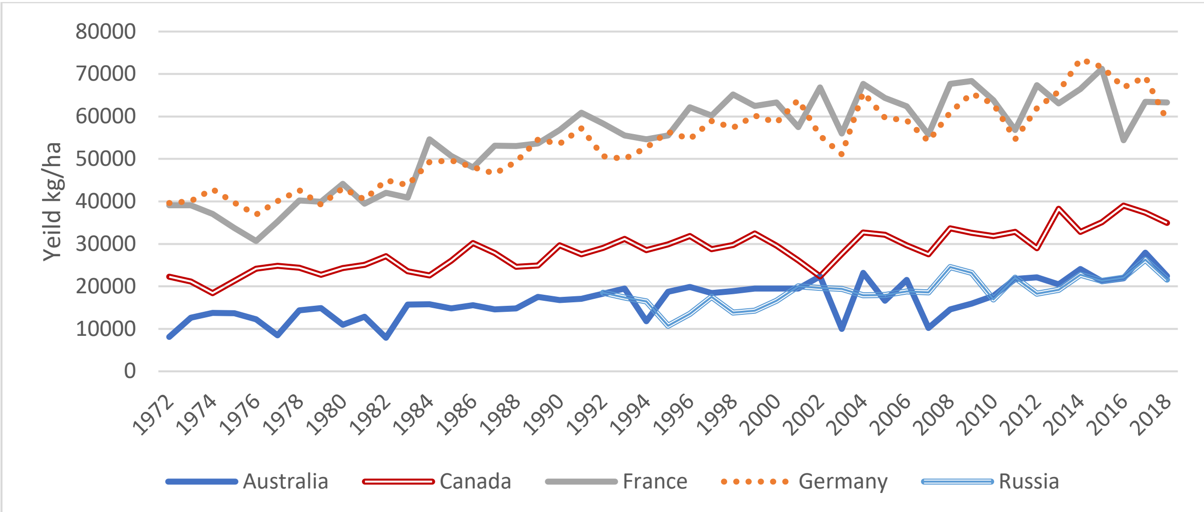

Figure 22: The average yield of barley in Australia, Canada, France, Germany, Russia, Ukraine and the United Kingdom 1972-2018
Source FAOSTATS 2020

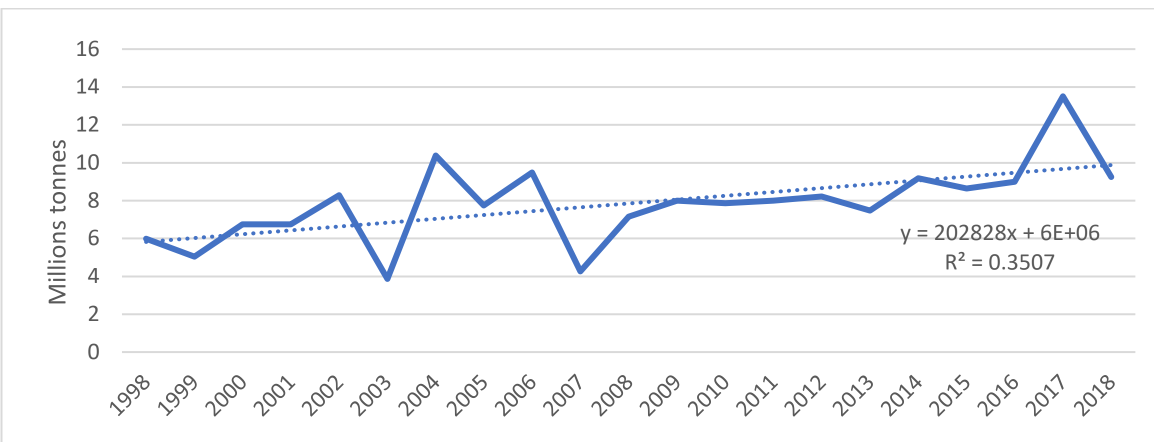

Figure 24: Total barley production in Australia 1998-2018
Source: FAOSTATS 2021

Because it is private activity undertaken by many firms, expenditures on barley breeding is difficult to assess in France and Germany, but from the number of barley breeders, it seems likely that Germany is investing more on barley breeding than Canada. Despite this investment and some increase in average yields, German barley production and exports have declined over the past 20 years. France continues to produce about 10 million tonnes of barley per year, something they have done for the past 50 years. The average yield of barley in France and Germany is higher than the average yield of barley in Canada. It is worth noting that barley production in Russia and the Ukraine has been increasing. With the completion of the double tracked rail link to China these regions could become increasingly competitive in the Chinese market.

4.What are the future investment needs for barley investment in Canada?

The benefit/cost analysis reveals a very high B/C ratio and internal rate of return to barley breeding. Past investments show that for every $1 not invested in barley breeding, producers would have forgone $26 in benefits. While this level of return is remarkable, these results are consistent with hundreds of international studies that have examined the returns to agricultural research. This strong record of performance suggests that producers need to work with other partners to significantly expand barley breeding efforts. An expansion of breeding effort could involve more extensive use of existing check-offs, an increase in the per tonne check-offs, or an increase in royalties used to fund breeding.

Our research confirms that faster adoption of new malting varieties would provide significant additional benefits from barley breeding, suggesting that market development in the malting industry continues to be important. Historically the lack of commercial brewing trials of new varieties, has impeded the willingness of the malting industry to adopt new varieties. The growth in micro brewing and the "buy local" movement creates an important opportunity to test new malting barley varieties in smaller markets. Continued efforts to promote the trials of new varieties in the brewing industry, could help foster faster innovation.

The Australian barley industry has expanded in area, yield, production and exports over the past 20 years. Currently Australia is spending about 8 times what Canada does in barley breeding. While it is too soon to see the results of these investments it does suggest Australia is likely to continue to be a very important competitor in the international barley market. It also suggests that if Canadian barley producers were to invest more in barley breeding they would not be outside the range of international experience.

As a whole, our results suggest that barley producers would reap large benefits from investing more in barley breeding. The current breeding rates of .14% of gross revenue is far lower than standards in other industries. While there might be other models with higher rates of return, the current breeding system has yielded $26 for every $1 invested, suggesting a significant opportunity to benefit by investing even more. The significant impact of slow malting variety adoption also suggests a need to explore further investments that can foster adoption.

Investing more will require a larger percentage of existing check-offs being invested in expanded breeding programs. Ideally, the funding base could also be increased to further increase investment. If there is a reluctance, or a limited capacity to increase breeding through existing funding agreements, new funding agreements and or new partnerships should be explored.

The takeaway meesagre from the report is that producers should be confident that past investments in barley breeding via check-offs have made large contributions to their bottom line. The barley commissions and other producer groups should be seeking ways to increase returns through even larger investments. Addressing the policy risks associated with government funding, may require transition away from funding agreements toward the creation of more permanent breeding partnerships.

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Barley Breeding in Canada - A path forward from 2021

Introduction

Barley was domesticated approximately 8000 B.C. and is likely to be the worlds' oldest cultivated grain (AgMRC, 2020). Barley is very robust and can be grown in different climates and environments, even in marginal areas and high altitudes. Nowadays, barley is used mainly for food products, animal feed, and as a malt to brew beer. In western Canada barley production has numerous benefits for growers. It helps with weed management, disease control, and improves soil fertility. Barley is also cheaper to seed and matures faster than many competitive crops (Feist and Barnes, 2020).

Over the last decade, the barley industry worldwide has been growing in production, consumption and yield. In contrast to these global trends, Canadian barley production and exports have decreased over the past decade, losing market share to several other crops. The Canadian barley industry is characterized by a slow rate of variety uptake. In spite of new varieties being registered every year, two barley varieties registered over twenty years ago, AC Metcalfe and CDC Copeland (Figure 1), have dominated annual market share. The brewing industry relies on an established reputation among beer consumers, therefore it is cautious to use new varieties. In Canada, the public breeders are not responsible for marketing of new varieties to the end-users and the grain companies usually do not take a part in the promotion of new barley varieties. The members of the malting barley supply chain in Canada typically work independently from one another. The end-users are often not directly involved in early stages of the varietal testing. The Canadian Malting Barley Technical Centre (CMBTC) has assumed some of the responsibility for international market development, though, being a small not-for-profit organization, the CMBTC has insufficient resources to undertake this role (Zmazhenko et al., 2017). Zmazhenko et al., 2017 stresses the need for vertical exchange of information and the transparency in supply chain.

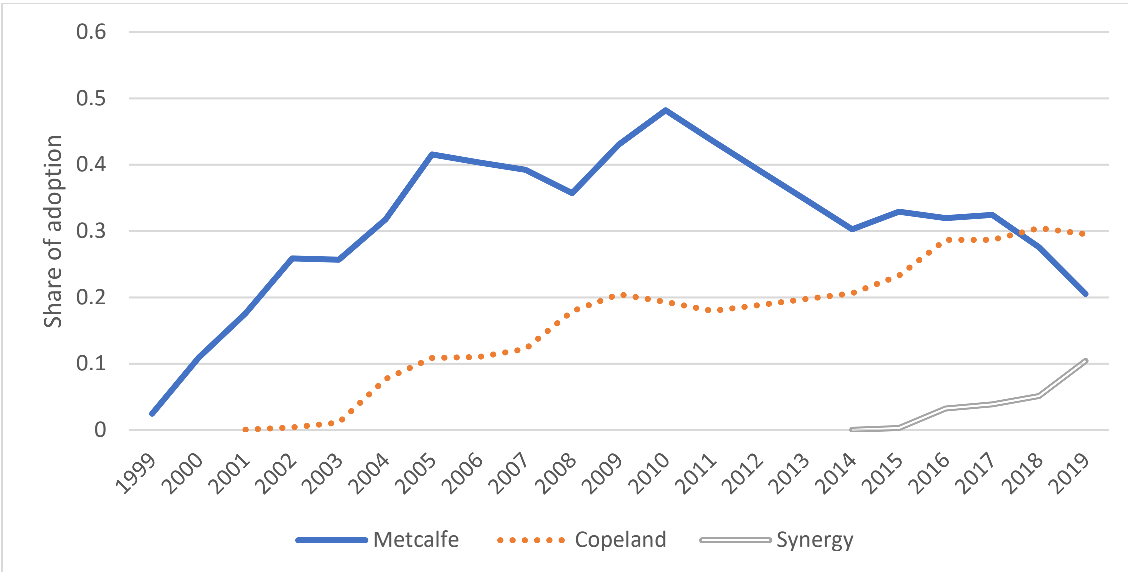

Figure 1: Seeded area shares of AC Metcalfe, CDC Copeland, AC Synergy 1999- 2019
Source: Adopted acreage share data based on crop insurance data, which reports acreage insured by variety.

During the Agriculture and Agri Food Canada (AAFC) value creation consultation (and variety development discussions as a whole), barley was considered from the same perspective as wheat. However, malting and feed barley are marketed differently, and the barley industry has different stakeholders than the wheat industry. Barley industry stakeholders include barley producers, beef producers, hog producers, as well as malt producers and beer companies. Canada's barley research funding is significantly lower than that for wheat. The Saskatchewan Barley Development Commission (SaskBarley) believes there are unique challenges facing barley variety development and advancement, and that these challenges have not been adequately analyzed throughout discussion of value creation or discussion on the future of variety development in Canada. Next to the slow variety adoption the challenges within the barley variety development system that should be accounted for include: the recent failure by Agriculture and Agri Food Canada (AAFC) of value creation consultation and economic analysis, the pilot project of the seed variety use agreements (SVUA) by the seed trade, and more recently, the implications that COVID-19 will have on federal budgets in coming years.

The value creation discussions have been happening for over a decade and were triggered by a visible decrease in cereal crop area. A number of models were investigated and presented to Agriculture and Agri Food Canada (AAFC) through a process of engagement with the Canada Grains Roundtable. In the fall of 2018, the AAFC conducted a series of consultations on two royalty collection models. The two models included the end point royalties and the trailing royalties for wheat, oat and barley seed. In 2019 the cereal commissions including the barley, oat and wheat commissions from Alberta, Manitoba and Saskatchewan asked for fundamental changes in the existing consultation process on value creation. The commissions stated they are unlikely to agree on either of the proposed models and requested more consultation together with consideration of other options. Additional consultations should place an emphasis on including producers in a new value proposition (Alberta Barley, 2021).

Another challenge within the barley development sector occurred on February 25th 2020 when the Canadian Seed Trade Association (CSTA) and the Canadian Plant Technology Agency (CPTA) announced plans to start a two-year pilot program of seed variety use agreement (SVUA), to test the collection of trailing royalties on farm saved seed in Canada. The producers who purchase a SVUA variety and save some of the grain for seed at harvest, to plant it the next spring, will have to pay a variety use fee (Seed Value Creation, 2021). The SVUA is designed to generate larger financial returns from the development and sale of new seed varieties protected by the Plant Breeder Rights. The larger financial returns should accelerate a private sector investment in plant breeding (e.g. Canterra/Limagrain; BASF, Syngenta). However, there is no industry agreement on SVUA. The wheat and barley commissions from Saskatchewan, Alberta and Manitoba are not a part to the pilot SVUA program nor supportive of it (Western Producer, 2021b).

The next challenge relates to the 2020-2021 pandemic caused by COVID 19 that has triggered a great increase of government expenditures announced in a very short period of time. The federal deficit for 2020-21 is surpassing $340 billion and the debt to gross domestic product (GDP) is rising from a steady 30-34% to over 60% in one fiscal year. Historically, increase of debt to GDP to 50% pushed the governments to reduce spending and increased taxes in attempts to control the deficit. Governments reduced programs deemed to be non-essential including agricultural research. That suggests COVID 19 may represent a threat to publicly funded agricultural research in the next few years (Feist and Barnes, 2020).

Finally, the uncertainty surrounding public and producer funded breeding programs in Canada needs to be addressed for the long-term sustainability of the barley industry. Since 2012 the Agriculture and Agri Food Canada (AAFC) is expressing its intention to move out of the variety finishing area for barley and wheat. However, Clayton and Jones (2020) reported that the AAFC will not exit the space without a replacement program in place or sufficient variety choice to avoid a technology gap. Producer funding through check-offs administered by the Canadian Barley Research Coalition (the CBRC) is an absolutely essential source of support to maintain the AAFC capacity and to release public barley varieties. Without producer funding and a mitigation strategy for operational funds, the AAFC variety development program will be severely diminished (Clayton and Jones, 2020).

Western Canada currently has three barley breeding centers: The Field Crop Development Centre (FCDC) in Lacombe in Alberta, the Crop Development Centre (CDC) at University of Saskatchewan in Saskatoon, and the Agriculture and the Agri-Food Canada (AAFC) station in Brandon in Manitoba. These breeding programs in recent years have been facing capacity pressures. The AAFC in Brandon has decreased from two breeders to one breeder (but has added a pathology position), the CDC in Saskatoon operates with a shared breeding position between oats and barley, while the FCDC in Lacombe has two barley breeders. The CDC in Saskatoon program has the most success defined by variety adoption by producers. Groenewegen et al., (2016) reported plant breeders from the CDC released 93 barley varieties since 1971. The CDC in Saskatoon and AAFC in Brandon programs have complementary disciplines and labs to support barley breeding (Jones and Clayton, 2020). The FCDC in Lacombe has the largest program but its activities have been hampered by uncertainty within the Alberta government. The Alberta Government has very recently announced that the programs at the FCDC will be transferred in early 2021 to Olds College, with a small amount of funding to restructure the research activities (OldsCollege 2020). Barley and livestock producers will also provide support. These changes have created significant uncertainty surrounding the future of the breeding program; in particular, it is unclear how pre-breeding research will be funded.

The objectives of this study are to address four questions related to western Canadian barley breeding: 1) What are the up-to-date costs and benefits of barley breeding in Canada? 2) What is the cost to producers of low barley variety uptake? 3) How competitive is the Canadian barley breeding program compared to Australia, Germany and France? 4) Per output of dollars spent, is the Canadian barley breeding program keeping pace now and what are the needs into the future?

The remainder of this report is organised in sections. Section 1 provides a brief overview of barley production in Canada including its funding mechanisms. Section 2 begins with a *Benefit Cost* analysis of barley research in the midst of an established and ongoing program. The objective is to provide information relevant to making timely program decisions such as expansion or contraction of the program, re-focussing the program, or ensuring those who are investing resources in the program are receiving good returns for their money (Gray et al., 2012). Our Benefit Cost analysis of barley research covers the investments made in the years 1995-2019. We also estimate the forgone benefits from low variety uptake, by simulating adoption of the highest yielding malting barley varieties by all malting producers and faster adoption of Copeland and Synergy by all malting producers. In Section 3 we review the barley breeding systems from Australia, Germany and France to compare breeding expenditures, barley production, yield and area seeded in Canada, Australia, Germany and France. Where possible the size and scope of the breeding programs is compared. This helps to benchmark where Canadian barley is relative to other countries that compete with Canadian barley. Finally, in Section 4 we discuss the implications our results have for SaskBarley future decisions.

Section 1 Barley production in Canada

Canada is the fourth largest barley producer and the second largest malt exporter in the world. The average annual production of barley in Canada in the years 2008-2018 was about 8.7 million tonnes and average area seeded with barley in the same time frame was about 2.5 million hectares (FAOSTATS, 2020). Barley is Canada's third largest crop in terms of the area seeded. The only crops with larger seeded area are wheat and canola (Alberta Barley, 2021). The mainstream of Canadian barley is exported to China (feed and malt barley, the majority being malt), the United States and Japan. Currently, China has a trade dispute with Australia, which is China's usual major barley supplier. The dispute is benefiting Canadian growers by enlarging market for their barley (Jamieson, 2020). The other important partners in trade for the Canadian barley sector are Saudi Arabia, South Korea and Mexico (CAFTA, 2021).

As can be observed in Figure 2 and Figure 3 there is a downward sloping trend in the total production of Canadian barley and in the area planted with barley. The average yield, on the other hand, has a positive slope (Figure 4).

