Canada’s Country Report for the

Third Report on the State of the World’s Plant Genetic Resources for Food and Agriculture

Submitted to the Commission on Genetic Resources for Food and Agriculture of the Food and Agriculture Organization of the United Nations, Rome, Italy

Agriculture and Agri-Food Canada

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Abbreviations

AAFC	Agriculture and Agri-Food Canada
AnGRC	Animal Genetic Resources of Canada at AAFC, Saskatoon
ARS	Agricultural Research Service of USDA
BFICSS	Bauta Family Initiative on Canadian Seed Security
BRM	Business risk management
CAD	Canadian Dollar
CANOVI	Canadian Organic Vegetable Improvement Project
CAPGERNet	Caribbean Plant Genetic Resources Network
CBD	Convention on Biological Diversity
CDC	Crop Development Centre, University of Saskatchewan, Saskatoon
CEROM	Le Centre de recherche sur les grains, Québec
CGIAR	Consultative Group on International Agricultural Research
CFIA	Canadian Food Inspection Agency
CCGB	Canadian Clonal Genebank at AAFC, Harrow
CGRFA	Commission on Genetic Resource for Food and Agriculture at FAO
CNPGS	Canadian National Plant Germplasm System
CPGR	Canadian Potato Genetic Resources at AAFC, Fredericton
CSO	Civil Society Organization
CWR	Crop wild relatives
DAO	National Vascular Plant Herbarium at AAFC, Ottawa
DAOM	Canadian National Mycological Herbarium at AAFC, Ottawa
FAO	Food and Agriculture Organization of the United Nations
FHB	*Fusarium* head blight
GAC	Global Affairs Canada
GBS	Genotyping-by-sequencing
GSD	Genetic sequence data
GPA	Global Plan of Action for PGRFA
GCDT	Global Crop Diversity Trust; short: Crop Trust
GRIN	Genetic Resources Information Network, recent version: GRIN-Global
IAFSI	Indigenous Agriculture and Food Systems Initiative of AAFC
IBPGR	International Board for Plant Genetic Resources (known today as Bioversity International)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IICA	Inter-American Institute for Cooperation on Agriculture
IPK	Institute for Plant Genetics and Crop Plant Research, Germany
ISAO	Indigenous Support and Awareness Office, AAFC
ISLO	Indigenous Science Liaison Office
ISMA	International Seed Morphology Association
ISTA	International Seed Testing Association
ITPGRFA	Internal Treaty on Plant Genetic Resources for Food and Agriculture
NCPGRU	National Plant Genetic Resource Centre in Kharkiv, Ukraine
NFGRC	National Forest Genetic Resources Centre, Fredericton
NORGEN	Task Force on Genetic Resources of PROCINORTE
NPGS	National Plant Germplasm System of the USDA

OWBM	Orange wheat blossom midge
PBR	Plant Breeders' Rights
PGRC	Plant Gene Resources of Canada at AAFC, Saskatoon
PGRFA	Plant Genetic Resources for Food and Agriculture
PROCINORTE	Cooperative Program in Research and Technology for the Northern Region of IICA
PROCISUR	Programa Cooperativo para el Desarrollo Tecnológico Agroalimentario y Agroindustrial del Cono Sur of IICA
RBG	Royal Botanical Gardens, Hamilton, Ontario
RDC	Research and Development Centre of AAFC
RDT	Research Development and Technology Transfer
REDARFIT	Andean Network on Plant Genetic Resources
REGENSUR	PROCISUR's Sub-program for Plant Genetic Resources
REMERFI	Mesoamerican Network on Plant Genetic Resources
SDGs	United Nations Sustainable Development Goals
STB	AAFC's Science and Technology Branch
TROPIGEN	Amazonian Network on Plant Genetic Resources
TUFGEN	Total Utilization Flax Genomics
UBC	University of British Colombia
UPOV	International Union for the Protection of New Varieties of Plants
UPOV-91	1991 – International Union for the Protection of New Varieties of Plants
USC	Unitarian Service Committee of Canada, today: SeedChange Canada.
USDA	United States Department of Agriculture
VIR	N.I. Vavilov Institute for Plant Genetic Resources, St. Petersburg, Russia
WIEWS	World Information and Early Warning System on Plant Genetic Resources for the UN Food and Agriculture Organization
WGRF	Western Grains Research Foundation

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Wheat (*Triticum aestivum* L.) germplasm lines at Plant Gene Resources of Canada ready for harvest.

Foreword

This is Canada's contribution to the preparation of the Third Report of the State of the World's Plant Genetic Resources by the United Nations Food and Agriculture Organization (FAO) and its Commission on Genetic Resources for Food and Agriculture.

The FAO was established as a specialized United Nations Agency in Québec, Canada, on 16 October 1945. Canada shares with FAO the vision of a world without hunger and poverty, focusing on resilience of agricultural production and livelihoods, food security and nutrition, including women's empowerment to achieve these goals.

Canada's firm commitment to conservation and sustainable use of plant genetic resources for food and agriculture builds on our long history of biodiversity stewardship among Indigenous Peoples of Canada. The Sustainable Development Goals adopted by all United Nations Member States in 2015, as part of the 2030 Agenda for Sustainable Development, outline significant global challenges tied to biodiversity and plant genetic resources for food and agriculture. Canada has long supported the FAO and its Commission on Genetic Resources. We are also Party to the International Treaty on Plant Genetic Resources for Food and Agriculture, as well as the Convention on Biological Diversity.

Agriculture and Agri-Food Canada supports the development of new opportunities and products for farmers and consumers. Innovative approaches in plant breeding require genetic resources of crops, including their wild relatives, to supply farmers with crops that are better adapted to changes in climate, new pests and diseases, new production methods and new consumer demands.

Canada values diversity and sharing, and is fully committed to the vision of Open Science that is being embraced by many governments around the world. For over half a century, Agriculture and Agri-Food Canada has been collecting, conserving and sharing plant genetic resources for food and agriculture from the Canadian National Plant Germplasm System. Canada has made all plant genetic resources in our national genebank collections and all associated information freely available to any user around the world for research, breeding and education.

This Country Report demonstrates how many Canadians from various backgrounds are collaborating to conserve and utilize plant biodiversity underlining Canada's continued commitment to safeguarding our precious plant genetic resources for current and future generations.

Summary

Plant genetic resources for food and agriculture (PGRFA) include the genetic diversity of all plant speciesused in agriculture and their wild relatives. They are essential raw material for plant breeding and relatedresearch in Canada.

The Canadian National Plant Germplasm System (CNPGS), managed by Agriculture and Agri-Food Canada (AAFC), is comprised of three genebanks for *ex situ* conservation of PGRFA: Plant Gene Resources of Canada (PGRC) located in Saskatoon, Saskatchewan; the Canadian Potato Genetic Resources (CPGR) located in in Fredericton, New Brunswick; and the Canadian Clonal Genebank (CCGB) located in Harrow, Ontario. The CNPGS manages and conserves over 110,000 accessions (samples) covering nearly 1000 species of cultivated plants and crop wild relatives. All materials in the CNPGS collections are available for breeding, research and education under the terms and conditions of the Multilateral System for Access and Benefit-sharing (MLS) of the International Treaty for Plant Genetic Resources for Food and Agriculture (ITPGRFA). During the review period (2012 to 2019), nearly 75,000 accessions were supplied to 51 countries around the world with the Standard Material Transfer Agreement of the ITPGRFA. This was a considerable increase in germplasm distribution compared to the past review periods and has impacted many research and breeding efforts nationally and internationally. Canada is in favour of extending the scope of the MLS of the ITPGRFA to cover all PGRFA and to capture the benefits for all.

Advances in regeneration as well as phenotypic and molecular characterization of CNPGS germplasm collections have been made over the last two decades. The implementation of a new genebank information system, GRIN-Global-CA, is completed. Cooperation of the CNPGS genebanks with researchers and plant breeders has been expanded. Additional efforts supporting conservation of native Canadian PGRFA including crop wild relatives, rangeland plants and fruit germplasm may be required so these resources are not lost. Training of genebank staff and key stakeholders on technical and regulatory issues including on the access and benefit-sharing aspects remains important as the world is getting more complicated for the exchange and use of PGRFA.

Biodiversity for food and agriculture and the sustainable use of plant genetic resources has received increased attention from governments, universities, industry, Indigenous Peoples and Civil Society Organizations (CSO). Interest in sustainable development has been increasing in Canada and all over the world. Climate change challenges as well as enhancing water and nutrient efficiencies have become critical considerations for plant breeding strategies.

Public plant breeding and research at AAFC and Universities remains particularly important for base broadening and pre-breeding for both conventional as well as new crops. Strengthening of private sector research and development has resulted in an increase in private plant breeding programs and releases of adapted cultivars. The number of cultivars registered for use by Canadian farmers increased during the review period. Germplasm development, including pre-breeding to adapt existing crop species as well as potential new crops often requires germplasm from other parts of the world. For Canada, cooperation on technical aspects and knowledge exchange for germplasm conservations and use is critical within the North America region and beyond. International fora such as ITPGRFA and the FAO Commission on Genetic Resources impact the PGRFA activities in Canada.

The Canadian Food Inspection Agency (CFIA), in collaboration and partnership with industry,consumers, and federal, provincial and municipal organizations has helped to ensurenational stakeholders have opportunity for input in the process of variety/cultivar registration as well into the overall seed sector regulations. The number of cultivars registered for use by Canadian farmers increased during the review period.

CSOs have enhanced their engagements in PGRFA especially in the organic agriculture sector. These include the use of genebank germplasm and on-farm preserved diversity to develop new cultivars with novel farmer assisted selection and commercializationstrategies. AAFC has supported such initiatives. The Government of Canada, through Global Affairs Canada, has also provided support to many PGRFA initiatives for on-farm andex situconservation internationally.

Indigenous Peoples engagement in conservation efforts has been strengthened with support of the federal government. This included holding workshops and seminars, participatory research and assisting in development of demonstration plantings, greatly enhancing the awareness for PGRFA among all Canadians.

Protected areas in Canada are supported by all levels of government. Inherent in this is the conservation of plant species, including many crop wild relatives and wild food plants used by all Canadians including Indigenous Peoples.

