GENOMICS AT WORK FOR

PRAIRIE'S CROP INDUSTRY

What We Heard Virtual Workshop Summary

MARCH 2024

Genome Prairie

Genome Alberta

OUR **VISION**

To inspire and catalyze genomics solutions that benefit Albertans and the world.

OUR **MISSION**

To promote and support genomics solutions for end-user needs to create value and investment opportunities through excellent science, technology and application development, collaborations and partnerships.

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ABOUT GENOME ALBERTA

Genome Alberta is a publicly funded not-for profit corporation which invests primarily in large-scale genome sciences research projects and technology platforms focused on areas of strategic importance to the province (human health, forestry, plant and animal agriculture, energy, and environment). By working collaboratively with all levels of government, universities, and industry, Genome Alberta is a catalyst for a strong life sciences sector with social and economic benefits for Alberta and for Canada.

ABOUT GENOME PRAIRIE

Genome Prairie is a non-profit organization that supports stakeholders across Manitoba and Saskatchewan in capturing and maximizing the benefits of advanced research in genomics and related biosciences. This role is achieved by aligning the partners and resources needed to develop and manage targeted projects addressing regional priorities. Genome Prairie also enables participation among regional researchers in Genome Canada's competitive granting process for large-scale projects.

EXECUTIVE SUMMARY

Agricultural productivity on the Canadian Prairies is directly linked to agricultural innovations. For example, over the last 60 years, food production has increased 3.9X whereas land use has only increased 1.1X. This contrast between production and land use is largely attributed to the implementation of innovative technologies for efficient weed control, including the adoption of genetically modified crops. Future investment in innovation, including the identification and implementation of new genomic-based technologies that build on progress made so far, is needed for future food security to meet the needs of the global population, predicted to reach 9.7 billion by 2050.

The discussion we heard at the workshop identified barriers to overcome for progressive adoption of genomic-based technologies for crop improvement.

To understand the current state of genomic-based technology for crop improvement in the Prairies, Genome Alberta and Genome Prairie co-hosted a 'Genomics at Work for the Prairie Crop Industry' workshop that brought together Canadian stakeholders working in scientific research, policy, funding, industry, and crop production to discuss the barriers and opportunities for genome-based technologies for the Prairie crop industry.

The workshop objectives were to:

- Provide a forum to engage the agriculture community about the current state of genome-based technologies in the Prairie's agri-food sector.
- Discuss any barriers to genomic technology adoption and implementation.
- Understand what changes are needed to drive genomics-enabled agriculture in the Prairies forward.
- Identify and prioritize future research programs for genomics-enabled plant agriculture to inform investment priorities of Prairie-based funding agencies.

This report summarizes what we heard from the workshop's panel discussion and Q&A period. It was supplemented with additional content informed by peer-review publications and expert consultations. The discussion we heard at the workshop identified barriers to overcome for progressive adoption of genomic-based technologies for crop improvement.

Barriers include, but are not limited to:

- Insufficient sharing and integration of big data in agriculture to develop robust genotype-phenotype prediction models and to exploit artificial intelligence's full potential,
- Ineffective communication strategies among scientists, policymakers, and the public for empirically based policy development, and,
- Inadequate stable, long-term funding to support genome-based crop variety development.

A detailed description of the forward-looking discussions regarding barriers and opportunities for genomics in the Prairie crop industry are summarized in the report under five main headings: (i) Genomics and Implementation, (ii) Big Data and Artificial Intelligence, (iii) Communicating Genomics for a Sustainable Future, (iv) The Genomics Regulatory Environment, and (v) Funding and Investments in Genomics.

Genome Alberta and Genome Prairie will continue to support efforts, in partnership with the broader crop community in the Prairies, to address identified barriers through the innovation and research funding programs we deliver. Knowledge and insights gained will help to inform future research and innovation programs that enable greater benefits to Albertans through the adoption of genomics-based technologies for sustainable crop improvement.

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INTRODUCTION

Food production on the Canadian Prairies is directly linked to investment and implementation of new technologies. This was made very clear beginning in the 1960s when production levels were decoupled from land use largely due to research and implementation of synthetic fertilizers. This production vs land use gap widened further decades later when no-till practices emerged and herbicide tolerance was introduced into crops.

Regulatory legislation such as Plants with Novel Traits (PNT) regulations in Canada play an important role in Canadian agriculture and our food safety.

The addition of herbicide tolerance into canola by genomics and genetic modification (GM) technology revolutionized how this notoriously weedy crop is produced. By 2022, food production had increased 3.9X while land use increased 1.1X since the 1960s[1]. Investment in agricultural innovation and variety development has been profitable with Canadian Western Red Spring (CWRS) wheat showing nearly 40X return on investment since the inception of the Western Grains Research Foundation (WGRF) wheat and barley checkoff in 1994.