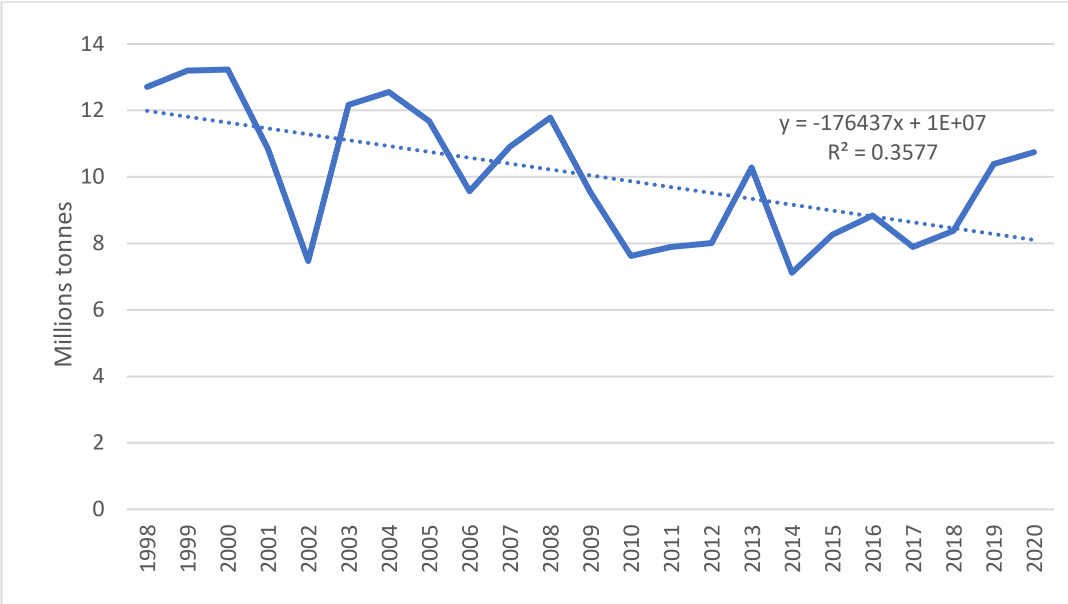

Figure 2: The total production of barley in Canada in tonnes 1998-2020
Source: FAOSTATS 2021 and Stats Canada 2021

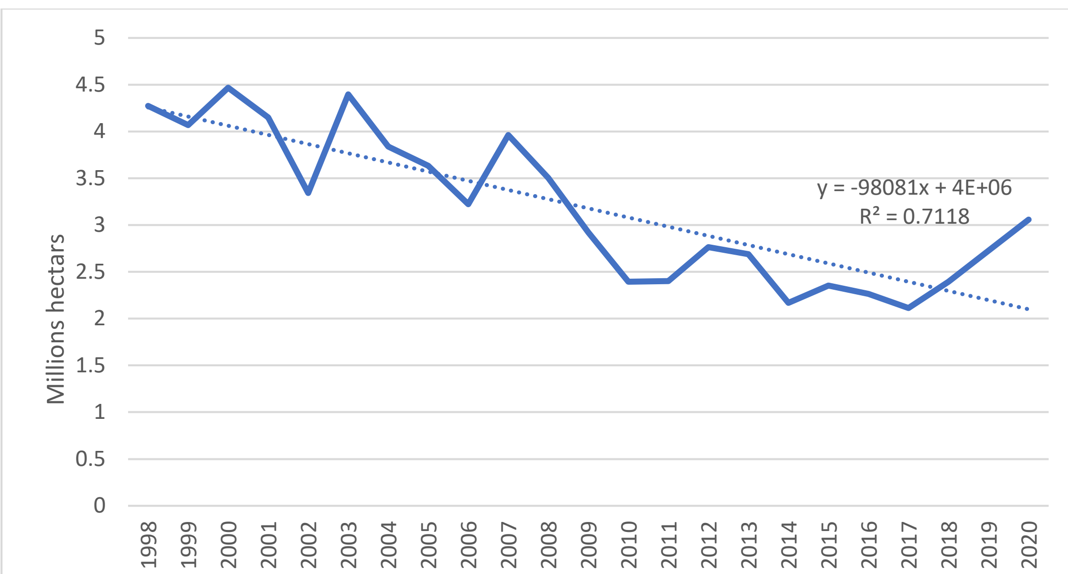

Figure 3: The area seeded with barley in hectares in Canada 1998-2020
Source: FAOSTATS 2021 and Stats Canada 2021

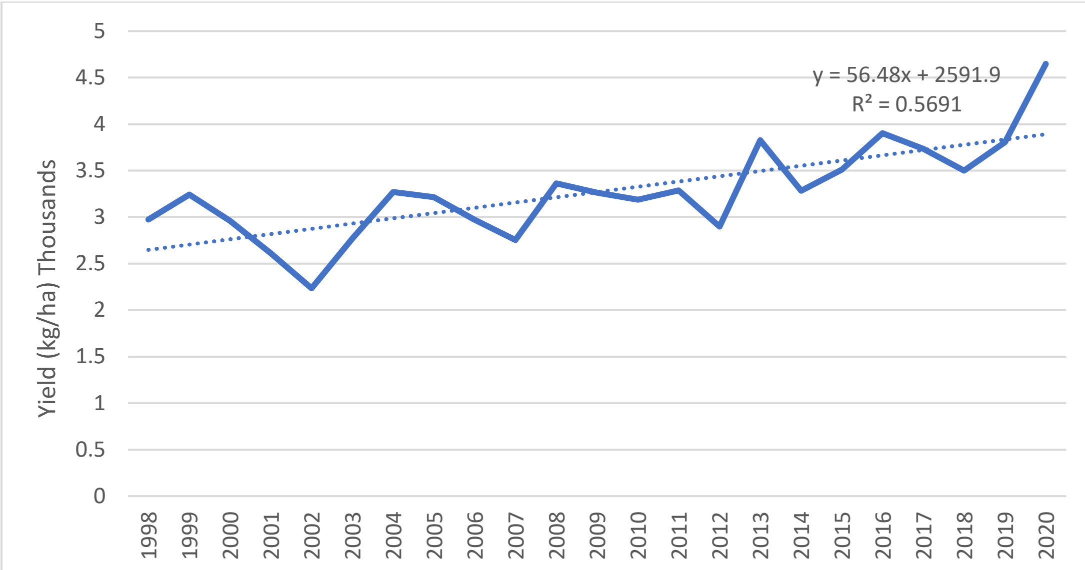

Figure 4 The average yield of barley in kg/ha in Canada 1998-2020
Source: FAOSTATS 2021

The vast majority of barley production in Canada is located in four western provinces: Saskatchewan, Manitoba, Alberta, and British Columbia (Zmazhenko et al., 2017). The total area seeded with barley in Western Canada in 2020 was about 2.994 million hectares, slightly higher than the area seeded to barley in 2019 and also higher than the Canadian average in years 1998-2018. The total barley production in Western Canada in 2020 was about 10.4 million tonnes, approximately 4.2% higher than total barley production in Western Canada in 2019 and also higher than the Canadian average in years 1998-2018. The average yield in Western Canada in 2020 was 71.8 bushels per acre (48,286.29 hg/ha), slightly higher than 71.1 bushels per acre (47,815.53 hg/ha) reported in 2019 and higher than the Canadian average between1998-2018 (Canadian Grain Commission, 2020).

Barley is categorized by its end use into three classes: malting, general purpose, and food barley (CAFTA, 2020). To be qualified for malting grade, a variety has to be on the malting barley variety designation list. Only approximately 20 percent of malting barley produced is selected for malting. The malting barley not selected for malting is used domestically as livestock feed, exported as feed barley, or can be selected for food grade. Food barley is a variety of barley that has been selected for a food market. The general-purpose class includes barley not selected for malting or food (Canadian Grain Commission, 2021).

The largest barley breeding center, the FCDC in Lacombe, used to separate the responsibilities of its barley breeders into two-row and six-row programs, however these responsibilities have now been transferred to be divided with the focus on the end uses and categorized into malting and general purpose (feed and forage) barley programs. Moreover, the lines are being evaluated for different end uses to check if the cross from one program (e.g. malting) does fit into second program (e.g. general purpose). A dual fit can produce a synergistic effect (King, 2020).

In 2020, 53.7% of the barley grown in Western Canada was malting barley, 38.5% was general purpose and 2.4% food barley (Canadian Grain Commission, 2020). Malting barley and general purpose barley have large barley market shares whereas food barley has only a small fraction of the market. The demand for food barley is limited and failed to keep up with the growth of demand for competitive food crops such as e.g., oat. The reason for limited demand for food barley may be an inadequate awareness of the important health benefits from barley consumption such as a reduction in human cholesterol levels. Another reason for small demand for food barley is limited knowledge in Canadian society on how to prepare barley. Also, an increasing popularity of gluten free foods take away demand from food barley (Feist and Barnes, 2020).

The proportion of the area seeded to malting barley, general purpose and food barley differs slightly among provinces. As presented in Figure 5, in Alberta and British Columbia in 2020 malting barley accounted for 46.1% of total area seeded with barley, while general purpose barley accounted for 49.7%. In Saskatchewan malting barley accounted for 65.4% of total area seeded with barley, while general purpose accounted for 21.9%. In Manitoba malting barley accounted for 42.7% of total area seeded with barley while general purpose varieties accounted for 51.7% (Canadian Grain Commission, 2020).

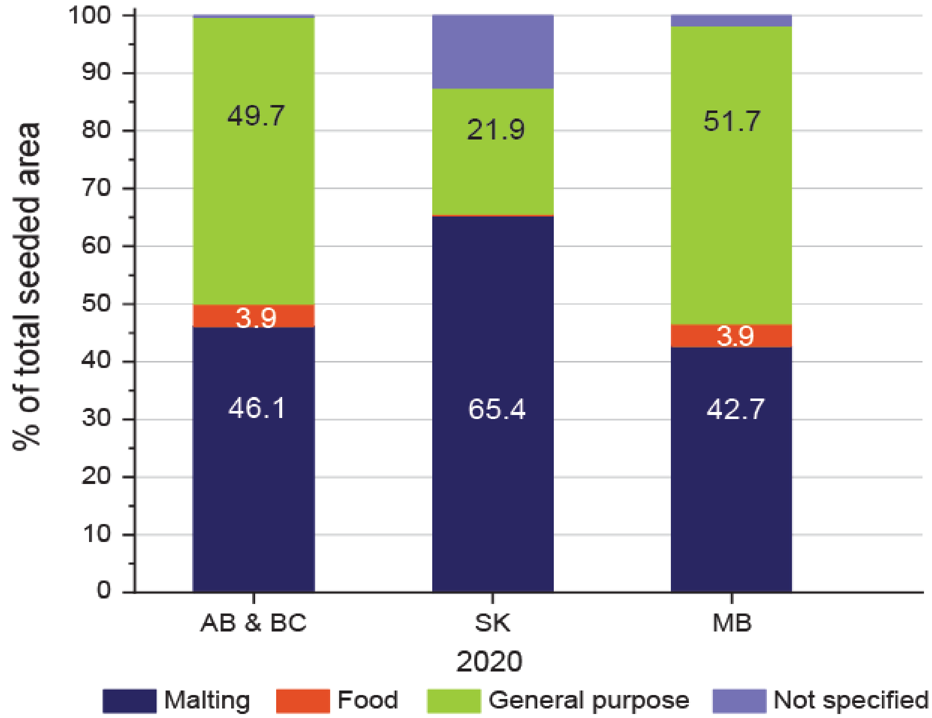

Figure 4: Provincial distribution of barley classes in Western Canada 2020
Source: Canadian Grain Commission, 2020.

1.1 Funding mechanism for barley breeding in Canada

Current funders of barley research include: Alberta Barley (ABC), Saskatchewan Barley Development Commission (SaskBarley), Manitoba Crop Alliance (MCA), Les Producteurs de grains du Québec (PGQ), Grain Farmers of Ontario (GFO), Atlantic Grains Council (AGC), Beef Research Council of Canada (BRCC), the Barley Council of Canada, Brewing and Malting Barley Research Institute (BMBRI), Saskatchewan Cattleman's Association, Western Grain Research Foundation (WGRF), provincial and federal Governments. Private sector, companies (e.g. SeCan, Viterra, MolsonCoors, Anheiser Busch, Sapporo) also contribute to public barley breeding programs (Feist and Barnes, 2020).

The investments in barley research have typically not been fully coordinated and therefore not as efficient as they should be. For example, there is no central list of current barley research in Canada. Each funder has his own website and is listing research investment separately (Feist and Barnes, 2020). In January 2020, the SaskBarley, Alberta Barley and Manitoba Crop Alliance, launched the Canadian Barley Research Coalition, a national not-for-profit organization that will facilitate long-term investments aimed at improving profitability and competitiveness for Western Canadian barley farmers.

1.1.1 Canadian Government contribution

The Canadian Government has a long history of funding barley research. The government supports barley sector via scientific contributions and joint investments. The testing and evaluation of varieties is done by the public sector although it would like to move from those activities. The avenues of government contribution include:

- The Core Breeding Agreements – organized as five-year agreements that originally supported a growth in both human resources and operational capacity and lately almost exclusively invested in AAFC human resource capacity. AAFC, the Canadian Wheat Research Coalition, and the Canadian Barley Research Coalition signed the Core Breeding Agreements in 2020. The Core Breeding Agreements are a commitment to continue working together and to share investment over the next five years. AAFC regards the core breeding agreements as an investment in applied breeding and has indicated their interest to continue breeding. However, AAFC's breeding program now relies on core breeding agreements to maintain capacity in the variety development pipeline (Clayton and Jones, 2020).

- The Agri-Science Program under the Canadian Agriculture Partnership (CAP). The objective of the program is to accelerate innovation by providing funding and support for pre-commercial science activities to keep the barley sector highly competitive. The program has two components:

  1. AgriScience – Clusters component: intended to mobilize industry, government and academia via partnerships.
  2. AgriScience – Projects component: A single project or a small set of projects that would be less comprehensive than a Cluster.

The National Barley Research Cluster (the Barley Cluster) is a $10.2 million research initiative that improves the competitiveness of barley. January 15, 2019 the Canadian Government announced support to the barley sector of a $6.3 million investment in the Barley Cluster under the CAP. The remining $3.9 million funding for the Barley Cluster is a commitment from the industry (WGRF, 2021). Support is through non-repayable contributions and/or collaborative support from AAFC research scientists. The Barley Cluster is being led by the Barley Council of Canada (AAFC, 2021; CAP, 2021). Clayton and Jones (2020) stated in the future cluster funding for breeding activities under the CAP will be reduced or discontinued. If public funding continues to include breeding activities the ratio of producer to public investment would be about 75:25 with producers contributing 75%.

The Canadian Agricultural Partnership

The Canadian Agricultural Partnership (CAP) program was launched in 2018 in succession to *Growing Forward 2.* The CAP is an investment by federal, provincial and territorial governments to strengthen the agriculture and agri-food sector and support region-specific agriculture programs and services that aim to meet regional needs. The investment covers the years 2018-2023 and has a value of $3 billion. Overall the federal government contributes 60% of program costs, while the provincial governments contribute 40% (CAP, 2021).

1.1.2 Producer contribution

Producers have contributed to the barley breeding programs via avenues such as:

- The Core Breeding Agreements –the investment is approximately $0.3 million per year.
- Agri-Science Clusters - the investment is approximately $0.8 million per year.
- Project funding - Funding in variety development has largely been directed to support longer term basic research such as genomics and accessing disease resistance traits. It is often matched with other funding agencies like WGRF, Saskatchewan's Agricultural Development Fund, The Natural Sciences and Engineering Research Council of Canada (NSERC).

Barley Check-off

The Western Grain Research Foundation (WGRF) administered check-offs from barley sales from the August 1993 until July 2017. The check-off was an annual deduction from Canadian Wheat Board (CWB) Final Payment to producers in Saskatchewan, Manitoba and British Columbia. As reported by Gray et al. (2012), the barley check-off, had a value of $0.40/tonne in years 1995 to 2005 and was enlarged to $0.50/tonne in years 2006 to 2012. In the years 1995-2012 the WGRF managed a total $13.1 million of check off revenue, with annual investment in research on new barley varieties averaging $773,000. These funds have been invested in breeding and germplasm development at Agriculture and Agri-Food Canada research centre in Brandon, Crop Development Centre in Saskatoon, and Alberta Agriculture Food and Rural Development in Lacombe. Until 2012, the WGRF investment resulted in over 40 new barley varieties being released (Gray et al., 2012).

On August 1, 2012 the federal government removed the Canadian Wheat Board's single desk authority on the sale and export of barley and wheat from Western Canada and established the Western Canadian Deduction (WCD) as a transitional check-off on barley and wheat. The aim of the WCD with the aim to continue providing a stable funding for the Canadian Malting Barley Technical Centre (CMBTC) and a research initiative administered through the WGRF (SaskBarley, 2020). The WCD ended on July 31st, 2017 when barley check-offs were collected by barley Commissions and associations.

It is worth noting that barley commissions face two constraints that limit their ability to finance research; 1) Not all barley production is subject to a check-off, particularly the barley fed on farms or sold farm-to-farm, and 2) the check-offs are refundable and are returned to a producer, if they make a request.

Western Grain Research Foundation (WGRF)

After July 31st 2017, when the WCD was discontinued, the WGRF has continued to be involved in barley breeding through a few partnerships and agreements with the crop development centres and government research facilities. Currently, the WGRF contributes $740,000 to the Barley Cluster via five projects focused on variety development, pathology and knowledge transfer. The invested money are the remaining funds from the western Canadian barley check-off and royalty funds (WGRF, 2021).

The Saskatchewan Barley Development Commission (SaskBarley)

The Saskatchewan Barley Development Commission (SaskBarley) was established in 2013 with a mission: "To identify, develop and support research, market development, and extension initiatives that establish long term profitable and sustainable barley production for Saskatchewan producers". The SaskBarley's primary research goals are to increase profitability of barley production for producers through yield gains and agronomic efficiencies, varietal uptake, enhanced desirable market quality characteristics and specifications, and yield parity between malt and feed barley. In its short existence, the SaskBarley has become the largest levy collector on barley in Canada, and is playing a key leadership role in funding and coordinating variety development.

On August 1st, 2013 the SaskBarley started a collection of mandatory but refundable check-offs at the rate of $0.50 per net tonne. On August 1st, 2017, the SaskBarley took charge of the administration of the WCD check-off, then $0.56 per tonne. This check-off, administered by SaskBarley, is currently $1.06 per net tonne (SaskBarley, 2020).

Alberta Barley Commission

Alberta Barley was established in 1991 as a farmer-directed, not-for-profit organization to represent Alberta's barley growers. Alberta Barley was the first established wheat or barley commission in Canada, and has been used as a successful model for commissions that have since been established in Western Canada (Alberta Barley, 2021).

The organization collects a mandatory, but refundable check-off with a rate of $1.20 per metric tonne. The check off is invested to grow the industry and increase its profitability. The top priority for Alberta Barley is barley research and market development. Alberta Barley invests in a number of a research projects concentrating on feed, malt, food, agronomy and bio-products. The organization undertakes market development activities such as the expansion of barley's market reach, promotion of grain, and consumer and producer outreach (Alberta Barley, 2021).

The Manitoba Crop Alliance (MCA)

The Manitoba Crop Alliance Inc. (MCA) is a commodity organization with a goal to continuously improve the competitiveness and profitability of barley, wheat, corn, sunflower and flax in Manitoba. Until August 1st, 2020, growers who produced and marketed these crops in Manitoba were represented by five separate commodity groups. August 1st, 2020 the MCA began collecting a mandatory but refundable check-off from all sales of barley, wheat, corn, sunflower and flax in Manitoba. The check-off amounts are the same as what was in place with the five former organizations. Barley check-off in Manitoba is $1.06/tonne (MCA, 2021).

The Canadian Barley Research Coalition

The Canadian Barley Research Coalition (CBRC) is a non-profit organization established in 2020 to improve the profitability and competitiveness of Western Canadian barley producers by coordinating long-term barley research investments. The CBRC's members are SaskBarley, Alberta Barley and Manitoba Crop Alliance. Using a collaborative approach, the coalition is funded with producer check-offs,and promotes regional and national research projects in variety development and agronomy, including core funding agreements with AAFC and the prairie Universities (Clayton and Jones, 2020; Western Producer, 2021a).

In September 2020, the CBRC signed a new $2.7 million core breeding agreement with the University of Saskatchewan's Crop Development Centre. Under the new agreement, the CBRC will contribute to the CDC over five years, with money going toward the development of new barley varieties with improved agronomic, disease resistance and end-use quality characteristics (Western Producer, 2021). The Canadian Barley Research Coalition and the Canadian Wheat Research Coalition, and also signed the Core Breeding Agreements with AAFC in 2020.

1.2 The seed royalties

Royalties are an instrument to capture benefits from variety development and are often seen as vital to attract private sector investment in plant breeding. In Canada a plant breeder can collect royalties on new registered barley varieties if they apply for Plant Breeders Rights (PBR). Typically, a royalty is paid by growers to seed companies at the point of sale of certified seeds. Farm-saved seeds do not generate royalties in Canada (exception is SVUA pilot project discussed above) (Zmazhenko et al., 2017). As a result of the farm saved seed exemption, royalty collection is only a modest revenue source even for the successful public barley breeding programs.

Royalties from the varieties developed at the CDC and the FCDC are invested in barley breeding programs. The seed royalties collected from the sale of AAFC varieties have flowed back via government of Canada to fund breeding the research center in Brandon.

1.3 Current research expenditures

Current reported annual average funding in barley research projects in Canada is about $3.8 million. As presented in Figure 7 approximately $2.6 million (60%) of $3.8 million, is invested in breeding and germplasm screening, the remaining (14%) annual average funding is invested in agronomy, (8%) in genomics and tools, (4%) in malting and brewing, (9%) in feed and (5%) in pest mitigation (Feist and Barnes, 2020). The investment of $2.6 million constitutes about 0.14% of barley gross revenue, a low rate of research investment relative to most industries. The average Canadian Gross Expenditure on Research and Development (GERD) in 2016 was 1.6% of industry sales, (lower than the OECD average of 2.2%

(https://www.ic.gc.ca/eic/site/062.nsf/eng/00088.html)). This GERDis over ten times the investment rate occurring in barley breeding and six times the rate occurring in total barley research.

The total reported value of the barley research projects underway on December 31st, 2020 in Canada was $18.1 million (does not include whole farm research with a systems approach). As presented in Figure 6, the funding is invested mainly in breeding and germplasm screening (66%) but also in genomics/research tool development (7%), agronomy (8%), pest management (6%), malting and brewing (3%), and feed (10%) (Feist and Barnes, 2020).

