AGRICULTURE-PLANTS: Crop genomics for a healthy Canada

Prepared by the Plant-Agriculture Genomics Group

Theme Leader: Wilf Keller – NRC/PBI

Writing Team: Michael Raine, Isobel Parkin, Raju Datla, Faouzi Bekkaoui

Lead Centre: Genome Prairie

Prepared for Genome Canada

July 3, 2007

GenomeCanada

GenomePrairie

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Executive Summary

"Agriculture is the foundation on which the bio-economy is built. Countries which allow their agricultural base to deteriorate over the next 10 years will not be able to participate in the new wealth creation." ***Canadian Agri-Food Policy Institute, 2007***

The health of Canadians and their economy is improved through investments in plant-based genomics research. Canada is building strong internationally competitive programs in this area. Canada has shown the strength and capacity of its plant science with the creation of canola, and the breeding of cereals and pulse crops that thrive in a harsh environment .Canadian innovations in plant breeding and genetic discovery have delivered improved human and animal health and created wealth at home and abroad. The nation's agricultural producers and manufacturers are the third largest food products exporters on the planet. On knowledge transformation, investment in the commercialization of knowledge-based discovery, the Conference Board of Canada ranks Canada second, behind our largest trading partner, the United States, and ahead of all other industrialized countries[1]. For each dollar of sales the Canadian agri-food industry is capable of generating double the after-tax profit of its American neighbour. Canada enjoys a 10.9% cost advantage over the U.S when it comes to research and development and 4.7% lower costs for agricultural and food production and processing[2].

The theme. The Crop Genomics for a Healthy Canada theme builds on Canadian industrial and scientific capacity. It seeks to keep Canada at the forefront of discovery providing its agri-food and agri-products industries with the key research they need to innovate and compete around the world. Research within this theme will deliver improved human and livestock health, security and safety of the food supply and create new economic opportunities for Canadians. This theme will expand genomic knowledge of plants where Canada already has international leadership. At the same time it will seek to reduce the environmental footprint of the sector through reduced water, fertilizer and pesticides use thus improving the sustainability of agriculture and food production. Investments in research, both public and private, have built a Canadian genomics science infrastructure with the capacity to deliver timely solutions to a variety of today's most important issues and create new opportunities for tomorrow: food and water; energy and the environment; society and the economy.

The 'omics. Employing high-throughput genomic, proteomic and metabolomic approaches to the examination of plant genomics research will develop improved understanding of systems that govern plant growth, development and performance. This theme will develop comprehensive understandings of the genetic and physiological factors that contribute to the underlying biological processes of Canadian crops using genomics tools. Genomics tools may preserve the identity and safety of Canadian agricultural production while delivering needed technologies to the Canadian farmer.

The GE^{3}LS. The Crop Genomics for a Healthy Canada theme's research and outcomes are focused on ensuring that research is undertaken to provide legal, ethical, environmental, economical and social sustainability. The enterprise of this theme has a high correlation of objectives with Canada's Science and Technology Strategy and the AAFC Science and Innovation Framework.

Projected outcomes. Through the applications of genomics technologies, this theme will capture benefits including increased productivity and quality and diversified uses of Canadian crops. This theme has the potential to add $10 billion to Canada's agribusiness sector over 10 years.

Introduction

Despite the improvements to plant breeding, agronomy and land reform the world still fails to properly feed 800 M people each day, leaving them chronically undernourished. More than six million children will die this year from the effects of poor nutrition[i]. Although international efforts are underway to put an end to malnutrition, this goal will not be achieved without contributions from countries such as Canada, who have access to extensive arable land and the ability to apply the latest technologies to crop improvement.

Many other important global and national issues also confront Canadian agriculture. International transfer and rapid adoption of biotechnology, agricultural growth in Asia, the former Soviet states and South America threaten Canadian markets. Arable land is finite and fragile. In many parts of the globe its conversion to biofuel production is coming at a cost to the food supplies of a hungry world[ii]. International trade issues are wearing the mask of food security. However rising populations in these regions, aging ones in the west and new demands for bioproducts and energy are creating vast new markets and opportunities for adaptive nations such as Canada. The burden of chronic disease is increasing worldwide. For example, a recent research study identified that 90% of all first heart attacks can be traced back to nine risk factors that include lack of daily consumption of vegetables and fruit. The Canadian Institute of Health Research estimated that a combination of lifestyle changes, including eating a healthier diet, could result in an 80% reduction of a risk of heart attacks and significant savings to health costs.