Genetically modified crops in Canada have had a profound impact[2,3]. Some of the key metrics surrounding these successes include:

- GM canola and corn adoption accounts for virtually all production, while GM soybean adoption is >80%.
- GM crops increased yields by 21% due to reduced crop damage as a result of increased pest control.
- Pesticide use decreased by an average of 37% as a result of GM crops, yielding pesticide savings of 39%.
- Farm level data on in-crop herbicide use from 2016 to 2019 indicate that the environmental impact of these herbicides is 65% lower than the impact of those used from 1991 to 1994.
- Profitability was increased by 69% for GM crop adopters compared to non-adopters.

However, are genomics-enabled innovations sustainable into the future? Regulatory restrictions placed on biotechnology crops pose a threat to continued agricultural productivity. For example, precautionary regulatory restrictions in the EU are linked to a modest 7% increase in crop production compared to more relaxed regulations in Canada (28%) and the US (35%) over the past 30 years[4]. Regulatory legislation such as Plants with Novel Traits (PNT) regulations in Canada play an important role in Canadian agriculture and our food safety. However, are regulatory restrictions still needed for traits

[1] Making Better Policies for Food Systems, https://www.oecd-ilibrary.org/agriculture-and-food/making-better-policies-for-food-systems_ddfba4de-en. Accessed Apr 30, 2024

[2] Carlberg, J. (2024). Sustainable Innovation in the Canadian Agrifood Sector: Past, Present & Future. The School of Public Policy Publications, 17(1).

[3] Smyth, S. J. (2023). Sustainability in Canada and Europe: An Assessment after 25 Years of GM Crop Production. ACS Agricultural Science & Technology, 3(12), 1114-1116.

[4] Paarlberg, R., & Smyth, S. J. (2023). The cost of not adopting new agricultural food biotechnologies. Trends in Biotechnology, 41(3), 304-306.

such as herbicide tolerance in canola which has become a mandatory trait for variety release for over two decades now? Surveys show that PNT regulations can be a deterrent for applying for and receiving research funding in Canada[5].

Yet, there are positive changes to the Canadian crop regulatory landscape as well. In 2015, Canada adopted the UPOV91 (International Convention for the Protection of New Varieties of Plants of 1991) convention that aims to protect the rights of breeders of new plant varieties by providing them with intellectual property rights. Adopting the UPOV 91 International Convention in 1991 led to an increase in private agriculture research investment and introduction of new varieties by foreign multinational breeding companies in Canada[6]. Further, in 2022/23, Canadian regulatory agencies approved gene editing as a method to create new crop varieties which will be treated as conventional varieties under Canada's regulatory system. Genome Canada was one of the advocates for this policy change, playing a significant role in developing a comprehensive submission in support of this regulatory change[7].

The introduction of genomic technology into crop production over the past 30 years has markedly increased agricultural productivity. Emerging genomic technologies can potentially change future crop production further with respect to quality, quantity, applications, and climate change. Given the global population continues to rise and is predicted to reach 9.7 billion by 2050[8], genomics-based crop improvements are instrumental for future food security. To understand the current state of genomic-based technologies for the Prairie crop industry, Genome Alberta and Genome Prairie hosted a workshop "Genomics at Work for the Prairie Crop Industry" focused on current opportunities and challenges surrounding the application of genomics in plant agriculture. We heard from both private and public sector experts on topics that include genomic technology, public trust and communication, regulatory issues, research investment and future priorities for the prairie crop industry.

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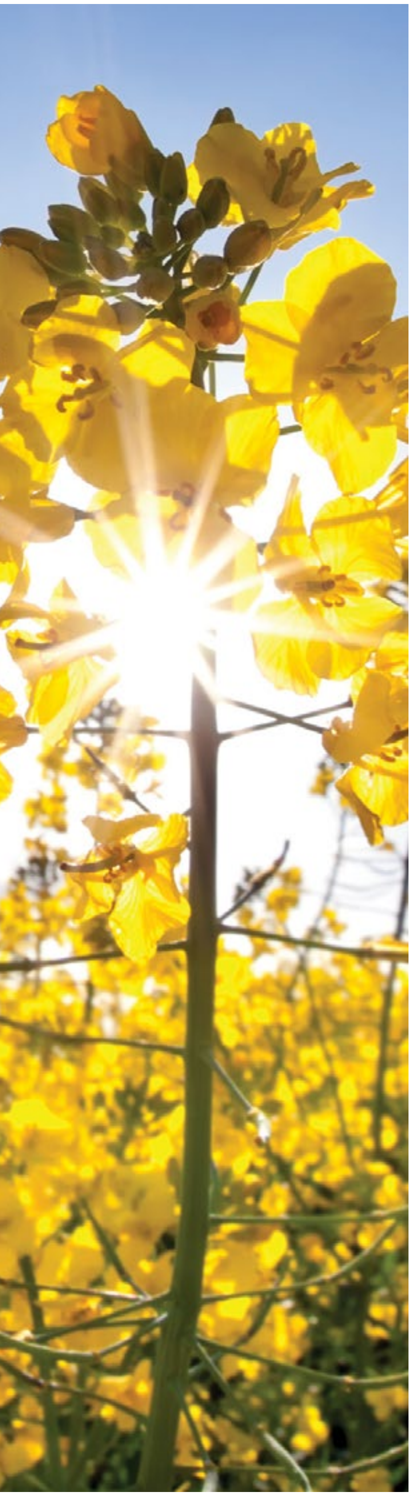
[5] Smyth, S. J., Gleim, S., & Lubieniechi, S. (2020). Regulatory barriers to innovative plant breeding in Canada. Frontiers in Genome Editing, 2, 591592.

