The Opportunity for AGRI-FOOD

Genomics in Canada: Ours for the Making

A Sector Strategy led by Genome Prairie and the Ontario Genomics Institute, with support from regional Genome Centres across Canada and funded by Genome Canada.

May 2013

GenomeCanada GenomeBritishColumbia GenomeAlberta GenomePrairie OntarioGenomicsInstitute GenomeQuébec GenomeAtlantic

Genomics* is the science that aims to decipher and understand the entire genetic information of an organism (i.e. microorganisms, plants, animals and humans) encoded in DNA and corresponding complements such as RNA, proteins and metabolites.

The knowledge and innovations emerging from this field are finding solutions to complex biological challenges, while at the same time raising questions of societal and economic importance.

Genomics has already brought huge economic and societal gains to Canadians through better healthcare, improving food quality, safety and production and protecting our environment and natural resources.

Looking ahead, genomics will be the foundation of Canada's growing bio-economy (all economic activity derived from life science-based research), which is estimated to be responsible for some 2.25 per cent of GDP, or about $38 billion, by 2017.

Increasingly, genomics is equipping a range of Canadian industries—agriculture, energy, mining, forestry, fisheries and aquaculture and health, among others—with cutting-edge science and technologies. This is driving growth, productivity, commercialization and global competitiveness, while finding solutions to environmental sustainability problems.

Genome Canada and the six regional Genome Centres across the country are working to harness the transformative power of genomics to deliver social and economic benefits to Canadians.

This paper is one in a series of four sector strategies funded by Genome Canada and co-led by the Genome Centres. They include: Agri-Food, Energy and Mining, Fisheries and Aquaculture and Forestry. Each strategy, developed in consultation with sector stakeholders, maps out how the sector can further leverage the transformative power of genomics, and related disciplines, to its advantage.

Given Canada's footprint in these key natural resource sectors, the time is ripe for our industries to take full advantage of the power and promise of genomics.

**Broadly speaking, our definition of genomics includes related disciplines such as bioinformatics, epigenomics, metabolomics, metagenomics, nutrigenomics, pharmacogenomics, proteomics and transcriptomics.*

For more information, visit **www.genomecanada.ca/en/sectorstrategies**.

Prepared by Agri-Food Project Services Ltd.
Published by Genome Canada, 2013

Cette publication est aussi disponible en français.

Genome Canada would like to thank the Government of Canada for its continued support.

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

The application of scientific advances in genetics to agriculture since the beginning of the 20th century has been one of the most successful enterprises in human history. In recent years, better understanding of the function and structure of the complete set of genetic instructions in crops, livestock and microorganisms through genomics has dramatically expanded the potential to address societal challenges and opportunities for the agri-food sector through genetics.

Canada's agri-food sector is one of the foundations of the national economy from coast to coast, accounting for just over eight per cent of the country's total Gross Domestic Product (GDP) and directly employing 2.1 million people in 2011. The sector is a major driver of exports, valued at $40.3 billion in 2011.

Population growth, climate change, resource depletion, global competitiveness, government policy and regulatory processes, human health and nutrition, and sustainability are all issues the world is grappling with, issues that are placing a growing strain on available resources. Producing more high quality, safe food on less land with less environmental impact will be one of the greatest challenges of the twenty-first century. By continuing investment in advances enabled by genomics, the agri-food sector will be positioned to master that challenge. Canada can play a leading role in providing solutions.

The agri-food sector also will be one of the major growth engines of Canada's economy in this century. Genomic research can directly contribute to advancing Canada as a world leader in this sector and gain a greater and more diverse global market share through competitive production systems and innovative products.

In Canada, the agri-food sector has embraced research, development and implementation of genomics in a significant way, on a level comparable to the other leading sector, human health. Canada's agri-food infrastructure is one of its strengths, in combination with world-class public-private (producer, corporate, foundational) partnerships (P3s), enabling the sector to make advances in the application of genomics.

Examples of Canadian genomics success stories include herbicide tolerant pulses that have made Canada a leading player in the global lentil industry; herbicide tolerant canola varieties that have resulted in considerable reduction in pesticide use and greater carbon sequestration; rapid improvements in improved diagnostic tests and vaccines; the elimination of the pork stress syndrome gene from pig populations that has improved meat quality; and Millennium Asparagus, widely lauded for the current competiveness of the asparagus industry.

A pan-Canadian approach to agricultural genomics can help address sector challenges in many ways. This includes adapting agricultural production to accelerated climate change, maintaining global competitiveness by increasing production efficiencies, achieving the safety and quality attributes demanded by the market, and improving the health of crops and livestock to improve global food security.

Agri-food is a sector that promises a high rate of return on funding that moves technological developments and innovations from the lab to commercialization on Canadian farms and in Canadian processing plants. Areas of need that present opportunity are remarkably well aligned with the recently launched Growing Forward 2 framework, which focuses on competitiveness and market growth, adaptability and sustainability, and innovation.

Overall, there is opportunity for investments to benefit human health and nutrition, deliver better solutions for environmental needs and climate change, and contribute to economic growth, expanding trade and political stability. These gains will be achieved through outcomes such as crop innovations that deliver more bioactive benefits to human health, pathogen reduction in livestock that lowers disease risk, and plants and animals that are better able to withstand Canada's changing climate. Genomics can drive change in all of these areas, but significant results will take time and sustained investment to be realized. Making investments supporting genomics in the agri-food sector a national priority will yield many long term benefits for Canada.

Recommendations for genomics-based agri-food activity include:

- **Boosting Canada's competitiveness through food quality.** Genomics can expand global market opportunities by addressing food quality opportunities through breeding for specific traits and attributes that have high-value food, health or bioproduct applications.
- **Adapting to climate change through hardier crops and livestock.** Production efficiencies can be improved by increasing resilience to disease, drought and temperature extremes and supporting the development of tools to detect invasive pathogens, insects and weeds.
- **Improving human and animal health.** Producing food with enhanced food safety or nutritional and functional attributes can improve human health, as well as health of livestock by improving their immune responsiveness. This latter kind of focus reduces the risk of transmission of animal diseases with human health implications to people.
- **Bolstering global food security and decreasing food waste.** Genomics can make crops better able to withstand transport, storage and handling, leading to less food waste and improved availability of food in many parts of the world.

There are also challenges identified in this report that, although not solvable through the use of genomics, must be addressed in order for the sector to be able to effectively address issues of food security and quality, climate change and human health. Additional recommendations include:

- **Smoothing the regulatory path.** Better and more efficient communications between different regulatory departments or agencies is needed to help streamline the regulatory system.
- **Maintaining public confidence in the food supply.** The sector must take a more proactive role in public outreach concerning science, agriculture and food production. Genomics can support sustainable production practices as well as help assure food safety by easily identifying origin and presence of contaminants.
- **Building strong networks between academia, government, producers and industry.** Maximizing the use of available resources and better alignment of industry research needs with academic research capacity and capability will help further advance the development and use of genomics in agri-food.

Continued investment in the development of genomics by both the public and private sectors can help Canada turn these challenges into market advantages and establish global leadership in this field.

Ultimately, the optimal uptake and use of genomics and related technologies will help create and support a better world for future generations—one with better health, increased food security, and more sustainable production practices. Continued public, producer and private sector support of genomics is essential to achieving the great outcomes that are ours for the making.

2. ABOUT THE INITIATIVE

A national steering committee of industry, academic and government representatives was assembled to develop this strategy. This committee met multiple times via conference call and members also provided input and feedback through review of documents and online discussion. In alphabetical order, members are:

- Brad Fournier, Executive Director, Alberta Livestock and Meat Agency
- Rory Francis, Executive Director, PEI BioAlliance
- John Kelly, Vice President, Ontario Fruit and Vegetable Growers Association
- Gord Neish, Consultant, Nature Niche Scientific Consulting
- Garth Patterson, Executive Director, Western Grains Research Foundation
- Peter Phillips, Professor, University of Saskatchewan
- Reno Pontarollo, President and Chief Executive Officer, Genome Prairie
- Alison Symington, Vice President Corporate Development & Communications, Ontario Genomics Institute
- Christine Tibelius, Oilseeds Portfolio Co-ordinator, Agriculture and Agri-Food Canada
- Janice Tranberg, Vice President Western Canada, CropLife Canada
- Gijs van Rooijen, Chief Scientific Officer, Genome Alberta
- John Webb, Director of Emerging Science, Maple Leaf Foods Inc.

Contributions were also made by:

- Chris Barker, Chief Scientific Officer, Genome Prairie
- David Castle, Professor, University of Edinburgh
- Klaus Fiebig, Independent Consultant
- Gabriel Piette, Science Director, Agriculture and Agri-Food Canada–Saint-Hyacinthe
- David Sparling, Agri-Food and Innovation and Regulatory Chair, Ivey School of Business

A larger group of sector stakeholders met for a workshop in Winnipeg on February 28–March 1, 2013 to review a draft of this strategy and provide input on a series of topics. They were also given the opportunity to review a final draft of the strategy and submit comments. There were 80–90 individuals who participated in the Winnipeg workshop, representing all regions of Canada. Approximately 60 per cent of participants were from the crops sector and 40 per cent from livestock; 70 per cent represented industry or academia and 30 per cent were from government. A summary of the key take-home messages from the workshop can be found in Appendix 1 of this document.