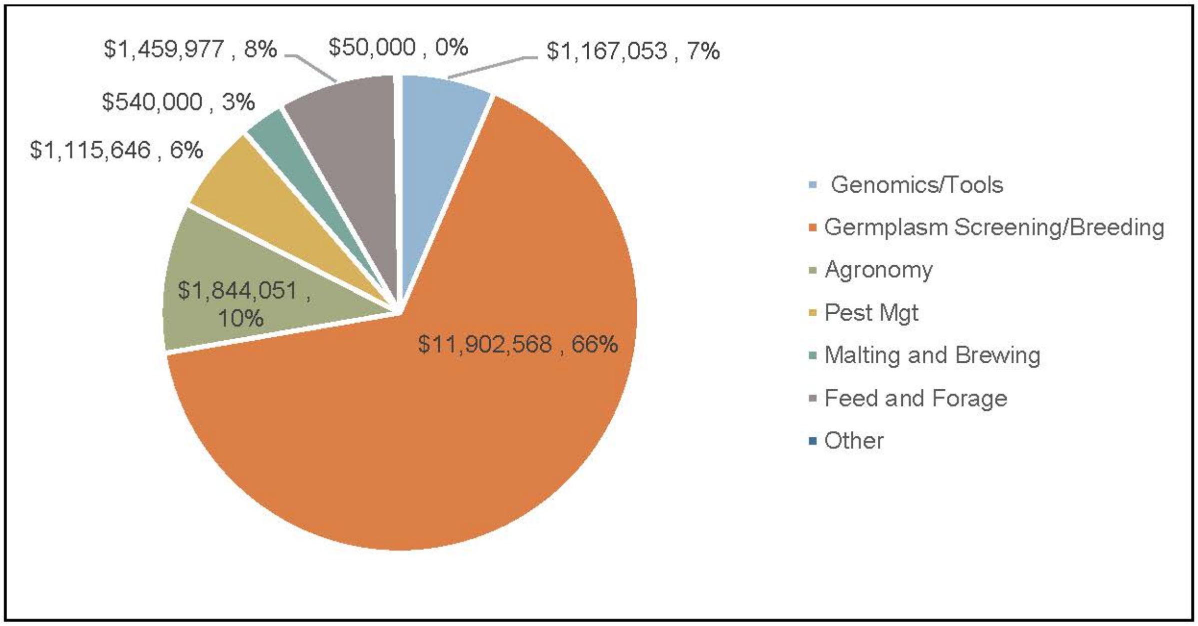

Figure 5: Total Reported Barley Project Funding Dec 31, 2020 by Research Category

Source: Feist and Barnes, 2020

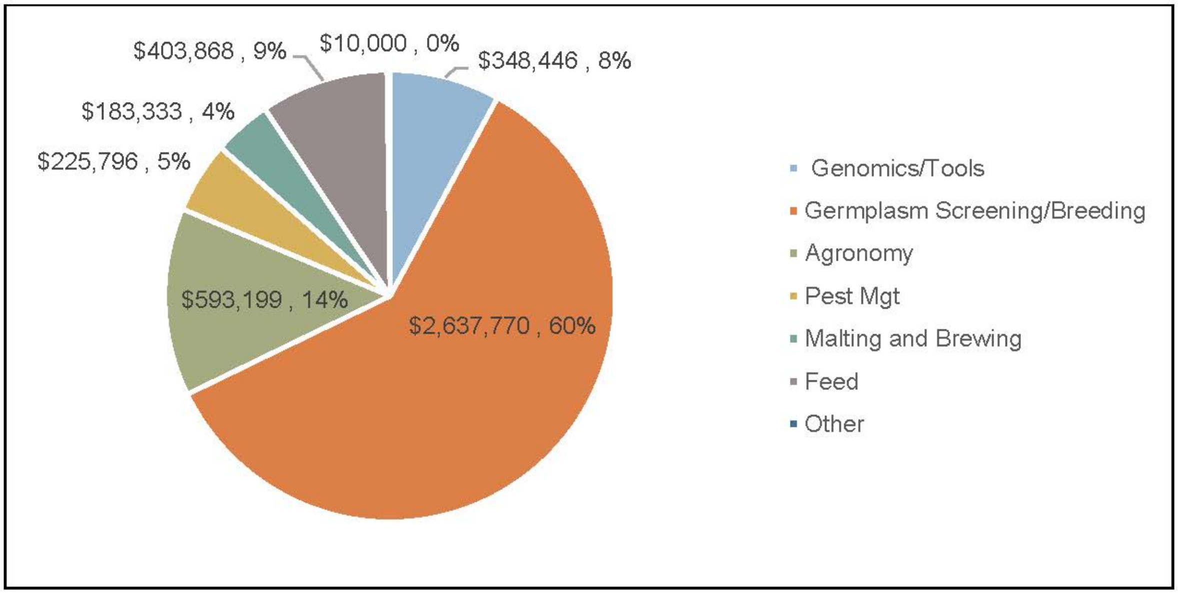

Figure 6: Annual Average Barley Funding by Research Category (Total $3.4M).

Source: Feist and Barnes, 2020

Section 2 Methodology

2.1 Factual and Counterfactual Scenarios in Estimating the Return

With the aim of assessing the effect of the barley's research and development on the return to funds invested, the factual situation (what actually occurred) has to be compared to the counterfactual situation. The counterfactual is the hypothetical situation that would have existed if there were no funding on research and development in barley in Western Canada. We claim in this counterfactual situation the yield gains from the adoption of the new barley varieties developed by these breeding programs would not have happened. The gross annual research benefit approach (Alston et al., 1995) used in this analysis is similar to one used in the assessments of the rate of return to the WGRF investment by Scott et al. 2005 and Gray et al. 2012. The consumer and producer surplus generated under the two scenarios is compared and the difference is the benefit from the investment in barley breeding.

2.2 Time Period for Measuring Costs and Benefits

2.2.1 Cost

The cost period in this study covers the years 1993 to 2019, the period when check-offs on barley have been collected. For the earlier period 1993 to 2011, the cost of estimates from the earlier WGRF study by Gray et al., (2012) are used. Given the lack of detailed expenditure data, Gray et al. estimated these expenditures based on the number of scientists engaged in barley breeding and an estimated annual cost per scientist of $375,000 (2004 dollars) adjusted by CPI. These per scientist costs were applied to 3.2 scientists in years 1995-2004 and 4.5 scientists in years 2005-2011.

For years 2012-2019, an annual average funding for breeding and germplasm screening of $2.989 million reported by Feist and Barnes (2020) were used to represent the costs associated with development of the new barley varieties (Germplasm Screening/Breeding plus Genomics/Tools). It is worth noting these expendures are only the reported project, core funding and CAP barley breeding related costs, while fixed costs such as research infrastructure are not included. Assuming that the reported expenditures are essential for breeding, these omitted fixed costs do not impact the producer return to the reported expenditures. Given the breeding programs are reliant on these investments, the beeding outcomes can be attributed to the investments. Figure 8 and Table 1 represent nominal and inflation adjusted expenditures for barley breeding. The present value figues reported in Table 1, reflect a 5% real discount rate, which increases the present value of past expenditures.

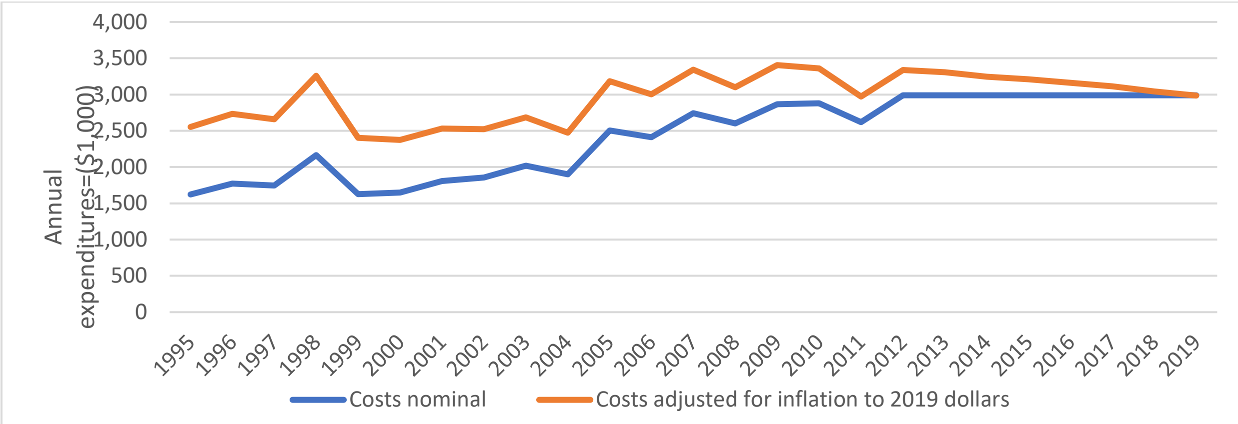

Figure 7: The reported nominal and real barley breeding expenditures on in Canada 1995-2019
Source: Gray et al, 2012 and Feist and Barnes, 2020.

Table 1: Estimated Producer and Public Barley Breeding Expenditures in Canada 1995-2019

	Total Cost[1] nominal ($million)	Costs adjusted for inflation[2] (million $2019)	Present Value produce levy expenditure (million $2019)	Present Value public cost (million $2019)	Adjustin for tax burden Present Value produce levy (million $2019)	Adjusting for tax burden Present Value public cost (million $2019)	Present Value Total Cost in (million $2019)
1995	1.622	2.553	3.199	5.035	3.045	5.189	8.234
1996	1.770	2.735	3.604	4.796	3.431	4.969	8.399
1997	1.744	2.661	3.216	4.567	3.062	4.721	7.783
1998	2.166	3.260	4.731	4.350	4.504	4.577	9.081
1999	1.625	2.405	2.238	4.143	2.131	4.250	6.381
2000	1.647	2.374	2.053	3.945	1.954	4.044	5.999
2001	1.808	2.528	2.328	3.757	2.216	3.869	6.085
2002	1.854	2.522	2.201	3.579	2.095	3.685	5.780
2003	2.020	2.686	2.456	3.408	2.338	3.526	5.864
2004	1.900	2.472	1.893	3.246	1.802	3.337	5.139
2005	2.504	3.182	1.954	4.347	1.860	4.441	6.301
2006	2.410	3.004	1.524	4.140	1.451	4.213	5.664
2007	2.741	3.343	2.061	3.943	1.962	4.042	6.004
2008	2.602	3.101	1.549	3.755	1.475	3.829	5.304
2009	2.865	3.405	1.971	3.576	1.876	3.671	5.547
2010	2.877	3.359	1.804	3.406	1.717	3.493	5.210
2011	2.618	2.970	1.143	3.244	1.088	3.299	4.387
2012	2.989	3.337	2.350	2.350	2.237	2.463	4.700
2013	2.989	3.307	2.218	2.218	2.112	2.324	4.436
2014	2.989	3.244	2.072	2.072	1.973	2.171	4.144
2015	2.989	3.208	1.952	1.952	1.858	2.046	3.903
2016	2.989	3.163	1.833	1.833	1.745	1.921	3.665
2017	2.989	3.114	1.719	1.719	1.636	1.802	3.437
2018	2.989	3.044	1.600	1.600	1.523	1.677	3.200
2019	2.989	2.986	1.495	1.495	1.423	1.567	2.989
SUM			**55.163**	**82.476**	**52.516**	**85.124**	**137.638**
Share			**0.4**	**0.6**	**0.4**	**0.6**	

**from 1995 to 2011 from Gray et al, 2012, from 2012 to 2019 Average annualized breeding and variety development expendures (Feist and Barnes, 2020)*

Source: Gray et al, 2012 and Feist and Barnes,2020.

2.2.2 Benefits

The benefit period in this study covers the years 2005 to 2049. The estimated benefits start in 2005, giving the benefits a 10-year lag from the initial investment in barley breeding in 1995. To estimate benefits, we use a gross annual research benefit approach calculate producer surplus and total surplus (producer surplus plus consumer surplus) for years 2005-2049. This assumes that new varieties resulting from the investments up to 2019 will continue to be adopted to 2029. For the years 2030 to 2049 we assume these varieties will contribute to the germplasm to future varieties with their economic impact depreciating at a rate of 5% per year after 2029.

2.2.3 Adjusting for Inflation and the Discount Rate

To adjust the streams of benefit and costs for inflation we used the consumer price index (the CPI) and arrived at constant 2019 dollars. To reflect the time value of money we use a real discount rate of 5%, which represents the producers' interest cost of money (Gray et al., 2012).

2.2.4 Adjusting for the producer share of levy dollars

When calculating a benefit/cost ratio for producers it is important to note that some of the levy costs are borne by the barley users through higher prices. When a check-off or levey is paid on the sale of barley this creates a wedge between the selling and buying price that tends to drive down the sellers price and increase the buyers' price. This price impact for buyers and sellers is calculated using Canadian supply and demand elasticities from the Iowa State University FAPRI Model as shown in Table 2. Producers pay 2/2.1 = 95.2% of the costs of the check-offs while barley buyers pay 4.8%.

Table 2: Supply and Demand Elasticities for Barley (%)

	Demand Elasticity	**Supply Elasticity**
Barley	10.0	0.5

Source: Iowa State University FAPRI Model

2.2.4 Benefit/Cost Ratio, Internal Rate of Return Estimation and Net Present Value

The described methodology is used to estimate the net present value (NPV), the benefit/cost (B/C) ratio and the internal rate of return (IRR) of the investment into barley breeding programs in Western Canada in years 1995 to 2049. To determine the B/C ratio we divide the total present value of the benefits by the total present value of the costs. The NPV is the value of all costs and benefits over the entire life of an investment discounted to the present. The IRR is the interest rate that equates the present value of the stream of benefits to the present value of the stream of costs.

2.3 Data

The producer and consumer surplus increase from increased yields is calculated using supply and demand elasticities from the Iowa State University FAPRI Model shown in Table 2. These proportions gains occur in the same share as the cost of the check-off with producers receiving 95.2% of the estimated benefits from breeding. The total barley production data are obtained from Statistics Canada (Table 32-10-0002-01 Estimated areas, yield and production of principal field crops by Small Area Data Regions, in metric and imperial units) for Saskatchewan, Alberta, Manitoba, and British Columbia for years 2005-2019. The barley farm prices are obtained from Statistics Canada (Table 32-10-0077-01 Farm product prices, crops and livestock) for Saskatchewan for years 2005-2019. Monthly Saskatchewan farm prices for barley were converted to yearly average and used as a representative for whole Western Canada. To simulate production and prices for years 2020-2029 we used 10-year rolling average of historical data.

2.4 Empirical results - Producer Benefits

The main benefit of plant breeding is the development of varieties with higher yields. To assess how breeding has affected yield we use a counterfactual where in the absence of any breeding, the barley varieties that were adopted in 2004 would be representative throughout the 2005-2049 time period. The weighted average yield index from 2004 would stay constant and yield improvements are measured against this benchmark. To simulate the yield's increase related to the investment in breeding we calculated percentage increase in weighted average yield for years 2005-2019 for Saskatchewan, Alberta and Manitoba and estimated the trend lines (Figure 8). Further, we used estimated coefficients of the trend lines to project the percentage increase in yield for years 2020 to 2029. We depreciate the estimated surplus 5% a year in years 2030 to 2049 to reflect the fact that new varieties eventually become more vulnerable to pests and diseases that evolve to overcome bred resistance.

The process used to estimate producer benefits started with identifying the yield increase from all of the barley variety adopted in Western Canada. For Saskatchewan we used yield index data from the Cooperative Performance Variety Trail (CPVT) from years 1972-2019. For Alberta and Manitoba, we used CPTV data from years 2004-2019. Yield indexes are relative. In Saskatchewan the variety Conquest was the check variety in 1972, the first year of our data set, and it is given an index of 100 for its average yield. The measured yields for other varieties are expressed as the indexes in relation to Conquest. Over time different check varieties such as Bonanza, Harrington and Metcalfe were used to report yield indexes in Saskatchewan. We converted all the varieties in Saskatchewan over the years to be expressed as a percentage of

Conquest. To convert yield indexes with Bonanza as a check variety to be expressed as a percentage of Conquest we multiply the yield index of each variety expressed as a percentage of Bonanza by yield index of Bonanza expressed as a percentage of Conquest and divide it by one hundred. The same is done with yield indexes of each variety expressed as a percentage of Harrington and Metcalfe. To convert measured yield indexes to be expressed as a percentage of Conquest we multiply the yield index of each variety expressed as a percentage of Harrington and Metcalfe by the yield index of Harrington and Metcalfe respectively expressed as a percentage of Conquest and divide it by one hundred. Similar methodology was used for Alberta and Manitoba. In Alberta yield indexes of all the varieties were converted to be expressed as a percentage of Harrington that was the check variety in 2004. In Manitoba yield indexes of all the varieties were converted to be expressed as a percentage of Robust that was the check variety in 2004.

After adjusting all of the varieties yield indexes to have all varieties in all years indexed relative to one check variety – Conquest in Saskatchewan, Harrington in Alberta and Robust in Manitoba we calculated a weighted average by acres yield indexes. The calculated weighted average yield index from Saskatchewan for 1972-2019 time period is presented in Figure 9. The calculated weighted average yield indexes from Alberta and Manitoba for years 2004-2019 are presented in Figure 10.

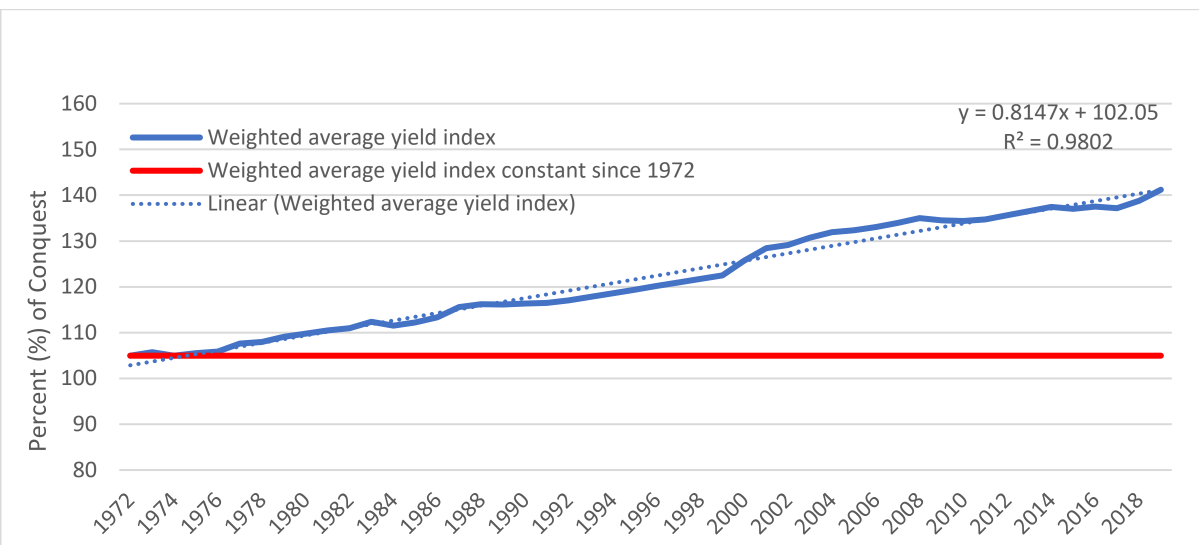

Figure 8: Weighted average by acres yield index of barley in Saskatchewan expressed as a percentage of Conquest 1972-2019
Source: Author's calculations based on data

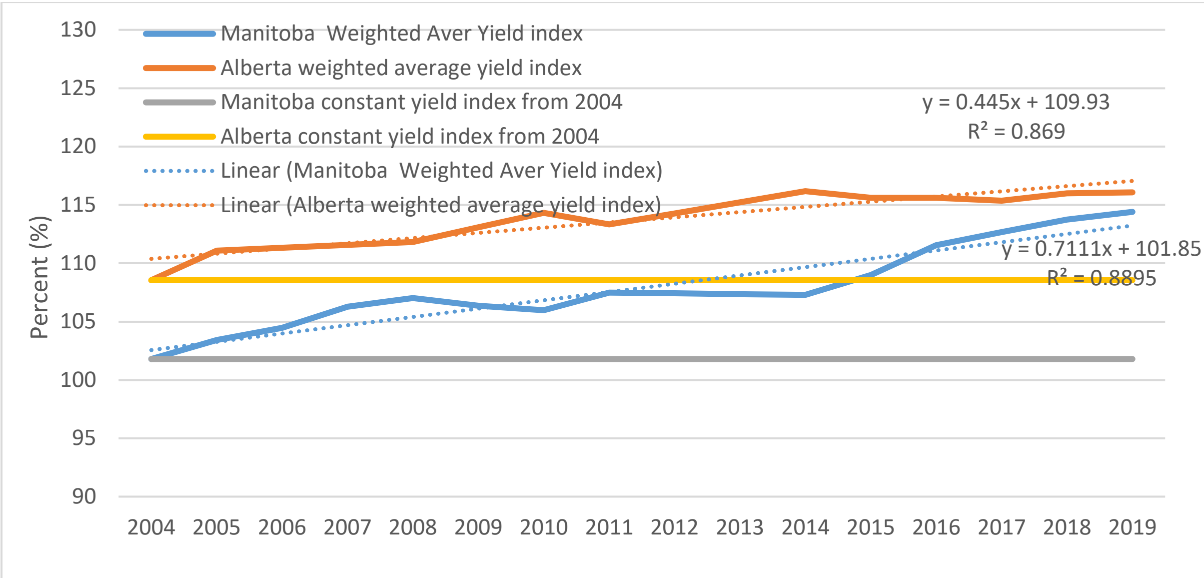

Figure 9: Weighted average by acres yield index of barley in Alberta and Manitoba expressed as a percentage of Harrington and Robust respectively 2004-2019.
Source: Author's calculations based on data

In our Benefit Cost analysis, we are interested in yield improvement in 2005 and later as that will capture yield improvement from investments made since 1995 with 10 years lag. To estimate a percentage increase in a weighted average yield for barley in Saskatchewan in benefit period (2005-2019) we divided the weighted average yield index from 2005 to 2019 by weighted average yield index from 2004 and multiply it by 100. The percentage increase in weighted average yield is the increase of calculated ratios over 100. The same is done for Manitoba and Alberta. The percentage increases in weighted average yield index since 2004 together with estimated trend lines in Manitoba, Alberta and Saskatchewan are presented in the Figure 11.