[6] Government of Canada Agriculture and Agri-Food Canada (2023). *Assessing impacts of the 2015 legislative amendments to Canada's Plant Breeders' Rights Act and UPOV'91 ratification.* Retrieved from Government of Canada website: https://www.lib.sfu.ca/help/cite-write/citation-style-guides/apa/gov-docs-apa

[7] Government of Canada Health Systems and Services (2022). *Consultation summary: Proposed guidance for Novel Food Regulations focused on plant breeding.* Retrieved from Government of Canada website: https://www.canada.ca/en/health-canada/programs/consultation-guidance-novel-foods-regulation-plant-breeding/what-we-heard.html

[8] United Nations Population Division (2022). *Population.* Retrieved from the United Nations website: https://www.un.org/en/global-issues/population



Panel participants at the workshop included:

- **Dr. Stuart Smyth** (Workshop Chair), Professor – Department of Agriculture and Resource Economics, University of Saskatchewan.
- **Dr. Cami Ryan,** Senior Business Partner for Industry Affairs and Sustainability – Bayer Crop Science Canada.
- **Dr. Francois Eudes,** Director Research, Development and Technology – Science and Technology Branch, Agriculture and Agri-Food Canada.
- **Ian Affleck,** Vice President of Plant Biotechnology – CropLife Canada.
- **Dr. Lorne Hepworth,** Chair – Agriculture Research Institute of Ontario, Formerly President of CropLife Canada.
- **Dr. Nancy Tout,** Chief Scientific Officer – Global Institute for Food Security

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This report provides an overview of discussions and learnings from the workshop. It was supplemented with additional content informed by peer-review publications and expert consultations.

DISCUSSION

GENOMICS TECHNOLOGY AND IMPLEMENTATION

Crop genomic technology was founded with high throughput sequencing of plant genomes. The vision then and now has been to associate genomic sequences (genotypes) with traits (phenotypes) thus leading to new, genome-based diagnostic tools (molecular breeding) such as genomic selection, that could accelerate and refine the plant breeding progress. The key to success in this approach is collecting large amounts of accurate genotype and phenotype data that are used to develop robust prediction models. The rapid advancement of genome sequencing technology has made genotyping inexpensive and fast, serving as the primary driving force in plant breeding. As technology for collecting phenotype data becomes more reliable, accessible, and inexpensive, it will facilitate better precision breeding of crops. Today we see most public and private breeding organizations routinely implementing crop genotyping methods such as genomic selection to breed both simple and more complex traits in crop plants. Moreover, high-throughput phenotyping and genotyping of crop wild relatives (CWRs) and landraces has once again enabled increased genetic diversity within breeding pools which has been lost over the last century due to the need of predictable, genetically uniform cultivars[9]. A broader reservoir of valuable traits across varying environmental conditions is crucial in the context of current and future climates, providing breeders more flexibility in their breeding programs.

The rapid advancement of genome sequencing technology has made genotyping inexpensive and fast, serving as the primary driving force in plant breeding. As technology for collecting phenotype data becomes more reliable, accessible, and inexpensive, it will facilitate better precision breeding of crops.

Genetically modified (GM) crops are used widely in Canada and many parts of the world. This technology typically involves introducing a novel gene sequence into a plant that will affect a substantial change in the plant phenotype, such as herbicide tolerance in canola.

Gene editing is any method where a specific gene sequence is identified, characterized and then modified in the plant in order to change the gene function and improve the trait(s) it controls. Gene editing methods are now available to manipulate genes that affect agronomically important traits.

CHALLENGES

- Cultivar development via typical molecular breeding approaches can still benefit from improvements in genotype and phenotype correlations. Genotyping capacity and precision are very well developed in the Canadian Prairies but our ability to collect accurate and sufficient amounts of phenotypic data could still be improved. For example, digital phenotyping from images provided by drones is an innovative way to collect data efficiently. Doing so would lead to improvements in genotype-phenotype prediction models and could potentially decrease costs. Digital phenotyping brings additional challenges with exponential increases in data and computing power required.

[9] Bohra, A., Kilian, B., Sivasankar, S., Caccamo, M., Mba, C., McCouch, S. R., & Varshney, R. K. (2022). Reap the crop wild relatives for breeding future crops. Trends in Biotechnology, 40(4), 412-431.

In contrast to the 10–15 year time lag of conventional variety development, breeders are considering gene editing an elite genotype and then releasing a new variety far more rapidly than possible using conventional breeding techniques.

- Gene editing approaches to crop improvement hold a lot of promise since elite varieties of a crop could be used as a starting point to introduce additional desirable traits. This approach leverages decades of breeding and selection efforts to develop better-adopted, higher-quality varieties, for example, drought-resistant varieties in response to ever-changing climatic conditions. One challenge with gene editing is understanding which gene(s) to edit. A considerable amount of research effort is still required to demonstrate which gene and gene modifications will make the desired changes to traits such as pathogen resistance, environmental resilience, or market quality.