Plant genomics can play a significant role in providing solutions to these issues. Plant genomics researchers working with genomics[iii] tools are linking genes to traits, taking plant breeding from an art to a science. Genomics is bringing predictability to plant breeding, speeding discovery and improving returns for those investing in the research. Many fundamental elements of plant physiology have eluded man until now. Genomics is helping plant researchers link plant growth, reproduction, development, photosynthesis and abiotic and biotic stress responses to a complete molecular genetic picture of targeted traits. Yield is one of those important/key traits. In Canadian small grains and oilseeds each 1% increase in harvested yield adds $136 M to rural economies. Encouraging development of under-utilized crops, such as flax, though the use of ‘Omic breeding tools, builds on existing Canadian market dominances. Unlike canola, the recognised Canadian crop, advances in flax breeding has fallen behind due to lack of genomics based research. Today flax varieties yield 73% of average canola crops. If flax yields were increased to 90% of canola, which breeders say is possible, it would deliver an additional $83 per ha to the industry, resulting in $65 M in increased production and helping to ensure Canada’s role as the world’s leading exporter of the crop. In the U.S. it is estimated the impact of biotechnology derived crops is more than $2.3 billion annually (see Table 5).

Scientists are looking at oilseed, cereals, fruit and vegetable crops to deliver safer, more stable foods. They also see these and other new emerging alternate crops as bio-factories, able to deliver nutraceuticals and pharmacologically active compounds that will improve human health through prevention and treatment, serving an aging Canadian population and its diverse health needs. Canada’s Science and Technology Framework demands of Canadian research that it delivers innovation. This theme’s research is linking discovery with plant breeding and new crop varieties with farmers, processors and exporters while reducing agriculture’s environmental footprint. The Crop Genomics for a Healthy Canada theme builds wealth, enhances existing research capacity, improves Canada’s place on the international stage, while putting Canadian’s health and security first.

[i] *WHO Global Burden of Disease and Risk Factors*
[ii] *Based on AAFC Grains and Oilseeds outlook, June 2007*
[iii] *Genomics as referred in this document encompasses but not limited to proteomics, metabolomics and bioinformatics.*

Theme Importance: Investing In Plants For A Healthy Canada

Size of the industry

The economic evidence of Canadian innovation in plant-based agriculture can be found on farms, in factories, grocery stores, universities, ports, rural communities and balances of trade. Its future will be reflected in the health of Canadians and their economy.

Agriculture and food is the fourth largest industry in Canada. One in seven jobs are related to the agri-food sector[4]. In the 2006 Canadian census of agriculture 230,000 farms reported being the business of crops and horticulture. Canadian agriculture will export 28.8 million tonnes (MT) of grains and oilseeds in 2007, worth $13.8 billion[5].

Fruit and vegetable production in Canada is a $5 billion business, based on farm-gate receipts[6]. The Canadian Seed Trade Association estimates the value of their industry to the Canadian economy at $800 million annually. Agriculture and Agrifood Canada predicts grain and oilseed production to increase 3% in 2006-2007 to 66.3 MT.

In Canada barley forms the backbone of the western livestock industry's feed system. In 2006-07 the crop's estimated value to grain producers is $1.7 billion. Livestock processing is a $15.4 billion industry in Canada. A complementary Genome Canada theme paper in animal-agriculture genomics deals with many of the issues related to animal production while research in this theme deals with the single largest cost of livestock production, feed, and its relationship to animal health, waste products and efficiency.

Exports

Canada is one of the world's largest exporters of agricultural products and produces about 10% of the world's GMO crops[7]. The nation is the world's largest exporter of flax, canola, lentils and durum wheat. In durum Canada has 49.8% of the world export market, with just 12.3 percent of production. Wheat crops form a $5 billion[iv] portion of agricultural production in Canada and canola just over $4 billion. The wheat industry produces just 4% of the world's supply, but exports 11% of the bread wheat and wheat flour shipped internationally.

Rural development and growth

Rural Canada is highly dependent on agriculture for its survival. One third of Canadians reside in rural areas and about 40% of those rely directly on agriculture for their livelihoods. Rural New Brunswick relies on potatoes and food processing. Southern B.C. looks to its fruit production. Fruit and vegetables are produced commercially on 3,100 farms in Ontario and Quebec covering 160,000 ha of land, while southern Alberta is focused on livestock production and food processing.[v] In many regions of Saskatchewan and Manitoba agriculture dominates every aspect of rural life and shifts in that industry decides the fates of small communities. These rural industries remain vulnerable to changes in international trade, however Canada has shown repeatedly its ability to adapt to market change. Genomic research offers Canadian agriculture and food processing the opportunity to compete on an even footing with other countries relying on the same technology and respond to change faster than ever before. With 68 million hectares of arable land[8], Canada is well positioned to create the feedstocks for the world's emerging bioeconomy.

Markets

Food and health. The grocery industry is a $90 billion business in Canada[9] and sits on the border of a $1 trillion[10] U.S. market for food and non-alcoholic beverages. Asia's expanding economy is creating new

[iv] *Calculated based on AAFC Grains and Oilseeds Outlook, May 2007.*
[v] *Statistics Canada Census of Agriculture, 2001, 2006*

market opportunities for food production globally. As incomes rise in China and India, food consumption patterns change[i]. Demand for food products from those regions is reducing grains and oilseed global reserves. Asian demand for animal proteins is also pushing up prices and limiting supplies, a trend that is expected to continue for many years to come. Canola and rapeseed demand continues to rise internationally. In 2007-08 prices have risen 10% over the previous year and 6% over the five-year average. The global supply is estimated to reach 55 MT this year with a value of more than $13.5 billion. The Canadian crop is expected to be almost 20% of that supply at just under10 MT with a farm gate value of nearly $4 billion and an economic impact of over $11 billion to the nation. The USDA estimates that vegetable oil demand will continue to grow at 4% per year, while production will lag at only 3%, creating long-term market opportunities[11].