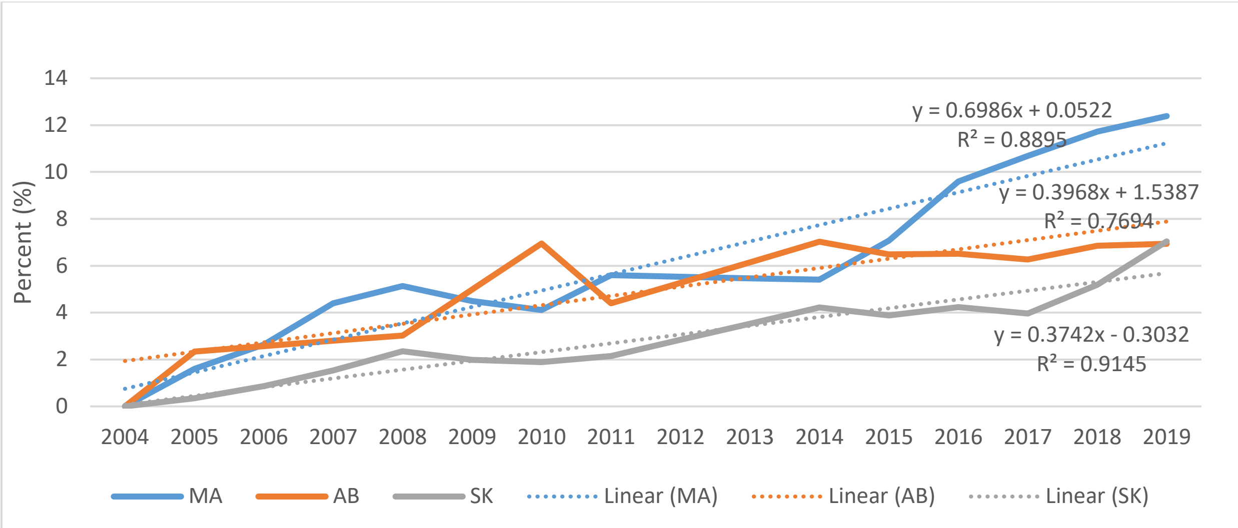

Figure 10: Percentage increase in weighted average yield index from 2004, in Saskatchewan, Manitoba and Alberta 2004-2019.
Source: Author's calculations based on CPVT data and adopted acreage share data based on crop insurance data, which reports acreage insured by variety.

As described before, we used Statistics Canada database to obtain the barley production data for Saskatchewan, Manitoba, Alberta and British Columbia. The estimates of counterfactual production, without breeding investment, are calculated by decreasing actual production by actual production times percentage increase in yield (Figure 11). The change in total production attributed to barley research investment is presented in Figure 12.

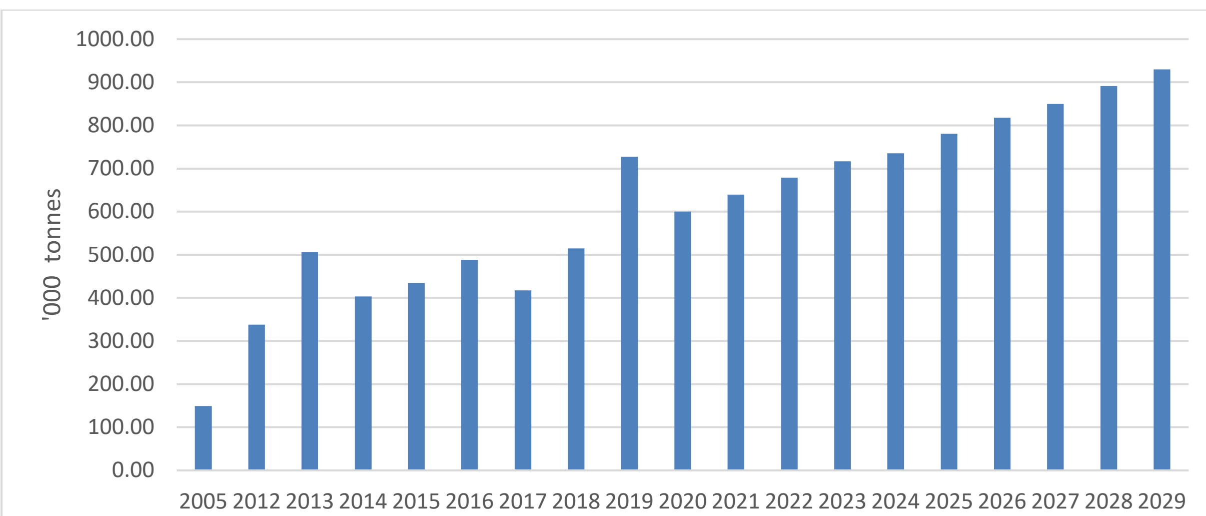

Figure 11: Change in total barley production in western Canada attributed to barley research investment 2005-2029
Source Author's calculations based on data.

The price data used in this analysis came from Statistics Canada database. We used monthly farm price data for barley in Saskatchewan to calculate yearly average price for barley. To calculate a forecasted increase in producer surplus in years 2020-2029 we estimate barley prices as a rolling average. The price used in our analysis is presented in Figure 13. We used the prices from Saskatchewan to calculate producer surplus in Saskatchewan, Alberta, Manitoba, and British Columbia.

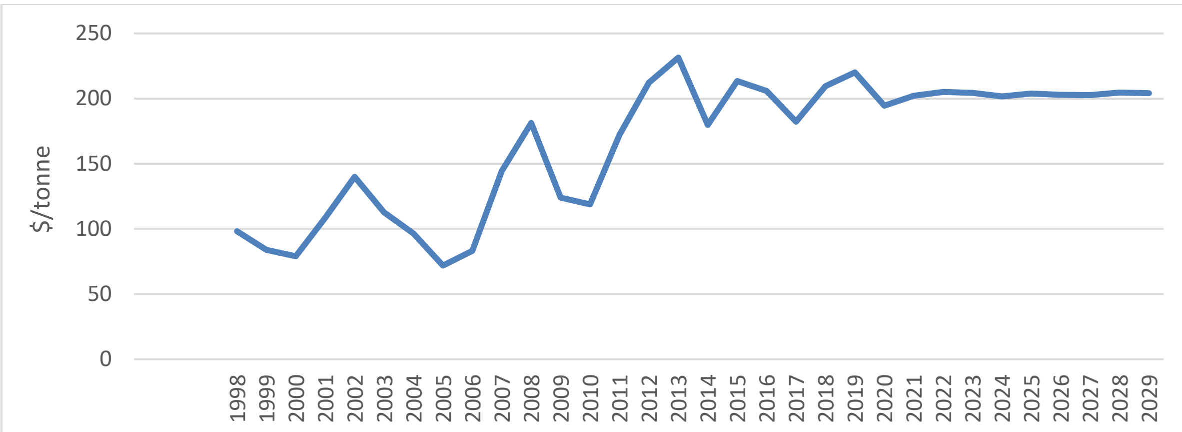

Figure 12: The average farm price of barley in Saskatchewan for 1998-2019 and the 10 year rolling average of the farm price for 2020 to 2029.
Source: The Data from Statistics Canada (Table 32-10-0077-01 Farm product prices, crops and livestock) transformed by author.

The present value of producer surplus increase due to yield improvement is estimated at $3.4 billion present value over the 2005 to 2049 period. Since producers contributed 40% of the research cost (Table 1) to develop the varieties, the producer surplus attributed to producer investment is $1.36 billion. Given the $52.3 million of the research costs were borne by producers, the benefit cost ratio is estimated to be 26.0 to 1.0. This implies that over the 2005 to 2049 period a grower can expect to receive $26.00 for every $1.00 invested in barley breeding from 1995 to 2019. An estimated internal rate of return of 32% was generated over the 1995 to 2049 period for the investments in genetic research (Table 3).

The estimated change in producer surplus in 2005 to 2049 attributed to producers' investment in 1995 to 2019 are presented in Figure 14.

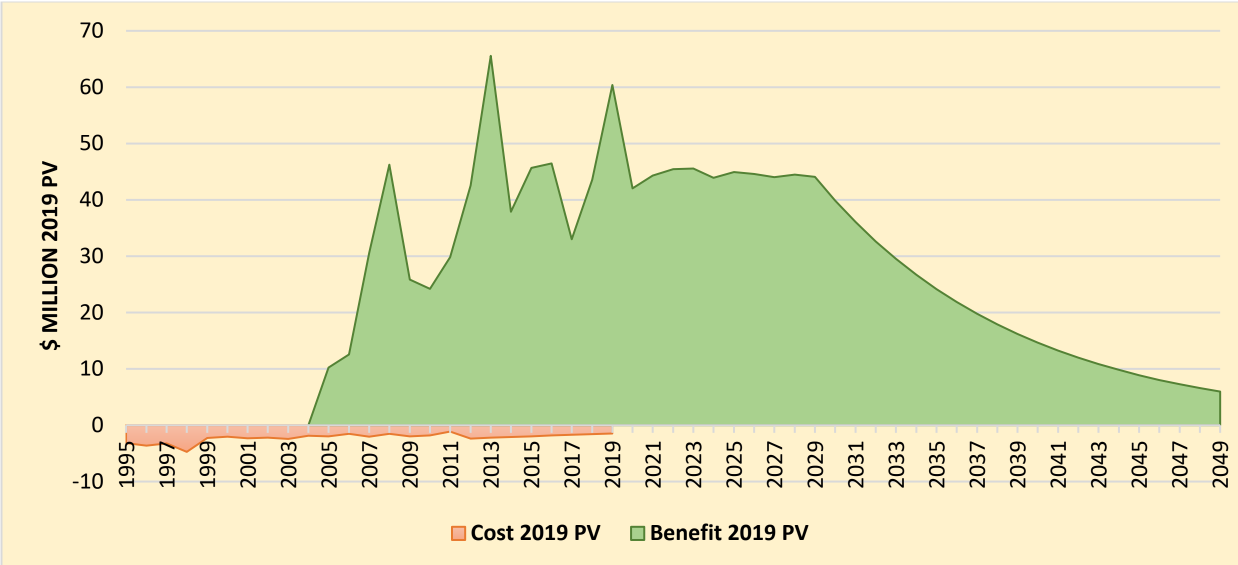

Figure 13 **Benefits and Costs of the producer investments in Western Canadian barley breeding from 1995 to 2019**
Source Author's calculations as described in the report

To check how sensitive our results are to estimated expenditures, we increased costs by 35% while holding outcomes constant. This would capture the public investment not included in core agreements and projects reported by Feist and Barnes 2020. It is worth noting reported expendures are only the reported project, core funding and CAP barley breeding related costs, while fixed costs such as research infrastructure are not included. Assuming that the reported expenditures are essential for breeding, these omitted fixed costs do not impact the producer return to the reported expenditures.

To check how sensitive our results are to estimated expenditures, we in Scenario B we increased costs by 35% while holding outcomes constant. This would capture the public investment not included in core agreements and projects reported by Feist and Barnes 2020. It is worth noting reported expenditures are only the reported project, core funding and CAP barley breeding related costs, while fixed costs such as research infrastructure are not included. Assuming that the reported expenditures are essential for breeding, these omitted fixed costs do not impact the producer return to the reported expenditures.

Table 3: The Estimated Benefits and Costs of Producer and Public Investments in barley breeding 1995 to 2019

Scenario		Costs 2019 Present Value *($ Million)*	Benefits 2019 Present Value *($ Million)*	Benefit/Cost Ratio	Internal Rate of Return	2019 Net Present Value *($ Million)*
Scenario A: The Base case	**Producer**	52.3	1,360	26.0	32.0%	1,308
	Total	137.6	3,580	26.0	32.0%	3,442
Scenario B: 35% Increase in Cost	**Producer**	52.3	1,020	19.3	28.9%	968
	Total	185.8	3,580	19.3	28.9%	3,394
Scenario C: Top yielding malting varieties immediately adopted	**Producer**	52.3	2,584	49.4	45.9%	2,532
	Total	137.6	6,803	49.4	45.9%	6,665
Scenario D: 4- year adoption of Copeland and Synergy	**Producer**	52.3	2,364	44.5	40.2%	2,312
	Total	137.6	6,122	44.5	40.2%	5,985

Source Author's calculations based on data

As presented in Table 3, Scenario B, our results of high returns to barley research are very robust. With 35% increase of investment in research in years 1995-2019, producer share of costs and benefits decreases to 30% and the estimated producers B/C ratio is 19.3 meaning for every dollar invested in research the producers benefit $19.3. The IRR is 28.9%, which is still much higher than the market interest rate.

Notably, these very high rates of return to barley breeding persisted despite the very slow uptake of new barley varieties. In the next section we consider how these rates of return would have been impacted if the malting variety uptake were faster.

3.0 The Impact of Accelerated Variety Adoption on the Rate of Return

As discussed in the introduction, the malting industry has been slow to adopt new barley varieties. As result many new higher yielding varieites are passed over, and other new varieties that are eventually successful take many years to reach widespread adoption. Recognising that the slow uptake of varieties reduces the rate of returns, SaskBarley asked us to estimate how the rates of returns would be impacted if new variety adoption could be accelerated.

We use two scenarios to estimate the impact of low malting variety uptake on the rate of return. In Scenario C, outlined in 3.1 we consider an idealistic scenario where producers grow and the malting industry always uses the highest yielding malting barley variety each year. In the more conservative Scenario D, we assume the adoption period for Metcalfe, Copeland and Synergy which all eventually became leading varieites, is shortened to four years following their release.

3.1 Scenario C: Complete adoption of the top yielding variety adoption each year

In this somewhat utopian hypothetical scenario all barley producers grow and sell the highest yielding malting barley variety each year. In Saskatchewan the malting barley varieties with top yield indexes in the benefit period from 2005 to 2019 were AC Newdale, CDC Meredith, FCDC Bentley and AAC Synergy. In years 2005-2009 AC Newdale had the highest yield index among malting barley varieties, in 2010 CDC Meredith, in 2011 FCDC Bentley and from 2014 until present AAC Synergy has top yield index among malting barley varieties. In Alberta the highest yielding varieties were Yorkton, Battleford, Merit, CDC Meredith and AAC Synergy. In Manitoba the highest yielding varieties were Excel, Tradition, AC Newdale, and AAC Synergy.

In our analysis the benefit period starts in 2005. The weighted average yield indexes with top malting variety from 2005, 2006 … 2019 are divided by actual weighted average yield index from 2004 times one hundred minus one hundred. That gives the percentage yield increase in weighted average yield index since 2004 if the top malting varieties were adopted by all malt producers. The calculations are done for Alberta and Manitoba and Saskatchewan (Figure 15).

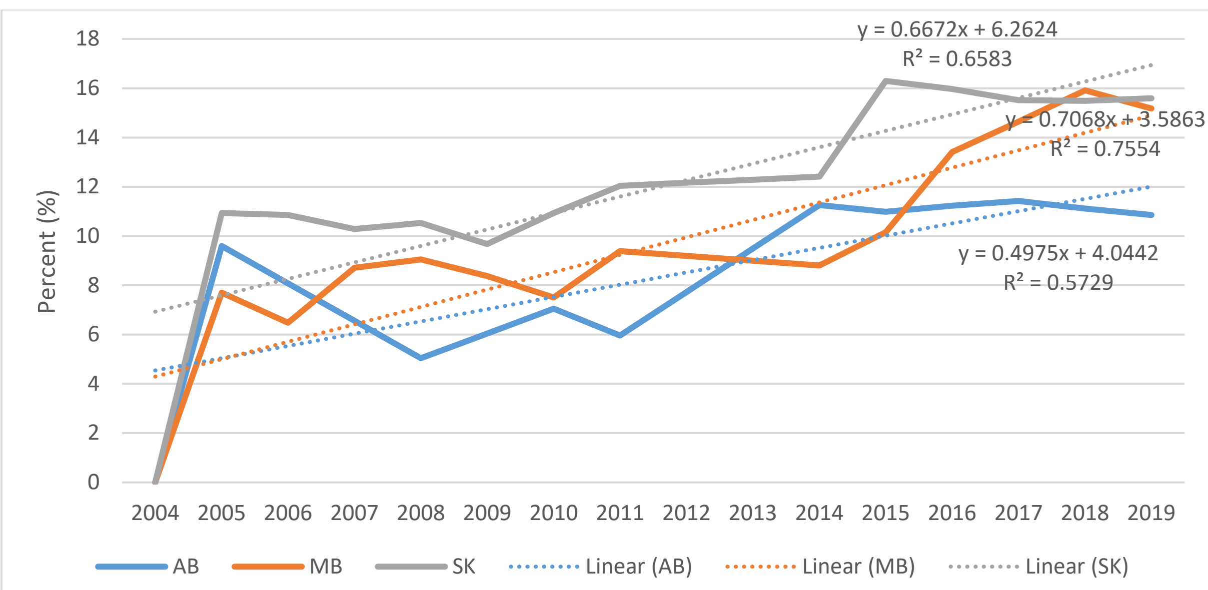

Figure 15: The percentage increase in weighted average yield index since 2004 if top malting varieties were adopted.
Source: Author's calculations based on data.

To undertake Benefit Cost analysis of that hypothetical scenario with all malting producers adopting top malting varieties we need to calculate percentage increase of weighted average yield index each year. To obtain those numbers we divide weighted average yield index with top malting varieties being adopted from years 2005, 2006 … 2019 by actual weighted average yield index from years 2005, 2006…2019 respectively times one hundred minus one hundred. That percentage increase in yield each year and the trend lines for Alberta, Manitoba and Saskatchewan are presented in Figure 16.