OPPORTUNITIES

- Conventional breeding programs have a considerable lag time (10-15 years) between initial crosses and final approval of a new cereal, pulse or oilseed crop [variety], due to the requirements for inbreeding and rigorous, multi-year testing. The breeding time can be reduced and more complex traits can be combined by implementing molecular breeding. For example, the recently funded Genome Alberta project, PeaCE (Pea Climate-Efficient) project[10], employs targeted gene editing to develop pea germplasm with improved root rot resistance, climate resilience and nutritional value. Genomic research has largely been invested in developing tools for plant breeding and these tools can lead to greater precision and efficient use of time and resources.
- Many crops have reduced genetic diversity relative to their wild ancestors. Advances in genomics and next generation sequencing capabilities have accelerated the identification of valuable CWRs and landraces for use in crop improvement. The inclusion of CWRs and landraces has increased genetic diversity within breeding pools. Genomic selection of agronomic traits in CWRs in combination with gene editing tools, provides an accelerated path to transform CWRs into optimal future crops. For example, the Genome Prairie projects 4DWheat and EVOLVES for wheat and lentils respectively, are researching agronomic traits in wild relatives as the basis of their research.
- In contrast to the 10 – 15 year time lag of conventional variety development, breeders are considering gene editing an elite genotype and then releasing a new variety far more rapidly than possible using conventional breeding techniques. However, regulatory barriers, particularly in international markets, have inhibited the uptake of this innovation in crop breeding (see Section "The Genomics Regulatory Environment" below).

[10] Genome Alberta (2023). *PeaCE (Pea Climate-Efficient): Developing climate-resilient, low carbon footprint field pea as a preferred rotation crop through the inter-disciplinary integration of genomic technologies.* Retrieved from Genome Alberta website: https://genomealberta.ca/project/peace-pea-climate-efficient-developing-climate-resilient-low-carbon-footprint-field-pea-as-a-preferred-rotation-crop-through-the-inter-disciplinary-integration-of-genomic-technologies/

BIG DATA AND ARTIFICIAL INTELLIGENCE

With the advancement of genome sequencing, machine-learning-assisted imaging processing for phenotyping, and the widespread adoption of various sensors to capture real-time information, large amounts of data can be quickly generated. Consequently, there is a pressing need for the capacity to store and process these large and complex datasets. To address this challenge, large data hubs have been established to house and analyze the data for record-keeping, research, and decision-making purposes. Of the many types of large data hub(s) possible, those with contributions from both public and private sectors should be operated to support pre-competitive research in order to alleviate privacy and IP concerns. A simple example of this is the National Center for Biotechnology Information (NCBI), where genomics data is housed and is freely available for data queries. A more local example is KnowPulse at the University of Saskatchewan, a hub for collecting data on pulse crops. In both cases, a team of experts manages the content of the data hub and builds bioinformatic tools to facilitate searches and extraction of data subsets. In the case of KnowPulse, both public and private funding has enabled the development of this platform and its data.

Of the many types of large data hub(s) possible, those with contributions from both public and private sectors should be operated to support pre-competitive research in order to alleviate privacy and IP concerns.

CHALLENGES

- Large, Prairie-wide data hubs could be envisioned to store and compile genotype and phenotype data across many species, environments, and experimental treatments for use in plant breeding prediction or crop production models. The 'big data' would be a combination of 'OMICs' (DNA, RNA, Protein) sequence information, agronomic, production and environmental factors, and digital phenotype data from images or sensors. The challenge will be standardizing data types and ensuring the quality of data to be housed within the hub. Data sets with variable quality lead to poor prediction models and a corresponding reduction in their reusability and value. Further, data privacy and IP issues may need to be resolved before public access to data in a hub is permitted.
- The development of big data sets must address data ownership and privacy. This is particularly important to farmers who have concerns about contributing data and then losing ownership of their data. This challenge could be alleviated with effective communication to the farming community over how the data is stored, shared and used to improve the agriculture industry. Private industry is also wary of generating data and sharing data on publicly accessible data hubs as competitors may be able to access this information. This largely disincentivizes private companies from investing in, or contributing to, public data generation as there is no clear advantage or gains from their investments.

- Sophisticated algorithms and computational methods are required to gain meaning from diverse, linked data sources, such as genomic sequences, plant phenotypic data, geographical information, and climate patterns. Trained personnel with integrated expertise across biology and computer science are needed to translate the data into practical recommendations and solutions. Highly qualified personnel (HQP) are required to realize the potential of artificial intelligence in agriculture.
- Full access to agriculture data is critical for technology-based agriculture practices. Infrastructure to store, manage, and analyze big data is necessary and has significant costs to establish, maintain and operate. An omnipresent challenge is accessing FAIR (findable, accessible, interoperable, reusable) crop data.
- According to an Agri-Food Innovation Council (2017) report[11], despite the potential for farmers to benefit enormously from new digital technologies, limited rural broadband service and the lack of a common analytics platform hinder greater uptake of these technologies.