Strategy development support was provided by James Farrar, Jayeff Partners (facilitator); Lilian Schaer, Agri-Food Project Services Ltd (writer and editor); and Faye Pagdonsolan, Genome Prairie (project management and workshop co-ordination). Funding for the strategy's development was provided by Genome Canada.

3. A NOTE ABOUT FOOD SECURITY

Food safety and food security are closely related—yet different—topics. Food safety addresses the production, process, storage, handling and preparing of food and food products in ways that do not cause injury or illness in those that are consuming it. Food security, on the other hand, is "…when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life", according to a definition from the World Food Summit of 1996[1].

According to *The State of Food Insecurity in the World 2012*, a joint publication of the Food and Agriculture Organization of the United Nations, the International Fund for Agricultural Development and the World Food Programme, almost 870 million people worldwide were chronically undernourished in 2010–12. Of those, 850 million live in developing countries, where approximately 15 per cent of the populations are estimated to be undernourished[2].

The report states that agricultural growth is particularly effective at reducing malnourishment, decreasing extreme poverty and hunger by generating employment and increased returns. However, economic and agricultural growth should be "nutrition-sensitive", meaning growth must lead to better nutritional outcomes for the poor.

Genomics and genomics-related technologies in agri-food can play a strong role in supporting and enhancing global food security. A country like Canada, with a well-developed research infrastructure and strong agricultural sector that has embraced the adoption of genomics, can be a global leader in helping to improve food security.

Canada has already acknowledged the importance of food security and the leading role it can play in this area through the establishment of the Global Institute for Food Security in Saskatchewan and the McGill Institute for Global Food Security in Quebec.

Canada's leadership potential in food security is two-fold: producing and exporting food stuffs and sharing and adapting innovations and technologies to be used in other parts of the world. This report will explore and address some of these opportunities.

[1] http://www.who.int/trade/glossary/story028/en/

[2] http://www.fao.org/docrep/016/i2845e/i2845e00.pdf

4. IMPORTANCE OF THE AGRI-FOOD SECTOR TO THE CANADIAN ECONOMY

Canada's agri-food sector includes farm input and service supply industries, primary agriculture, food and beverage processing, food distribution, retail, wholesale, and foodservice. In 2011, it directly provided one in eight jobs, employing 2.1 million people and accounting for eight per cent of the country's total Gross Domestic Product (GDP). Primary agriculture has grown an average of 1.4 per cent annually since 1997.

Export opportunities are critical for the growth of most sectors of the Canadian agri-food industry. In 2011, Canada was the sixth-largest exporter of agricultural and agri-food products in the world (EU countries are counted as a single bloc), with exports valued at $40.3 billion. Canadians enjoy some of the lowest food costs in the world, with spending on food from stores accounting for less than 10 per cent of personal household expenditures.

Canada's agri-food sector is a major employer in most provinces, contributing jobs and economic activity in primary agriculture as well as related sectors. Employment in primary agriculture sits at 2.3 per cent of Canada's total employment, which is comparable to the average of G7 nations but higher than in the United States and the United Kingdom[3].

Canada's agri-food sector is widely dispersed and diversified across the country and is therefore uniquely integrated from a national standpoint. It also connects the rural population of Canada, where primary agriculture is done, to the urban centres, where most food processing is undertaken and where the major domestic markets are situated.

It should also be noted that Canada is also a producer and exporter of key foodstuffs needed for world food security. According to data from the Food and Agriculture Organization (FAO), Canada produces about two per cent of the world's cereals and 3.4 per cent of the global oilseeds and pulses. Canada's share of world trade is even larger: Canadian farmers satisfy about eight per cent of the international trade in pork, 12 per cent of the wheat trade, and almost one third of the total edible oilseed and pulse markets[4].

The province of Saskatchewan alone provides over 60 per cent of global exports for lentils, 57 per cent of field peas, 55 per cent of flax and 34 per cent of global durum exports[5].

[3] *An Overview of the Canadian Agriculture and Agri-Food System 2013*, produced by Agriculture and Agri-Food Canada–http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1331319696826

[4] Food and Agriculture Organization of the United Nations (FAO) at www.faostat.fao.org

[5] *Saskatchewan Agriculture, highly cultivated*; http://www.agriculture.gov.sk.ca/Default.aspx?DN=dcc42704-e01a-40c5-928d-ce64a5dd5844

5. CANADA'S AGRI-FOOD RESEARCH CAPACITY, LEADERSHIP AND STRENGTHS

Canada has extensive and varied agri-food research capacity in agriculture, food and biotechnology clusters across the country in both public and private institutions. Industry partners are leading or supporting research in many areas and producer-funded commodity organizations at both the national and provincial levels, including beef, pork, grains, oilseeds, pulses, and fruits and vegetables, are also involved in funding and supporting agri-food research.

Canada has among the world's best scientific infrastructure (including our universities, key research facilities and federal labs), vibrant and engaged public-private (producer, corporate, foundational) partnerships (P3s) and a regulatory system that is generally well regarded by international counterparts.

An extensive list of major Canadian academic and governmental research centers, institutes and networks involved in agri-food sector research and innovation activities (excluding aquaculture and fisheries) can be found in the Appendix of this report.

Federal, provincial and industry investments have contributed to many leading-edge initiatives. Key examples include:

5.1 INTERNATIONAL AND NATIONAL INITIATIVES

- **Wheat Initiative**, where several Canadian scientists are involved in an international effort coordinating worldwide research in the fields of wheat genetics, genomics, physiology, breeding and agronomy. The results will contribute to increased yields, improved yield stability and better quality wheat[6].
- **Canadian Wheat Alliance**, where the National Research Council of Canada is working with partners on developing a wheat program focusing on research in genomics, biotic/abiotic stresses, cell technologies, plant development, and beneficial wheat-microbe interactions. The goal of the program is to improve wheat yield for the benefits of Canadian farmers. Partners include Agriculture and Agri-Food Canada, the University of Saskatchewan and the province of Saskatchewan.
- **Genomics Research and Development Initiative**, the funding program for genomics research in federal laboratories that has invested $86.3 million in crop genomics research at Agriculture and Agri-Food Canada since 1999. In addition, two interdepartmental genomics projects addressing quarantine and invasive species that threaten agricultural production, and food and water safety, respectively, are currently underway.
- **Canadian Agri-Science Clusters Initiative**, part of Agriculture and Agri-Food Canada's Growing Canadian Agri-Innovations program that includes 10 science clusters focused beef cattle, dairy, swine/pork, poultry, canola/flax, pulse, wheat breeding, edible horticulture, ornamental horticulture and organic agriculture[7]. Under Growing Forward 2, the AgriInnovation Program will build on this work[8].
- **International Barcode of Life**, based at the University of Guelph, which has a growing library of DNA-categorization of thousands of species. It is the largest biodiversity genomics program ever launched and has a wide range of funders, especially through Genome Canada's International Consortium Initiative[9].

5.2 GENOME CANADA'S LARGE-SCALE AGRI-FOOD GENOMICS PROJECTS

- **Application of Genomics to Improve Swine Health and Welfare**, a $12.4 million project that is applying genomics to help reduce the impact of two of the most common diseases in commercial pig

[6] http://www.wheatinitiative.org/

[7] http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1316118882467&lang=eng

[8] http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1354301302625&lang=eng

[9] http://ibol.org/about-us/sponsors/

production—Porcine Circovirus Associated Disease (PCVAD) and Porcine Respiratory and Reproductive Syndrome (PRRS).