Feed. The value of livestock feed in Canada has risen by 40% in the past year as a result of increasing commodity prices and demand for high yielding, lower protein grains and oilseeds to feed the international demand for biofuels. International demand for animal protein is expected to expand the livestock sector in North America over the longer term and with it, demand for feed[ii]. Application of genomics in plant breeding offers the tools necessary to improve the same feedstock that produces ethanol and biodiesel and its byproduct, livestock feed.

Energy and bioproducts. Biofuel markets in Canada are still emerging, but demand for cereal grains over the next two years is expected to double, rising to more than 2.5 MT, nearly half of the annual Canadian carryover for those crops[iii]. Demand for cereal grains with improved starch profiles for the distilling industry is expected. Niche markets for specialty starches and natural industrial fibres are expanding across North America and are expected to become part of future export and domestic sales as they become available.

National Strategy

Health and Agriculture. Canada's strategy to sustain agricultural development has been through the national Agriculture Policy Framework (APF). The APF has established principles for taking sustainable action in five priority areas - food safety and quality, business risk management, environment, science and innovation, and renewal. The government is now focusing on promoting better integration of the three pillars of sustainable development – economic, environmental, and social. Health Canada has identified promoting and supporting population health, identifying and reducing environmental health risks, strengthening partnerships on health, environment and sustainable development as targets the agency is pursuing. The Crop Genomics for a Healthy Canada theme's pursuit of reduced pesticide use, increased efficiency of fertilizers, improved crop yields, added nutritional benefits and economic sustainability for rural Canada have a strong correlation with these federal goals.

Science and Technology. Canada is investing in research through its new Science and Technology Framework. Innovation will need to be supported by strong science and effective regulation to protect human health and the environment while supporting Canadian competitiveness. In 2005 the federal government invested more than $9B to support and advance the national S&T strategy. The S&T strategy recognizes the role of genomics and biotechnology in the future success of Canada as a nation.

> "*Improvements in our quality of life and standard of living will depend on our increasing success in bringing scientific and technological innovations to life.*" ***Canada's S&T Strategy, 2007***

Canadian Agrifood Policy Institute. CAPI is undertaking a major project, through a series of studies to examine the relationship between the agri-food sector and Canadian health. This theme has attracted

[i] *Richard Gray, UofS Ag Economics presentation, Ottawa June 1, 2007*
[ii] *Barry Flinchbaugh, KSU, Panel debate and address to the SCFA, January 2007*
[iii] *McKinnon, UofS, WBDC presentation, June, 2007*

significant interest from the research community to provide support for projects related to improved population health as it relates to breeding of healthier oilseeds, fruit and vegetables.

Strategy on the environment Canada has chosen to develop sustainable resources within the environment and create, as a matter of public policy through Environment Canada, long-term national capacity for sustainable development that will result in a safe and healthy environment and a sound and prosperous economy. The theme's relationship to reduced greenhouse gas production, lowered pesticide loads on the environment and improved water use support this national direction on the environment.

The Challenge: What Plant-Based Genomics Delivers To Canadians

Discovering and harnessing the genes that cause plants to produce more, protect and feed themselves, and express useful products is the basis for the research proposed under this theme. Solutions to challenges facing Canadian health, food security, agriculture, manufacturing and energy will be found for a number of key and uniquely Canadian crops. Genomics technologies addressing these challenges through translational research contributing to discovery and innovation supporting distinctly Canadian industries with solutions that protect and build markets and industries and protect and reassure the public are the goals of this theme. These are also pivotal issues for Canada's Science and Technology Strategy, the AAFC Science and Innovation Framework and Canada's recent federal government commitments to Canadian and North American competitiveness internationally. Though many of these challenges are important and relevant globally, the priority and focus of this theme is to address major problems and bottlenecks facing Canadian crop industry through genomics. These are:

- Enhancing yield and improved productivity in Canadian crops
- Production of healthy and quality food products
- Crop varieties to meet the renewable energy needs
- New and diversified crop platforms for industrial bioproducts
- Efficient and environmentally friendly sustainable agriculture

Health begins at home and competes abroad. Improvements to the health, safety and supply of Canadian food through improved nutritional traits, traceability and crop resistance to biotic and abiotic stress are all related to the economic and physical health of the nation and this theme. Nutritionally enhanced foods and nutraceuticals are an emerging area of the agri-food industry that will improve the health of an aging Canadian population. A complementary Genome Canada theme deals with the exploitation of these compounds in human health, while this theme explores the mapping and identification of the genes responsible for the traits of interest and the methods plant breeders might employ in their creation and enhancement. Proteomics and metabolomics are aiding researchers in understanding the plant molecular function and pathways enabling plants to act as bio-factories in Canada's new bioeconomy. Analysts say the U.S. market for functional foods and nutritional supplements, based in biotechnology, is currently $66 billion, with accelerated growth predicted over the next two decades.[12]