Canadian native plant diversity is impacted by climate change as well as by increasing populations and urban sprawl. Strategic approaches for conservation of Canadian genetic resources will require enhanced cooperation amongst federal and provincial governments as well as local communities, Indigenous Peoples, CSOs, botanical gardens and the private sector.

The genebanks of the CNPGS are integrated in the AAFC Science and Technology Branch and are in a good position to connect PGRFA conservation with research and innovation to the benefit of all Canadians and to support global food security.

Introduction

The United Nations FAO Commission on Genetic Resources for Food and Agriculture (CGRFA) has a broad and important global mandate regarding genetic resources for food and agriculture. The CGRFA requested member states (including Canada) to prepare a Country Report leading towards the Third Report on the State of the World's Plant Genetic Resources for Food and Agriculture.

This "stock-taking" exercise will help Canada to understand the current situation of PGRFA in Canada and to make strategic decisions. Such an overview will also help to assess the achievements of the Second Global Plan of Action (GPA) of the FAO-CGRFA for Plant Genetic Resources for Food and Agriculture (PGRFA) in Canada. The first country report on PGRFA by Canada was submitted to FAO in 1995 (Reid and Mosseler 1995). Country reports led to the landmark first and second Reports on the State of the World's PGRFA (FAO 1997, 2010). Furthermore, Canada's country report underlines its commitment to the objectives of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) that Canada ratified in 2002, as well as the Convention on Biological Diversity (CBD), ratified in 1992, both relating to the conservation, to their sustainable use and to the fair and equitable sharing of benefits arising from the use of PGRFA. (FAO 2009, Government of Canada 2020a, Katepa-Mupondwa 2017).

The ITPGRFA defined plant genetic resources for food and agriculture as "any genetic material of plant origin of actual or potential value for food and agriculture." The term PGRFA includes for this report the genetic diversity of plants that are wild foods.

This report documents Canada's contribution to relevant United Nations Sustainable Development Goals and in particular goal no. 2 "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" and its target 2.5:

> *"By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed."* (FAO 2021a).

Context is also provided by a hemispheric conservation strategy developed for the Americas as part of an initiative of the Global Crop Diversity Trust (GCDT) to assist countries in developing effective and efficient *ex situ* conservation programs for PGRFA (Davidson 2008). Nature-based solutions such as plant breeding for adapting to environmental challenges, including climate change, depend on availability of PGRFA. Food security for all Canadians including for Indigenous People, depends on PGRFA (Council of Canadian Academies, 2014).

The Country Report presented here describes the status of PGRFA in Canada for the review period from January 2012 to December 2019 by addressing each of the 18 Priority Activities defined by the Global Plan of Action (GPA) (CGRFA 2020). The information presented here can also be found in the World Information and Early Warning System on Plant Genetic Resources for Food and Agriculture (FAO 2021b). Occasionally the report goes beyond this review period to assist the reader in understanding the broader context of PGRFA in Canada (see also Fraleigh et al. 1995).

For preparation of this country report many stakeholders were contacted and provided input. Some of the key players include:

- Federally or provincially supported government plant breeding and genetic resources programs
- Indigenous Peoples, agriculture and horticultural producers and researchers
- Private sector breeding programs
- Civil Society Organizations
- Universities with agricultural, horticultural or plant breeding programs
- Botanical gardens and Arboreta

This country report has two major purposes:

1. Provide the reader with an overview of the current status of PGRFA in Canada and indicate where action on the national level may be required; and

2. Contribute to the CGRFA's preparation of the Third Report on the State of the World's PGRFA leading to the development of a Third Global Plan of Action (GPA) for PGRFA.

Canadian National Plant Germplasm System

The Canadian National Plant Germplasm System (CNPGS**)** is a network of centres and personnel dedicated to preserving and providing access to the biodiversity of crop plants and their wild relatives. The CNPGS is part of Agriculture and Agri-Food Canada (AAFC), a federal government department. CNPGS is comprised of three major genebanks for *ex situ* conservations of PGRFA: Plant Gene Resources of Canada (PGRC) located in Saskatoon, Saskatchewan, the Canadian Potato Genetic Resources, (CPGR) in Fredericton, New Brunswick, and the Canadian Clonal Genebank (CCGB) in Harrow, Ontario. The *ex situ* conservations of the CNPGS plays a significant part in Canada's commitments to the FAO and its CGRFA, the ITPGRFA, to the CBD and to the United Nations SDGs.

The mandate of the CNPGS is to acquire, preserve and evaluate the genetic diversity of crops and their wild relatives with focus on germplasm of economic importance or potential for Canada (PGRC 2021). The main deliverables of the CNPGS are:

- Viable disease-free germplasm of cultivated plants and crop wild relatives (CWR) important to Canada;
- Providing and generating relevant information on its germplasm holdings;
- Contributing to conservation and utilization of PGRFA on a national and global level by cooperation; and
- Representing Canada and Canadian agricultural interests in global fora related to PGRFA.

The CNPGS genebanks are a national network and connected with other national and international stakeholders and genebank collections. The CNPGS collections focus on needs of Canadian clients but are also serving the global community. Having back-up samples available from several genebanks helps to assure germplasm is preserved and accessible in times of crisis, as became evident during the COVID-19 crisis in 2020-21.

Other significant players involved in PGRFA conservation and use

Federal, Provincial and Territorial Governments

In situ conservation is of great relevance for native Canadian species. Canada has extensive protected areas programs; nationally, provincially, and territorially (Government of Canada 2020b). At the national level, three Government Departments have a role to play in the designation of protected areas: Parks Canada, Environment and Climate Change Canada, and Fisheries and Oceans Canada. Similarly, on the provincial, territorial and civic levels, various departments have responsibility for parks and protected areas that are under their jurisdiction. In 2015, about 10.6% of Canada's terrestrial area was protected and under governance of the federal or provincial governments.

Civil Society Organizations

The role of Civil Society Organizations (CSO) in contributing to conservation and sustainable use of PGRFA in Canada has increased considerably since 2012. Biodiversity of agro-ecosystems and PGRFA have been an important topic with Canadians general public and not only among those involved in agricultural research and plant breeding.

Both *ex situ* conservation (e.g., genebanks) by the Canadian National Plant Germplasm System (CNPGS) and other organizations with *in situ*/on-farm conservation and management of many CSOs are essential elements in Canada's PGRFA conservation and management strategy.

Botanical gardens

Public outreach and education are important functions of botanical gardens. This includes raising awareness of the importance of biodiversity conservation and sustainable utilization including for food and agriculture (Moreau and Novy 2018). Many botanical gardens in Canada conserve species, cultivars and selections of garden plants in a systematic manner, maintain collections of species in jeopardy, and/or study their biology and culture. Some also manage nature reserves and/or help coordinate the restoration of degraded habitats.

The University of British Columbia conducted in 2021 a preliminary analysis of crop wild relatives established and documented in Canadian botanical gardens. Interpretation of the results indicated that 10 botanical gardens across Canada maintain over 2100 accessions of crop wild relatives with documented collection sites in Canada. This inventory will be useful for making future strategic decisions for collecting, particularly additional CWR. Some of the larger Canadian gardens include: Memorial University Garden, St John's Newfoundland; Montreal Botanical Garden, Montreal, Québec; Royal Botanical Gardens, Burlington-Hamilton, Ontario; The Arboretum, University of Guelph, Guelph Ontario; Toronto Zoo Toronto Ontario, University of Alberta Botanical Garden (former Devonian Botanical Garden), Edmonton, Alberta; and University of British Columbia Botanical Garden, Vancouver, British Columbia.

Public and private plant breeding

The Canadian government and the Provincial/Territorial governments support public research. AAFC plays a lead role in agriculture research in general as well as in plant breeding. Some of the major crops for

AAFC breeding include bread wheat, durum wheat, barley, oat, *Brassicaceae* oilseeds, mustards, maize, stone fruits and berries (see Priority Activity 9).

Plant breeding programs are also located at the University of Guelph (Guelph, Ontario), University of Saskatchewan (Saskatoon, Saskatchewan), McGill University (Montreal, Québec) and University of Manitoba (Winnipeg, Manitoba). Dalhousie University in Halifax, Nova Scotia, has breeding programs for organic production. The public sector has been releasing fewer finished cultivars than previously, but research continues on germplasm development and base broadening and pre-breeding as well as playing a critical role in educating plant breeders for Canada and many other countries.

The private sector has become increasingly active in Canadian plant breeding and has increased its research and development expenditures between 2012 and 2017 (an increase of 56% to CAD 171 million annually) (Canadian Seed Trade Association 2018). Major crops for the commercial plant breeding sector include maize, rapeseed/canola and soybean. Wheat and pulse crops are increasing in their importance with the private sector and plant breeders located in all provinces of Canada. This enables them to work on regionally adapted crops as well as those broadly adapted across many agro-ecozones. The increasing investments made by the private sector in plant breeding demonstrate that the industry is profitable. In 2012, private seed companies employed 2300 people with more than half of them conducting research and plant breeding.

All plant breeders maintain working collections of germplasm and exchange material with partners. Research programs at Canadian Universities are one of the main clients of the CNPGS genebanks. The direct use of germplasm supplied from CNPGS genebanks by plant breeders is limited. However, the indirect use of genebank germplasm is very significant for both public and private plant breeding due to the research results generated using germplasm obtained from the genebanks for research and pre-breeding.

Climate change and plant genetic resources

Climate change is one of the major challenges faced by farmers, plant breeders, agronomists and agro-biodiversity specialists. CNPGS is actively evaluating key germplasm holdings, searching for adaptive traits, in order for breeders to utilize the best germplasm in their breeding programs. Many climate models are predicting longer growing seasons with higher temperatures and less or more variable precipitation in many parts of Canada making it much more difficult to develop novel production practices or to develop suitable cultivars. New pests and diseases add additional challenges for breeders and farmers. These challenges could be quite apparent in crops like potatoes that have a long history of significant pest and disease challenges (e.g., *Phytophthora infestans*, which caused the Irish Potato Famine).