- **Canadian Cattle Genome Project** (formerly Whole Genome Selection through Genome Wide Imputation in Beef Cattle), is conducting research to define the social and economic benefits and costs of using genomic technology in livestock improvement; developing tools for low-cost, accurate genome wide selection methodologies for breeders; and completing research so that genome wide selection can be used in Canadian herds for particularly difficult yet valuable traits. The total project value is $8.2 million.
- **Canadian Triticum Advancement through Genomics (CTAG)**, an $8.5 million project aimed at developing genomic tools and increasing genomic capacity in Canadian wheat breeding programs. This is Canada's contribution to the sequencing effort led by the *International Wheat Genome Sequencing Consortium*.
- **Designing Oilseeds for Tomorrow's Markets (DOTM)**, a $14.8 million project where researchers identified more than 100,000 expressed sequence tags in canola. This research will help create oil seeds with improved yield, composition, and quality.
- **Enhancing Canola through Genomics (ECTG)**, where over 250,000 genetic sign-posts were created and over 40,000 canola genes were identified. A number of important canola genomic tools were developed, including a method called DNA microarraying that allows researchers to study which canola genes are important in various growth phases. The project's total value was $9.5 million.
- **Functional Genomics of Abiotic Stress (FGAS)**, a $19.4 million project focused on wheat and canola that has provided foundational tools for the development of plants that are resistant to certain abiotic stresses, such as early frost, extreme temperature or adverse soil conditions.
- **Genomics in Agricultural Pest Management**, which is creating tools and technologies to control spider mites. Insects and mites destroy 13 per cent of all potential crops; spider mites alone feed on more than 1,000 different plant species. The total value of the project is $6.3 million.
- **Genomics of Sunflower**, a $10.5 million project that is sequencing the genomes of the sunflower family, the largest plant family on earth with over 24,000 described species that include economically important crops, wildflowers, common allergens, valuable medicinals and costly invasive plants and weeds. The project also includes development of sunflower as a new biofuel source with unique advantages as an annual woody plant.
- **Grape and Wine Genomics**, which is applying genomic and genetic techniques to studying important wine varietals and yeasts used in wine production. This project is valued at $3.4 million.
- **Total Utilization of Flax Genomics (TUFGEN)**, an $11.8 million project to increase the benefits and versatility of flax by developing genomic-based tools to assist in crop breeding, to improve field performance and to enhance seed and fibre traits.
- **Value Addition through Genomics and GE3LS (VALGEN)**, a diverse team of researchers from across Canada that is working to shape public policy and streamline regulation in order to move innovation from the laboratory towards practical applications. Key project areas include the role of regulation, knowledge management, intellectual property and technology transfer in moving discoveries into the marketplace. The total value of the initiative is $5.4 million.

The total value of Genome Canada's agri-food research effort is approximately $202.7 million[10].

[10] http://genomereports.ca/section.php?Action=List2&Lang=En&addnew=&Report=consolidated_commitments.php&Report_Text=Funding+Commitments&Nav=Section&ID=3&Login=&Password=&Consolidated_Centre=ALL&Consolidated_Category=ALL&Consolidated_Sector=Agriculture&Consolidated_Competition=ALL&Consolidated_FY=ALL&Consolidated_Status=ALL

6. THE SOCIO-ECONOMIC IMPACT OF SUCCESSFUL GENOMICS-ENABLED SOLUTIONS

Current evidence and opinion is that global investment in research and development in agri-food innovation is inadequate.

Pardey, Alston and Beintema (2006)[11] reported that global agri-food research and development (pre-, on- and post-farm effort, including biotechnology-related research and development) totaled $36.5 billion US in 2000. Approximately 37 per cent of that was conducted by private firms, virtually all of it in developed countries. As Graff, Zilberman and Bennett (2009)[12] showed, the research sieve culls all but an increasingly small percentage of inventions. The implication is that one would need a large flow of effort upstream to realize even modest uptake and use.

Pardey, Alston and Beintema (2006) used similar data to develop a longitudinal database of agricultural research. Both those and other related analyses concluded that while private sector investments in research and development accelerated in the 1990s, public sector research remained relatively flat, which many estimate will have a negative impact on productivity in primary agriculture.

In May 2013, the Chicago Council on Global Affairs released a report urging the United States to double its investment in agricultural research and development by 2023 and to focus funding on priorities that will help address water shortages, climate change and weather variability; align agricultural production with nutrition and ensuring food is produced in a sustainable manner[13]. The study's authors, a committee of U.S. development, agriculture and foreign policy experts, recommended more investment in science in order to increase agricultural production sustainably.

Expanding the flow of research and development funds to the agri-food sector is only part of the solution. To succeed, both Canada and our major global research collaborators and trading partners need to develop and enhance our absorptive capacity to identify and repurpose the best and most appropriate research from wherever it comes and to established adaptive systems to deal with the uncertainties of both scientific development and commercial demand. The literature[14] suggests that the mostly likely successful strategy would involve strategically linked or networked science through public-private partnerships, and locally-based but globally-linked innovation systems.

The gains to research in agri-food investment remain high. A recent landmark meta study on returns to research by Alston et al. (2000)[15] shows that the return on investment on more than 1800 research efforts was over 70 per cent, suggesting there is woefully inadequate investment. This finding was also supported in a 2007 policy brief by Gray and Malla, who indicated that the high rates of return suggest a persistent underinvestment in agricultural research by both the public and private sectors[16].

[11] Pardey, Philip G.; Alston, Julian M.; and Beintema, Nienke M. 2006. Agricultural R&D spending at a critical crossroads. Farm Policy Journal 3(1): 1-9.

[12] Gregory Graff, David Zilberman, and Alan Bennett, "The Contraction of Agbiotech Product Quality Innovation," Nature Biotechnology, Vol. 27, No. 8 (August 2009), pp. 702-704.

[13] http://www.thechicagocouncil.org/files/About_Us/Press_Releases/FY13_Releases/2013_Symposium_Report_Global_Food_Security.aspx

[14] Phillips, P., Webb, G., Karwandy, J, and Ryan, C. 2012. Innovation in Agri-food Research Systems: Theory and Case Studies. CABI.

[15] Alston, J., M. Marra, P. Pardey and T. Wyatt. 2000. Research returns redux: a meta-analysis of the returns to agricultural R&D. Australian Journal of Agricultural and Resource Economics 44(2), 185-215.

[16] Gray, Richard and Stavroula Malla, Cairn Policy Brief 2007. The Rate of Return to Agricultural Research in Canada.

Smyth and Phillips (2008)[17], Singla and Naseem (2012)[18] and others show that the optimal gains to research are often not realized due to delays in the gestation of the new products. In comparable analyses of the relative returns under different regulatory regimes, these studies show that the returns to investment are most affected by delays in decision-making, and not by the absolute cash cost of regulatory compliance or the underlying structure of the intellectual property regime.

[17] Smyth, S. and P. Phillips. 2008. Thresholds for Profitable Genomic Innovations. Presentation to the ICABR Conference, Ravello, Italy, June 12-14.

[18] Singla, R and A. Naseem (2012) "Ex-Ante Economic Impact Analysis of Novel Traits in Canola" Presented at the triennial meetings of the International Association of Agricultural Economics, Foz du Iguacu, Brazil, August 20-25, 2012.

7. SUCCESS OF CANADIAN INVESTMENTS IN AGRI-FOOD GENOMICS

In Canada, the agri-food sector has embraced research, development and implementation of genomics in a significant way, on a level comparable to the other leading sector, health.

Advances like herbicide tolerance and conservation tillage systems have completely changed how we farm and grow crops[19]. Genomics tools play a significant role in genetic research—plant and livestock breeding—and have already generated much efficiency. All significant crop and livestock breeding programs in Canada utilize genomics as a primary selection tool.

The use of Marker Assisted Selection and other genomics technologies has made a vast difference to breeding, reducing the cost through less phenotyping and shortening the cycle time to commercial introduction. The University of Guelph, for example, is ranked as Canada's most inventive university, a ranking based on the number of innovations introduced[20]. This ranking is almost entirely due to its breeding introductions—the genetic selection tools provided by genomics have made this pace of new introductions possible.

Compared to other sectors of the Canadian economy, agri-food is already very active in commercialization and technology translation. It's a sector that is ripe for additional investment to continue to advance the move of genomics-based technological developments and innovations from labs to farms and processing facilities. Examples of Canadian success stories include:

HERBICIDE-TOLERANT LENTIL PRODUCTION MAKES CANADA WORLD'S LARGEST LENTIL EXPORTER

A trait for herbicide tolerance was discovered and incorporated into lentil breeding lines and then finished into varieties by researchers at the University of Saskatchewan with funding from Saskatchewan's Agriculture Development Fund (ADF), BASF and the Saskatchewan Pulse Growers. The varieties were commercialized in collaboration between BASF and the Saskatchewan Pulse Growers, and have helped establish Canada as the world's largest lentil exporter[21].

HERBICIDE-TOLERANT CANOLA REDUCES IMPACT ON THE ENVIRONMENT

Farmers began growing herbicide-tolerant canola in Western Canada in 1997. A study one decade later showed a decrease in herbicide active ingredient use of approximately 1.3 million kg and fewer tillage passes resulted in an estimated one million tonnes of carbon being sequestered or no longer being released[22].

MILLENNIUM ASPARAGUS INCREASES PRODUCER COMPETITIVENESS

Millennium Asparagus was developed by a team of University of Guelph researchers led by Dr. Dave Wolyn. It is rich in nutrients and widely renowned for its outstanding performance, sustainability, marketability and industry impact. Millennium is a major contributor to the current competitiveness of the asparagus industry and accounts for an estimated 70 per cent of all seed

[19] http://www.fao.org/docrep/006/Y5031E/y5031e0i.htm

[20] http://catalystcentre.uoguelph.ca/pages/news/u-of-g-ranked-most-inventive-university-in-canada

[21] https://agro.basf.ca/West/News/item3462.html

[22] http://www.sciencedirect.com/science/article/pii/S0308521X11000151

sold in Ontario[23], and was recognized at the Royal Agricultural Winter Fair in 2005 as Seed of the Year. In 2012, a new Ontario grower-driven asparagus seed business called Fox Seeds was formed to help develop Millennium's presence in other markets[24].