Grains and oilseeds around the world. Canada's export crops are well developed, but factors such as new production in Eastern Europe, Asia and South America pose threats. Europe, the U.S. and Australia are powerful competitors that Canada meets in the marketplace every day. But initiatives like the EU's $40 M Grain Legumes Integrated Project, while expanding genomic knowledge of pulse crops, requires Canada to mobilize its research and industry to keep pace or face losing markets that now generate $1.4 billion annually. Opportunities in Brassica development and designer oils are opening, but competition around the world will rapidly fill those market voids. Ethanol is swallowing corn supplies as fast as they can be grown, creating new opportunities in cereals such as wheat and barley. However long-term predictions are for a move to cellulosic crops replacing seed-based ethanol and this creates uncertainty about future corn supplies

and demand. Securing markets while corn is out of the trading-room builds opportunities for new and uniquely Canadian crops.

The energy issue. The European Union estimates a five-fold increase in demand for biofuels by 2010, a $300 billion business.[13] In response to demand for corn and soybeans to fill and explosion of American bio-refineries food commodity prices have risen 34% in 2006-07[i].

A new opportunity for Canadian canola is opening as biofuel subsidies drive U.S. soybean supplies into biodiesel production and American farmland into corn cropping for ethanol. Canadian demand for vegetable oil to satisfy government led biodiesel initiatives is expected to further erode supplies. The Canadian biodiesel mandate will require production of 600 M litres of the fuel, equivalent to oilseed production from nearly 800,000 ha of land. The USDA reports that global soybean production in 2007-08 will decline 10.1 MT to 225.3 MT due to a rise in corn acreage for ethanol production. Brazil's shift to sugar cane for ethanol and Argentina's and China's moves to cereal production will fail to replace lost vegetable oil production, especially for premium human food markets where Canadian canola already has strong market demand. International market analysts say at the same time U.S. consumers are both demanding improved nutrition in their foods and becoming more skeptical of health claims. The Canadian canola industry requires the ability to move quickly to develop improved varieties that meet rapidly evolving market needs both in quality and production. A complementary Genome Canada theme is examining biofuels development, while this theme will focus on improved performance and production of plant species that contribute to biofuels.

Minor increase = Major dividend. The Canola Council of Canada has observed canola crop yield increases of 35% in the past 20 years. A sizeable portion of this increase has been delivered through plant breeding "a bushel or two at a time", says the industry association.

Newer hybrid *Brassica napus*, Argentine-type canola, many of which were bred and developed in Canadian labs taking advantage of the full suite of biotechnology (genomics) tools, produce average yields 40% higher than open pollinated crops of 25 years ago. Manitoba Agricultural Services Corp., analysis shows prairie per ha yield doubled in nearly all crops since 1973[14].

While improved management plays a significant role, plant breeding through biotechnology dramatically improved yield. The most recent generations of crops are bred to take full advantage of improved production practices, optimizing fertilizer and water-use, benefiting all Canadians. Crops with tolerance to lower cost, more environmentally sustainable herbicides, such as glyphosate, have reduced the environmental impact of herbicides. Farmers taking advantage of this technology also receive direct savings though reductions in field operations and tillage. Fewer operating hours and reductions in soil disturbance cut greenhouse gas emissions and improve labour efficiency and supports Canada's S&T strategy.

> *"This strategic framework for S&T will guide the Government of Canada in how it approaches investments in S&T intended to increase our competitiveness, improve the quality of our environment, reduce greenhouse gas emissions, improve the health of Canadians, promote the sustainable growth of our energy sector, and ensure national security".* ***Canada's S&T Strategy 2007.***

Research Capacity: We've Got The Right Stuff From Coast To Coast

Canadian plant-based research has delivered improved crops and better health and has the capacity to deliver innovation through genomics to Canadians. This theme supports Canadian advantages and builds on the investments in plant biotechnology Canada has made including Genome Canada, regional genome centres, AAFC, NRC's Plant Biotechnology Institute (PBI), BC's Genome Sciences Centre (GSC) and numerous other facilities both public and private. Linkages to international genomics researchers and the increasing

[i] *Calculated from AAFC Canadian Grains and Oilseeds Outlook for those crops, 2005, 2006, 2007*

multinational collaborative initiatives, further add to the resources accessible to this theme. A list of those supporting this theme is available in Appendix 1 at www.genomecanada.ca.