PGRFA from other regions (e.g., warmer, dryer) will be important resources for breeding programs in the years ahead, with breeders looking to select for resistance and adaptation to new conditions. For example, crops such as maize and soybean that have been dominating southern Ontario agriculture (warmer and longer growing season) are becoming more important in western Canada. Adaptation to the specific day-length regimes in more northern latitudes is important for such plants. New crops such as heat and drought adapted millets, or serving new markets such as quinoa or buckwheat, are providing new opportunities for Canadian farmers to diversify.

Climate change challenges are common to all countries and in particular in the circumpolar region (Solberg et al. 2014). Computer simulations that can help predict expected climate changes (e.g., Prairie Climate Centre, 2021) may be useful for researchers and farmers alike. The agricultural sector will be instrumental in mitigating the effects of climate change (e.g., CO2 sequestration) and adapting to it (Speaker of the House of Commons 2018).

Databases and "omics" for PGRFA

There is a major change happening in the profile of users of the germplasm preserved by the CNPGS genebanks. Researchers working in the genomics metabolomics and phenomics areas are requesting increasing numbers of samples of germplasm. These researchers can generate enormous amounts of data in support of plant breeding as well as contributing to managing germplasm collections. Initiatives such as the DivSeek International Network (http://www.divseek.org) have been established with input from Canada as a forum for discussing these questions. DivSeek may help to link "omics" data held by various databases with physical germplasm held by genebanks in the CNPGS and documented in genebank database systems that are not designed to manage "omics" data. These emerging disciplines hold potential to change the way conserved germplasm is utilized for developing new cultivars.

Canadian National Plant Germplasm System (NPGS) in the international context

Canada has been a party to the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) from the very beginning. Canada provides facilitated access to the germplasm under its management and control as mandated by the ITPGRFA. After the adoption of the ITPGRFA in 2004 Canada has included all CNPGS germplasm in the main collection and under its management and control of the Government of Canada into the Treaty's Multilateral System (MLS) for Access and Benefit-sharing. This refers not only to the 64 crop species listed in Annex I of the ITPGRFA (FAO 2009), but to all accessions of close to 1000 species held in the *ex situ* collections of CNPGS (including non-Annex I crops). Canada's policy is that the objectives of ITPGRFA are the conservation and sustainable use of all genetic resources for food and agriculture and they apply equally to all PGRFA. This includes the equitable sharing of the benefits arising from the use of the PGRFA as per the ITPGFA. Canada is in favour of extending the scope of the MLS to all PGRFA to reflect this policy.

CNPGS germplasm is available to users for research, breeding or education purposes at no cost nationally and internationally. Genebank clients must agree to the terms of the Standard Material Transfer Agreement (SMTA) of the ITPGRFA prior to obtaining germplasm. Phytosanitary regulations must be observed. The Canadian Food Inspection Agency (CFIA) cooperates with the CNPGS genebanks on phytosanitary related issues.

International interdependency

It has been widely recognized that no country is self-sufficient when it comes to PGRFA which are essential for food security. Canadian agriculture depends largely on cultivated plants introduced from other countries and in return Canadian breeders and researchers are developing unique germplasm that is made available to the world. Canada is also home to unique PGRFA which have significant potential for other areas of the world as well as for local production opportunities, e.g., in berries and fruits.

Canada has been active in a global context in discussions and negotiations at the CGRFA, the ITPGRFA and the CBD with the objective to ensure all PGRFA remain accessible for future generations, and that the benefits arising from their use are shared equitably. This requires that the genetic diversity of PGRFA and the associated information are shared and that capacities to do so are maintained or enhanced.

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Chapter 1. *In situ* conservation

Priority Activity 1. Surveying and inventorying plant genetic resources for food and agriculture

During the review period (2012-2019) PGRC intensified the efforts to gather more information about Canadian crop wild relatives (CWR). Suggestions for a more strategic approach for surveying PGRFA *in situ* were developed (Diederichsen and Schellenberg 2018, Greene et al. 2018). The *in situ* monitoring of CWR with complementary *ex situ* conservation at the CNPGS or at botanical gardens is aimed at slowing genetic erosion. *Ex situ* conservation is seen as a critical approach for CWR and native Canadian genetic resources that have special characteristics or are threatened by extinction. It is an important approach especially for Canadian genetic resources of CWR, while *in situ* conservation of these is preferred. Genebanks such as Plant Gene Resources of Canada (PGRC), Canadian Clonal Genebank (CCGB) and Canadian Potato Gene Resources (CPGR) complement *in situ* as well as on-farm conservation.

In Canadian agriculture, landraces of cultivated plants remain primarily on small farms and in home garden situations (Appendices 2 and 3). A growing awareness for these as genetic resources has been nurtured by non-governmental/civil society organizations (CSO) such as Seeds of Diversity Canada. CSO agencies that manage/track collections of PGRFA in Canada include collections of 5000 or more accessions (e.g., SeedChange, Seeds of Diversity) and informal collections of 100 or fewer accessions. Publicly accessible information is available only for the larger of these collections.

Many of Canada's native genera and species are related to crop plants. A review of different crop groupings revealed that over 3O% of native plant material is related to crop species at the genus level (Davidson 1995). Fruit crops (111 species) and forage and turf grass (138 species) crops had the highest number of related wild species. Nut crop species had relatively few native representatives (11 species) as did cereal, oilseed and other field crop relatives (18 species). Regarding the secondary and tertiary gene pool for sunflower (*Helianthus*) breeding, there are 14 *Helianthus* species in Canada that are considered crop wild relatives. Special and minor acreage crops were represented by 86 species while landscape plants were represented by 137 genera. Forest trees are a very important economic resource (see Appendix 5). Over 70 species of coniferous and deciduous trees are native to Canada. Many species, particularly in the fruit crop grouping, could be identified as significant at the international level (e.g., *Amelanchier, Rubus, Ribes,* and *Vaccinium*) with a major part of their distribution occurring on Canadian soil.

The Indigenous Peoples of Canada harvested many native plant species for food and other important uses. Catling and Cayouette (1994) identified important small fruits, berries, and nuts occurring in the Gaspé Peninsula of Québec. Some of the more important species cultivated by Indigenous Peoples in Canada prior to immigration from Europe included maize (*Zea mays* L.), garden bean (*Phaseolus vulgaris* L.), squash (*Cucurbita pepo* L.), Jerusalem artichoke (*Helianthus tuberosus* L.), tobacco (*Nicotiana rustica* L.), and possibly sunflower (*Helianthus annuus* L.). Much of the domestication history of some these plants started in the more southern parts of the American continent. The "Three Sisters crops" (maize, beans and squash) were grown by a number of First Nations in the Great Lakes – St. Lawrence Lowlands region (Ngapo et al. 2021). Some of the diversity of these species has been conserved in the national genebanks of Canada and the United States. For further details regarding Indigenous Peoples and genetic resources for food and agriculture see Priority Activity 4.

Wild rice (*Zizania palustris* L., *Z. aquatica* L.) are important species and were utilized by Indigenous Peoples for a long time. *Zizania aquatica* was an important supplement to meat as seeds could be carried easily and stored against the leaner times. Not only was it a source of food for Indigenous Peoples, but it also enabled the explorers to extend their journeys. Today, Canadian production varies from 100,000 pounds to more than a million pounds in a year. For wild rice, *ex situ* conservation is not a feasible option because the seeds cannot be dried for storage without losing viability. *In situ* conservation is the approach to take. Similarly, *Helianthus tuberosus* (common name Jerusalem Artichoke) has had a long history of utilization by Indigenous Peoples and early settlers in western Canada. Kuhnlein and Turner (1991) published a monograph on this subject. Catling and Porebski (1998) added to our understanding of native Canadian plant genetic resources. They identified 56 taxa of rare wild plants that should be priorities for protection.

Gaps and needs

Inventorying PGRFA *in situ* requires considerable taxonomic skills. Many cultivars/species look very similar to each other. Using modern tools such as software for species recognition and for communication, there is potential to engage citizen scientists, Indigenous Peoples and local communities in surveying plants of interest. Botanical surveys that specifically address *in situ* and/or on-farm PGRFA are limited. Use of the native flora for food by Canadians in general is better documented (see also Priority Activity 4). The challenge to revise and update floristic inventories is considerable. In the future, we anticipate that researchers and specialists will continue to work in this area as opportunity, funding and resources arise.

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Priority Activity 2. Supporting on-farm management and on-farm improvement of plant genetic resources for food and agriculture

Globally, on-farm conservation is complemented by the *ex situ* collections of PGRFA by genebanks. In Canada, the three CNPGS genebanks distribute germplasm for research and breeding, including initiatives for participatory breeding. In October 1991, PGRC signed a Memorandum of Understanding with the Seeds of Diversity Canada, which is engaged in the on-farm conservation of vegetables (Seeds of Diversity Canada 2021). Since then, collaborative activities have continued, PGRC has stored security back-up samples, has hosted visitors and field tours, provided seminars using on-line technology and suggested several on-farm conservation projects. Seeds of Diversity Canada regenerated seed of genebank accessions chosen in common with PGRC and engaged in a Citizen Science project that focused on tomato diversity. Canadian Farmers have rarely requested PGRC germplasm directly, and if so, this was done for small research projects. Civil Society Organisations have been involved in the on-farm conservations of vegetables and potatoes in Canada for many years and more recently increased their involvement to include cereal crops.

PGRC hosted the Executive Director of the Bauta Family Initiative on Canadian Seed Security (BFICSS) in 2012. The BFICSS has a unique focus on on-farm research, and on low-input ecological production practices. The BFICSS is part of a larger organization SeedChange, formerly known as the Unitarian Service Committee of Canada, USC (BFICSS 2021).

In fostering an environment for plant breeding, new and improved cultivars are bred giving farmers options for growing cultivars that require less input (e.g., efficient use of nutrients, resistance to plant pests and diseases, salt and drought tolerance, and better adaptation to climatic stress). This gives farmers options to sustainably increase productivity and product quality in agriculture, horticulture and forestry, whilst minimizing the pressure on the natural environment. Farm-saved seeds are still common in Canada. Resistance to seed borne diseases is part of the breeding objective in many public breeding programs and helps to reduce the need to apply chemical seed treatments.