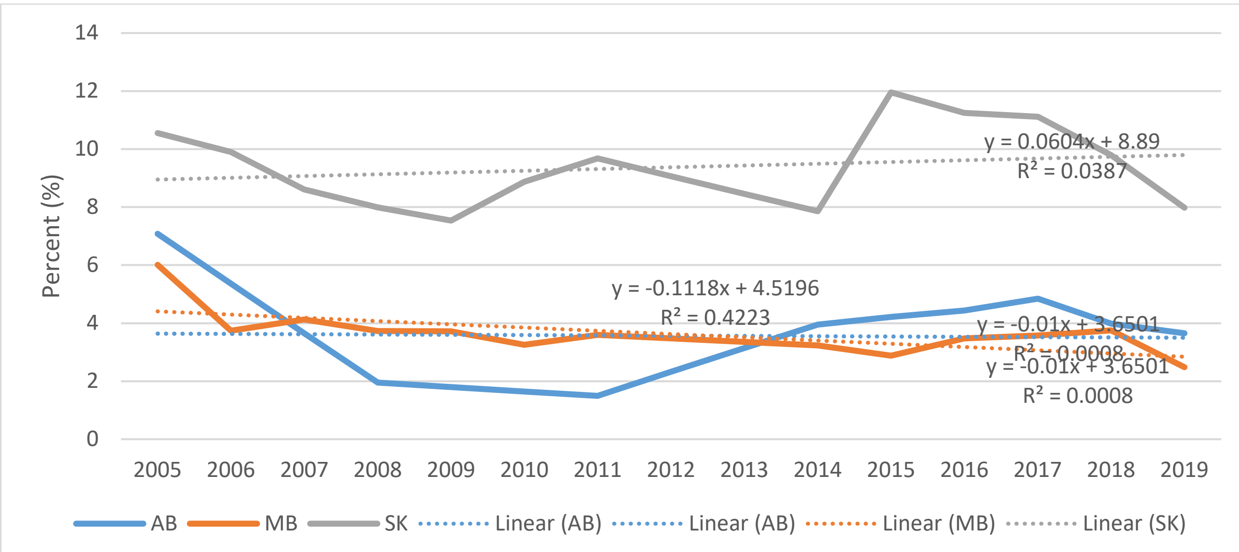

Figure 14: The percentage change in weighted average yield index each year if all malting producers adopted top malting variety.
Source: Author's calculations based on data.

Using the percentage change in weighted average yield we estimate the change in barley production and related producer surplus and total surplus. We then calculate the change in producer surplus and total surplus comparing the scenario with a top malting variety adopted by all malting producers to a second scenario without breeding investment (calculated in basic case scenario above). The results of that Benefit Cost analysis are presented in Table 3.

Not surprisingly, adoption of the higher yielding varieties increased estimated benefits and the returns to research. As presented in Table 3, the high returns to barley research would further increase if top yielding malting varieties were adopted by all barley producers. With top yielding varieties being adopted the estimated B/C ratio is 49.4 meaning for every dollar invested in research the producers' benefit is $49.40. The IRR is 45.9 % which is much higher than the market interest rate.

We also recognize Scenario C is an extreme upper bound for what is possible with faster adoption. The assumption that the top yielding varieties would be immediately adopted purely because they have the highest yield in unrealistic. Furthermore, even if producer grow these varieties the brewing industry may not accept top yielding varieties because of brewing characteristics. It does illustrate however that instant adoption would approximately double the returns to barley breeding.

3.2 Scenario D: 4- year adoption of Copeland and Synergy

In this scenario we consider the case where the varieties that eventually became a leading malting barley variety (Copeland and Synergy), were adopted much faster by the producers and the maltsters. We assume that once variety appears in the market it gets 25%, 50%, 75% and 100% market share in year one, two, three and four respectively. Four years after a variety first appears it has 100 percent of the malting market. In this scenario CDC Copeland has 100% market share and replaces CDC Metcalf in 2005. In 2014 AAC Synergy would start being adopted and replaces Copeland by 2017 (Figure 17). Using assumed adoption, we calculate weighted average yield index for malting barley. Then we calculate weighted average yield index of all barley with Copeland and Synergy replacing all the malting varieties.

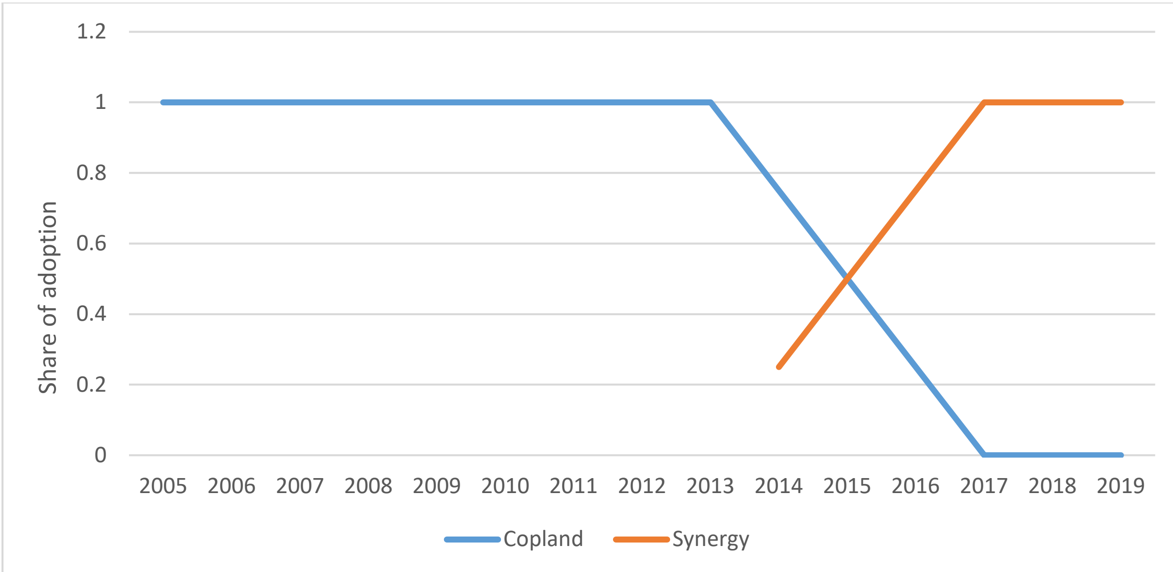

Figure 15: Assumed market shares of CDC Copeland and AC Synergy in Scenario D. .
Source: Author's calculations based on data.

Further, we calculate the percentage increase in weighted average yield index each year. The percentage change in weighted average yield index and trend lines for Saskatchewan, Manitoba and Alberta are presented in Figure 18.

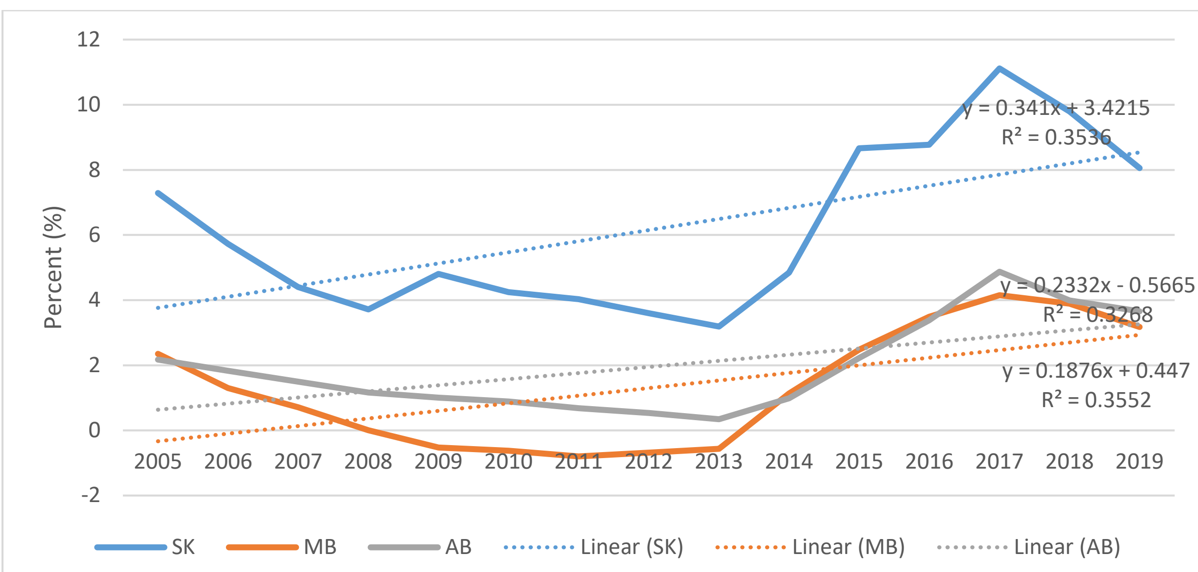

Figure 16: The percentage change in weighted average yield index with faster adoption of Copeland and Synergy in Saskatchewan, Alberta, and Manitoba.
Source: Author's calculations based on data.

Using the percentage change in weighted average yield we calculate the change in barley production and related producer surplus and total surplus. We calculate a change in producer surplus and total surplus comparing two hypothetical scenarios: one with Copeland and Synergy replacing all malting varieties and a second scenario without any breeding investment. The Benefit Cost analysis is presented in the Table 3.

With Copeland and Synergy varieties being adopted four years after their introduction the estimated B/C ratio is 44.5 meaning for every dollar invested in research the producers' benefit $44.5. The IRR is 40.2 %, far higher than the market interest rate.

The calculated changes in total production in Western Canada is presented in the Figure 19.

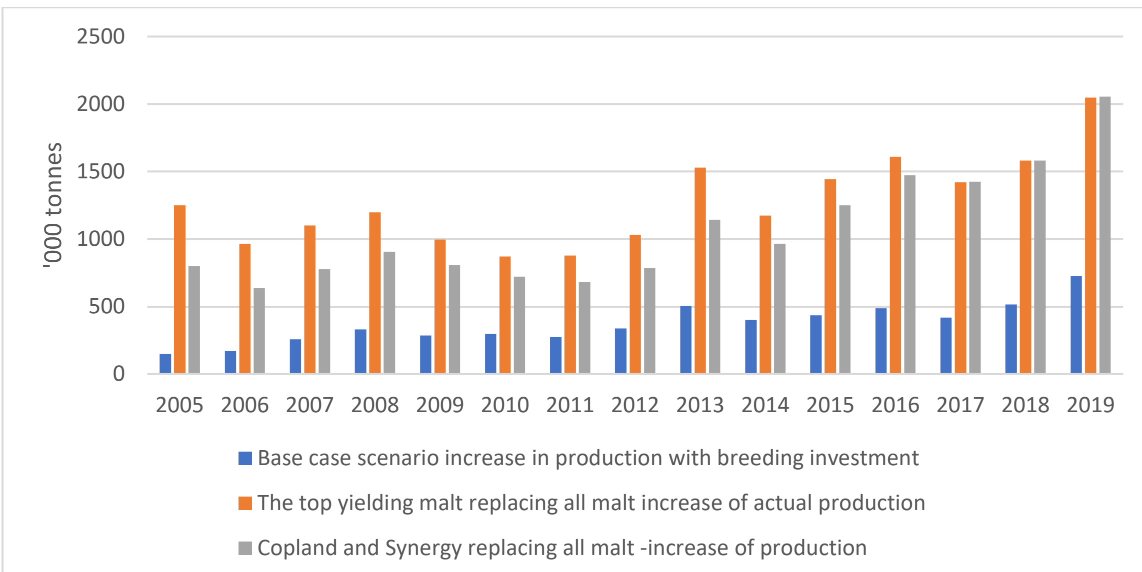

Figure 17: The change in production in Scenario A, C and D
Source Author's calculations

Section 4: Major competitors' investment in barley breeding and R&D

The majority of global barley production takes place in 10 countries; Russia, Germany, France, Ukraine, Australia, Canada, Spain, Turkey, the United Kingdom, and the United States of America (FAO, 2021). Figure 20 presents barley production in Australia, Canada, France, Germany, and Russia in years 1972-2018. Notably, Australia is the only country that shows an increase in barley production over this 46 year period.

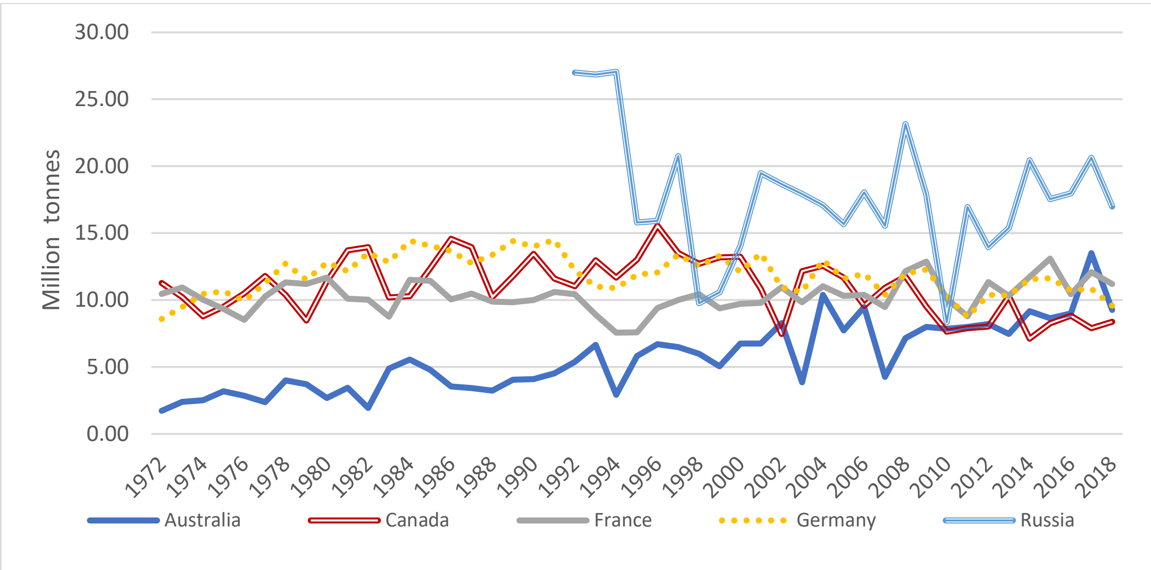

Figure 18: The production of barley in Australia, Canada, France, Germany and Russia, in tonnes 1972-2018
Source: FAOSTATS 2020

Figure 21 shows the area seeded with barley in Australia, Canada, France and Germany in years 1972-2018. Figure 22 compares the average yield for barley in Australia, Canada, France, Germany and Russia in years 1972-2018. Again Australia, is the exception to the general trend of declining barley area.

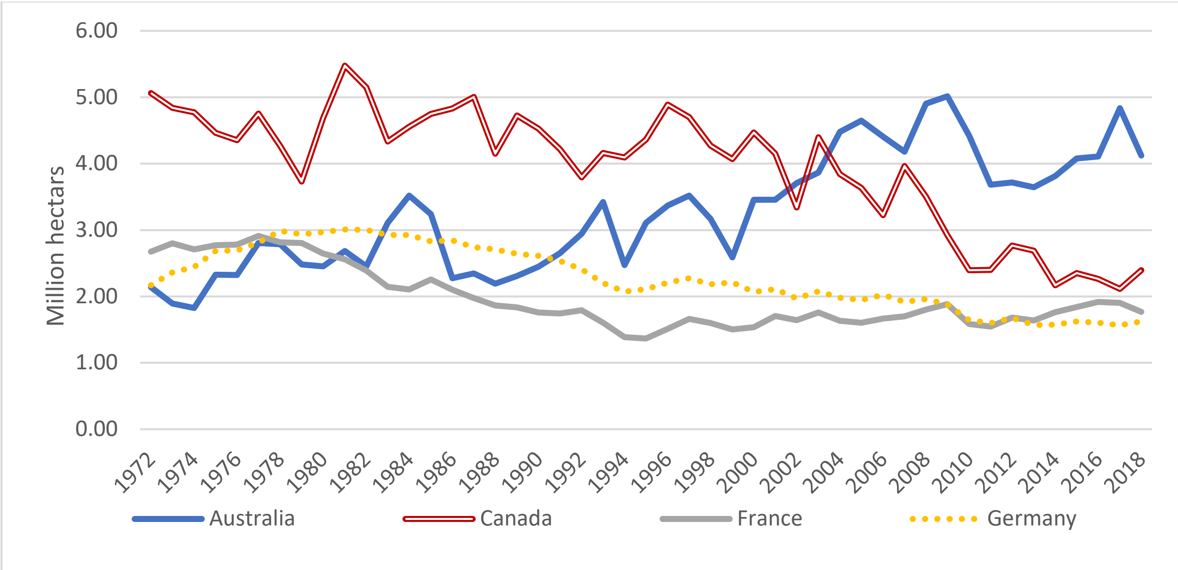

Figure 19: The area seeded with barley in Australia, Canada, France and Germany 1972-2018.
Source FAOSTATS 2020

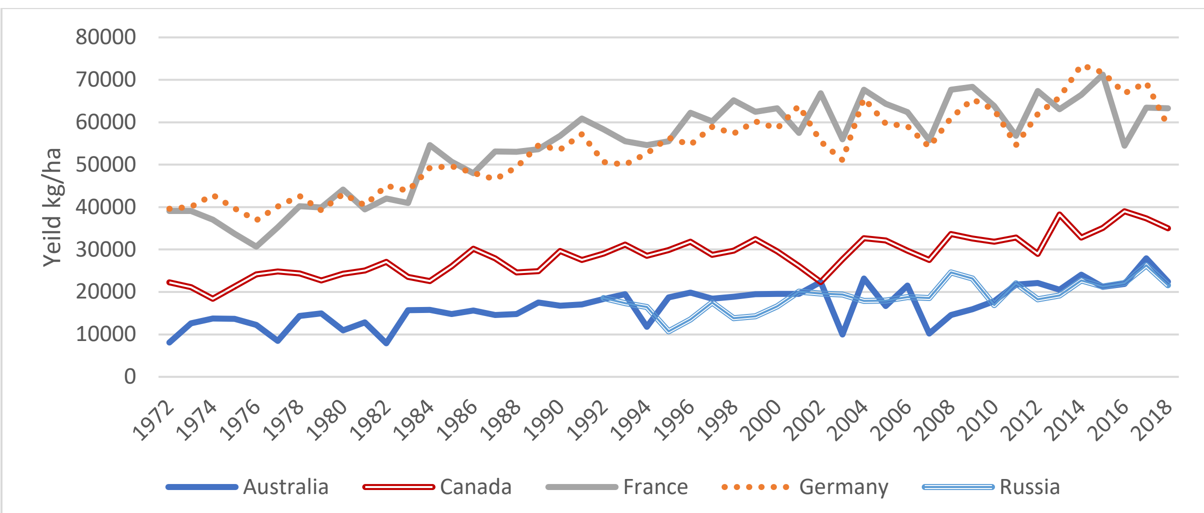

Figure 22 The average yield of barley in Australia, Canada, France, Germany and Russia 1972-2018
Source FAOSTATS 2020

As presented in Figure 23 the leading exporting countries include France, Australia, Germany and Canada. France and Australia are the largest competitors. Australia shows an upward trend between 2007 and 2017. A trade dispute with China has recently limited malting exports.