Tomorrow's toolbox. This theme requires a Canada-wide approach. The capacity of Canadian genomics is based on its highly qualified people having the best tools. Discovery creates opportunity for innovation, but without the scientific means Canadian research will lag that of its competitors. While no true measure of researchers using genomics for their plant-agriculture inquiries exists, it is estimated that Canada has about 1,000 scientists working with the tools in at least 27 larger academic institutions and private industrial sites. This does not include the economists, sociologists, legal and ethics specialists that are working on GE^{3}LS issues. Over the past six years, since the creation of Genome Canada, the country has expanded its genomics infrastructure to meet the challenges of the science and the markets. Today there are key technologies including the latest advancements such as next generation high throughput sequencers found at genome centres, universities and government labs. Specific resources are listed in Table 1. Further, Canadian researchers have leveraged their research advantages through international collaborations. This theme is supported internationally by industry and researchers from around the world (see Appendix 1 at www.genomecanada.ca). Modern plant science is based in genomics. Genomics is the foundation and a major driver for agriculture-plant research globally. No new research project of any scale involving plant breeding takes place without genomics support. Its cost efficiencies and ability to perform previously theoretical tasks has created unprecedented opportunities for innovation in plants and seeds. Around the world large-scale genomics projects are mapping whole plant genomes with new discoveries being made daily.

Plant genomes by their very nature are complex and large. The scale of inquiry necessary must meet this challenge and quickly deliver discoveries that will result in rapid innovation. Most of today's successful genomics discoveries come through the accumulation of vast amounts of genetic data followed by the efficient management and exploitation of the information using bioinformatics tools. Canadian researchers have already built significant resources for a number of crops with genomic DNA libraries, single nucleotide polymorphism panels, expressed sequence tags, microarrays, and whole proteomes (see Table 1). This theme will attract programs which will build on not only this capacity but International efforts to ensure a significant impact on the industries or research of the co-funders and add to Canada's overall genomics capacity. Under this theme Canada has ongoing genomics research in canola, wheat, barley, rye, flax, soybeans, lentils, chickpeas, peas, beans, other pulses, cereals, oilseeds, forage crops, fruit, vegetables, nutraceutical compounds, GE^{3}LS, bioinformatics, proteomics and metabolomics. Canada is an internationally recognized leader in genomics for many of these crops and has the opportunity to expand its leadership in new sectors such as flax and sweet cherries. Countries around the globe are investing in genomics and advancing plant science rapidly, creating opportunities for their nations, and some will come at the expense of Canadian markets.

GE^{3}LS: Making It Right The First Time

GE^{3}LS research is a natural fit under the Crop Genomics for a Healthy Canada theme as a living laboratory for innovation and societal change. While agriculture has shown high rates of commercialization and productivity growth, it has also faced high profile challenges, with GMOs and the public's perception of food products developed from transgenic plants. The rapid innovation in the sector is also built on a rich history of public and private research and development. As agricultural value chains evolve to realize opportunities they will spawn wide variety of new innovation systems. The heterogeneity of these systems will provide insight into successful strategies for commercialization, which will better serve Canada's overall S&T strategy.

The theme will attract GE^{3}LS research because it will deliver a better Canada and a better world. Social sustainability is built from plants and plant forms, through food security and improved human and animal

health from better food and feed. On the Prairies there is an expression “Canola saved the family farm.” If canola had been developed with today’s genetic tools the saying might very well be “Genomics saved the family farm.” Researchers submitting EOIs to this theme will find genes responsible for traits that produce health-giving compounds in our seeds, fruits and vegetables. Strategically applied, the work of this theme will be a springboard for Canada internationally, showcasing the value of our science and agricultural exports; alleviating hunger and poverty and improving human health, keeping Canada at the front of the world’s stage.

Canadian Solutions – Canadian Outcomes

Genomics technologies have revolutionized plant research, giving a tantalizing glimpse at the complex pathways and processes controlling the development and adaptation of different crop species. Canadian researchers have successfully targeted the genomics tools to key Canadian crops and are at the cusp of making incremental improvements to the quality and the profitability of these core staples of the bioeconomy. The proposed theme will transfer these fundamental breakthroughs from the laboratory to the field, empowering breeders, producers and ultimately consumers, with choices that benefit not only the wealth but the health of Canadians.

The theme will fund research with the objectives to:

- Increase the yield per hectare of Canadian crops by at least 25%
- Reduce the environmental impact of large scale agriculture by lowering nutritional inputs and pesticide use
- Create new designer crops with increased levels of available bioactive molecules, reducing the burden on the Canadian Health system
- Facilitate the rapid development of Canadian niche markets - Sour cherries will become the new ‘pomegranate’

The anticipated economic gain from these activities is estimated to exceed $10 billion to Canada's agribusiness sector over 10 years.