PLANT GROWTH AND MATURATION CONTROL BOOSTS RESILIENCE, YIELD AND RESISTANCE

Dr. John Thompson and colleagues at the University of Waterloo have discovered that the eIF5A gene acts like a biological switch that regulates senescence (maturation) in one position and growth in another. By controlling the switch, it is possible to affect yield, resistance to disease, and resilience to environmental stresses. The versatile capability of the eIF5A technology is currently licensed to and being field-tested by multinationals Bayer Crop Science (canola, rice, and cotton) and Monsanto (soybean and corn). The technology is also licensed and being field-tested in trees (ArborGen; More Wood-Less Land) and alfalfa (Cal/West Seeds) and bananas by Rahan Meristem out of Israel. Researchers at this firm have demonstrated that the eIF5A switch can double shelf life and are testing its ability to promote resistance to the fungus that causes black Sigatoka, the most important disease in banana production world-wide.

GENOMIC TESTS MEASURE MEAT TENDERNESS

Canadian investment in agri-food genomics has resulted in a variety of novel ways to measure the quality of meat we consume. Canada played a leading role in the development of the first high-density genomic test in cattle, which was used in a number of genome-wide association studies that have resulted in the development and patenting of numerous efficiency, carcass quality, and health traits in cattle. One such Canadian-led discovery was the identification of a single nucleotide polymorphism (SNP) in a gene encoding the protein calpastatin, which is associated with meat tenderness.

BOV50SNP CHIP USED GLOBALLY TO TEST GENETIC MERIT IN CATTLE

The Alberta Bovine Genomics Program resulted in Canada playing a key role in the sequencing of the first bovine genome and in the development of the first commercial high-density genomic tests in the cattle industry. The first of these tests, the 50k SNP panel, resulted from a collaborative effort between various institutions and organizations and the Illumina Bov50SNP chip is now used routinely for testing genetic merit in cattle, especially dairy breeds, around the world.

GENE REMOVAL IMPROVES PORK QUALITY

Researchers at the University of Guelph and University of Toronto discovered the halothane gene (HAL-1843 mutation in RYR1) in pigs responsible for porcine stress syndrome (PSS) and extreme muscling. Pigs carrying this gene are more likely to produce pale, soft and exudative (PSE) pork whose unappealing appearance makes it unattractive to consumers. It is also less suitable for processing due to its low water-holding capacity. Use of the gene to reduce stress was patented and licensed worldwide; elimination of this gene from pig populations has resulted in improved meat quality[25].

[23] http://www.asparagus.on.ca/article.php?id=12

[24] http://www.delhinewsrecord.com/2012/03/20/asparagus-growers-start-seed-company

[25] Genetic factors influencing pig meat quality", Polish Academy of Sciences, Institute of Genetics and Animal Breeding, Jastrzębiec, Poland; page 1 (http://lhu.emu.ee/downloads/Welfood/WP3T6L2.pdf)

GENETIC MARKERS TO REMOVE ODOUR AND IMPROVE PORK TASTE

Work in progress at the University of Guelph has identified approximately 100 SNP markers for boar taint. Boar taint is an offensive odour or taste that can be evident when cooking or eating pork from non-castrated boars.

RAPID GENOMICS TESTING FOR PATHOGEN PRESENCE BOOSTS FOOD SAFETY SYSTEM

Joint initiatives including Genome Canada, Genome Alberta and the Canadian Food Inspection Agency are helping to bring genomics into the Canadian food inspection system. The development of rapid genomics testing for the presence of harmful *E. coli and Listeria monocytogenes*, two common food pathogens, represents the next level in food safety and ensuring a safe Canadian food supply.

8. GLOBAL CHALLENGES THAT CAN BE ADDRESSED BY THE AGRI-FOOD SECTOR

The challenges outlined in this section are affecting societies and governments globally in many different ways. The agri-food sector, with the help of genomics, has the potential to master these challenges, which are discussed here in the context of production, risk mitigation, and quality. Some issues can be directly solved by the use of genomics and genomics-based technologies; others cannot, but they must also be addressed in order for genomics to be successful and help the agri-food sector realize its true potential.

8.1 ENVIRONMENT AND CLIMATE CHANGE

Climate change is occurring at an unprecedented rate. Changes in global precipitation patterns, increasing extreme weather variability and changes in the effects of climate on animal and plant life pose both a direct and indirect challenge to the agri-food sector in Canada. The Agriculture and Agri-Food Canada Foresight Committee has identified climate change as the key challenge for agricultural production in the next 20 years. Genomics has a role to play in devising adaptation strategies by contributing to improved and accelerated crop and livestock breeding.

- **Production**
  Direct impacts can be felt by farmers through drought or flooding that can prevent crops from being planted, grown or harvested. Crops and livestock can also be impacted by inclement weather, such as damaging hail, wind, extreme hot or cold temperatures, and storms, particularly at critical times during the growing cycle. Indirectly, fluctuations in weather patterns impact the presence and severity of pests and diseases, creating production problems for affected farmers. The future challenge lies in increasing yield per unit area in the face of the changing climate and a decrease in the availability of land suitable for agricultural production, while providing for the nutritional needs of a growing human population.

- **Risk mitigation–food safety and security**
  Climate change challenges can pose food safety risks, such as novel food-borne pathogens and toxin-producing organisms that have the potential to contaminate the food supply and affect the health of consumers. Pests that were previously unable to survive in Canada's climate may become able to establish and increase their range, resulting in lower yields and quality.

  Another risk is the threat posed to food security—the availability of sufficient food supplies to feed the global population. Although this risk is somewhat diminished in Canada due to the sheer size, diversity and capacity of our agricultural production, it is of great concern in countries that depend on imports for a significant portion of their food supply.

- **Quality**
  Growing middle-class populations in emerging economies are seeking better quality food, as well as more meat, dairy, oil and sugar in their diets. In Canada and other developed nations, consumers are seeking foods with enhanced quality attributes, whether to boost health or to address social, environmental or animal welfare concerns.

  As well as decreasing production, pests and diseases in crops and livestock can have a significant impact on the quality of food and feed being produced. The challenge of fusarium-infested wheat in grain production, for example, can greatly diminish the availability of high quality feed for livestock. Too much or too little rain directly affects crop quality, such as forages fed to dairy cattle, which can impact the milk they produce. Fruit and vegetable crops can easily sustain damage from frost or hail, making them unsuitable for market.

8.2 GLOBAL COMPETITIVENESS

Staying competitive in the global agricultural market is an ongoing challenge for the Canadian agri-food sector. Canada accounted for 3.3 per cent of the total value of global agriculture and agri-food exports in 2011 and ranked sixth in global exports valued at $40.3 billion[26].

- **Production**

  Further improvement in the genetic potential for crop yields awaits new scientific advances. Additionally, diverse crop traits, such as health, plant protection and industrial applications, are driving new developments. Growing economies elsewhere in the world are emerging as major competitors in areas where Canada has traditionally been strong.

  Costs for inputs such as seed, fertilizer and crop protection have been rising rapidly, in many cases faster than the gross margins for crops. Other production costs, such as energy and labour, are also increasing. In the fruit and vegetable sector, in particular, high labour costs and the availability of workers is a concern as many horticulture crops must be grown and harvested manually to preserve quality. Escalating land costs are affecting all agricultural sectors and diversion of land from forage production to more valuable cash crops requires increased productivity from available forage acres. International market access is also increasingly influenced by sanitary and phyto-sanitary issues.

  Societal demands are changing, particularly with respect to animal welfare and the environment. Production challenges that were previously addressed using chemical, pharmaceutical, or housing solutions must now increasingly be addressed in other ways as consumers challenge conventional agricultural practices. Addressing these consumer expectations can drive up costs as well as lower production volumes. However, it also increases opportunity for developing niche markets that offer consumers choices in conventional, organic or genetically modified food and feed.

Risk mitigation

Prices for food, feed and commodities are increasingly volatile and unpredictable. This price volatility poses risks to both food producers and food consumers. Globally, there is greater competition for use of arable land, as well as key resources such as water, crop nutrients, and other natural resources. Environmental impacts of declining soil health and reduced fertilizer efficiency are of particular concern. The natural resource base is depleting and the population is growing. According to the latest United Nations projections, the global population is expected to reach nine billion people by 2043, up from the current high of seven billion reached in October 2011[27].

The expectations for high yield and other desired traits have led modern agriculturalists to select varieties that have resulted in potential fragility of the genetic makeup of certain varieties. This genetic concentration poses a potential risk to the production stability of affected commodities in both livestock and crop sectors, especially due to the increased presence and severity of new pests and diseases. Genetic diversity is essential for the continued improvement of crops and livestock to adapt to future challenges, and this diversity needs to be conserved in order to protect agricultural productivity and with that, the source of the global food supply.