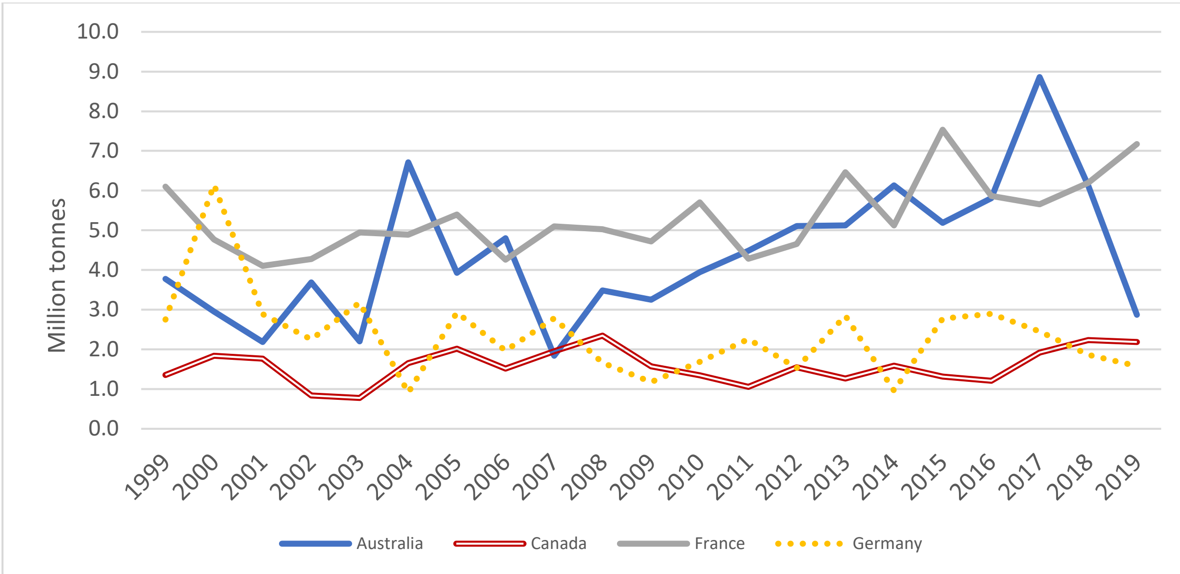

Figure 23: Barley exports from Australia, Canada, France, and Germany 1999-2019.
Source: FAOSTATS 2021

4.1 A review of the barley breeding systems in Australia

The Australian barley industry is a major competitor to Canada. Australia is one of the 10 largest producers in the world, producing about 5% of global barley supply (Barley Australia, 2021). Figure 24, Figure 25 and Figure 26 show total production of barley, the area seeded with barley, and barley yield in Australia over the past twenty years. There are some fluctuations in production caused by weather conditions, but on average Australia produces about 9 million tonnes of barley each year with the barley industry the second largest grain industry after wheat (Zmazhenko, 2017). 60-70% of the annual barley production is used for feed and 30-40% of the (approximately 2 to 2.5 million tonnes) is accepted as a malting barley. Australia exports approximately 70% of production, primarily to Asia; approximately 1.3 million tonnes of malting barley, and 4.2 million tonnes of non-malting barley. In the global scale it is about 30-40 % of the world's malting barley trade and about 20% of the world's feed barley trade (Barley Australia, 2021). Australian barley has a reputation of being high-quality and grown in a contaminant-free climate. It is highly demanded by the malting, brewing, distilling, Shochu (Japanese distilled spirit) and feed industries around the world and is recognised for its low moisture content and low foreign material (Barley Australia, 2021).

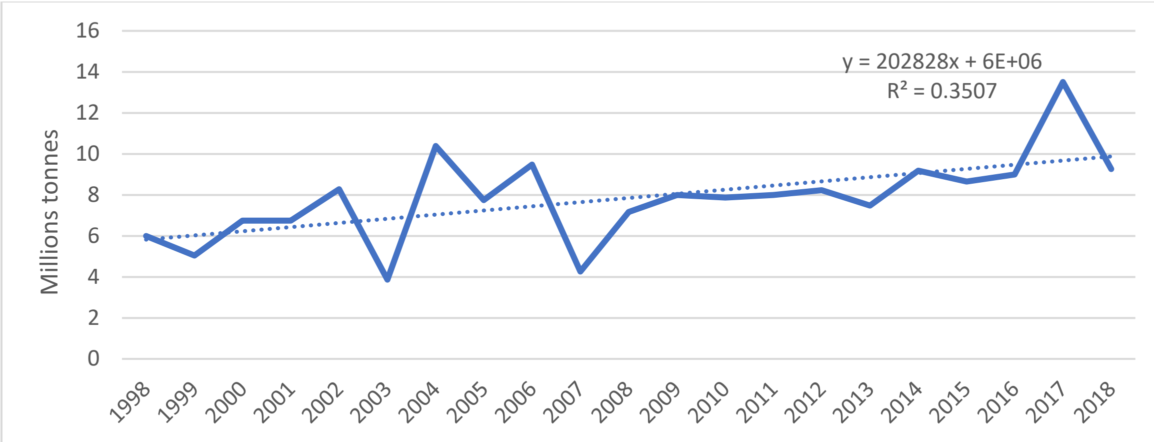

Figure 24 Total barley production in Australia in tonnes 1998-2018.
Source: FAOSTATS 2021

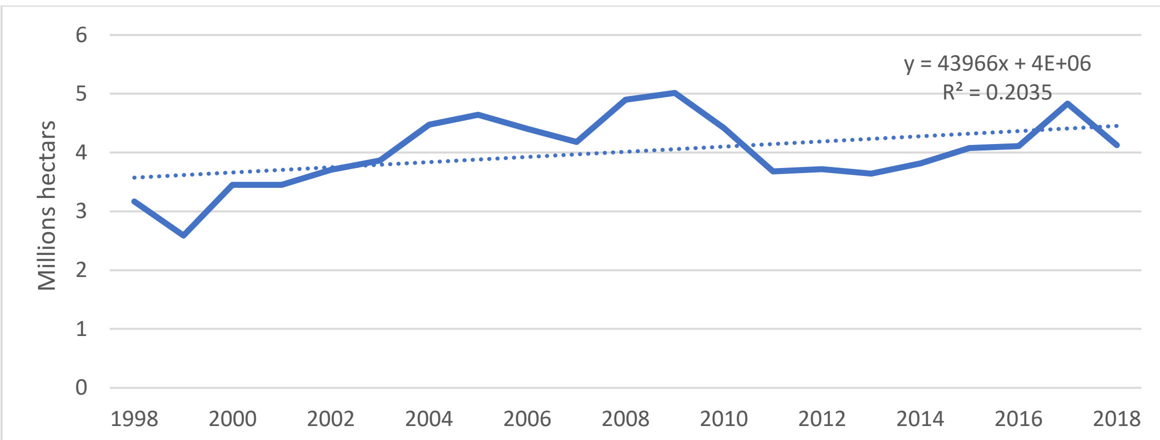

Figure 20 The area seeded (ha) with barley in Australia 1998-2019
Source: FAOSTATS 2021

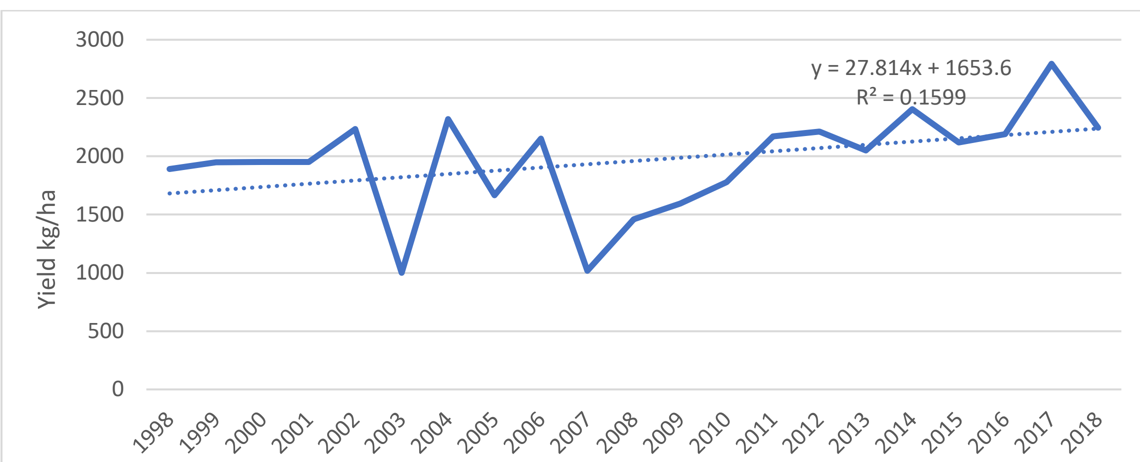

Figure 26: Average barley yield in Australia 1998-2018.
Source: FAOSTATS 2021

Over the past four decades barley breeding in Australia has transitioned from public breeding supported by state governments, to levy based funding supported by the Grain Research and Development Corporation (GRDC) levy, to the current situation dominated by end point royalty-based funding.

Although historically, most agricultural R&D in Australia was publicly funded (Kingwell 2005; Brennan and Mullen 1998), as early as 1900 there have been rural R&D levy regimes introduced by producers. Most of those regimes (e.g. Pastoral Research Trust and Wheat Growers' Soil Fertility Research Fund) were funded by voluntary producers' levies and had numerous 'free-rider' problems. By the 1980s, the Government was generally dissatisfied with the way the agriculture research system was performing. Research tended to be fragmented, with a number of policy problems (Watson 2011). A main issue was allocation of funds to projects without considering expected rates of return. The Primary Industries and Energy Research and Development Act 1989 (PIERD Act) addressed those issues by establishing the existing statutory model for the Research and Development Corporations (RDCs). Barley now falls under the Grain Research and Development Corporation (GRDC). As defined in the GRDC annual report 2008-2009, "The GRDC is a statutory corporation, operating as a research investment body on behalf of Australian grain growers and the Australian Government. As well as its responsibilities under the PIERD Act, the corporation has accountability and reporting obligations set out in the Commonwealth Authorities and Companies Act 1997 (CAC Act)." (GRDC 2009, p.11). The skill based GRDC Board is accountable to Australia's grain growers through the industry's organization, and to Parliament through the Minister for Agriculture, Fisheries and Forestry (GRDC 2009). The GRDC manages the grower levies, collected from 25 crops. For grain the levy rate is 1% net farm gate value matched by government up to 0.5 % of GVP. The GRDC is responsible for setting the agenda in many critical areas of applied breeding and breeding infrastructure. The GRDC does not conduct research; it co-ordinates a research investment plan and invests in R&D for its stakeholders (GRDC 2009; Bolek 2015). The creation of a corporation model improved the efficiency in funding R&D. The producer's involvement in the RDC model led to more efficient use of the research funds by investing in research that address market needs (Kerin 2010). The RDCs intend to address not only the industry-specific but also the broader research needs, thus the reason of government matching funds (Productivity

Commission 2011). The RDCs operate as a broker in research and have a large amount of funding to divest, therefore integrate the research system in the industry.

By the 1990's the GRDC believed there was no need for so many breeding programs in Australia and a small number of bigger programs run at the world leading standards would be more efficient. It felt a few larger breeding programs could become profitable in time by using the End Point Royalties (EPRs) and that the larger programs would be able to adopt technologies coming from multinational companies (such as Monsanto). Consequently, by the end of the1990s, the GRDC led transformation of the wheat innovation system and then the barley breeding system (Budd 2011). Currently, there are two main barley breeding companies in Australia: InterGrain Ltd and Australian Grain Technologies Ltd (AGT). Pre-breeding is usually the province of universities, CSIRO, and state government agricultural agencies (Kingwell, 2020). All breeding is privatised; but the main owners of the two barley breeding companies are state governments and the GRDC. The GRDC provides funds to barley breeding programs run by private companies and supply some R&D funding for pre-competitive breeding activity.

The Australian Grain Technology Pty Ltd, (AGT) is the largest breeding company in Australia. AGT was established in 2002. Initially, focused on wheat, in 2015 AGT expanded to barley breeding. It's barley breeding program is supported by germplasm from AGT's international shareholder and partner, the grower-owned French cooperative Limagrain (AGT 2020). The original shareholders of the AGT were the GRDC, the South Australian Research and Development Institute and, the University of Adelaide. In 2005, there was a merger between AGT and SunPrime Seeds Pty Ltd. With the merger AGT became Australia's only completely joint wheat breeding and commercialization company. AGT Pty Ltd and the Council of Grain Grower Organizations established a partnership in 2007. In 2008 Vilmorin & Cie, an exclusively owned subsidiary of Limagrain Holdings, acquired a 25 per cent share in AGT (AGT, 2012; Bolek, 2015).

InterGrain Pty Ltd (InterGrain) is the second largest crop breeding company in Australia with approximately 80% of the market shares in Western Australia. InterGrain was established in 2007, by the Department of Agriculture and Food Western Australia (DAFWA) and the GRDC. The DAFWA initially held 70% and GRDC 30% of the shares. August 2010, Monsanto became a minority shareholder in InterGrain, buying 19.9% of the shares in return for a cash injection and InterGrain's access to Monsanto's proprietary market assisted breeding technologies. Later, Monsanto purchased additional shares in InterGrain and now Western Australia Government, the GRDC, and Monsanto are the major shareholders holding 48.7, 25.3 and 26 % shares respectively (InterGrain, 2012; Bolek, 2015). Similar to AGT, InterGrain was initially focused on wheat breeding but in 2009/10 expanded to barley breeding. The established barley breeding program from DAFWA that had been developing successful varieties for Western Australia growers for more than 50 years was transferred to InterGrain.

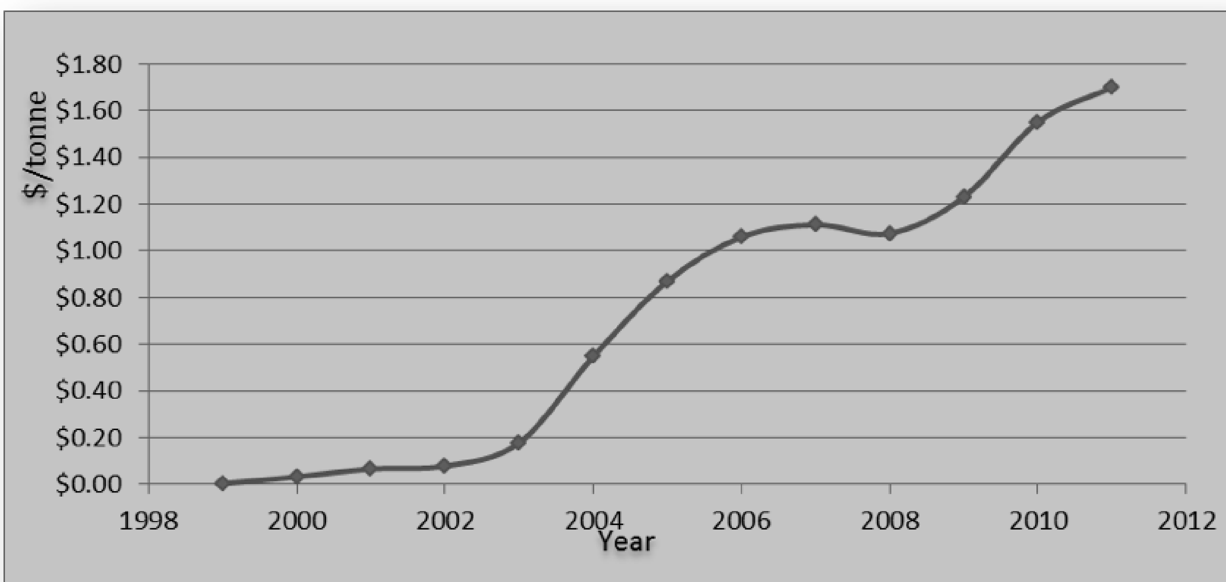

Figure 27: Weighted Average Wheat EPR Rate in Western Australia 1999-2011.
Source: Bolek 2015

The EPR were introduced in Australia in 1994 with the introduction of the Plant Breeders Rights Act. At first the EPR rates were small as new varieties with EPR attached to them had to compete with free varieties available in the market. Figure 27 shows how EPR rates for wheat varieties increased in years 1998-2011.

Currently the EPR rates are mostly $3 AUD to $4 AUD per tonne . The listing of EPRs for 2020/21 is provided at this link: http://varietycentral.com.au/varieties-and-rates/2021-22-harvest/barley/. Over the last 15 years the rates have increased from around $2 AUD per tonne to now, the newest varieties can attract EPRs around $4 AUD per tonne (Kingwell, 2020).

Noting that over the last 5 years the average barley production in Australia was 9.8 million tonne and, using an average effective EPR rate of $2.5 AUD per tonne, this suggests that annual revenue to support barley breeding is $24 AUD million (Kingwell, 2020). At current exchange rates and expenditures this royalty flow will support over ten times the level of barley breeding currently undertaken in Canada. Australia is likely to become even more important competitor for Canada over time.

The outcomes of Australian barley breeding programs are mostly in the form of higher yielding feed and malt varieties with sound quality attributes (Kingwell, 2020). Both Australian barley breeding programs aim for higher yields through higher water use efficiency, more disease resistance, and also to meet malt standards. Australian varieties need to withstand a hot dry finish to the season and the more recent breeding work covers heat traits during grain fill. Canada has the opposite problem with a sudden cool finish (Farrell, 2020).

The peak industry organization for barley in Australia was established in 2005, Barley Australia. The organization represents the interest of barley stakeholders such as the end users of malting barley, large maltsters and beer producers in the country and conducts an evaluation of malting barley for the recommendation list trails. The Australian Crop Accreditation System (ACAS) is managing the National Variety Trials (NVT). The objective of ACAS is to deliver to growers sound information on the performance and characteristics of cultivars so that growers can compare available varieties (Barley Australia, 2021). Each new variety of malting barley has to pass a rigorous series of evaluations in order to get an accreditation as a recognised malting barley variety. Breeders are responsible for providing a large quantity of crop for malting barley evaluation by the first year of Barley Australia's trials (Zmazhenko et al., 2017). The evaluation process takes over two years to allow a comprehensive examination of the variety. Full accreditation is attained after second-year positive evaluation results have been inspected, referred for approval by the Australian barley industry's technical evaluation panel (MBIBTC), and accepted by the board of Barley Australia (Barley Australia, 2021). The grain traders play a critical role in domestic and international market development. The involvement of the end users in early stages of evaluation of new varieties sends a strong message about the acceptance of new varieties to the remaining members of the malting barley supply chain (Zmazhenko et al., 2017; Barley Australia, 2021).

In summary, Australia has two large barley breeding programs funded through EPRs. Total EPR royalty income is $24 million AUD per year. In addition, industry development, agronomic research and pre breeding research is heavily supported via the GRDC, which is funded through a 1% check-off matched .5% by government. Not surprisingly, Australian barley area, yield and production have all increased over the past 20 years. It is also worth noting that despite these far greater levels of investment, periodic reviews of the GRDC continue to find high rates of the return to the grower directed investments in agricultural research.

4.2 A review of barley breeding systems in France

France is one of the largest producers and exporters of barley in the world. Barley production in France sharply increased in the 1960s and since, the production is stable with small variability in it caused by weather conditions (Statistica.com, 2021). As presented in Figure 28, the total production of barley in France in years 1998 -2018 stayed between 8.7 and 13 million tonnes a year with average production of 11.3 million tonnes. Figure 29 shows the area seeded with barley in those years is also stable. The average lifespan of new barley varieties in France is between 5 to 7 years. The fast turnover keeps barley competitive with other crops as new, better varieties continuously enter the market. Also, there is a stable demand for barley that keeps growers interested in growing barley (Znazhenko et al., 2017). The average yield of barley in years 1998-2018 is presented in Figure 30.

Barley in France divides into winter and spring barley. All of the spring barley varieties are intended for malting and most of the time they fall within the specifications for maltsters. About 50% of winter barley can be used for malting. A spring barley is more resilient and travels easier therefore spring barley programs are often located in one country (Germany, the UK or France) and distributed to other countries.

In France barley breeding is dominated by private companies. Public breeding has a small presence through Agri-Obtentions, a subsidiary of INRA that focuses on breeding varieties, with unique performance characteristics. The largeer seed companies that have their barley breeding programs in France are Limagrain, Secobra, KWS, Momont, Unisigma, Lemaire Deffontaines, RAGT, Florimond Desprez, Syngenta (100% hybrids). Selection programs not based in France but registering varieties in France also include, Ackermann & Nordsaat (via Asur Plant Breeding), Breun, Sejet, Florimond Desprez (Giraudeau, 2021).

The competitive environment of barley breeding led to widespread marketing of new malting varieties by seed companies/breeders to growers and end users. The breeders take a risk and engage in early seed multiplication. Consequently, early in the process of the varietal evaluation and registration there is enough available seed to conduct micro-trials as well as commercial (i.e. macro-scale) trials. The commercial trails are done by the Association of Maltsters of France (Malteurs de France), in collaboration with the Association of the Brewers of France (Association des Brasseurs de France). To maximize adoption of new varieties, many seed companies try to have their barley varieties accepted in the Recommended List evaluation processes in other countries. All members of the barley supply chain are involved in international market development (Zmazhenko et al., 2017).

The barley stakeholders in France (e.g. breeders, grain companies, maltsters) are integrated through the grower cooperatives, joint grain trading companies, and collaborative breeding programs. The integration leads to easier exchange of information, common interest in the success of new varieties, and a faster turnover of new varieties.

SEMAE (previously GNIS) is an interprofessional establishment that represents the sector's stakeholders as well as seed consumers. SEMAE helps to carry discussions, exchanges, and decision-making. It also promotes the French seed sector inside and outside of the country. The seed production market is very competitive, and SEMAE boosts the image of the French seed industry abroad (SEMAE, 2021).