It is anticipated that due to past successes and established genomics resources some Canadian crops will be obvious beneficiaries of this theme. For example:

Canola – the crop that became an industry and saved the farm. Canadian canola genomics researchers have established linkages with Germany, UK, South Korea, and the Netherlands and are represented in the multinational Brassica rapa genome sequencing initiative. A group of NRC and AAFC researchers have generated the world’s largest EST collection >500,000 from Brassica species and are focusing on molecular understanding of genetic factors that regulate seed development and metabolism. Genomics tools have given researchers the opportunity to examine issues such as why some crops such as canola accumulate oil in the seeds more efficiently, than others, such as soybean, which accumulate more protein. The Canola Council of Canada is planning for Canadian research to deliver an increase from 42.5% oil in the seed to 45% in just eight years. The CCC estimates that for each one percent increase in oil content the industry will squeeze another $60 million in revenue.

This theme will also allow recent remarkable Canadian genomics discoveries to be developed to the point of delivery. For example:

eIF5A leading the World. Dr. John Thompson and his colleagues at the University of Waterloo discovered that eIF5A acts as a biological switch that regulates senescence in one position and growth in another. Controlling this switch increases growth, enhances resistance to disease and environmental stress, such as drought, and improves shelf life of perishable produce. Perhaps most remarkably this gene has been shown to enhance resistance to disease and improve the shelf life of bananas, a dietary staple as well as a source of hard currency for poor subsistence farmers in tropical Africa, Asia and the Americas. Discoveries like eIF5A enhance Canada's reputation as an international plant-based genomics research leader.

This theme will support research to keep Canada competitive in key crops. Examples include:

Pulse Crops – a Canadian natural leader. The edible seeds of legumes, pulse crops are a global dietary staple. Canada is the world's largest exporter of several of these crops and is one of the top five producers globally.[i] Nearly all of the varieties of peas, chickpeas, lentils and beans being grown in Canada having been bred through Canadian research programs and Canada is recognized as a world leader in this area. Production of these crops generates 4% of Canada's farm cash receipts and averages $1.4 billion. The industry has grown from 526,000 ha in 1991 to over 2.6 M ha in 2005[15]. Legumes fix their own nitrogen from the air and leave deposits of large surplus supplies in the soil. Canadian farmers grow the crops in rotations that allow them to reduce their use of N fertilizer from natural gas sources by up to 30% in a season following a pulse[16]. This increases margins for growers and cuts greenhouse gas emissions, helping Canada meet its international commitments to the environment. One third of pulse crop production remains in Canada for domestic consumption and it's good thing. Pulse crops are high in complex carbohydrates, such as fibre and resistant starch, proteins, minerals, vitamins including cancer-fighting folate. Other regions of the world have recognized the advantages of pulse crops and new crop development initiatives outside of Canada threaten the Canadian industry's foothold. The EU has created the Grain Legumes Integrated Project and is working closely with the UK's Grain Legume Technology Transfer Platform to expand production of pulse crops for human and animal consumption. These research programs are based extensively on the use of genomics tools[17].

There are several opportunities for genomics research that will help keep Canada competitive and a world leader in pulse production. Bio-fortification of targeted nutrients and the enhancements in bioactive peptides, proteins, starches, particularly amylase, and fibre fractions will help the industry meet its competition. Enhancements will also target significant reductions or complete elimination of anti-nutritional factors to enhance the use of pulses as food, functional foods, livestock feed, pet food and aquaculture feed. The industry is also seeking production enhancements including yield improvement and adaptation to abiotic plant stress such as drought and heat and biotic stresses from disease, particularly fungus, and pests.

Potato – a hot one. Canada is known internationally as a potato processing giant, employing over 33,000 people, generating $6.4 billion in economic activity and adding over $1 billion annually to Canadian agriculture and food exports. It is home to one of the world's largest potato companies, McCain Foods with 55 processing plants in 13 countries, 20,000 employees and global sales of $5.8 billion.[18] Potatoes are the fourth largest food crop in the world with an annual sales growth of 4.6%, centered mainly in Asia.[ii] Potato production and processing takes place in rural areas and as a result has added to the sustained health of many small communities across Canada. Due to high costs of transportation and perishable nature of the crop most value-added processing takes place in the communities where potatoes are produced. In New Brunswick alone potatoes produce $1.3 billion annually, employing 5,600 fulltime equivalent workers.[19] Government and industry have jointly created a strong research and development community of highly qualified researchers relying on world-class technology. The Potato Innovation Network 2020 is developing new potato-based products including nutraceuticals and healthy food ingredients. The project is also working to improve potato traits by breeding in more human friendly carbohydrates and fats.

[i] *AAFC Pulse and Special Crops Statistics 2007*
[ii] *AAFC market analysis, June 2007*

Potato plant genomics research is necessary to deliver traits that provide carbohydrate platforms for bioplastics, bioadhesives and biocoatings. Development of enzyme platforms to create protease inhibitors and improved fermentation characteristics will create opportunities in alcohol production. Enhanced antioxidants, carbohydrates and new development platforms for therapeutic drug products such as anti-coagulants, anti-hyperglycemic and anti-dermatitis are all part of the PIN 2020 strategy. Genomics offers the opportunity to reduce levels of undesirable secondary metabolites such as steroidal glycoalkaloids.