Support to on-farm management internationally

In 1996 Canada supported the establishment of Pan-Africa Bean Research Alliance (PABRA). PABRA is a pan-African research and development alliance comprising three regional networks operating in 24 countries in Eastern, Central, Southern and Western Africa. PABRA works focuses on improving bean (*Phaseolus* spp) crop to increase its productivity for the benefit of the urban and rural poor, enhancing food security, reducing malnutrition and generating income from the sale of beans. Canada's CAD 15 million contribution to PABRA (2009-2015, phase IV) reached out to an estimated 6.5 million households that benefited from new drought-resistant and more nutritious beans varieties. PABRA's major beneficiaries are women, who play the main role in the crop's production and sale.

The Canadian International Food Security Research Fund (CIFSRF) has been a CAD 124.5 million research for development program implemented by the International Development Research Centre (IDRC) and Global Affairs Canada (GAC) since 2009. CIFSRF has contributed to the development of more productive, sustainable, and gender-sensitive agricultural techniques for women subsistence farmers, with the ultimate goal of making food sources more secure and accessible, and the food produced more nutritious, for poor households – particularly for women and girls, who face the heaviest burden of chronic hunger and malnutrition in developing countries. CIFSRF has contributed directly to capacity building on PGRFA including the sustainable production and utilization of underutilized vegetables to enhance rural food security in Nigeria (to assess 18 varieties of indigenous vegetables harvested in the wild and commonly consumed in southwest Nigeria to determine their production potential, nutritional content, drought tolerance and disease resistance) and the synergistic use of fertilizer micro-dosing and indigenous vegetable production to enhance food and economic security of West African farmers (to promote innovation in field production practices including fertilizer micro dosing and optimum water management, to innovation in food processing and value addition).

Canada provided CAD 8.2 million (2012-2020) to promote regional opportunities for produce through enterprise and linkages (PROPEL). Canada's contribution supported economic growth in the Caribbean through increased sales of fresh produce by small-scale local farmers to high value markets. The project helped small farmers in Jamaica, Trinidad and Tobago, St. Lucia, Grenada, St. Vincent and the Grenadines, Dominica, Barbados and Guyana to increase the quality and quantity of fresh, regionally grown fruits and vegetables, linking them to buyers such as regional grocery chains, cruise lines, airlines, hotels and restaurants.

Canada contributed CAD 14.9 million (2015-2020) to scale up the CSO – USC Canada's "Seeds of Survival" program in Central America and Africa. USC (now SeedChange) works with smallholder farmers (women, men and youth) in Africa, South and Central America, Asia and Canada, to strengthen their knowledge and their food and seed systems through participatory plant breeding, community seed banks and agroecological practices. This project reached an estimated 293 communities and over 44,000 beneficiaries, improving their food security and climate resilience, with particularly strong results in Ethiopia and Honduras.

Gaps and needs

The on-farm sector PGRFA is growing. Novel strategies for plant breeding serving this sector are in demand and additional coordination with regulatory agencies of the Canadian seed sector is required.

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Priority Activity 3. Assisting farmers in disaster situations to restore crop systems

With the availability of germplasm from national and international genebanks, breeders have access to PGRFA to help improve existing cultivars by incorporating genetics of existing and/or older cultivars, and/or CWR or landraces into new cultivars that will be better adapted to the newer stresses and market opportunities. The CNPGS genebanks were established as a source of genetic diversity for plant breeders whose research helps to alleviate potential and actual disasters that can strike Canadian agriculture. However, the seed samples held in the genebank are very limited in size, so impacts on the restoration of crop systems are indirect. Seed growers are in a much better position to provide immediate assistance in a disaster situation as they specialize in increasing propagation materials.

AAFC engages in related projects to prevent disasters that could affect the agricultural sector, such as new diseases. An example is the wheat stem rust disease UG99. While the disease hasn't reached North America yet, a team of AAFC scientists made a breakthrough discovery in an international effort to control the disease by identifying and isolating three new genes with high levels of resistance not previously used in wheat breeding (AAFC 2015).

Since 2001, Federal and provincial governments have a agreed on a number of framework policies and programs (e.g., Agricultural Policy Framework, Growing Forward, and Growing Forward 2 and the Canadian Agriculture Partnership) to help ensure the continuity of agricultural production and to further support farmers facing unique challenges (CAP 2021).

Support is given in disaster situations such as drought, hail and flooding. Many of these programs are implemented provincially to better address the most critical issues in the region. An example of this is the provincial crop insurance programs listed below:

1. Prince Edwards Island: https://www.princeedwardisland.ca/en/information/agriculure-and-land/agriinsurance-production-insurance
2. Newfoundland and Labrador: https://www.gov.nl.ca/ffa/programs-and-funding/programs/prodinsur/
3. Nova Scotia: https://novascotia.ca/agri/documents/AgriInsurance-Booklet.pdf
4. New Brunswick: https://www2.gnb.ca/content/gnb/en/services/services_renderer.1 1995.Agricultural_Insurance.html
5. Quebec: https://www.fadq.qc.ca/fr/assurance-recolte/description/
6. Ontario: https://www.agricorp.com/en-ca/Pages/Default.aspx
7. Manitoba: https://www.masc.mb.ca/masc.nsf/index.html?OpenPage
8. Saskatchewan: https://www.scic.ca/about-u
9. Alberta: https://afsc.ca/crop-insurance/
10. British Columbia: https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/programs/agriculture-insurance-and-income-protection-programs/redirect-production-insurance

Business risk management (BRM) programs are tools that provide agricultural producers/farmers with protection against income and production losses, helping them manage risks that threaten the viability of their farms (AAFC 2020).

AgPal and other federal government programs help farmers and agri-businesses find relevant resources by gathering agricultural information and presenting it all in one place. Search and navigation tools make it quick and easy to find exactly what you are looking for (AgPal 2021).

- AgPal provides support when producers experience a large margin decline
- AgriInvest provides cash flow to help income declines
- AgriInsurance provides cost-shared insurance against natural hazards to reduce the financial impact of production or asset losses
- AgriRecovery is a federal, provincial, territorial disaster relief framework to help producers with the extraordinary costs of activities necessary for recovery following natural disaster event
- Advance Payments Program is a federal loan guarantee program which provides agricultural producers with easy access to low-interest cash advances of up to CAD 1 million.

Gaps and needs

The resilience of the Canadian seed sector needs steady attention as perturbations can arise at any time. In addition, climate change challenges require strengthening plant breeding initiatives including incorporation of novel and often exotic germplasm or new species from genebanks.

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Priority Activity 4. Promoting *in situ* conservation and management of crop wild relatives and wild food plants

***In situ* conservation**

Canada's land area amounts to 9,984,670 sq. km which is about 7% of the terrestrial surface of the globe. The longest east - west distance is about 5514 km, and the longest north - south distance is 4634 km. The Arctic tundra in the north is vast, and the boreal forest stretches as a belt from the Pacific to the Atlantic coast. These two vegetation zones cover two-thirds of the country and are very sparsely settled with little agricultural activity. Canada has 15 terrestrial ecozones that are subdivided into 53 eco-provinces with 194 eco-regions. A large, forested band covers more than 40% of Canada's land surface and includes, from west to east, the Pacific Maritime, Boreal Cordillera, Montane Cordillera, Boreal Plains, Boreal Shield, Hudson Plains, and Atlantic Maritime ecozones (see Appendix 1).

Canada established one of the world's first national park management agency the Dominion Parks Branch, in 1911 (now Parks Canada). Today, federal, provincial, territorial and municipal governments and Indigenous communities, along with individuals and private organizations, acquire and manage lands to help conserve lands along with their related biodiversity.

Canada has extensive protected areas programs; nationally, provincially and territorially (Government of Canada 2020, Table 4.1). At the national level, three Government Departments have a role to play in the designation of protected areas: Parks Canada, Environment and Climate Change Canada, and Fisheries and Oceans Canada. Similarly, on the provincial, territorial and civic levels, various departments have responsibility for parks and protected areas that are under their jurisdiction. Greater emphasis on biological inventories would be useful especially if the materials present included crop wild relatives or other PGRFA.

Table 4.1 Proportion of area conserved, Canada, 2015 to 2019 (Government of Canada 2020)

Year	Terrestrial area protected (square kilometres)	Percentage of terrestrial area protected	Terrestrial area conserved (square kilometres)	Percentage of terrestrial area conserved	Marine area protected (square kilometres)	Percentage of marine area protected	Marine area conserved (square kilometres)	Percentage of marine area conserved
2015	1,047,284	10.5	1,121,842	11.2	52,644	0.92	71,515	1.2
2016	1,050,065	10.5	1,124,622	11.3	55,002	0.96	82,719	1.4
2017	1,052,418	10.5	1,126,975	11.3	168,443	2.9	451,510	7.9
2018	1,095,194	11.0	1,169,751	11.7	179,923	3.1	462,987	8.1
2019	1,133,907	11.4	1,211,813	12.1	511,906	8.9	794,974	13.8

In 2015, the 2020 Biodiversity goals and targets for Canada were established. Target 1 states: "By 2020, at least 17 per cent of terrestrial areas and inland water, and 10 per cent of coastal and marine areas, are conserved through networks of protected areas and other effective area-based conservation measures." At the time, 10.5% of Canada's terrestrial area and around 1% of its marine area were recognized as protected. Conserved areas have increased to approximately 12.1% of terrestrial area. These areas include many species that are related to crop plants (Table 4.1).

Many wild plants have economic potential in today's ever-changing marketplace. Historically, some important crops such as oats, rye and camelina have evolved out of wild species that were weedy. Some of the weedy species that were historically part of agroecosystems are threatened by extinction (e.g., *Camelina microcarpa* Andrz. ex DC., *Agrostemma githago* L). Invasive species are a threat to native biodiversity and weeds can cause big damage. However, all species that occur in agroecosystems may have some positive effects (ecosystem services). Positive impacts include protection for beneficial insects and pollinators, positive effects on the biome of the rhizosphere, ground cover to help prevent erosion and act as indicator species for soil compaction, nutrient deficiencies or nutrient imbalances. However, care must be exercised to prevent invasive alien species from being introduced. New and updated Canadian floral inventories could be used to promote *in situ* conservation leading towards improved management of PGRFA including Crop Wild Relatives (CWR) and wild food plants. Such inventories could include traditional uses, folk names, specific genotypes or traits of interest of germplasm from a plant breeder's perspective.