[26] *An overview of the Canadian agriculture and agri-food system 2013*, Agriculture and Agri-Food Canada, http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1331319696826

[27] http://esa.un.org/unpd/wpp/Other-Information/faq.htm#q1

Global multinational firms dominate in many key areas of the agri-food value chain, such as seed genetics, grain handling, and food processing. There is competition both between and *within* these companies for investments in research and development to occur in Canada and globally. Thus it is critical for Canada to provide an attractive investment environment; if we are successful in attracting investment from these companies, it will be easier for Canadian needs, concerns and opportunities in these areas to be addressed.

Strong signals from the federal government about the importance of and support for research investment in this sector will increase the interest and commitment of global firms to Canada. At the same time, the reality of scale is that in global terms the Canadian market for seed is small and therefore not the focus of R&D effort of the global firms in most cases. As a result, public breeding investment, using advanced selection tools provided by genomics, is more important to Canada than large market countries, in order to ensure that Canadian farmers have access to genetic material well adapted to our needs.

- **Quality**

  Canada is a source of high quality food to many countries around the world. Although we are a significant exporter, many of our international agricultural export markets have been built on quality attributes, as opposed to volume. Pork and food grade soybean exports to Japan are examples of this niche focus, as are canola oil, high protein wheat and the sweet cherry. It is important for Canada to maintain high quality in its food and feed exports in order to keep—and potentially expand—its international markets.

  The quality bar must be aligned with the needs of the market and what the market is willing to pay. Not all global markets are premium markets and not all production can be targeted for premium markets—therefore, a balanced approach between seeking high value markets and securing significant volume commitments must be pursued. It is in the national interest to export food products in their highest value form rather than as undifferentiated commodities as this approach creates jobs and wealth at home and more stable markets abroad.

  Food quality also affects the nutritional well-being of consumers. Like other developed nations, Canada's population is aging. Good nutrition, rooted in the availability of high quality food with positive nutritional attributes, can positively impact future healthcare costs.

8.3 REGULATORY PROCESSES

- **Production**

  Although regulations are necessary to establish and maintain standards of quality and production, international trading relationships and environmental stewardship, they also create tensions between global trade and local supply. This dichotomy applies especially where domestic producers of a certain product must follow specific production or environmental standards, but producers of the same commodity in other countries are not required to, allowing them to put their product on the market at a lower cost.

- **Risk mitigation**

  It is important for the Canadian agri-food sector to maintain its ability to continue to develop new agricultural products, whether food, feed, fuel or fibre. Equally important is to be able to secure export markets for these products. An inability to do so due to regulatory pressures or constraints inhibits the sector's growth potential.

  As research and innovation evolve, particularly in the field of genomics, a streamlined, effective regulatory system is critical to ensure new technologies make it from the lab to the farm or the processing facility. Regulators need to be aware of the latest developments and technologies, as well as have a well-founded understanding of the agri-food sector.

- **Quality**

  Many world food shortages are influenced by factors other than production capacity, including distribution inefficiencies, waste and spoilage, poverty and political unrest. Although infrastructure-related factors cannot be directly impacted by genomics, advances in science can provide solutions to many waste and spoilage issues that affect global food supplies. Similarly, genetic tools can be very useful for ensuring authenticity and purity in the production and marketing channels, as well as in the identification of adulterants and contaminants.

8.4 HEALTH AND NUTRITION

- **Production**

  Canadians, along with people in many developed nations, have access to more food than they've ever had before. The availability and quality of food is not a problem from a food security perspective. It is, however, a growing one from a health perspective—a plentiful food supply means people as a whole are also heavier than they have ever been before.

  Adult and child obesity are on the rise, which bring with them a host of health problems, including high blood pressure, type 2 diabetes, elevated blood cholesterol levels and increased risks for cancer, heart disease and stroke. Former U.S. Surgeon General Richard Carmona has warned that *"Because of the increasing rates of obesity, unhealthy eating habits and physical inactivity, we may see the first generation that will be less healthy and have a shorter life expectancy than their parents."*[28]

  According to a study by the Canadian Institute for Health Information and the Public Health Agency of Canada, obesity costs the Canadian economy between $4.6 billion and $7.1 billion annually. This represents direct health-care costs as well as indirect costs due to lost productivity[29].

- **Risk mitigation and quality**

  The link between human health and food and nutrition is undeniable. Many health problems can be resolved or even prevented through healthy lifestyle choices. Genomics can play a strong role in helping forge that connection between health and diet by supporting the production of food with enhanced food safety, nutrition and functional attributes, and addressing specific health concerns through increased availability of high quality products.

  It is also important to consider animal health and nutrition. Healthy livestock are a source of healthy, high quality food products—and there is a reduced risk of disease transmission between animals and humans, which is a growing global health concern.

8.5 ROLE OF RESEARCH AND DEVELOPMENT IN GOVERNMENT POLICY

- **Production**

  Traditionally, Canadian agricultural policy has focused primarily on farm income and farm income support programs. Research and development investment by Agriculture and Agri-Food Canada is mostly concentrated internally, although recent years have seen a change in focus with funding available to support industry priorities and encourage industry leadership. Canada's role in research and technology development is very important and there's a need for government, as well as private industry and producer investment, to make that happen.

  Much of the funding that does go into research in Canada is of a short-term nature, usually three to five years. Significant advances in fields like genomics can take decades to develop successfully, so there is

[28] http://www.heart.org/HEARTORG/GettingHealthy/Overweight-in-Children_UCM_304054_Article.jsp

[29] http://www.theglobeandmail.com/life/health-and-fitness/health/conditions/obesity-costs-economy-up-to-7-billion-a-year/article583803/

a real need for longer-term research funding commitments to align with research and commercialization cycles. Long-term commitment by government will help attract and retain more private investment and top talent in Canada.

- **Risk mitigation**

  Considerable current research and development work in genomics is driven by multinational companies for which the Canadian market is a small portion of their total global market. Public and producer support of basic and applied research is essential to keep Canada at the forefront of agricultural research and development and ensure that the needs of producers in our climate zones are sufficiently addressed. However, the investment and role of multinational companies is vital as they bring extensive expertise and resources to undertake research and facilitate commercialization, including navigating through the regulatory approval process.

  Canada has tremendous capacity for research and development in the agricultural sector, and should continue leveraging this capacity to attract international investment. Additionally, using investment levers such as the Scientific Research & Experimental Development (SR&ED) tax credit policy, national and provincial funding programs, Canada must have significant outreach programs to companies and other organizations to encourage prioritized development.

Quality

Canada has realized commercialization successes in canola, pulses, wheat, and many other field and horticultural crops, but in spite of strong returns on investment, there are inefficiencies with transmission of government and university research and ideas to industry, which can hinder commercialization efforts.

The challenges in moving from discovery to commercialization are attributable to numerous factors, including limited capital, lack of receptor capacity in companies to continue development of an idea into a marketable product, and an inability or unwillingness on the part of scientists to develop new technologies or products to a point where companies can take them over successfully. The next generation of genomics research investment can help to address the post-discovery part of the process by providing support to drive development to successful commercial introduction.

8.6 SUSTAINABILITY, EDUCATION AND AWARENESS

- **Production and quality**

  Buyers of agricultural products—processors, retailers, food service providers and consumers—are all increasingly seeking assurances that the products they're using have been produced responsibly in a sustainable manner. They also want to know where their food comes from, sometimes right down to the farm of origin, and that its path through the food system can be tracked. This is all part of the sector's social license to operate; maintaining consumer confidence in Canadian products and production practices is key to keeping that social license.

Risk mitigation

Lack of scientific knowledge and understanding of modern agricultural production practices by consumers and regulators can pose a threat to the development and adaptation of new technologies. Many advocacy groups are able to leverage significant public support to advance their causes, which can directly result in underinvestment, high development costs, and delays in commercialization. The lack of knowledge and understanding also impacts regulatory modernization.

The Arctic® Apple[30], for example, illustrates how genetic engineering can be used to reduce waste and help create new opportunities for apples in the minimal processing sector, but this advance is facing stiff opposition from anti-GM advocacy groups and the regulatory approvals that would allow this product into the market are not yet in place.

The Enviropig™ is another example, making headlines in 2012 when it was shelved due to lack of market. It's a transgenic pig created at the University of Guelph that is better able to utilize phosphorous from plants, reducing the possible environmental impact of pig manure on soil and water. Enviropig™ has become a case of discovery ahead of its time in terms of regulatory approval and market acceptance, although it has pushed government officials around the world to develop regulatory policies for the use of animal transgenics.

Genomics, although it can include transgenic technologies, involves many conventional breeding practices too. This application of genomics to shorten the cycle time and increase the efficiency of conventional breeding is not generally known or understood by the general public, who commonly but mistakenly assume that genomics work is focused on genetic engineering or modification. This lack of appreciation for full range of applications of genomics means education and awareness amongst consumers and regulators of modern agricultural practices and scientific knowledge are necessary to allow further genomic development to move forward.

The agri-food sector has realized many successes in genomics and it is important that these stories be told in a relevant, meaningful way to help support further advancement.