The key to success is standardizing the type and quality of the data and meta-data incorporated in the hub adhering to common data standards that foster interoperability and data sharing.

OPPORTUNITIES

- There is an opportunity to assemble public and private research experts to design and implement data hubs that will be useful for multiple prairie crop species. If appropriate (meta) data standardization and quality controls are enforced, software tools interrogating legacy data stored in the hub(s) could be tailored to harvest information relevant to Prairie environments, pests, diseases and farming practices. The key to success is standardizing the type and quality of the data and meta-data incorporated in the hub adhering to common data standards that foster interoperability and data sharing. With a solid, connected database, it is possible to integrate artificial intelligence (see below) and more robust analytics on newly generated data and previously generated data to maximize the value derived from each dataset (e.g., to further increase yields, improve the efficiency of input resources, and build sustainable, resilient crops). The advantage of creating a data hub with private, controlled access is that it will allow many authorized users to examine the data and make unique discoveries that benefit the industry. Sharing data will be important to extracting the maximum value of these dynamic data sets but should be done with proper policies regarding ownership and privacy.

[11] Agricultural Institute of Canada (AIC), (2017). *An Overview of the Canadian Agricultural Innovation System.* Retrieved from Agri-Food Innovation Council website: https://www.aic.ca/wp-content/uploads/2021/04/AIC-An-Overview-of-the-Canadian-Agricultural-Innovation-System-2017.pdf

- Implementing artificial intelligence (AI) in genomics has huge potential and has numerous opportunities. Some of these opportunities include:

  1. Identify patterns and information humans and conventional statistical analysis wouldn't be able to detect with better speed and fewer resources.
  2. Promote the development of remote sensors or image analysis for big data collection.
  3. Develop predictive models of genotype-phenotype combinations suitable to increasingly fine-grained environments.
  4. Identify key regulatory factors in complex biochemical pathways by incorporating whole-genome interactions, thus providing novel candidate genes as targets for gene editing. AI technology is rapidly developing, has immense potential in crop genomics and breeding, and will be implemented in many aspects of variety development and gene discovery.

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COMMUNICATING GENOMICS FOR A SUSTAINABLE FUTURE

There is a general consensus among scientists that the application of genomic technologies for crop production is critical for a sustainable future. However, the excitement of the scientific community about genomic technologies is not necessarily reciprocated by different stakeholders, including the public and regulatory bodies, despite a shared interest in food security and sustainable development. The discrepancy can be fuelled by ineffective communication which creates barriers between the experts and the public.

As panelist Camille Ryan articulated during the workshop, "public perception drives public policy", showcasing the need to revisit communication strategies to avoid repeating mistakes of the past at communicating first generation GM crops. For example, implementing a more transparent communication strategy and consistently informing the public about the implications of ongoing and upcoming genomic technologies throughout their development can ensure awareness and address public concerns before the technologies are implemented.

Communication to Regulators and Policy Makers

CHALLENGES

- Communication remains a challenge in the genomics research space and must change in order to enhance public trust, and educate funders and policymakers on the benefits of investing in genomics technology. Policymakers often lack the expertise to fully appreciate the potential of such technologies, and how to utilize them to align with regulatory mandates effectively. If the message regarding the impacts of genomic research is not consistently communicated effectively to the public and policymakers, then funding and research progress may stall rather than accelerate to meet the needs of Canadians.
- Frequent turnover in key regulatory positions complicates consistent messaging and progress in regulatory decisions. New policymakers may have different focuses or introduce different agendas and approaches to address current issues. The turnover often results in the loss of prior investments in communication and education, necessitating a restart of these efforts.

There is an opportunity for scientists and producers to engage more with policymakers and funders as the knowledge exchange can facilitate favourable policy changes and inform funding programs to mobilize resources that benefit researchers and producers.

OPPORTUNITIES

- There is an opportunity for scientists and producers to engage more with policymakers and funders as the knowledge exchange can facilitate favourable policy changes and inform funding programs to mobilize resources that benefit researchers and producers. Greater engagement could alleviate technical misunderstandings surrounding genomics and breeding timelines, and set realistic expectations for implementing new policies that take time and collaborative efforts, such as addressing climate change and fertilizer reduction targets. Communication should be expanded to more mainstream media outlets to limit “talking to ourselves” inside the usual agriculture trade publications.
- Continuous efforts should be made to educate incoming personnel in key regulatory positions and build relationships. At the same time, science communicators need to establish a robust foundation with regulatory bodies that oversee biotechnologies, particularly concerning GM and gene-edited crops, spanning multiple levels of institutions and organizations to ensure the continuity and retention of previous efforts.

Communication to the Public (a Rural/Urban divide)

CHALLENGES

- The demand for sustainable and safe food production is growing[12]. Empirical evidence should govern sustainable and safe food production practices, founded in societal, economic, and environmental stewardship. Unfortunately, there is a knowledge gap between urban consumers and rural food producers in terms of sustainable, safe practices, which has been driven by the spread of misinformation that is not based on scientific findings. We know that public perception influences public policy. The communication gap threatens empirically-based policy development.