Many native Canadian plant species have potential for food, feed and or fibre use. Marles et al. (2000) compiled information on more than 200 species in Canada's northwest boreal forest used by Indigenous Peoples for nutrition or as sources of functional foods, nutraceuticals, or medicines. Arnason *et al*. (1981) listed 175 species for food, 52 for beverages, and 400 for medicinal use by Indigenous Peoples in Eastern Canada. Most of these species are native to Canada. Small (2014) published a compendium of 100 species of indigenous food plants from North America (United States, Mexico, and Canada) with emphasis on species of greatest economic potential. For example, blueberry (*Vaccinium myrtilloides* L. *Vaccinium angustifolium* Aiton) and cranberry (*Vaccinium macrocarpon* Aiton), all native species with a broad range of distribution, have been significant contributors to rural and farm income in Canada.

Many medicinal plants were used by the Indigenous Peoples and early settlers of Canada (e.g., American ginseng, *Panax quinquefolius* L.; Bearberry, *Arctostaphylos uva-ursi* (L.) Spreng., Clubmoss, *Lycopodium clavatum* L.). Large scale commercial production is very limited (Turner 1981). Cultivation may be a solution to help to avoid these species being over-collected or over-harvested in the wild.

Canada's total fresh fruit exports in 2020 rose in value by 2.8% to reach CAD 843 million compared to 2019 mainly due to an increase of the country's exports of low-bush blueberries (*Vaccinium myrtilloides* Michx. and *Vaccinium angustifolium* Aiton) (+23.4%), high-bush blueberries (*Vaccinium corymbosum* L.) (9.3%) and strawberries (*Fragaria* spp.) (+12.6%) (AAFC 2021). Blueberries are one of Canada's top fruit exports by volume and by value, accounting for 53.4% of export tonnage and 65.5% of export dollars. Low-bush blueberries, largely harvested from wild stands, accounted for 53.3% of total blueberry value and 60.6% of total blueberry tonnage. Careful management of the wild stands of blueberries is essential for a sustainable production system. The United States remains Canada's top export destination, accounting for 64.8% of all fruit exports by value and 65.7% by tonnage in 2019.

Saskatoon berries (*Amelanchier alnifolia* Nutt.), also known as Serviceberry, is another fruit in which Canada is a world resource (Catling and Cayouette 1994; Mazza and Davidson 1993, Davidson 1995). Larger scale commercial production on the Prairie provinces has helped to speed development of processing facilities and new products.

There are many other woody plants that are used as food sources. The majority of native woody plant species of interest to food and agriculture are not key species for forestry. In Canada, forest genetic resource conservation is managed by Canadian Forest Service. (See Appendix 5 for additional details).

Indigenous Peoples *in situ* conservation and management of crop wild relatives and wild food plants

As of 2016, Indigenous Peoples represent 4.9% of the total Canadian population and manage reserve lands with an area of more than 3.5 million hectares (see Appendix 4). Locally harvested traditional foods are central to the cultural, spiritual, and physical health of Indigenous Peoples and communities. About 550 different species of plants have been utilized in the traditional diets of Indigenous Peoples in Canada. Among Indigenous communities in Canada, a wealth of traditional knowledge exists regarding natural resources, particularly plants which are a large part of their traditional diet (Yi et al. 2007). Because of their close and long-term relationships with their traditional territories, Indigenous Peoples have knowledge, methodologies, practices and social controls that enable them to engage in beneficial sustainable resource use and management (Turner and Hebda 2013). Indigenous Peoples in Canada have a long history of effectively managing food plant production and plant habitats using practices such as succession, regeneration, selective harvesting, pruning/coppicing berry bushes, controlled burns, habitat creation, and distributed use and harvest across landscapes and over time (seasonal rounds).

The Government of Canada is committed to advancing reconciliation with Indigenous Peoples through a renewed, nation-to-nation, Inuit-Crown and government-to-government relationship based on the recognition of rights, respect, cooperation and partnership; enhanced departmental capacity and Indigenous representation; and inclusive policies and programs. A key objective is increasing awareness and appreciation of traditional methods and fostering reciprocal, non-transactional partnerships with Indigenous communities to increase food security, revitalize Indigenous agricultural practices, revive traditional knowledge systems, conserve traditional food/medicine plant genetic resources and empower Indigenous Peoples including communities, organizations, businesses, and individuals. In 2018, AAFC launched the Indigenous Agriculture and Food Systems Initiative (IAFSI), a five year (2018-19 to 2022-23), CAD 8.5 million Initiative that supports Indigenous communities that seek opportunities in agriculture and the food system more broadly.

AAFC also launched an Indigenous Pathfinder service in 2018. This is a one-stop shop for advice and referral to help Indigenous Peoples and communities to navigate relevant information, tools and support available to start or expand activities in the agriculture and agri-food sector.

In October 2017, AAFC officially established an Indigenous Support and Awareness Office (ISAO), to enhance departmental capacity to support Indigenous cultivation through knowledge and awareness of the history, cultural contexts, and current barriers and opportunities for Indigenous cultivation through the development of an Indigenous Awareness Learning Series (IALS). The ISAO is also mandated to increase recruitment and retention of Indigenous employees by supporting the activities of the Indigenous Student Recruitment Initiative (ISRI), the Indigenous Network Circle (INC) for employees, and the departmental Elder. ISAO provides access to Elder services, which ensures on-going support for Indigenous employees and activities across the department of AAFC. Learning content providers within the office support stronger cultural awareness for employees and senior management.

AAFC's Science and Technology Branch (STB) established a Senior Indigenous Science Liaison Officer position in 2017 to act as a liaison between AAFC researchers and potential Indigenous partners in the context of scientific research partnerships. This position now leads the Indigenous Science Liaison Office (ISLO) which was established by STB in 2020 to support AAFC researchers in building relationships, engaging, and ultimately co-developing research projects with Indigenous partners. ISLO does this by providing science-specific Indigenous cultural literacy and intercultural competency training to STB staff, researchers, and management, liaising between researchers and potential Indigenous partners, creating guides, tools, and providing input in science policy and programming to facilitate Indigenous research partnerships.

AAFC supports several Indigenous science projects:

Agricultural Living Laboratories functions as a local innovation hub, where various participants explore, demonstrate, and adapt beneficial management practices and technologies within a working agricultural landscape. The Agricultural Living Laboratory initiative has established a national network of Agricultural Living Laboratories situated in a variety of production systems and landscapes across Canada, including First Nations' lands in cooperation with Indigenous people. The establishment of the network allows for the development of comparative studies, cross-sectoral collaborations, and sharing of lessons learned.

AAFC STB Transformative Workshops – In recent years, STB carried out several transformative workshops related to Indigenous cultivation. The *Empowering Indigenous Communities and Seeding Agricultural Resilience by Revitalizing Indigenous Food Plant Production* workshop encompassed an STB initiative to capitalize on the collective expertise and creativity of leading government and academic researchers and First Nations traditional knowledge holders, community members, and leaders to identify the potential for collaboration on traditional foods production, and specifically, bridging Indigenous Traditional Knowledge and AAFC research (Sharifi and Edwards 2017). The 2017 *Transformative Workshop on Vertical Farming*, which was initially held as a general workshop 2016, focused specifically on northern greenhouses.

AAFC STB funded several Indigenous agriculture and Northern agriculture projects since 2018. This initiative was followed up by allowing internal funding research priorities to cover Indigenous Agriculture. Examples of these project include:

- "Understanding Indigenous food systems and revitalizing key Indigenous food plants in Interior and Coastal regions of British Columbia": Many Indigenous communities are looking to revitalize traditional lifestyle practices. This three-year project (2019-2022) was developed as a first step toward learning about Indigenous food systems and enhancing access to food plants for Indigenous communities in British Columbia (B.C.).

- The "Three Sisters" project conducted by AAFC was initiated in 2015 to study characteristics of accessions of corn, squash and beans and the products derived from them in order to develop added value for Indigenous communities, while also studying health benefits. The value chain includes characterization of attributes and functionalities of Indigenous corn, squash and bean landraces, and preservation of genetic material. The project brought together participants from different backgrounds, including AAFC scientists, technical staff and Indigenous people. The following Indigenous communities took part: Akwesasne, Kahnawake, Tyendinaga, and Six Nations of the Grand River. The germplasm was purchased from artisanal seed growers and one sample was provided by the PGRC. In May 2016, as part of the "Three Sisters Project", the United States, Mexico and Canada participated in a collaborative workshop on the "Conservation and Development of

Ancestral/Indigenous Plant Genetic Resources: Challenges, Tools and Perspectives Sharing the Canadian, Mexican and American Experiences". Agriculture and Agri-Food Canada, the University of Laval and the PROCINORTE / NORGEN Task Force on Genetic Resources organized this workshop. Best practices were shared on the preservation of Indigenous traditional knowledge in agriculture (Gariepy et al. 2017).

- Supporting Makkovimiut food systems: This six-year project is the result of two years of consultations (2019-2020) with the Inuit community of Makkovik. AAFC scientists worked with Makkovimiut in Labrador to identify shared priorities in developing agricultural opportunities in this remote northern community. Key needs identified by the community include identifying factors limiting fruit production of regional small fruits (especially bakeapple, *Rubus chamaemorus* L.), and evaluating potential management practices to increase harvest of these foods. The project will also explore adapting conventional agricultural methods (including industrial composting and season-extending techniques) to subarctic coastal conditions.

- "Lingonberries project": This project is a STB research project on the genetic and climatic conditions affecting lingonberry (*Vaccinium vitis-ideae* L.) cold-hardiness and antioxidant content. This project explores how lingonberries, which are endemic to Canada and are a traditional food plant for many Indigenous groups, can be integrated into a supply food chain that could help engage Indigenous communities and establish partnerships with university, government, NGOs, and industry groups. The demand for lingonberries currently outstrips the supply from wild harvest; thus, there is a market opportunity for Canadian producers that could financially benefit Indigenous communities.