THE NEED FOR PEOPLE

One key challenge that faces all areas of the sector is human resources. Many research institutions are grappling with a shortage of faculty due to retirement and budget limitations, and there is a general shortage of highly qualified personnel in areas such as bioinformatics, which has evolved into a key part of many areas of biology. In genomics, for example, it is critical in the sequencing and annotation of genomes and their observed mutations; skilled personnel are needed who can move data gathered and/or generated through new technologies forward into practical applications.

Regulators struggle with attracting and retaining employees with knowledge and understanding of agricultural practices and new technologies in the sector. Primary producers and processors need a steady, reliable and increasingly skilled workforce on-farm and in processing facilities.

The need for highly qualified personnel has never been greater and is expected to continue as the sector expands and as Canada's workforce transitions through the retirement of Baby Boomers.

Key for the agri-food sector is positioning itself as an attractive employer and putting resources into recruitment and retention efforts.

For example, more needs to be done to attract students and workers into these fields and to retain them once they are there. Strategic research grants that generate networks and train new high quality personnel in different areas are important and innovative approaches to engaging and mobilizing new workers. Some organizations, including Genome Canada, the National Science and Engineering Research Council, the Networks of Centres of Excellence and the Social Sciences and Humanities Research Council, already have programs of this nature in place.

[30] http://www.hoover.org/publications/defining-ideas/article/126886

9. ROLE OF GENOMICS IN MITIGATING THE CHALLENGES AND CREATING THE OPPORTUNITIES

Genomics technology represents a powerful selection tool in crop and livestock breeding and genetics, as well as an excellent diagnostic tool to identify potential contamination or misrepresentation of products. This application of genomics technology has benefits to human health and nutrition, animal welfare, food safety and security, environmental sustainability and economic health and competitiveness.

9.1 ENVIRONMENT AND CLIMATE CHANGE

Canada has many natural advantages when it comes to agriculture, including availability of water and arable land, and diversity of commodities produced. Genomics is already playing a key role in helping to adapt Canadian agricultural production to accelerated climate change, and there are many yet untapped areas where there is potential for development and expansion. These opportunities include:

- Maximizing yield through increased resilience to disease, drought, and temperature extremes. In cereal crops, for example, Canadian breeders have already developed plants that reach maturity more quickly, avoiding frost damage risks.
- Supporting the development of molecular tools to detect invasive pathogens, insects and weeds. Initiatives such as the Barcode of Life and the Quarantine and Invasive Species project under the Genomics Research and Development Initiative[31] are currently developing databases and diagnostic tests that can be used to more quickly and accurately identify organisms on imported products that may pose a risk to Canada's crops.
- Accelerating yield growth, especially wheat, oilseeds and pulses. For example, soybeans can now be grown in Manitoba and other parts of Western Canada as a result of work to adapt varieties to the climate in that province. Manitoba's soybean acreage doubled between 2006 and 2011[32].
- Studying defense and disease pathways in livestock and poultry to make them better able to deal with the presence of current and emerging pests and diseases.
- Maximizing crop values by breeding for specific traits and attributes that have high value food, health or bioproduct applications. For example:
  - » Improved food oil profiles in canola and soybeans increases stability for processing.
  - » Higher levels of essential amino acids in soybeans and corn results in more nutritious food/animal feed[33], which can in turn result in fewer days to market and better meat quality.
- Breeding for traits that will lessen farming's footprint on the environment, such as adaptation for minimum tillage production to reduce greenhouse gas emissions or herbicide tolerance that lowers use of crop protection materials. For example:
  - » No till practices are now used on more than half of Canada's crop land, with a 23.8 per cent increase in the area of land seeded using no-till practices in 2011 compared to 2006[34].
  - » Use of herbicide tolerant canola in Saskatchewan has lowered the use of crop protection materials by 38 per cent[35].

[31] http://grdi-irdg.collaboration.gc.ca/eng/annual_reports/2011_2012.html

[32] http://www.gov.mb.ca/agriculture/statistics/pdf/crop_soybean_sector.pdf

[33] http://www.croplifeamerica.org/phillipsmcdougallstudy; http://www.pewhealth.org/reports-analysis/reports/application-of-biotechnology- for-functional-foods-85899368184

[34] http://www.statcan.gc.ca/pub/95-640-x/2012002/05-eng.htm

[35] Smyth, S.J., M. Gusta, K. Belcher, P.W.B. Phillips and D. Castle. 2011. Changes in Herbicide use Following the Adoption of HR Canola in Western Canada. *Weed Technology* 25:3:492-500.

To address both the climate change and competitiveness issues, the key lies with incorporating desirable production traits into the crop varieties available to Canadian farmers. The main focus should be on traits most closely associated with climate change, which can drive competitiveness and productivity. Changes in climate impact the availability of water, pest incidence and temperature, all of which affect crop yield and quality, so traits associated with mitigation or adaptation to these factors will be very beneficial. Survival traits from many wild relatives of agricultural crops that have adapted to specific environmental and climatic conditions could be introduced into commercially produced crops and increase the diversity of genetic material.

Safeguarding the existing genetic diversity of livestock and crops through conservation efforts, such as work currently underway by the Global Crop Diversity Trust[36], is critical to protecting the biological underpinning of our food supply. The potential presented by the seeds of many diverse crops and varieties, including heirloom, landrace and wild crop relatives, which are being saved by individual farmers and in global gene banks, can be developed and maximized through the use of genomics-enabled technologies.

With genomics tools, we can accelerate the adoption of traits from these saved seeds and other wild varieties into breeding programs and their introduction into the market place. Not only will this help strengthen the diversity of our food supply and protect it from potential risk posed by new pests and diseases, it will also address challenges posed by climate change and help the Canadian agri-food sector, which needs to be both competitive and profitable in order to be self-sustaining, expand its market opportunities.

9.2 GLOBAL COMPETITIVENESS

Canada has established a good reputation as a source of high quality food products for foreign markets. There is a real opportunity through genomics to expand global market opportunities through addressing food quality and quantity issues. These opportunities include:

- Research on drought tolerance and more efficient resource use (e.g. water), which can both improve yields and manage risks in Canada and could have benefits outside of our borders as well. For example, increasing harvest yields in Africa while using less water during production can have profound impacts on endemic food security and climate-related challenges on that continent.
- Fruits and vegetables, for example, that are more resilient can be transported longer distances or through less ideal conditions while still maintaining sensory and nutritional attributes. Not only can this boost domestic consumption, it can also help Canadian farmers build sales in other markets at counter-seasonal times when there is less competition from local sources in those markets. In British Columbia, for example, late season cherries have been developed that come to market after the main crops in Canada and the U.S. have been consumed. The combination of high quality and market timing has enabled Canadian sweet cherry growers to obtain high returns from marketing these cherries in Asia.

[36] http://www.croptrust.org/

9.3 REGULATORY PROCESSES

Canada's current regulatory system, although highly regarded by international counterparts, must keep pace with new technology. A predictable, science-based regulatory framework is the key to Canada's innovation policy and to developing and maintaining export markets. Industry in particular needs to know that the path to commercialization is clear and predictable or else Canada is at risk of losing continued investments by companies in this country.

To that end, better and more efficient communications between different regulatory departments or agencies is needed, especially if they are evaluating the same product for different aspects. As well, there is a need to identify and articulate clearer regulatory triggers on new products and to reduce triggers on familiar products with a history of safe use. Harmonization of requirements and data sharing with regulatory departments in other countries will also help to facilitate trade.

As more products come into the system for regulatory approval, regulatory agencies are going to need funding, training and personnel to keep up with demand. While there were approximately 30 GM crops grown worldwide in 2008, that number is predicted to increase to 120 by 2015[37].

9.4 HEALTH AND NUTRITION

The link between food and health is clear. Plants, animals and humans, as well as the microbiomes of humans and cattle and the metagenome of the plant soil, all have an impact on health and nutrition. The agri-food sector, supported by genomics, can help boost human health by producing food with enhanced food safety, nutrition and functional attributes, and addressing specific health concerns through increased availability of high quality products. The bio-fortification of pulse crops to counter dietary vitamin and mineral deficiencies is one such example.

Canadian expertise in nutritional genomics enables us to understand differences in nutrient-gene interactions and what that could mean for acute and chronic conditions. Agri-food genomics can be used to develop functional foods and nutraceuticals—for example, expressing certain traits in greater quantity or selecting varieties with traits that will be more responsive or resilient to further processing—to deliver better health solutions. Addressing health issues through better nutrition and improvements in the food system opens new strategies for controlling burgeoning health care costs.

Genomics can also impact animal health by improving immune responsiveness in livestock. This outcome not only has significant positive welfare benefits to animals, but also reduces the risk of transmission of zoonotic diseases from the animal population to humans, such as salmonella or Methicillin-Resistant Staphylococcus Aureus (MRSA), a bacterium responsible for several difficult-to-treat infections in humans.

There is also an opportunity to address food quality and security issues through genomics. For example, many global food shortages are as much the result of human factors as they are of production shortages. A study by the Institution of Mechanical Engineers released in 2013 estimates that 30 to 50 per cent or 1.2 to two billion tonnes of all food produced never reaches a human stomach[38].