Unfortunately, there is a knowledge gap between urban consumers and rural food producers in terms of sustainable, safe practices, which has been driven by the spread of misinformation that is not based on scientific findings.

OPPORTUNITIES

- In the era of genomics science, rapid advancements in crop improvement are feasible by adopting genomic-based technologies, which invariably result in societal, economic, and environmental implications. Genome Canada integrates GE3LS (Genomics and its Ethical, Economic, Environmental, Legal and Social aspects) research into every large-scale applied research project to evaluate genomics-enabled innovations' ethical, environmental, and social aspects. GE3LS research has the opportunity to identify barriers to uptake of genomics technologies including but not limited to producer willingness to adopt, public perception, economic constraints, and environmental impact.

[12] Smyth, S. J., & Charlebois, S. (2024). Agricultural chemical use and the rural-urban divide in Canada. GM Crops & Food, 15(1), 32-39.

- Effective science communication strategies for communicating the benefits and risks of genomic technologies can be directed to producers and consumers. Engaging the public and producers in a dialogue to understand their needs and address their concerns is important to effective communication. It will help foster trust within the research community and mitigate the spread of misinformation. Science communication can focus on storytelling rather than data crunching, showcasing how genomics can serve the needs of producers (e.g., higher yields, higher profits, sustainable practices) and consumers (e.g., safe and sustainable food sources).
- Communication needs to consistently go beyond the usual trade publications and expand into more consumer-facing media and venues to build public awareness and trust around plant genomics. For example, Alberta has open farm days, where the public is invited to participating farms to see how their food is grown.
- Farmers are a great resource for collecting big data on crop performance in different environments that can be connected to genotypes to inform breeding strategies. The hesitancy to participate and contribute data should be addressed through effective communication specifically with the farming community. The approach should show how data is aggregated, kept private and used to extract valuable genotype / phenotype relationships that are directly applied to variety development and growth in the agriculture industry. We should also ensure that the data collected directly benefit on-farm decision-making for farmers, providing incentives for farmers to share data consistently.

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THE GENOMICS REGULATORY ENVIRONMENT

Regulatory bodies are intended to safeguard the public, a commitment that needs to balance the competing goals of fostering innovation and protecting the public welfare. In general, Canada's approach has encouraged innovation in the crop industry. In 2015, Canada adopted the UPOV91 convention regarding variety development which strengthened the rights and privilege of plant breeders[13]. The adoption of UPOV91 led to an increase in Canadian agriculture research investment since the private sector would have improved IP protection. Further, in 2022/23, Canadian regulatory agencies approved gene editing to create new crop varieties that will be treated as conventional varieties under Canada's regulatory system.

CHALLENGES

- Obtaining regulatory approval from the Canadian Food Inspection Agency (CFIA) under plants with novel traits (PNT) regulations is still considered expensive, time-consuming and a barrier to innovation in crop research. A plant breeder applying to register a plant variety carrying a new trait that is not present in cultivated forms of that crop species could trigger PNT regulatory approval, and thus delay the release of the new variety.
- Globally, crops with novel genes have been a topic of contention, as is reflected in Europe's precaution-based approach, resulting in the approval of only one GM crop this century[14]. Many international regulatory frameworks oppose genomic-based technologies for crops[15], creating potential trade barriers[16] for the Canadian Prairies.

OPPORTUNITIES

- Canada approves Plant Breeders Rights (PBR) based on the final product not the method used to create the new variety. Therefore, genetic modification and different forms of gene editing will not necessarily trigger PNT regulations. Plant breeders can develop new varieties using these advanced genomic technologies potentially leading to greater pathogen resistance, environmental resilience and improved crop quality that benefits all stakeholders in the value chain.
- The European Parliament recently voted to ease the regulation of gene-edited crops[17]. Unlike GM crops which are created by introducing foreign DNA into plants, gene-edited crops have their existing DNA altered. Although the European Union originally ruled to treat gene-edited crops as GM crops in 2019, a recent vote now treats them as conventional plants, opening up avenues for genomic innovations.

[13] Seed World. (2020). *Is UPOV 91 Right for You?* Retrieved from Seed World website: https://www.seedworld.com/europe/2020/03/02/is-upov-91-right-for-you/

[14] European Parliament. (2015). *Eight things you should know about GMOs.* Retrieved from European Parliament website: https://www.europarl.europa.eu/topics/en/article/20151013STO97392/eight-things-you-should-know-about-gmos

[15] Turnbull, C., Lillemo, M., & Hvoslef-Eide, T. A. (2021). Global regulation of genetically modified crops amid the gene edited crop boom–a review. Frontiers in Plant Science, 12, 630396.

[16] Smyth, S. J. (2017). Genetically modified crops, regulatory delays, and international trade. Food Energy Secur 6: 78–86.

[17] European Parliament (2024). New Genomic Techniques: MEPs back rules to support green transition of farmers. Retrieved from European Parliament website: https://www.europarl.europa.eu/news/en/press-room/20240202IPR17320/new-genomic-techniques-meps-back-rules-to-support-green-transition-of-farmers

FUNDING AND INVESTMENT IN GENOMICS

These stakeholder relationships need to be maintained and even further enhanced by attracting additional for-profit private sector investment.