- Labrador Tea project (2012-2019): AAFC-STB research in collaboration with an industrial partner carried out a controlled extraction of medicinal ingredients from Labrador tea (*Rhododendron tomentosum* Harmaja and *R. groenlandicum* (Oeder) Kron & Judd). Labrador tea grows wild in most regions of Canada and a number of Indigenous Peoples use the infusion as a traditional medicine. In the short-term, a concentrate and a freeze-dried tea extract were produced on a pilot-scale for commercial operation purposes. In the longer term, the Indigenous-owned company plans to establish its own facilities and become an autonomous producer.

Examples of Non-AAFC native plant conservation initiatives:

1. T'Sou-ke First Nation garden: A garden was established for teaching children. The garden includes vegetable plants, Indigenous medicinal plants and medicinal teas. T'Sou-ke First Nation wants to be the leader in regional planning and help the management of plants and habitats in their territories.
2. Harvest for Knowledge Project: This project supported the establishment of an Indigenous Garden at Victoria, British Columbia high schools.
3. Indigenous garden at Royal BC Museum in Victoria, British Columbia.
4. Working group on Indigenous Food Sovereignty (founded by Dawn Morrison).
5. Horner Foundation, a family foundation with a focus on youth development. They administered several Indigenous food related projects.
6. PEPÁḴEṈ HÁUTW̱ (Blossoming Place): a native plant nursery, community school garden, restoration project, and the home of the PEPÁḴEṈ HÁUTW̱ Native Plants and Garden Education Program. Located at the ŁAU,WELṈEW̱ Tribal School in British Columbia.

7. West Kootenay city's Millennium Park Camas garden nurtured by Kootenay Native Plant Society in Castlegar, British Columbia.
8. En'owkin Centre Indigenous plants nursery and garden in Penticton, British Columbia.
9. Examples of Indigenous plant nurseries in British Columbia: Saanich Native Plants (Victoria), Sagebrush nursery (Oliver), Splitrock Environmental Nursery (Lillooet), Mountain Edge Nersery (Salmo)
10. K’nmaĺka? Sənqâĺtən (Kalamalka Garden): is an Indigenous garden created in 2017 through a unique collaboration among the Okanagan Indian Band (Elders and community members), Okanagan College and the Food Action Society of the North Okanagan. The garden is located in Vernon, British Columbia, and is a tranquil and serene space where tradition, knowledge and learning meet so Syilx Okanagan culture can flourish for generations to come.
11. Westbank First Nation Indigenous Garden in West Kelowna, British Columbia
12. Lower Nicola Indian band community garden in Merritt, British Columbia

Gaps and needs

Natural ecosystems and agroecosystems contain important PGRFA, including rare, endemic and threatened crop wild relatives and wild food plants. Monitoring populations could be strengthened to avoid the need for costly *ex situ* conservation in botanical gardens or genebanks. Future floristic-inventories could be enhanced by assessing conservation status as well as actual and potential relevance and genetic diversity of species as genetic resources for food and agriculture. For some species (e.g., crop wild relatives) the major range of distribution is outside national borders. This suggests that new adaptions might be identified (cold tolerance, disease resistance etc.). Better cooperation with university taxonomists, botanical gardens and other stakeholders including Provincial and Territorial governments is required to continue to develop comprehensive inventories of the Canadian flora to better reflect the aspect of plant genetic resources for food and agriculture.

The field of ethnobotany is important to help understand the traditional uses of many of the native plants by Indigenous Peoples. Traditional plant uses also arrived with many of the immigrant communities as well as they settled across the country. The ethnic mix that makes up modern Canadian society creates a very rich global cultural heritage. For example, the systematic study of local names used by Indigenous Peoples for native plants can help guide researchers to capture genetic diversity by describing features of certain genotypes that were distinguished based on these qualities. Such studies have great value for reconciliation by showing respect for Indigenous knowledge that can guide western science. It will be required to show sensitivity to the many approaches take by different cultural groups to gain a more holistic comprehension.

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Chapter 2. *Ex situ* conservation

Priority Activity 5. Supporting targeted collecting of plant genetic resources for food and agriculture

Plant germplasm collecting

The Canadian National Plant Germplasm System (CNPGS) has been conservative in collecting native plant species during the review period. Between 2012 and 2019 PGRC added a total of 8503 accessions of 218 taxa from *in situ* and on-farm sites to its active genebank collection.

PGRC collections of native species were mainly native species in western Canada; these included *Linum, Helianthus, Lupinus* and *Hordeum* spp. as well as rangeland species. These collections will be integrated into the active genebank collection at PGRC as sufficient quantities of seed become available and initial characterization has been completed.

About 200 accessions of crop wild relatives of *Avena* were recently collected during a project led by the Global Crop Diversity Trust in collaboration with the Millennium Seed Bank Project at Kew Royal Botanic Gardens. In 2019, these accessions were integrated into the PGRC *Avena* world base collection at PGRC and are now available. Sufficient seed has been increased and initial characterization has been completed.

The Aurora Institute in the Northwest Territories collected seed of native species for use in reclamation projects (Aurora Institute 2021). Seed samples from such collection activities were deposited in CNPGS**.** Only a few grass and forage species from these collections have been regenerated and integrated into the active PGRC genebank collection. Capacities to work on native germplasm for *ex situ* conservation have been limited in the CNPGS.

Many native trees, shrubs, perennial and annual species have been identified that have potential value as ornamentals (Davidson 1995, see also Appendix 5). This may guide future collecting efforts. Local industries promoting native plants for ornamental use can be found across Canada, and numerous websites exist for native plant societies in several Canadian provinces (e.g., North American Native Plant Society http://nanps.org/). Another important use for native plant species is in reclamation projects such as mine site, wild fowl restoration project (Ducks Unlimited https://www.ducks.org/).

Collecting of native germplasm of *Lonicera caerulea* L. in Canada was conducted in collaboration with the N.I. Vavilov Institute for Plant Genetic Resources, St. Petersburg (VIR), Russia (Bors 2009). Similarly, Fofana and Sanderson (2015) identified a natural hybrid rose from *Rosa Carolina* L. x *R. virginiana* Mill. for rosehip production. The hybrid found on Prince Edward Island was collected in 2003. Samples of their germplasm were deposited at the CCGB Harrow.

Mixtures of native Prairie species that were collected and subsequently registered as so called "ecovars™" and have been released in western Canada since the 1990s (May et al. 1997). Initially, several AAFC researchers and the University of Manitoba collected materials with Ducks Unlimited staff. Early introductions of "ecovars" included 24 species of native grasses, legumes and shrubs including awned wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners subsp. *subsecundus* (Link) Á. Löve & D. Löve), little bluestem (*Schizachyrium scoparium* [Michx.] Nash var. *scoparium*), northern wheatgrass (*E. lanceolatus* (Scribn. & J. G. Sm.) Gould subsp. *lanceolatus* var. *lanceolatus*), western wheatgrass (*Pascopyrum smithii*

[Rydb.] Barkworth & D. R. Dewey), plains rough fescue (*Festuca hallii* [Vasey] Piper) and Canadian milkvetch (*Astragalus canadensis* L. var. *canadensis*). Initially, this effort focused on revegetation needs, but on-going research has addressed broader agricultural and medical needs. This research has found characteristics within the native plant species that provide benefits beyond forage use. For example, purple prairie clover (*Dalea purpurea* Vent.) was found to have a condensed tannin profile that decreases the shedding of *Escherichia coli* bacteria in cattle (Jin et al. 2015). Winterfat (*Krascheninnikovia lanata* [Pursh] Meeuse & Smit), a winter forage shrub, is noted as improving digestibility of low-quality plant material when ingested together (Schellenberg 2005). Utilization of the native legume *Thermopsis rhombifolia* (Nutt. ex Pursh) Richardson is also being investigated for medical purposes such as anti-cancer affects in humans (Kerneis et al. 2015).

There is a need to increase targeted conservation activities for many native Canadian species since some are vulnerable to climate change (Richards 2007). Native Canadian Prairie vegetation has experienced a great decrease in area, from 61.5 M ha prior to European settlement to 11.4 M ha in recent years (Statistics Canada Census 2006). The potential benefits to agriculture of many native Canadian plant species are largely unexplored. The examples outlined above provide an insight into the potential benefits of further exploration. Ideally, CWR and wild food plants should be conserved *in situ* where they can continue to evolve under natural conditions. Collecting them for long term conservation *ex situ* must be evaluated very carefully as the costs are considerable and the genetic integrity of wild plants would be difficult to preserve.

Gaps and needs

A roadmap for understanding, documenting, protecting, providing and raising awareness for North America CWR and wild underutilized species was suggested by Khoury et al. (2019) and Botanic Gardens Conservation International (2016). These publications may stimulate future collecting activities in Canada.

Enhanced collection activities for native Canadian PGRFA are essential with a focus on native fruit species and wild relatives, rangeland plants and other crop wild relatives (Davidson 1995).

A strategic approach such as pilot projects on native Canadian PGRFA conservation involving governmental and non-governmental stakeholders, Indigenous Peoples and local communities should be expanded. The collaboration amongst the CSOs Universities, industry and the national system needs to continue to ensure a broad base and synergistic approach to conservation and management of PGRFA in Canada. For research, education and breeding, *ex situ* collections are an advantage but the capacities to commit to that must be ensured. In some cases, it is justified to commit to *ex situ* conservation to avoid loss of a species (extinction) or to ensure easier access for users.

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Priority Activity 6. Sustaining and expanding *ex situ* conservation of germplasm

Canadian National Plant Germplasm System (CNPGS) – the national genebanks for PGRFA

The long term economic and environmental sustainability of the Canadian agricultural sector is supported in part by the three CNPGS genebanks. Each year Canada allocates approximately CAD 2 million to operate the national genebank system (CAD 1.3 million on operational costs including salaries and CAD 0.7 million on fixed costs).

The CNPGS supports the implementation of the AAFC Science and Technology Branch strategic objectives to:

(1) increase agricultural productivity,
(2) enhance environmental performance,
(3) improve attributes for food and non-food uses and
(4) address threats to the value chain.