[37] Stein, Alexander J. and Emilio Rodríguez-Cerezo, 2009. The global pipeline of new GM crops: implications of asynchronous approval for international trade, http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=2420

[38] http://www.imeche.org/knowledge/themes/environment/global-food

Much food is wasted or spoiled due to production inefficiencies, an inability to transport, store or distribute it properly due to political instability or lack of infrastructure. In developed nations, food waste is more often a result of retail and customer behaviour—perfectly edible fruits and vegetables can be rejected by produce buyers because they do not meet exacting marketing standards for physical characteristics such as size and appearance. Globally, retailers generate 1.6 million tonnes of food waste annually in this way[39].

Genomics can be used to improve the resilience and hardiness of crops, in particular horticultural crops, to ensure they are better able to withstand transport, storage and handling even in less than ideal circumstances. This outcome could help stabilize global food security, reduce food waste and boost human health and nutrition in many parts of the world.

9.5 ROLE OF RESEARCH AND DEVELOPMENT IN GOVERNMENT POLICY

In order to maintain a strong base of research and development in Canada, it is important not to concentrate all research in the hands of a few players or to rely solely on work being done in other countries. To complement public efforts, producer organizations must be mobilized to invest and help attract multinationals and other organizations to use their productivity tools for sectors such as corn and soybeans—much as has occurred in canola development in western Canada.

P3s that engage producer groups in Australia are credited, for example, with helping challenge Canada's wheat export market share; Australia is spending four times as much on wheat research and development compared to Canada[40].

Strong networks between academia, industry, producers, government and other funders of research are necessary to facilitate and support ongoing investment in genomics research. There is a role for academia to keep industry up to date with research developments so that they know "what is possible", a role that extends to government research scientists also. Similarly, there is an onus on industry to reach out to academia and government to let them know what their customers—consumers, retailers, food processors and others—are asking for.

Building these networks will help better align industry research needs with academic research capacity and capability, and pool knowledge, talent and financial resources to ensure that genomics tools are developed and adopted. It can be the role of the genome centers and/or other organizations to help facilitate these linkages and to be a catalyst for helping to bring promising research through commercialization and into the hands of end users with public acceptance.

9.6 SUSTAINABILITY, EDUCATION AND AWARENESS

The agri-food sector is challenged by a lack of public understanding of how food is produced. Less than two per cent of Canadians are involved in primary agriculture. A public attitudes study conducted by Ipsos Reid for Farm and Food Care Ontario in 2012 showed that 56 per cent of Canadians have a positive or somewhat positive view of Canadian agriculture, with 32 per cent reporting neither positive or negative impressions. Generally, they felt that Canadian food is safe, well inspected and regulated and farmers are seen as ethical and trustworthy.

However, in the same study, 34 per cent of Canadians have some level of concern about Canadian food production practices today. This indicates that the

[39] Ibid.

[40] Valgen.ca policy brief no 35, August 2012: Public private partnerships and Canada's Agricultural Sector

sector needs to take a more proactive role in public outreach concerning science, farming and food production, particularly to counteract well-funded campaigns of groups who are challenging the ethics, safety and environmental impacts of the industry. Those advocacy organizations use any tools at their disposal—including playing to public fears and misinterpreting the truth—to discredit scientific advances and further their own causes.

Genomics can play a role in helping to ensure consumer confidence in the food supply. It can support sustainable production practices through hardier plants and animals that require less water and other inputs, and boost health and nutrition through crop and livestock products that offer nutritional and health benefits to both humans and animals. It can also help the agri-food sector assure food safety and tell the story of where food comes from through the use of genomic-based diagnostic tools that can easily identify origin and the presence of contaminants, for example.

10. NEXT STEPS TOWARD SUCCESS

Global competition in the agri-food sector is tough—but with competition also comes opportunity. Higher yielding, more efficient crops and livestock are needed to feed more people and meet increasingly diverse consumer demands, while keeping costs down and addressing climate change issues.

In addition to an abundance of arable land and water resources, Canada's competitive advantage in agriculture lies with the quality of its products and of the markets it serves. It is therefore important that the sector be commercially competitive so that the Canadian industry can make the most of available opportunities.

Canada's agri-food sector is deeply entrenched in using genomics as a tool to help meet our needs. There are established success stories in many sectors, but there are also identified areas of need for further investment and action. These needs are well aligned with the recently launched Growing Forward 2 framework, which focuses on competitiveness and market growth, adaptability and sustainability, and innovation.

Overall, there is opportunity in:

- **Human health and nutrition –** capitalizing on the link between health and diet to improve human health through the use of genomics in food production.
- **Environment and climate change –** establishing technology for optimizing the water and nutrient requirements of crops to increase crop yields and contribute to more sustainable agricultural practices. Advancements in livestock genomic research can increase productivity while reducing greenhouse gas emissions.
- **Economics and political stability –** domestically, a strong agri-food sector means jobs and the maintenance of Canada's rural economic structure. Globally, genomics can positively impact food security, potentially reducing political upheaval, often caused by skyrocketing food prices and shortages of food or water.

10.1 SHORT TERM GOALS

The short-term goals of Canada's agri-food genomics strategy focus on economy and trade. Further development of genomics research will help create jobs and opportunities here at home, as well as allowing farmers, processors, exporters and others to create and expand export markets. Canada's land base, climate and natural resources make it an ideal candidate for increased market-driven production.

Canada has also been a leader in agri-food research and innovation, and there is opportunity to share those advances with other countries so that exports include not only agri-food production but also scientific know-how.

10.2 LONGER-TERM GOALS

In the longer-term, Canada's agri-food goals are built around health, trade and the economy. Genomics can drive change that will help realize these goals, but significant results will take time to be realized so it is important that priority be placed on long term investment commitment in the genomics area.

10.3 IDENTIFIED NEEDS

Through the development of this strategy, specific needs have been identified as being important to the next steps toward success:

- **Improving education and outreach**
  There is a need to raise awareness and understanding amongst consumers and regulators about genomics technology and its benefits. Regulators need to be informed so that they can make sound regulatory approval decisions regarding new technologies and products that result from genomics research. Consumers should have some general understanding of genomics and modern food production; misinformation and misconceptions have the potential to lead to non-acceptance of technologies vital to future health and nutrition.
- **Building networks**
  Strong networks are needed to link academia, industry and government to better align research needs with capacity and or capability. These effective networks will help facilitate and support ongoing investment in genomics research and enable synergies in research efforts to be fully realized.

  There is a role for academia to keep industry and regulators up to date with research developments so that they know "what is possible" and have a general understanding of new technologies when they are coming through the system for regulatory approval.

  Similarly, there is an onus on industry to reach out to academia to let them know what their customers—consumers, retailers, food processors and others—are asking for. Organizations like the genome centers and others can help facilitate these networks and be a catalyst for helping to bring promising research through commercialization and into the hands of end users.
- **Strengthening human resource capacity**
  The genomics field is challenged by the unfilled need for highly qualified personnel in areas like bioinformatics. There are growing shortages in research faculty due to retirements and budget constraints. Regulatory agencies are faced with the challenge of attracting and keeping personnel, a need that will only continue to grow as more products are brought forward for regulatory approvals.

11. RECOMMENDATIONS

For challenges identified in this report that can be directly addressed through the use of genomics-based agri-food activity, the following recommendations are put forward:

- **Boosting Canada's competitiveness through food quality.** There is a real opportunity through genomics to expand global market opportunities by addressing emerging food quality needs. Crop values can be maximized by breeding for specific traits and attributes that have high-value food, health or bioproduct applications.
- **Adapting to climate change through hardier crops and livestock.** This effort includes maximizing yields by increasing resilience to disease, drought and temperature extremes; supporting the development of tools to detect invasive pathogens, insects and weeds; breeding for traits that will lessen the environmental footprint of farming.
- **Improving human and animal health.** Genomics can help boost human health by producing food with enhanced food safety or nutritional and functional attributes. It can also positively impact animal health by improving immune responsiveness in livestock, which reduce the risk of transmission of zoonotic diseases from animal populations to humans.
- **Bolstering global food security and decreasing food waste.** Genomics make crops, in particular horticultural crops, better able to withstand transport, storage and handling even in less than ideal circumstances, leading to better availability of food in many parts of the world and less food waste.

There are also challenges identified in this report that, although not solvable through the use of genomics, must be addressed in order for genomics to be used in agri-food to its fullest potential and for the sector to be able to effectively address issues of food security and quality, climate change and human health. Therefore, further recommendations include:

- **Smoothing the regulatory path.** Better and more efficient communications between different regulatory departments or agencies is needed to help streamline the regulatory system. There is also a need to identify and articulate clearer regulatory triggers on new products and to reduce triggers on familiar products with a safe use history.
- **Maintaining public confidence in the food supply.** The agri-food sector must take a more proactive role in public outreach concerning science, agriculture and food production to help maintain public confidence and trust in Canada's food products and production systems. Genomics can support sustainable production practices as well as help assure food safety and tell the story of where food comes from through the use of genomic-based diagnostic tools that can identify origin and the presence of contaminants, for example.
- **Building strong networks between academia, government, producers and industry.** Effective networks will help maximize the use of available resources and allow for better alignment of industry research needs with academic research capacity and capability.