Finally this theme will allow the development and application of genomics tools for uniquely Canadian crops:

Fruits' sweet success. Fruit production within the Rosaceae family, including apples, strawberries, peaches, sweet cherries, raspberries, pears, plums, sour cherries and apricots is a $276 M per year industry in Canada.

Canada is very competitive in crops such as sweet cherries, a $24 M crop and has strong domestic markets in apples, $132 M and strawberries $52 M[20]. Sweet cherry production is an example of a Canadian niche market advantage. Our colder Canadian climate delays ripening by several weeks producing fruit that enter the international market with little or no competition. In combination with late-ripening, high quality new Canadian cherry varieties this opportunity continues to grow. Canadian producers have higher labour costs and face market challenges in many Rosaceae fruits from commodity producers in developing countries and where climates favour production in the U.S. However Canada has fewer disease and pest issues, helping to level the industry playing field. Canadian produce has a reputation for being of high quality and produced in a country with strong environmental standards.

Genomics tools which are presently limiting for these crops could providing solutions in issues of water use, plant stress and the environmental impact of fertilizer. Investment in comparative genomics and proteomics in a few important fruit species in Canada will accelerate the development of molecular marker technologies within the next 5-8 years, resulting in new gene, protein, and metabolite databases for fruit crops in Canada. Currently there are few publicly available gene sequences for raspberry, a fruit species reported to contain high antioxidant properties in animal systems. Sequences in raspberry could create nutraceutical and health claim opportunities for the crop.

Further similar to its leadership role in wine grape genomics there is an opportunity for Canada to take on an international leadership role through sequencing the sweet cherry genome. Other countries have selected different Rosaceae crops to sequence, but so far the cherry genome remains unclaimed. Cherry has a small genome size of 338 million base pairs (Table 2) making it an achievable goal in a relatively short time frame.

Theme Attraction

The success of the previous Genome Canada and the regional Genome Centre expressions of interest[i] related to this plant-based genomics theme indicates both the capacity for the research and its importance. This position paper process alone generated 13 EOIs directly related to plant-based themes out of 57 EOIs in total. But looking beyond the plant research titles most of the proposed themes have elements related to bioenergy, nutrition, bioactive compounds from plant sources and the health of animals and people. All of those subjects require an element of plant-based solutions. Plant-based genomics develops the facilities and bioinformatics tools that are necessary for inquiry and discovery in all molecular genetic studies.

Genomics research is well supported in the agricultural industries as can be noted from the list of supporters in Table 4 and Appendix 1. Canadian plant science researchers adopted genetic tools as they became available, including mutagenesis, double haploidy, genetic transformation and molecular markers. Canadian farmers, strong competitors internationally, have been early adopters of technologies from reduced tillage and global positioning systems to the use of genetically modified crops including high yielding, nutrient and

[i] *A list of previous EOI and Genome Canada and regional Genome centre plants-projects resides on the Internet at www.genomecanada.ca*

water efficient hybrids, and herbicide and insect resistant varieties of oilseeds and corn. Their support is assured, as is their determination to commercialize the discoveries outcomes of this theme.

The Agriculture-Plants Position Paper Workshop in Ottawa June 1 had 44 participants with 14 presentations from interested parties and potential co-funders. These included CropLife Canada, the Canadian Seed Growers and Seed Trade Associations and from industries as diverse as flax, soybean, canola, potato, vegetable, cereal, fruit and human health as well as researchers from several universities across Canada and AAFC in New Brunswick and British Columbia and the National Research Council. Prior to this workshop, consultations with researchers from across Canada and a primer workshop with participation from all plant related EOIs and international experts.[i]

Funding: Four Years of Growth

It is expected that the theme will attract 15 to 20 research proposals with six to 10 being funded. This represents a total investment of $100 to $120 M, with Genome Canada taking a 50% stake in the theme through a $50 to $60 M investment. Matching funding from the two senior levels of government's agriculture, food and health departments, universities, grower associations, bioproducts and biofuels companies, livestock organizations, grain companies, and the major life sciences corporations is assured.

Funding this theme has the potential to create some very high ROI. For each 1% increase in grains and oilseeds production as a benefit of this theme's work will yield $136 million [ii] annually. Each year the manufacturing of synthetic nitrogen fertilizer, applied to Canadian crops, contributes 5,800 kilotonnes of CO_2 to the atmosphere[21]. Environmental benefits to reductions in CO_2 losses are still hard to quantify, however to Canadian farmers a 10% savings in N fertilizer will save a small Prairie, 1,000 ha, farmer $14,700 annually[iii]. In addition there is the value of defending Canadian export industries, creating new ones, improving feed efficiency in livestock, adding traceability to foods and creating savings in Canada's expanding $100 billion health care costs through nutraceuticals and improved foods.

Conclusions

"Anything can wait but agriculture can't" ***Jawaharlal Nehru (1st Prime Minister of India) 1947***

Agriculture is as important to India in 1947 as it is now to every nation. It is relevant not only for food and feed but also for health, renewable energy, environment, and many other important issues as articulated in this document.