As of 2019, the CNPGS germplasm holdings of the three national genebank locations totalled 111,158 accessions covering 47 botanical families, 258 genera and about 1000 botanical species (Tables 6.1 and 6.2) (https://pgrc-rpc.agr.gc.ca/). CNPGS observes the "Genebank Standards for Plant Genetic Resources for Food and Agriculture" as developed and agreed by the CGRFA (2014).

The PGRC collection has large numbers of accessions of cultivated cereals and their crop wild relatives (Table 6.1). The cereal collections, and in particular the oat (*Avena* L. spp.) and barley (*Hordeum* L. spp.) collections at PGRC are very unique because they are so genetically diverse. Canadian scientists have been very active in collecting crop wild relatives of cereals since the 1960s. For example, the flax collection at PGRC is very diverse and as a result it is frequently used and is one of the best characterized collections in the world. Canadians were actively involved in collecting much of the material.

Between 1977 and 1981 PGRC reached agreements with the International Board for Plant Genetic Resources (IBPGR, now known as Bioversity International) to host the world base collections of oats (*Avena* spp.) and barley (*Hordeum* spp.), and world duplicate collections of pearl millet (*Pennisetum* Rich. spp.) and oilseed and green manure crucifers (*Brassica rapa* L., *B. juncea* (L.) Czern., *B. napus* L. and *Sinapis alba* L.) (Thormann et al. 2019). With the exception of 3544 *Pennisetum* accessions, the material has been regenerated and characterized and is now included in the active collection. Globally unique *Pennisetum* accessions were sent by PGRC to ICRISAT.

Table 6.1. Major cereal germplasm collections at PGRC

Genus	---- Cultivated ----		-------- Wild --------		Total
	Taxa	Accessions	Taxa	Accessions	Accessions
Avena	6	12,502	25	15,288	27,790
Hordeum	2	38,858	38	5,955	44,813
Triticum	21	8,357	4	2,988	11,345
Aegilops	n.a.	n.a.	22	632	632
Total	**30**	**59,717**	**89**	**24,863**	**84,580**

The world base collections preserved by PGRC are globally important. The *Avena* collection is the largest and most diverse collection world-wide, and the flax (*Linum* L. spp.) collection is one of the largest and best characterized in the world. PGRC also has a significant number of accessions of forage species including native Canadian plant material (Table 6.2).

Table 6.2. Other major germplasm holdings (accessions) at CNPGS genebanks

Crop group	Number of accessions
Native Canadian (PGRC)	3,500
Flax (*Linum*) (PGRC)	3,500
Pearl Millet (PGRC)	3,500
Crucifers (PGRC)	2,500
Vegetables (PGRC)	2,300
Fruit Clonal/Vegetative (*Fragaria*) (CCGB)	2,000
Forages (PRGC)	1,600
Fruit Clonal/Vegetative (*Malus, Prunus, Pyrus*) (CCGB)	1,500
Maize (*Zea*) (PGRC)	1,200
Potato (CPGR)	230

The CNPGS genebanks are a national network and connected with other national and international stakeholders and genebank collections. The CNPGS collections focus on needs of Canadian clients but are also serving the global community. Having back-up samples available from several genebanks helps to assure germplasm is preserved and accessible in times of crisis, as became also evident during the COVID-19 crisis in 2020-21.

Documentation and information on germplasm in the CNPGS

Information on all PGRC, CPGR and CCGB holdings is stored in a publicly accessible genebank information system (GRIN-CA). An update from GRIN-CA to the GRIN-Global-CA system is on-going. Detailed searches for material based on crop type, botanical species, origin, and quality characters, and germplasm requests are facilitated (PGRC 2021) (See also Priority activity 15).

Plant Gene Resources of Canada (PGRC), Saskatoon 2012-2019

Seed germplasm maintenance

Seed samples are stored in the PGRC seed vaults for medium term storage at +4°C and a relative air humidity of 20%. Under these conditions, seeds have the optimal moisture content for storage. This material is regularly used for distribution. The long-term storage (-18°C in airtight containers) holds duplicate samples for storage over many years and functions as the base collection. This allows staff to reduce the frequency of seed regeneration. Due to active seed regeneration at PGRC in recent years, the volume of seed numbers was brought up to the recommended standards for most accessions but has resulted in an overflow of the existing capacity of the long-term seed storage which will require additional capacity. Seed viability testing follows international standards (ISTA 2021) and is conducted regularly. All recently increased material is tested prior to storage and monitoring over time is done with particular focus on groups that are inclined to lose viability over time.

Additional seed storage is provided in part at the Svalbard Global Seed Vault (SGSV) sponsored by the Government of Norway, the Global Crop Diversity Trust and NordGen (SGSV 2021). PGRC was among the early contributors of black box samples of germplasm for long term last resort storage at Svalbard. No monitoring of seed viability is done on these samples at the SGSV, hence the name black box storage. The last deposit event at SGSV which Canada participated in was on February 26, 2018 bringing the total tally of PGRC accessions at SGSV to 32,609 seed samples.

PGRC also has an agreement with the USDA – National Laboratory for Genetic Resources Preservation in Fort Collins, Colorado, for black box back-up storage and has deposited a total of 8591 accessions in this facility.

Hence, more that 30% of the PGRC seed germplasm has such black-box storage. PGRC maintains the original seed samples under similar long-term storage and can monitor germination on a regular basis.

The PGRC Saskatoon also preserves a large collection of Jerusalem artichoke (170 accessions) as field genebank samples as well as minor field genebank collections of horseradish and rhubarb.

Seed germplasm acquisition

Between 2012 and 2019 PGRC Saskatoon acquired a total of 8,503 accessions covering about 200 botanical species from various sources (Table 6.3).

Table 6.3. Germplasm samples added at PGRC 2012-2019 (donors)

Internal AAFC	4,034
Other Public Research/Breeding – Canada	2,164
Other Genebank/Botanical Gardens	597
Wild Collected	147
Public Research/Breeding – International	99
Private Research/Breeding – Canada	8
Private Research/Breeding International	5
Other – CSO	28
Other – Individuals	1,421
Total	8,503

Significant additions were made for the following taxa:

Bread wheat (*Triticum aestivum* L.)	2,083 accessions
Triticale (*xTriticosecale* spp.)	1,015 accessions
Durum wheat (*Triticum durum* Desf.)	832 accessions
Pea (*Pisum sativum* L.)	737 accessions
Grass pea (*Lathyrus sativus* L.)	699 accessions
Tomato (*Solanum lycopersicum* L.)	699 accessions

Barley (*Hordeum vulgare* L.) 509 accessions
Garden bean (*Phaseolus vulgaris* L.) 323 accessions

The origin of the germplasm varied (see also Priority Activity 5). The majority of the donations came from public research programs (universities and AAFC breeders). For example, the pulse breeding programs at the Crop Development Centre of the University of Saskatchewan donated many samples as did Seeds of Diversity Canada with a focus on vegetable taxa. When importing seed samples, PGRC works closely with the CFIA to obtain the required import and phytosanitary permits. PGRC uses growth cabinets if required for a first seed increase so material can be grown under quarantine conditions.

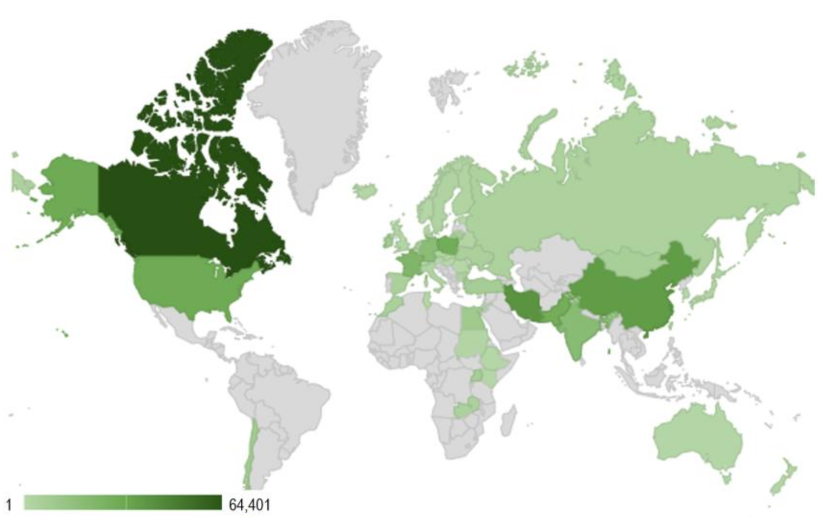
In the review period, germplasm donations of samples of new cultivars or breeding lines from Canadian private breeding companies were limited. A long-term goal of PGRC is to have samples of all registered cultivars in the national collections. For seed donations that are F_1 hybrids the current practice is to keep such material as a segregating population. For cultivars that contain transgenic constructs, enhanced efforts for avoiding genetic contaminations are required during genebank regeneration.

In 2017 an agreement was put in place at PGRC which requires all donors to confirm that samples will be in the public domain and the germplasm and all associated information will be made available according to the conditions of the Multilateral System for Access and Benefit-sharing of the ITPGRFA.

Seed germplasm distribution

PGRC seed germplasm distribution continued to increase during the review period compared to the previous decade. From 2012 to 2019, PGRC shipped 74,781 samples (accessions) of seed germplasm serving 914 clients in 51 countries (Figure 6.1). This amounts to more than 8,300 accessions annually. About 67% of the germplasm shipments were sent to Canadian clients. Public research with focus on disease resistance and molecular evaluations of germplasm accounted for more than 90% of the germplasm accessions provided by the CNPGS (Table 6.4). After 2018, all clients served signed/agreed to the SMTA of the ITPGRFA. PGRC works closely with the CFIA to ensure phytosanitary regulations are observed when sending germplasm to other countries.

Figure 6.1. Heat map for shipping of 74,781 seed samples from PGRC 2012-2019 to 51 countries.



The average number of clients served by PGRC each year was about 114 and did not vary greatly amongst years. However, there is a clear tendency of an increasing number of samples requested from PGRC per shipment (Figure 6.2). A smaller number of clients are requesting larger quantities of germplasm, typically for molecular research type projects.