In France the plant breeders are protected by the Plant Variety Certificate (PVC). The PVC secures intellectual property rights for a period of 25 to 30 years. After that protected period, the varieties enter the public domain and become royalty-free. With PVC protection the breeders have the exclusive right to *produce, package, sell and export the propagating material* of the varieties. The breeders can produce and market their varieties by themselves or grant licence agreements to seed and plant companies which supply farmers. The matching part of this licence is the royalty, which is included in the final price of seed.

The remuneration for research comes from seed royalties and a compulsory endpoint royalty paid on all cereals harvested and delivered to storage agencies. The farmers who have bought certified seed receive a refund of royalties already paid (SICASOV, 2021). That levy system, also called the uniform end point royalty system, is very efficient and results in over 90% of the royalty returned to the breeders.

According to the law a farmer is allowed to produce his own barley seeds from purchased certified seeds. It is called a farm-saved seed exemption and the farmer has to pay compensatory remuneration to the breeder. The SICASOV is responsible for the management and defence of breeder rights. The SICASOV also collects the royalties and remunerations (SICASOV, 2021).

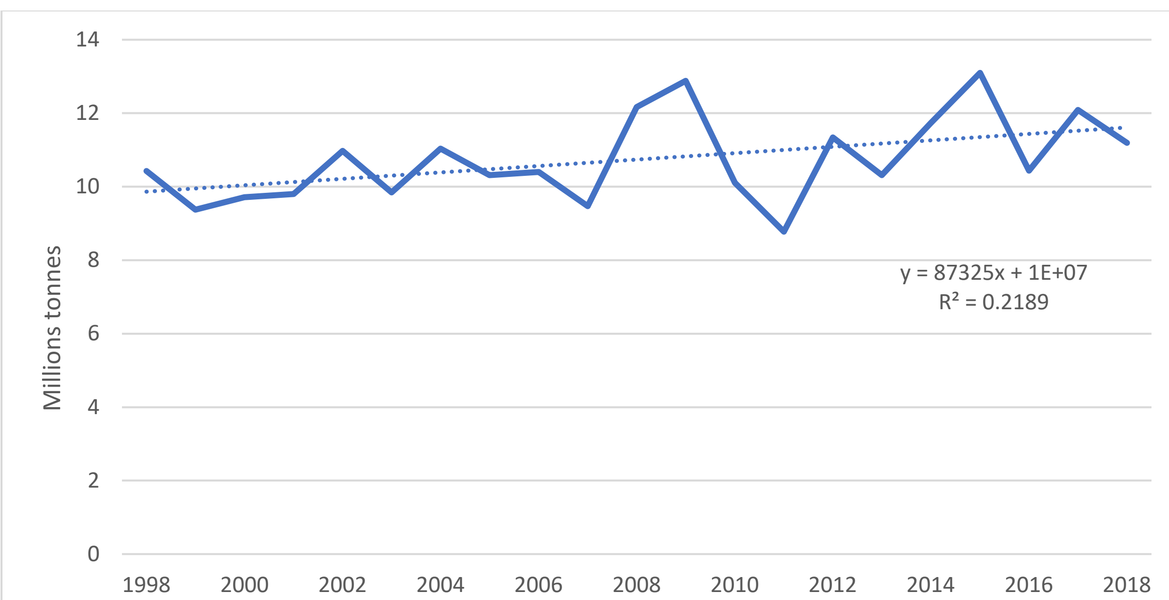

Figure 28: The total production of barley in France 1998-2018.
Source: FAOSTATS 2021

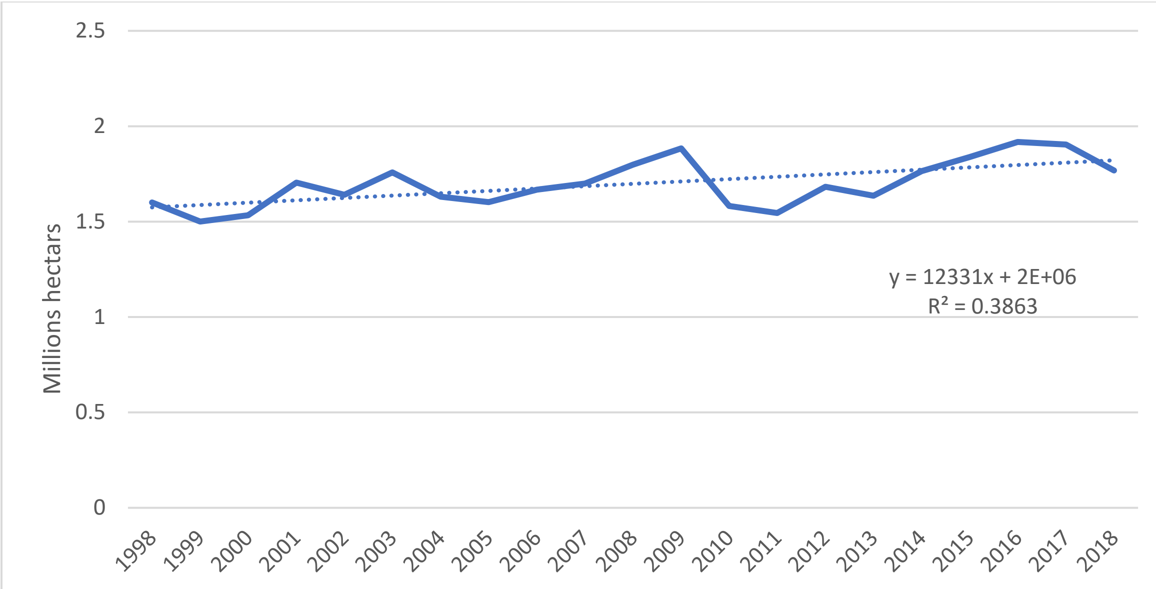

Figure 29: The area seeded with barley in France 1998-2018
Source: FAOSTATS 2021

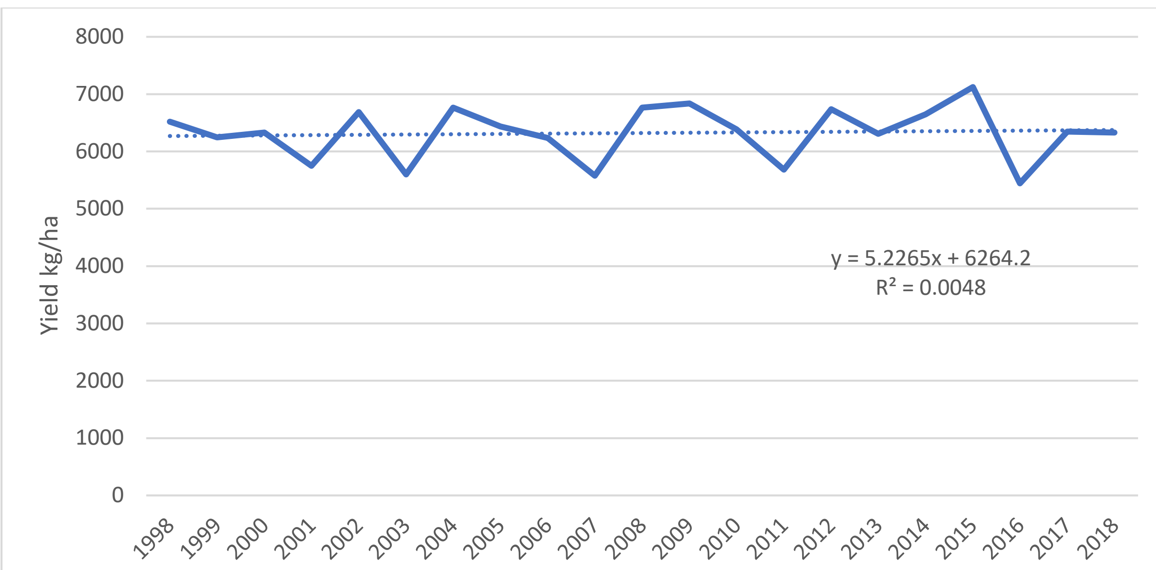

Figure 30: Average yield of barley in France 1998-2018
Source FAOSTATS 2021

The overall budget for barley breeding in France is difficult to estimate, but there are approximately $22.9 million (€ 15million) in royalties that include $15.25 million (€10million) for the winter barley varieties and $7.65 million (€ 5 million) for the spring barley varieties. Knowing that straw cereals do not make much money, the overall investment in barley breeding probably does not exceed that amount (Giraudeau, 2021).

4.3 A review the barley breeding systems in Germany

Germany is another major producer of barley. The annual average barley production in Germany in the last decade was about 10.8 million tonnes. The total barley production and total area seeded with barley in Germany in years 1998-2018 are presented in Figure 31 and 32 respectively and have downward sloping trends. Figure 33presents average yield of barley in years 1998-2018.

Approximately 80% of R&D investments in barley in Germany happens in the private sector. The rest is a public-private or pure public research and usually focuses on pre-breeding (Gerullis, 2021). In Germany, malting barley breeding is primarily carried out by medium-sized companies. Breeders are using traditional cross breeding, which is enhanced and supported by biotechnological methods. In the traditional breeding it takes about 10 to 12 years until a new variety is approved. Using double haploid plants or marker-supported selection can speed up development of new varieties by 2 to 3 years. Also by breeding winter generations of spring barley under glass and during the summer in the southern hemisphere, additional generations can be produced per calendar year, that accelerates the breeding process (CMA_Braugerstensortenmappe_en_update_2008.pdf (themodernbrewhouse.com 2021).

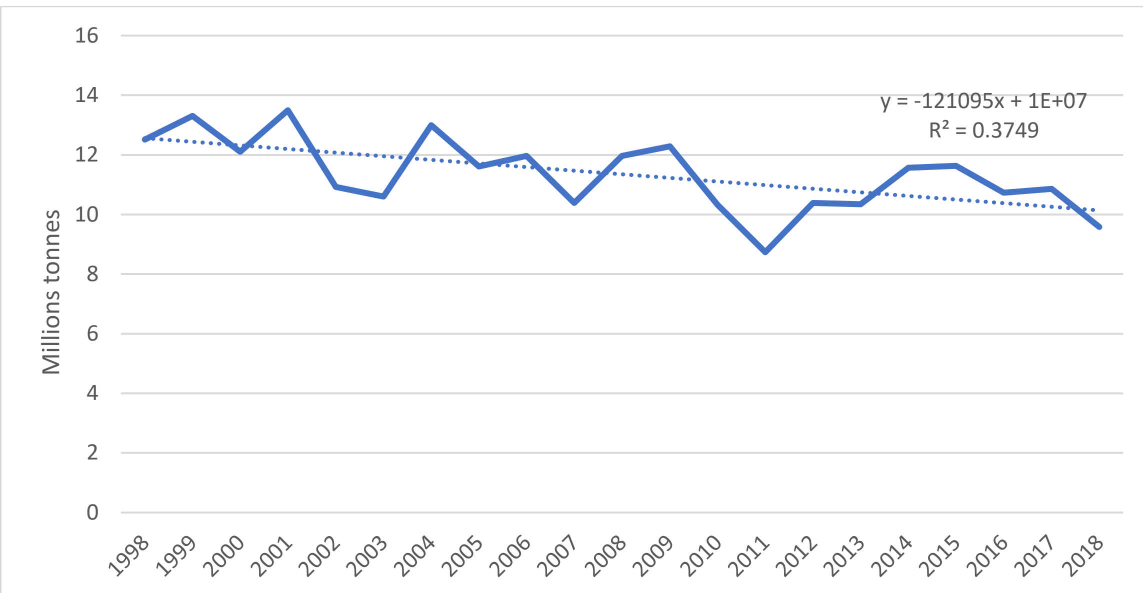

Figure 21: The total production of barley in Germany 1998-2018.
Source: FAOSTATS 2021

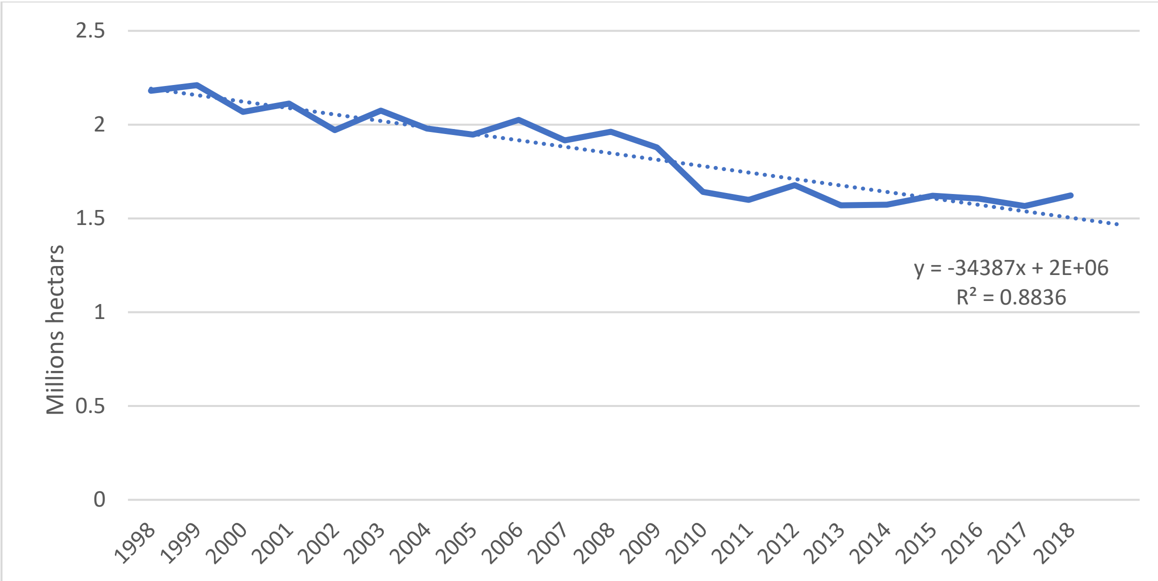

Figure 32: The area seeded with barley in Germany 1998-2018.
Source: FAOSTATS 2021

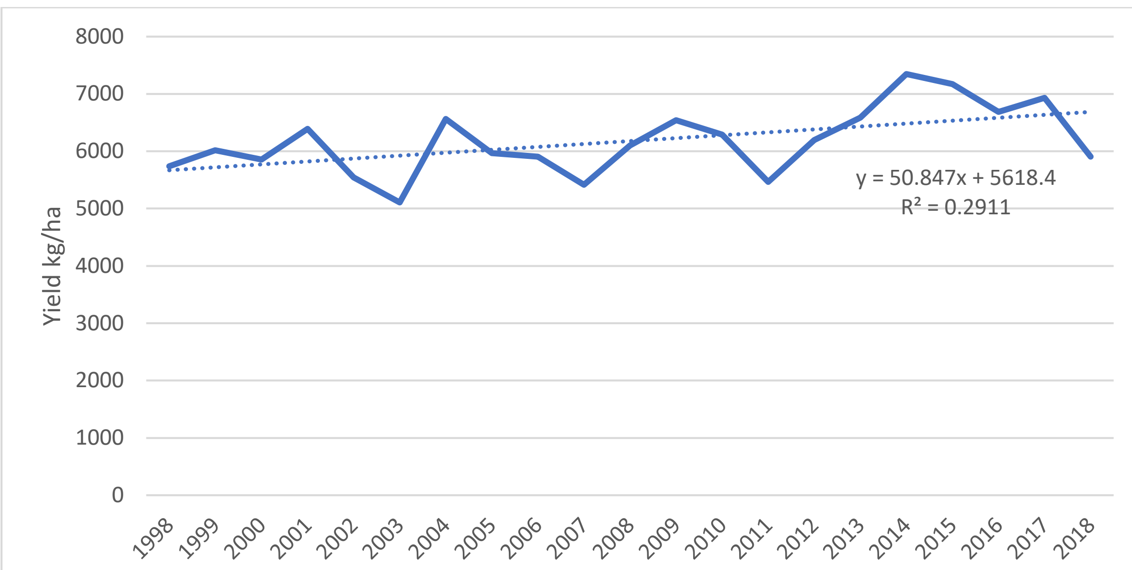

Figure 33: The average yield of barley (kg/ha) in Germany 1998-2018.
Source: FAOSTATS 2021

As in other European Union countries, in Germany the end-users are involved in varietal evaluation at an earlier stage. In Germany, the German Malting Barley Association (BraugerstenGemeinschaft e.V) manages trials of new varieties for the Recommendation List (RL). The German Malting Barley Association represent most of the maltsters and beer producers in the country (Zmazhenko et al., 2017).The malting barley in Germany is produced mainly in Bavaria, Thuringia, Saxony, Baden-Wuerttemberg, Rhineland Palatinate and Lower Saxony, because the natural conditions there are the most favourable. In those regions malting barley is grown as a special crop entirely assigned for brewing purposes.

Germany has been breeding malting barley for over 100 years and the breeding programs have been very successful. The largest success is the considerable increase of the malting barley's yield. In the past the high yield was a priority of breeding programs; nowadays a stability of yield and a quality have joined the yield as the top objectives of breeding (CMA_Braugerstensortenmappe_en_update_2008.pdf (themodernbrewhouse.com 2021).

The high quality of malting barley is a result of collaboration among malting barley breeders, specialised cropping farms, associations for promoting malting barley, the collectors, traders, maltsters and breweries in addition to thorough testing and approval of varieties by the Bundessortenamt.

Using the data from variety guides, which included seed propagation acres, and regional trial data for barley's varieties yield in (dt/ha) we calculated weighted average by seed propagation acres yield, presented in Figure 34.

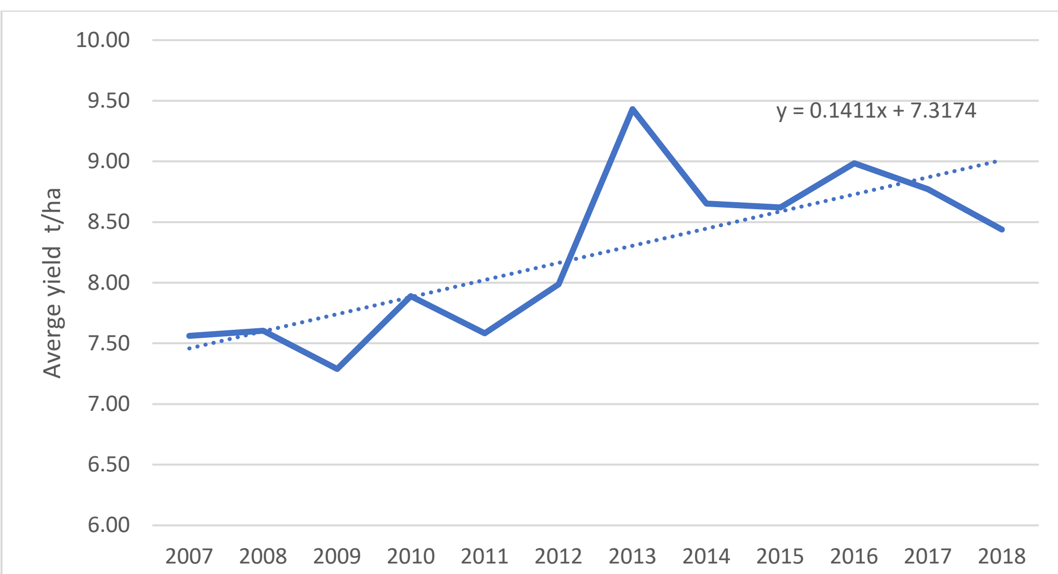

Figure 34: Average Barley Variety Research Trial Yields -Weighted by propagation area 2007 to 2018.
Source: Authors' Calculation

Section 5 Summary and Conclusions

Over the last decade, the barley industry worldwide has been growing in production, consumption and yield. However, existing trends in the Canadian barley industry show a reduction in production and in barley's exports. The Canadian malting barley industry is characterized by a slow variety uptake. In spite of new varieties being registered every year, only two barley varieties registered over twenty years ago, "AC Metcalfe" and "CDC Copeland" have an established demand and have the largest market share of all the barley varieties grown in Canada. In recent years AAC Synergy is gaining in demand.