The impact that genomic technologies are having on Prairie plant agriculture is substantial. This progress in crop genomics development is tightly linked to crop commodity groups and public funding programs, including the Natural Sciences and Engineering Research Council of Canada (NSERC), Agriculture and Agri-Food Canada (AAFC), and Genome Canada, with further support from provincial programs. These stakeholder relationships need to be maintained and even further enhanced by attracting additional for-profit private sector investment. Prairie plant agriculture will require skilled researchers, more infrastructure, and long-term commitments from investors to span the time required from creation to release of new crop varieties. The technical and creative capabilities of the research institutes in the Prairies are well established, and research programs must be guided by balancing industry needs and government research priorities.

CHALLENGES

- Crop research and the development of new crop varieties take time which contrasts with the short grant/funding cycles that typically span 2-4 years. Moreover, based on political priorities and the imminent periodic ministerial shuffling, publicly-funded research priorities shift, opposing long-term stable public investment. Often, private investments in crop genomics are provided for longer terms. However, investments are driven by corporate priorities. Private investment in publicly-funded research can occur if the outcomes benefit a crop species or industry. However, risk sharing, intellectual property ownership and pathways to implement research outputs need to be considered. Long-term sustainable funding models considering producers, researchers, and market needs to inform public research investment are needed.
- Another challenge is finding the right balance between government priorities and industry/producer wants/needs. Recent government research funding has emphasized sustainable agriculture and mitigating greenhouse gas emissions that affect climate change. As government funding greatly impacts industry funding via co-funding requirements, this change in policy has resulted in a shift in research funding directions. This position contrasts with farmers' interests, who typically would like to see research and investment in agronomic performance. Investment should find the right balance between sustainability and profitability to make the biggest impact.

- Research capacity, HQP, and infrastructure are lagging behind the needs of the agriculture research sector. Underinvestment in these factors is part of the reason why there is a growing research and development gap between the United States and Canada. This challenge may become more evident as genomic research transitions towards AI, phenomics, and big data and the current shortage of HQP to process and interpret important data sets is expected to worsen.

OPPORTUNITIES

- Driving genomics-based plant agriculture in the future will partially depend on attracting people with a wide array of skill sets to this innovative industry. There is an opportunity to consider the trends in genomics and plant research to preemptively train HQP in areas of high demand. Organizations like Western Grains Research Foundation and Manitoba Crop Alliance are initiating funding to support capacity building in response to the limited HQP and infrastructure required to advance biotechnology and innovations in the Prairie crop industry[18,19,20].
- The implementation of AI and big data analysis will be prevalent in the future. Education, training and support should be improved to attract more HQP to this area. Genome Alberta, in collaboration with BioNet and the Government of Alberta, has a work placement program[21] that supports internships for recent graduates with computer sciences skills in Alberta-based life sciences companies.
- Large-scale research projects should take the opportunity to include public, and private partnerships (P3) and elevate the level of private investment in capacity building and infrastructure. This has many benefits including, a) sharing the financial burden over the long term, b) more immediate commercial implementation via private partners, c) industry pull for innovation to focus on project deliverables and d) attracting and training HQP with a more innovation-focused mindset.

The implementation of AI and big data analysis will be prevalent in the future. Education, training and support should be improved to attract more HQP to this area.

[18] WGRF (2022). *Accelerating Capacity.* Retrieved from WGRF website: https://wgrf.ca/accelerating-capacity/

[19] WGRF (2022).*Investing in Future Scientists.* Retrieved from WGRF website: https://wgrf.ca/special-initiatives/graduate-scholarship/

[20] Manitoba Crop Alliance (MCA). (2024). *Bursary Program.* Retrieved from MCA website: https://mbcropalliance.ca/news-and-events/bursary-program/

[21] Bioinformatics Network (BioNet) Alberta. (2024). *BioNet Work Placement Program.* Retrieved from website: https://www.bionet-alberta.org/

WHAT'S NEXT

The March, 2024 workshop 'Genomics at Work for Prairie's Crop Industry' was an opportunity to engage participants representing a broad range of agriculture innovation players. Approximately 150 participants including industry, academia and other agriculture organizations joined the forum to build a better understanding of the current state of genomic technologies for crops and discuss both opportunities and barriers in the broader adoption of genomic-based innovation into crop production in the Prairies.

Genome Alberta and Genome Prairie, as part of the national Genome Enterprise, are key players in advancing agriculture innovation across Canada.

Through the utilization of genomics technologies, significant progress has been made towards improvements in crop breeding. During the presentations and discussion, it became clear that the barriers to the broader adoption of genomics technologies are no longer associated with the technical limitations of generating the data as they once were. In part, this is due to the declining costs associated with generating genomics data which have come down exponentially from the early days of the genomics revolution that began in earnest with the launch of the human genome project in the 1990's.