12. FINAL THOUGHTS: CANADA, GENOMICS AND GLOBAL FOOD SECURITY

Producing more high quality, safe food on less land with less environmental impact is one of the greatest challenges of the twenty-first century. Resources are being depleted, the human population is growing and climate change is affecting everything from water availability to weather patterns. And even though phenomenal gains have been made in global food production, yields and food quality over the last century, approximately 870 million people globally remain chronically undernourished.

The agri-food sector, through the use of genomics, can play a leading role in global food security in developed nations as well as in emerging economies and underdeveloped regions of the world. The use of genomics and genomics-derived technologies in agri-food is a powerful tool for crop and livestock breeding and genetics, as well as diagnostics such as identifying potential contamination, presence of disease or misrepresentation of products. The application of genomics technology has benefits to human health and nutrition, animal welfare, food safety and security, environmental sustainability and economic health and competitiveness.

Canada has many natural advantages when it comes to agriculture, including availability of water and arable land, and diversity of commodities produced. It also has a well-developed research infrastructure, is highly regarded globally and has widely embraced the use of genomics in the sector.

Globally, Canada's leadership here can be two-fold: the production and export of food, feed, fuel and fibre, as well the sharing and adapting of innovations and technologies for use in other parts of the world. Africa, for example, could vastly change the food security equation on that continent if its agricultural potential could be more fully realized. The BRIC countries—Brazil, Russia, China and India—represent market opportunities as well as being competitors for Canadian food and farming as they grow their own agricultural sectors.

Continued investment in the development of genomics by the public, producer and private sectors can help Canada turn challenges into market advantages and establish global leadership in this field. Ultimately, genomics and related technologies will help us create and support a better world for future generations—one with better health, increased food security and more sustainable production practices. Continued public, producer and private sector support of and commitment to genomics is essential to making that happen.

APPENDIX

AGRI-FOOD SECTOR WORKSHOP, FEBRUARY 28–MARCH 1, 2013

As part of the development process for this strategy, a group of 80–90 industry leaders and experts met for a workshop in Winnipeg on February 28–March 1, 2013 to review a draft of the document and provide input on a series of topics.

Workshop participants represented all regions of Canada. Approximately 60 per cent of participants were from the crops sector and 40 per cent from livestock; 70 per cent represented industry or academia and 30 per cent were from government.

Here are some of the key take-home messages that resulted from the presentations and facilitated discussions at the workshop:

- Genomics has been fully embraced by the agri-food sector in Canada, especially in the private sector. All significant crop and livestock breeding programs utilize genomics as a primary tool.
- The sector is well placed for the GAPP program as there are already strong linkages formed between academia, government, and industry. Breeders are end users and many producer groups collect producer fees, also known as "check-offs," that are reinvested in the sector for research and development and/or marketing activities.
- Feeding the world is a great motto, but the reality is that Canada's agri-food production currently feeds less than one per cent of the global population. Nevertheless, Canadian production far exceeds domestic consumption and is of high quality. Our capacity to deliver and our systems to ensure quality are key competitive advantages on world trade markets.
- There is a need to tell Canada's genomics story. There have been many successes in agri-food using genomics approaches, which need to be brought to light in a newsworthy manner.
- Major areas to focus on:
  - » Nutrigenomics, (CVD, metabolic syndrome, etc). Personalized health starts in the kitchen, not the doctor's office. Agricultural solutions to health care are possible. Therefore this sector deserves and needs access to relevant health research funding.
  - » Production traits
    - For producers and processors—these are still important for incremental improvement in food production
    - Improving crop and livestock resilience to deal with changing climate conditions
    - Incorporating diversity from wild relatives of domesticated species
  - » Food Security and safety goes beyond bio-terrorism. It also means sustainable and well monitored supply chains.
  - » Customer needs. Research must focus as much on the buyer of the food as it does on the producer. How do we balance research priorities?
  - » Predictable, science-based regulatory policy. This measure of certainty is key to our export markets.
  - » Highly Quality Personnel. Bioinformatics training is required across the spectrum of agri-food research.

A SURVEY OF MAJOR AGRI-FOOD RESEARCH CAPACITY IN CANADA

The following chart lists major Canadian academic and governmental research centers, institutes and networks involved in agri-food sector research and innovation activities (excluding aquaculture and fisheries). Please note that although extensive, this list is not comprehensive. Entries are listed in alphabetical order grouped by province.

CATEGORY	ORGANIZATION, INSTITUTE OR NETWORK	PROVINCE
Academic and/or Private	**Post-secondary agric ulture and agricultural programs:** University of British Columbia, University of the Fraser Valley, University of Alberta, University of Lethbridge, University of Saskatchewan, University of Manitoba, University of Guelph, Trent University, Western University, McGill University, Nova Scotia Agricultural College	BC, AB, SK, MB, ON, QC, NS
	Veterinary medicine programs: University of Calgary, University of Saskatchewan, University of Guelph, Université de Montréal, University of Prince Edward Island	AB, SK, ON, QC, PE
	Okanagan Plant Improvement Corporation	BC
	Field Crop Development Center	AB
	Food Processing Development Centre	AB
	Livestock Gentec (University of Alberta)	AB
	Crop Development Centre (University of Saskatchewan)	SK
	Feeds Innovation Institute (University of Saskatchewan)	SK
	Global Institute for Food Security	SK
	Saskatchewan Food Industry Development Centre (University of Saskatchewan)	SK
	Vaccine and Infectious Disease Organization (University of Saskatchewan)	SK
	Manitoba Agri-Health Research Network: Richardson Centre for Functional Foods and Nutraceuticals, Canadian Centre for Agri-Food Research in Health and Medicine, Food Development Centre	MB
	BIO	ON
	Canadian Centre for Swine Improvement	ON

CATEGORY	ORGANIZATION, INSTITUTE OR NETWORK	PROVINCE
	Canadian Dairy Network	ON
	Canadian Food and Wine Institute Research Centre (Niagara College)	ON
	Canadian Research Institute for Food Safety (University of Guelph)	ON
	Centre for Genetic Improvement in Livestock (University of Guelph)	ON
	George Morris Centre	ON
	Human Nutraceutical Research Unit (University of Guelph)	ON
	International Development Research Centre	ON
	Livestock Research Innovation Corporation	ON
	NSF-GFTC (formerly Guelph Food Technology Centre)	ON
	Ontario Ginseng Innovation and Research Consortium (Western University)	ON
	PigGen Canada	ON
	Value Chain Management Centre	ON
	Vineland Research and Innovation Centre	ON
	McGill Institute for Global Food Security (McGill University)	QC
	L'Institut des nutraceutiques et des aliments fonctionnels (Université Laval)	QC
	BIO|FOOD|TECH	PE
	Atlantic Poultry Research Institute	NS

CATEGORY	ORGANIZATION, INSTITUTE OR NETWORK	PROVINCE
Government	Agriculture and Agri-Food Canada (centres across Canada)	Canada
	Canadian Food Inspection Agency (centres across Canada)	Canada
	Public Health Agency of Canada (centres across Canada)	Canada
	National Research Council (related institutes across Canada)	Canada
	Environment Canada (centres across Canada)	Canada
	Centres of Excellence for Commercialization and Research (CECR)	Canada
	Provincial research organizations (across Canada)	Canada
	Canadian Institutes of Health Research	Canada
	Canadian Agri-Food Policy Institute	ON
	AARD Food Processing Development Centre	AB

FOR MORE INFORMATION CONTACT:

Genome Canada
Cindy Bell
Executive Vice-President, Corporate Development
Tel.: 613-751-4460, ext. 218
cbell@genomecanada.ca
www.genomecanada.ca

Genome British Columbia
Gabe Kalmar
Vice President, Sector Development
Tel.: 604-637-4374
gkalmar@genomebc.ca
www.genomebc.ca

Genome Alberta
Gijs van Rooijen
Chief Scientific Officer
Tel.: 403-210-5253
vanrooijen@genomealberta.ca
www.genomealberta.ca

Genome Prairie
Chris Barker
Chief Scientific Officer
Tel.: 306-668-3587
cbarker@genomeprairie.ca
www.genomeprairie.ca

Ontario Genomics Institute
Alison Symington
Vice President, Corporate Development
416-673-6594
asymington@ontariogenomics.ca
www.ontariogenomics.ca

Genome Quebec
Catalina López-Correa
Vice President, Scientific Affairs
Tel.: 514-398-0668
clopez@genomequebec.com
www.genomequebec.com

Genome Atlantic
Shelley King
Vice President, Research and Business Development
Tel.: 902-421-5646
sking@genomeatlantic.ca
www.genomeatlantic.ca