Genomics research is critical to any major crop improvement in agriculture

Canada's investment in agriculture genomics seriously started in 1999 (with Genome Canada) and in a short time established credible presence and in some cases leadership (e.g. wheat, canola). These investments are beginning to deliver promising outcomes and without continued investments and support to Agriculture genomics – Canada will loose its competitive position and has to depend on others for addressing Canadian agriculture priorities. Canada can't afford to have this to happen.

[i] *Industrial products from plants workshop, Genome Prairie, March 1st 2007*
[ii] *2007 grains and oilseeds outlook predicts $13.6B in farm receipts.*
[iii] *Fertilizer cost of $1.47 Kg applied at 224 Kg per ha*

Table 1. Canadian Genomics Infrastructure

Next generation sequencing	Solexa 1G Sequencer, B.C.'s Michael Smith Genome Sciences Centre
Proteomics	BC GSC, University of Victoria's Genome BC Proteomics facility, the University of Ottawa, IBC and at the NRC/PBI.
Microarray facilities	Affymetrix at McGill, UofT and BC GSC; Oligo Array Spotting at the UofA and NRC's BRI; Combimatrix NRC/PBI.
Targeted metabolomics	A number of universities and government labs and there is a hormone profiling centre at NRC/PBI
Non-targeted metabolomics	FTMS Phenomenome Discoveries Inc. and BC GSC

Table 2. Relative Genome Size

Genome	Size in Mbase pairs
Arabidopsis	125
Sweet Cherry	338
Rice	400
Brassica rapa	500
Medicago	550
Poplar	550
Cassava	770
Tomato	950
Sorgum	1,000
Corn	3,000
Barley	4,850
Wheat	17,000

: Canadian participation

Table 3. The status of some of the genomes related to this position paper and Canadian Participation

Plant	Crop Plant Sequencing
Arabidopsis thaliana	Sequenced. Databases of genetic and molecular biology data, e.g. Multinational Coordinated Arabidopsis Project, www.arabidopsis.org
Grape	Pinot noir cultivar sequenced. Italian Government and Myriad Genetics.
Poplar	Sequenced. US Department of Energy Joint Genome Initiative (JGI)3, http://genome.jgipsf. org/Poptr1/poptr1.home.html
Medicago trunculata (related to alfalfa)	International consortium, scheduled for completion in 2006, www.medicago.org/genome; genomics also funded by Noble Foundation, www.noble.org
Sorgum	US Joint Genome Initiative, in annotation, http://www.phytozome.net/sorghum
Tomato	Nearing completion at Cornell University, an international project. http://www.sgn.cornell.edu/about/tomato_sequencing.p
Corn	US National Science Foundation/DoE/USDA consortium, http://www.corngenome.org
Brassica rapa	International consortium, www.brassicagenome.org
Potato	US Joint Genome Initiative, www.jgi.doe.gov/sequencing plus other work underway in Canadian Initiative
Wheat	International consortium, www.wheatgenome.org
Soybean	US Joint Genome Initiative, www.jgi.doe.gov/sequencing In annotation.

: Canadian participation

Table 4. Supporters

Expressed support	#	%
Academic	69	38
Industry	44	24
Government	34	19
International	18	10
Organizations	16	9
Total	181	100

Table 5. The U.S. Experience with Biotech Crops

The American National Center for Food and Agricultural Policy' reported that in 2005 the eight biotech crops being planted by U.S. growers increased crop yields by 3.8 MT, saved growers $1.49 billion by lowering production costs, and reduced pesticide use by 31,600 T. [1]Based on increased yields and reduced production costs, growers realized a net economic impact or savings of $2.13 billion.

In its report "Conservation Tillage and Plant Biotechnology," the Conservation Tillage Information Center at Purdue University reports tillage reduction through the use of herbicide-tolerant varieties produced through biotechnology decreased soil erosion in the U.S. by 1 billion tons of soil material per year saving $3.8 billion per year in sedimentations costs and decreases fuel use by 39 litres per hectare.

According to the International Service for the Acquisition of Agri-Biotech Application Bt cotton, has led to significant environmental and economic benefits. In China between 1999 to 2000 insecticide use decreased by 67 % and yields increased by 10 percent, creating improving returns to the farmer of $540 per hectare. In India the 40 % yield increases were observed with 50% reductions in insecticide use increasing returns by $135 per hectare.

	Impact of biotechnology derived crops on U.S. agriculture				
Year	Planted hectares	Yield increase	Reduction in production costs	Net economic impact	Pesticide use reduction
	Million hectares	Million tonnes	Billion dollars	Billion dollars	Thousand tonnes
2005	49.7	3.8	1.49	2.13	31.6
2004	47.7	3	1.81	2.45	28.1
2003	42.8	2.5	1.59	2.02	21

Source: Sankula, S., Quantification of the Impacts on US Agriculture of Biotechnology-Derived Crops Planted in 2005, National Center for Food and Agricultural Policy, November 2006.

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