Effective communication, along with education about new technologies, are now being recognized as critical factors for building broader acceptance and trust with the public (consumers). These important factors are often necessary for the successful implementation of genomic technologies. The Canadian Food Inspection Agency's guidance for plants with novel traits (PNT) is regarded by many as a global leader in science-based and transparent regulation. While this has been a helpful step, additional policy direction that balances the need for environmental, food and feed safety with the need to innovate to feed a growing population will also be required. This theme reflects similar points which have been raised by other groups. For example, the Agri-food Innovation Council (AIC)[22] and the Grain Growers of Canada (GGC)[23], stress the importance of aligning policy with practical implementation strategies.

Additionally, the discussion during the workshop raised the significant advances made in high-throughput phenotyping which combined with the ability to generate large amounts of genomics data and machine learning/ AI approaches are shaping the trajectory of crop genomics. With the ability to generate more of these large and complex data sets comes the challenge of storage, standardization, processing, and integration. Also discussed, was the need to make new data resources and tools accessible to small farms, small to medium-sized enterprises and big industries alike to foster widespread adoption and enable further innovation.

[22] *An Overview of the Canadian Agricultural Innovation System (2017)*. Retrieved from Agri-food Innovation Council website: https://www.aic.ca/publications/an-overview-of-the-canadian-agricultural-innovation-system/

[23] *Road to 2050 Policy Recommendations*. Retrieved from Grain Growers of Canada website: https://graingrowers.ca/wp-content/uploads/2024/03/GGC_Road-to-2050-Policy-recommendations-v2.pdf

Genome Alberta and Genome Prairie, as part of the national Genome Enterprise, are key players in advancing agriculture innovation across Canada. Our role has been to support genomics-based research while considering the social, legal, environmental, and economic considerations that such research may impact. The outcomes of this workshop again reinforced the need to consider these socio-economic factors well before designing a genomics research program. In the furure, these themes and other insights gained through the workshop will help to inform future research and innovation programs to enable the greatest benefits to our agriculture sector.

ACKNOWLEDGEMENTS

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LIST OF ORGANIZATIONS PARTICIPATING ON THE PANEL

Genome Alberta

Genome Prairie

University of Saskatchewan - Department of Agriculture and Resource Economics

Agriculture and Agri-Food Canada - Science and Technology Branch

Agriculture Research Institute of Ontario

Canadian Grain Commission

CropLife Canada

Bayer Crop Science Canada

Global Institute for Food Security (GIFS)

LIST OF ORGANIZATIONS/DEPARTMENTS THAT ATTENDED THE WORKSHOP

AgriView Inc.

Agri-West Bio

Alberta Beekeepers Commission

Alberta Canola Producers Commission

Alberta Grains

BASF Canada

Bayer CropScience Canada

BioAro

Birds Eye Agricultural solutions

Brewing and Malting Barley Research Institute (BMBRI)

Canadian Agri-Food Automation and Intelligence Network (CAAIN)

Canadian Food Inspection Agency

Canola Council of Canada

Corteva Canada

Earthmaster Environmental Strategies Inc.

Farm Credit Canada (FCC)

Farmland Legacy Biotech

Government of Alberta

Government of Canada - National Research Council Canada

Government of Manitoba

Government of Ontario - Ministry of Agriculture, Food and Rural Affairs

Government of Saskatchewan - Ministry of Agriculture

Humaterra

Manitoba Crop Alliance

NRGene Technologies LTD

Olds College - Field Crop Development Centre

Pacific Ridge Corporation

Prairies Economic Development Canada (PrairiesCan)

Protein Industries Canada

Results Driven Agriculture Research (RDAR)

Sask Wheat Development Commission (SaskWheat)

Saskatchewan Barley Development Commission (SaskBarley)

Saskatchewan Canola Development Commission (SaskCanola)

Saskatchewan Polytechnic - School of Natural Resources and Built Environment

Seeds Canada

Shahid Bahonar, University of Kerman, Department of Mining Engineering

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University of Alberta - Department of Agricultural, Food and Nutritional Science

University of Alberta - Department of Resource Economics and Environmental Sociology

University of Alberta - Department of Chemistry

University of Alberta - Faculty of Engineering - Electrical & Computer Engineering Dept

University of Alberta – Faculty of Medicine & Dentistry - Dentistry Dept

University of Alberta - Faculty of Science - Biological Sciences

University of Calgary - Department of Biological Sciences

University of Calgary - Department of Ecosystem and Public Health

University of Calgary - Department of Microbiology, Immunology and Infectious Diseases

University of Calgary - Faculty of Veterinary Medicine

University of Calgary - Haskayne School of Business

University of Calgary - School of Public Policy

University of Laval - Department of Phytology

University of Lethbridge - Department of Biological Sciences

University of Manitoba - Faculty of Agricultural and Food Sciences

University of Saskatchewan - Department of Agricultural and Resource Economics

University of Saskatchewan - Department of Plant sciences

University of Saskatchewan - Department of Soil Science

University of Saskatchewan- Johnson Shoyama Graduate School of Public Policy

Verschuren Centre

Western Grains Research Foundation (WGRF)

Yield10 Bioscience

ZYUS Life Sciences Inc.

Genome Alberta

403.210.5275

info@genomealberta.ca

3512-33 Street NW Suite 200

Calgary, Alberta T2L 2A6 Canada