The barley variety development in Canada is facing significant challenges. The recent failure by AAFC on its value creation consultation and economic analysis, the pilot project of the seed variety use agreements (SVUA) by the seed trade, and more recently the implications that COVID-19 will have on federal budgets in coming years, all contributed to the challenges of the barley variety development system. The uncertainty surrounding public and producer funded breeding programs in Canada needs to be addressed for the long-term sustainability of the barley industry. Barley breeding in Western Canada has been facing capacity pressure for the past five years. Three barley breeding centers serve Western Canada: The Field Crop Development Centre (FCDC) in Lacombe, the Crop Development Centre (CDC) in Saskatoon, and the Agriculture and the Agri-Food Canada (AAFC) station in Brandon. The AAFC has decreased from two breeders to one breeder (but has added a pathology position), the CDC operates with a shared breeding position between oats and barley, while the FCDC has two barley breeders. The FCDC activities have been hampered for the past four years by uncertainty within the Alberta government. Provincial government restructuring of research activities has created significant uncertainty surrounding the future of that breeding program.

The objectives of this study were to analyze: What are the up-to-date costs and benefits of barley breeding in Canada? What is the cost to producers of low barley variety uptake? How competitive is the Canadian barley breeding program compared to large barley producers such as Australia, Germany and France? Per output of dollars spent, is the Canadian barley breeding program keeping pace now and what are the needs into the future?

Canada is the fourth largest barley producer and the second largest malt exporter in the world. The average annual production of barley in Canada in the years 2008-2018 was about 8.7 million tonnes and average area seeded with barley in the same time frame was about 2.5 million hectares (FAOSTATS, 2020). The majority of grain producers in Canada are located in four western provinces: Saskatchewan, Manitoba, Alberta, and British Columbia (Zmazhenko et al., 2017).

Current reported annual average funding in barley research projects in Canada is about $3.8 million. On average $2.6 million (60%) is invested in breeding and germplasm screening, the remaining (14%) annual average funding is invested in agronomy, (8%) in genomics and tools, (4%) in malting and brewing, (9%) in feed and (5%) in pest mitigation (Feist and Barnes, 2020). The investment of $2.6 million constitutes about 0.14% of barley gross revenue, a low rate of research investment relative to most industries.

With the aim of assessing the effect of barley's research and development on the return to funds invested we conducted a Benefit Cost analysis. In our analysis the factual situation (what actually occurred) has to be compared to the counterfactual situation. The counterfactual is the theoretical case that would have existed if there were no funding on research and development in barley in Western Canada. We claim that in this counterfactual situation, the yield gains from the adoption of new barley varieties would not have happened. The model used in this analysis is similar to one that was used in the assessments of the rate of return to the WGRF investment by Scott et al., 2005 and Gray et al., 2012. The consumer and producer surplus generated under the two scenarios is compared and the difference is the benefit from the investment in barley breeding.

Our empirical results show high return to barley research. The estimated B/C ratio is 26 to 1 meaning for every dollar invested in research the producers benefit $26.. The estimated annual IRR is 32% which is significantly higher than market interest rate. The results are robust to used level of investment. If we increase estimated expenditures on breeding by 35% the estimated B/C ratio is 19.3 to 1, meaning for every dollar invested in research the producers benefit $19.30. The IRR is 28.9%, which is also much higher than the market interest rates, or other investment opportunities.

To assess a cost of low variety uptake we conducted Benefit Cost analysis for hypothetical Scenario C where only top yielding malting variety each year is being adopted by all malt producers. The results suggest with top malting varieties being adopted the estimated B/C ratio is

49.4 meaning for every dollar invested in research the producers' benefit $49.40. The IRR is 45.9 % which is much higher than the market interest rate.

We also conduct a more conservative Scenario D where varieties with the highest market shares, Copeland and Synergy, are being fully and faster adopted by all malting producers within four years of release. Our results suggest the high returns to barley research would also increase if Copeland and Synergy were adopted by all of the malt producers. The increase would be not as large as if only top malting varieties were adopted. With Copeland and Synergy varieties being adopted the estimated B/C ratio is 44.5 meaning for every dollar invested in research the producers' benefit $44.50. The increase in the B/C ratio from experienced, suggests that increasing industry adoption rates could provide very significant additional benefits for producers.

Further, we analyzed barley breeding programs in competitive countries. The majority of global barley production takes place in Russia, Germany, France, and Ukraine, Australia, Canada, Spain, Turkey, the United Kingdom, and the United States of America (FAO, 2021).

Australia spends about $24 million on barley breeding, which is almost 8 times more than Canada does. As one of the largest barley exporters, and the only country showing an increase in barley area and production Australia will continue to be a major competitor.

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Appendix A

Weighted average yield index for 2 row malting barley, 6 row malting barley, 2 row general purpose and 6 row general purpose in Saskatchewan are calculated for years 1972 to 2019 and presented in Figures 11, 12, 13 and 14 respectively. The yield index and adoption data for years 1993-1998 and 2012-2013 were missing and for purpose of our analysis were linearly filled in calculation of weighted average yield index.

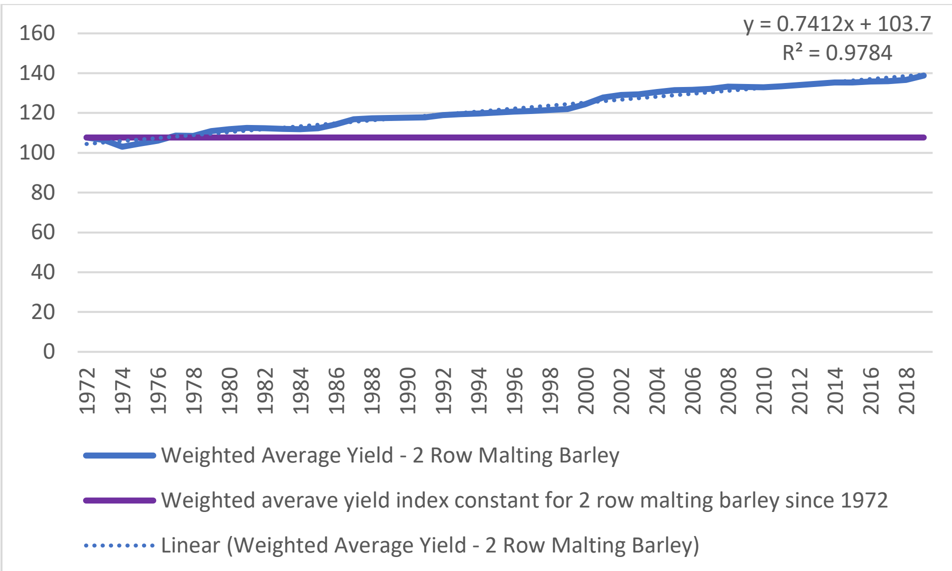
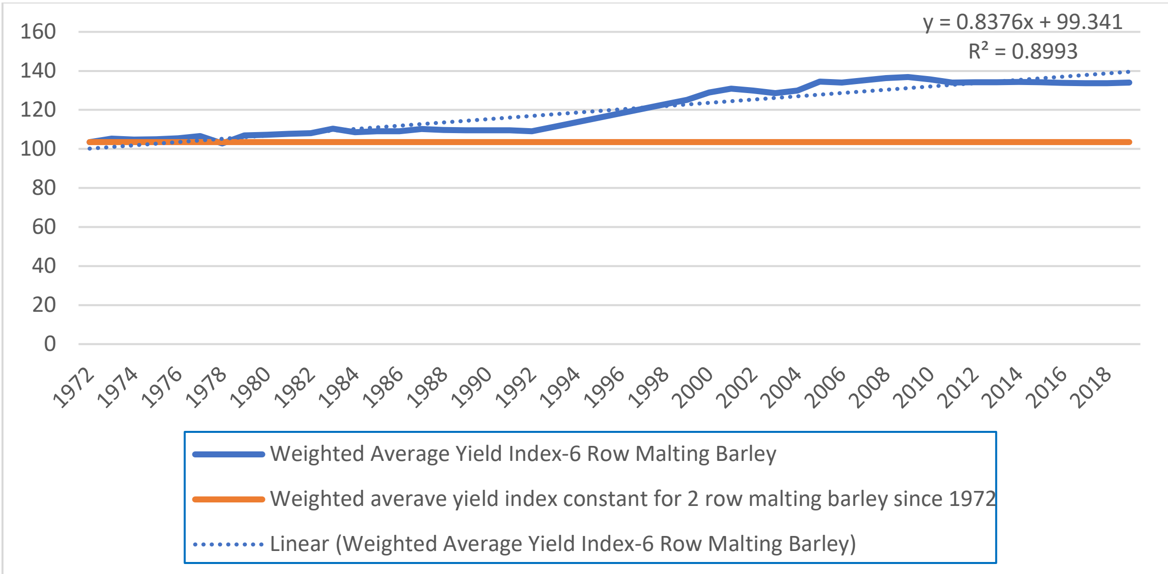


Figure A1: Weighted average yield of malting barley 2 rows in Saskatchewan expressed as a percentage of Conquest variety (a check variety in 1972) 1972-2019

Source: Author's calculations bases on yield indexes and variety adoption



Firgure A2: Weighted average yield of malting barley 6 rows in Saskatchewan expressed as a percentage of Conquest variety (a check variety in 1972) 1972-2019

Source: Autor's calculations based on data

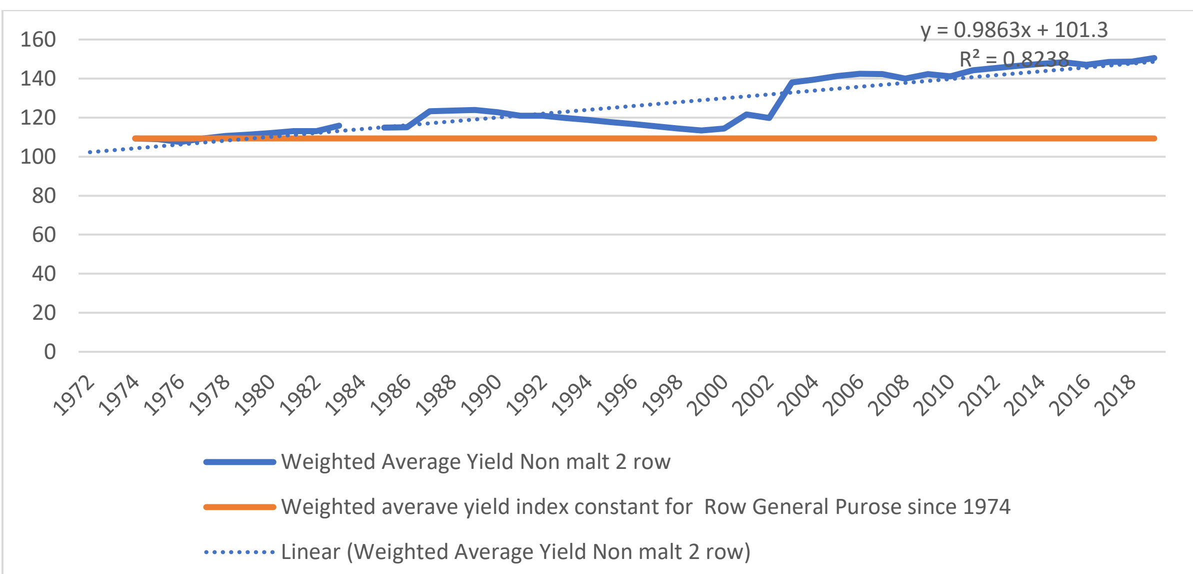


Figure A3: Weighted average yield of non-malting barley 2 rows in Saskatchewan expressed as a percentage of Conquest variety (a check variety in 1972) 1972-2019

Source: Author's calculations basedon yield indexes and variety adoption

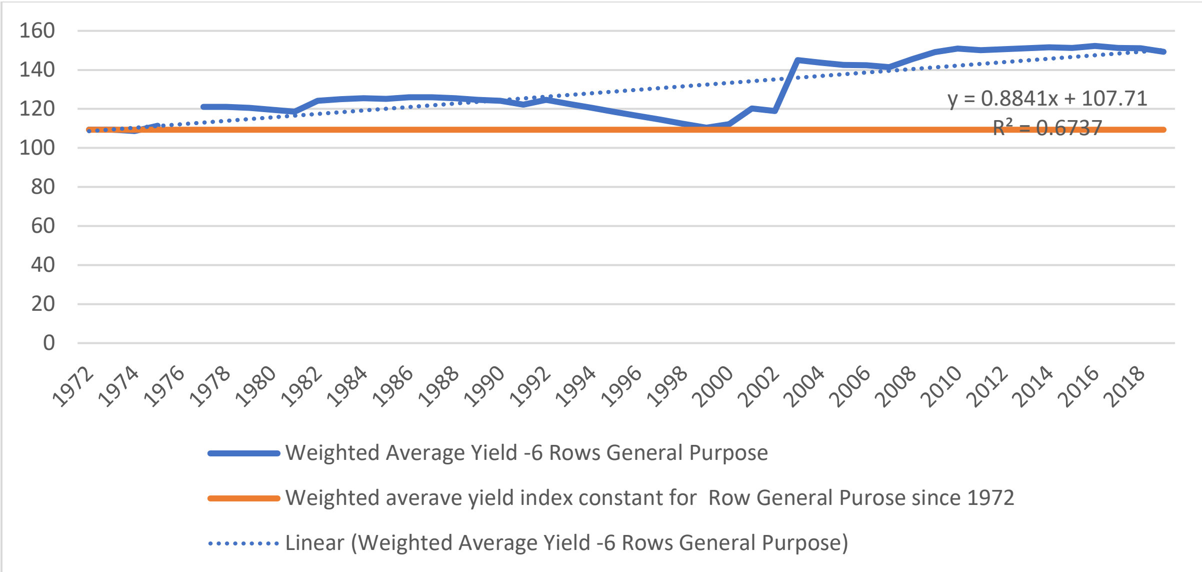


Figure A3: Weighted average yield of non malting barley 6 rows in Saskatchewan expressed as a percentage of Conquest variety (a check variety in 1972) 1972-2019

Source: Author's calculations bases on yield indexes and variety adoption

We also calculated a compound annual growth rate. The compound annual growth rate of weighted average by areas yield index in Saskatchewan was calculated using the formula below

$$\text{CAGR} = \left(\frac{Y_{2019}}{Y_{2005}}\right)^{\frac{1}{2019-2005}} - 1$$

Where Y_{2019} and Y_{2005} are the weighted average yield indexes from 2005 and 2019.

The compound annual growth rate in barley yields using Saskatchewan variety performance trial data in years 2005 to 2019 is

$$CAGR = .46\%$$

The compound annual growth rate for weighted average barley yield using Saskatchewan CPVT data in years 1972 to 2019 is:

$$\text{CAGR} = \left(\frac{Y_{2019}}{Y_{1972}}\right)^{\frac{1}{2019-1972}} - 1$$

$$CAGR = .58\%$$

Where Y_{2019} and Y_{1972} are the weighted average yield indexes from 1972 and 2019.

The changes in the producer surpluses under each scenario are presented in Table A1. The change in producer surplus under each scenario attributed to the producer investment and the producer share of breeding cost in million dollars. The present value of the changes in producer surplus under each scenario and present value of cost of breeding are reported in Table A2.

Table A1: Yearly Expediture and Producer Surplus Scenario A, C and D

	Producer portion of expenditures adjusted by inflation ($ million)	Scenario A: Base Case Change in Producer Surplus ($ million)	Scenario C: Complete adoption of highest yielding malting varieity each year Change in Producer Surplus ($ million)	Scenario D 4 year adoption of Copeland and Synergy Change in Producer Surplus ($ million)
1995	0.992			
1996	1.173			
1997	1.099			
1998	1.698			
1999	0.843			
2000	0.813			
2001	0.967			
2002	0.960			
2003	1.125			
2004	0.911			
2005	0.987	5.154	37.500	22.217
2006	0.808	6.664	30.702	18.035
2007	1.148	17.027	55.197	34.166
2008	0.906	27.039	69.356	46.263
2009	1.210	15.861	38.984	28.768
2010	1.163	15.612	29.486	21.928
2011	0.774	20.170	43.868	29.794
2012	1.268	30.224	60.949	39.745
2013	1.256	48.922	96.837	61.131
2014	1.232	29.674	55.346	40.872
2015	1.219	37.566	85.006	69.036
2016	1.202	40.158	89.672	78.869
2017	1.183	29.953	69.956	70.210
2018	1.157	41.495	83.470	83.531
2019	1.135	60.379	106.427	106.994
2020		44.137	78.473	76.334
2021		48.876	85.395	84.574
2022		52.618	90.218	90.883
2023		55.378	93.501	95.660
2024		56.047	93.230	96.773

2025		60.185	98.728	103.882
2026		62.726	101.496	108.161
2027		65.082	103.817	111.977
2028		68.984	108.483	118.357
2029		71.769	111.282	122.731
2030		68.180	105.718	116.594
2031		64.771	100.432	110.765
2032		61.533	95.410	105.226
2033		58.456	90.640	99.965
2034		55.533	86.108	94.967
2035		52.757	81.802	90.218
2036		50.119	77.712	85.708
2037		47.613	73.827	81.422
2038		45.232	70.135	77.351
2039		42.971	66.628	73.483
2040		40.822	63.297	69.809
2041		38.781	60.132	66.319
2042		36.842	57.126	63.003
2043		35.000	54.269	59.853
2044		33.250	51.556	56.860
2045		31.587	48.978	54.017
2046		30.008	46.529	51.316
2047		28.508	44.203	48.750
2048		27.082	41.993	46.313
2049		25.728	39.893	43.997

Source Author's calculations based on data

Table A2: Present Values Yearly Expediture and Producer Surplus Scenario A, C and D

	Producer portion of expenditures adjusted by inflation ($ million)	Scenario A: Base Case Change in Producer Surplus ($ million)	Scenario C: Complete adoption of highest yield malting varieity each year Change in Producer Surplus ($ million)	Scenario D 4 year adoption of Copeland and Synergy Change in Producer Surplus ($ million)
1995	**6.398**			
1996	**7.207**			
1997	**6.432**			
1998	**9.463**			
1999	**4.476**			
2000	**4.107**			
2001	**4.655**			
2002	**4.402**			
2003	**4.911**			
2004	**3.787**			
2005	**3.907**	**10.205**	**74.247**	**43.989**
2006	**3.048**	**12.566**	**57.894**	**34.008**
2007	**4.122**	**30.578**	**99.127**	**61.357**
2008	**3.098**	**46.246**	**118.622**	**79.126**
2009	**3.941**	**25.836**	**63.501**	**46.860**
2010	**3.608**	**24.219**	**45.743**	**34.017**

2011	**2.287**	**29.801**	**64.814**	**44.019**
2012	**3.568**	**42.528**	**85.762**	**55.925**
2013	**3.368**	**65.560**	**129.771**	**81.921**
2014	**3.146**	**37.872**	**70.638**	**52.164**
2015	**2.963**	**45.662**	**103.325**	**83.914**
2016	**2.782**	**46.487**	**103.807**	**91.301**
2017	**2.609**	**33.023**	**77.126**	**77.406**
2018	**2.429**	**43.569**	**87.644**	**87.708**
2019	**2.269**	**60.379**	**106.427**	**106.994**
2020		**42.035**	**74.736**	**72.699**
2021		**44.332**	**77.456**	**76.711**
2022		**45.453**	**77.934**	**78.509**
2023		**45.560**	**76.924**	**78.700**
2024		**43.915**	**73.048**	**75.824**
2025		**44.911**	**73.672**	**77.518**
2026		**44.578**	**72.131**	**76.868**
2027		**44.050**	**70.267**	**75.790**
2028		**44.468**	**69.929**	**76.294**
2029		**44.060**	**68.317**	**75.346**
2030		**39.864**	**61.811**	**68.170**
2031		**36.067**	**55.924**	**61.678**
2032		**32.632**	**50.598**	**55.804**
2033		**29.524**	**45.779**	**50.489**
2034		**26.712**	**41.419**	**45.681**
2035		**24.168**	**37.475**	**41.330**
2036		**21.867**	**33.906**	**37.394**
2037		**19.784**	**30.676**	**33.833**
2038		**17.900**	**27.755**	**30.610**
2039		**16.195**	**25.112**	**27.695**
2040		**14.653**	**22.720**	**25.058**
2041		**13.257**	**20.556**	**22.671**
2042		**11.995**	**18.598**	**20.512**
2043		**10.852**	**16.827**	**18.558**
2044		**9.819**	**15.225**	**16.791**
2045		**8.884**	**13.775**	**15.192**
2046		**8.038**	**12.463**	**13.745**
2047		**7.272**	**11.276**	**12.436**
2048		**6.580**	**10.202**	**11.252**
2049		**5.953**	**9.230**	**10.180**

Source: Author’s calculations based on data