Figure 6.2 Number of accessions shipped by PGRC in the years 2012 - 2019

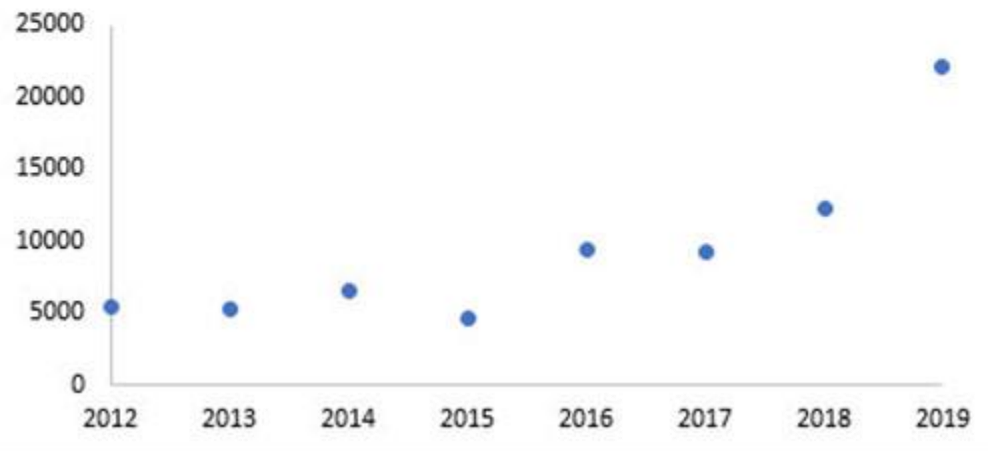


Table 6.4. Clients who obtained germplasm from PGRC 2012-2019.

PGRC client category	Number of accessions
Research – Evaluation	34,017
Research – Molecular	25,686
Research – Internal AAFC	7,648
Plant Breeding – Public	3,372
Plant Breeding – Private	2,702
Genebank\Botanical Garden	697
Education	154
Individual	282
Civil Society Organization	12
Other	211
Total	**74,781**

Canadian Potato Genetic Resource (CPGR), Fredericton, 2012-2019

The Canadian potato genetic resources collection was established in 1992 as part of multi-nodal system of the CNPGS. The potato germplasm collection is located at the AAFC Fredericton Research and Development Centre, Fredericton, New Brunswick, to facilitate collaboration with one of the AAFC potato breeding teams. The strategy behind the multi-nodal system was to establish nodes at locations where there are active plant breeding programs, which is in line with recommendations of FAO that the expertise of plant breeders be used to characterize, rejuvenate and document the diversity in collections. Germplasm holdings in CPGR total 230 accessions and are composed of a mixture of very old heirloom varieties, modern cultivars, and advanced breeding lines that have been important in potato variety development in Canada and abroad.

Most of these holdings are well characterized and have proven to be environmentally adapted to Canadian growing conditions, providing valuable genetic resources for breeding and associated research.

The repository maintains a close association with other genebanks, especially the USDA Potato Introduction project at Sturgeon Bay Wisconsin for exchange of specific germplasm with distinct genetic background for further diversifying the genetic resources collection. Duplicate samples of the potato germplasm from CPGR are maintained by PGRC in Saskatoon as micro-tubers which need to be regularly replaced.

Potato breeding expertise is located in two AAFC Research and Development Centers in the west part of Canada in Lethbridge, Alberta, and in Fredericton New Brunswick in the east. Local potato breeding expertise at Fredericton has been used to evaluate potato genetic resources accessions and has generated information relevant to breeding, including disease resistances, cooking quality or niche market traits that may contribute genes to the breeding of new varieties.

Main goals of the CPGR

- Preserve potato germplasm of importance to Canadian researchers, breeders, heritage growers and educators (Table 6.5)
- Acquire and maintain a disease-free collection of clonal potato germplasm
- Describe and document the characteristics of the clones in the collection
- Distribute clones to researchers, breeders, heritage growers / conservationists, and educators (Table 6.6)

Table 6.5. Potato germplasm holdings (230 accessions).

Potato holdings	*Percent*
• Canadian bred cultivars	34%
• Heritage cultivars	40%
• Wild relatives/Hybrids	11%
• Breeding stocks	10%
• Disease checks – Differentials	5%

Genetic Traits Conservation – Trait Characterization

- Adaptation to northern latitude
    - Phenology
    - Morphological traits
    - Yield
- Screening for disease and pest resistances
    - Late blight, *Fusarium* Dry Rot, Scab, *Verticillium* wilt, viruses (Potato Virus Y, Potato Virus X, Potato Leaf Roll Virus), Wart, Cyst Nematodes, Colorado Potato Beetle
- Nutritional / quality traits
    - Culinary traits, Glycoalkaloid levels, Antioxidant levels (flesh pigmentation), and processing quality traits.
    - Tuber shapes, dry matter & sugars content, cold-induced sweetening resistance (cold storage)

Table 6.6. Potato germplasm distributions by the CPGR Fredericton from 2012-2019 for research, training and conservation.

Number of requests					
Year	**Research**	**Training**	**Conservation**	**Total**	**Number of accessions**
2012	20	2	7	29	165
2013	15	2	3	20	83
2014	13	2	11	26	103
2015	14	1	7	22	107
2016	23	4	5	32	123
2017	15	3	0	18	93
2018	20	3	0	23	55
2019	19	3	0	22	120
Total	**139**	**20**	**33**	**192**	**849**

Canadian Clonal Genebank (CCGB), Harrow, Ontario – 2012-2019

CCGB maintains fruit germplasm of a variety of species including trees (apple, pear, peach, and cherry) and berries (strawberry, and raspberry) (Table 6.7). Many taxa of these include native Canadian plant material. Approximately 2200 fruit trees are maintained in a field collection. During the years 2012 to 2017, CCGB acquired 119 accessions including apple, grape, strawberry and roses. The *Prunus* germplasm (plum, apricot, peach) maintained in orchards is threatened due to a combination of factors and needs more attention. A small number of the native Pawpaw trees (*Asimina triloba* L.) and grape *(Vitis)* obtained from an "orphaned" university breeding program are retained in the genebank's field collections. Pawpaw is near its northern edge of the native distribution in Canada and as such is seen as a very unique source of cold tolerance.

Table 6.7. Major fruit germplasm collections at CCGB

Taxon	**Number of accessions**
Fragaria chiloensis (L.) Mill.	895
Fragaria x*ananassa* Duchesne ex Rozier – Strawberry	896
12 other *Fragaria* taxa. . – Strawberry	293
Malus domestica (Suckow) Borkh. – Apple	789
29 other *Malus* L. spp.	152
10 *Rubus* L. spp. – Raspberry	223
Prunus persica (L.) Batch – Peach	99
Prunus domestica L. – Plum	53
Prunus cerasus L. – Sour cherry	49
20 other *Prunus* L. spp.	175
Pyrus communis L. – Pear	130
6 other *Pyrus* L. spp.	14

A total of 231 samples of clonal germplasm were distributed during the same period with the majority or requests being from Canadian clients. CCGB utilizes the GRIN-Global-CA database as a data management tool for all the collections (PGRC 2021).

A new *Malus* orchard using dwarfing rootstock was established between 2012-2019. The dwarfing rootstock assists in the long-term management of the collection, making pruning and harvesting budwood easier. Greenhouse culture is used for *Fragaria* germplasm (2,000 accessions). The collection includes different sources of *Fragaria chiloensis* (L.) Mill. which was an important parent in the development of the commercial strawberry. The *Fragaria* collection is very rich in Canadian native germplasm. Plants are regularly rejuvenated by taking root cuttings and using tissue culture techniques. For wild *Fragaria* germplasm, seed is used as a backup of the material. Thermotherapy is used for virus cleanup.

The CNPGS genebanks in context of the Science and Technology Branch (STB) of AAFC

PGRC, CPGR and CCGB genebanks have primarily a service function. Associated research is conducted on a project basis by AAFC research scientists, at Universities (see Priority Activity 8) or with Industry partners. The CNPGS genebanks are part of the portfolio of the Associate Director Research Development and Technology Canadian Biological Collections located at the Ottawa RDC of AAFC. This links the CNPGS to the other collections that AAFC maintains. Other genetic resources collections of AAFC include:

- The Canadian Collection of Fungal Cultures at Ottawa, Ontario
- The Canadian Plant Virus Collection (CPVC) at Summerland, British Columbia
- The Animal Genetic Resources of Canada (AnGRC) at Saskatoon,Saskatchewan

In addition, AAFC maintains a series of reference biological collections located at the AAFC Ottawa Research and Development Centre; namely the National Vascular Plant Herbarium (DAO) and the Canadian National Mycological Herbarium (DAOM). About 7000 genebank accessions preserved at PGRC are also deposited as herbarium specimens in DAO. The Science and Technology Branch of AAFC developed in 2013 a Biodiversity and Bioresources Science Strategy that addresses the area of work for the CNPGS genebanks and the other collections (see Priority Activity 18).

Germplasm holdings of PGRFA by Civil Society Organizations in Canada

CSOs that manage and/or track *ex situ* collections of PGRFA in Canada range from formal collections of 5000 accessions (Seeds of Diversity Canada 2021), the Atlantic Seed Bank (ACORN 2021), and the Dan McMurray collection, to informal collections of 100 or fewer accessions. Prior to 2012, CSO seed conservation was essentially informal and difficult to measure. Important improvements in collection standards, storage, documentation, and sharing of both seeds and information have been made since then. Since 2012, the Canadian CSO seed conservation sector has improved significantly in the quantity, quality, and diversity of its efforts to collect, store and document domestic PGRFA (Table 6.8). SeedChange has provided support to many of the collections.

Table 6.8. Germplasm holdings by Canadian CSOs surveyed by SeedChange

	Current total	Accessions added since 2012	De-accessioned since 2012
Accessions	5790	4370	111
Species	86	17	0
Cultivars	2928	1879	10

PGRFA in Canadian botanical gardens

A total of 121 institutions or facilities in Canada self-identified as botanical gardens during a recent (April 2021) survey conducted by the University of British Columbia (UBC). Twenty-two of the respondents reported using a digital database for managing collections, 9 reported managing a seed gene bank, 10 reported they have a plant collections policy, and 3 reported that they publish a catalogue of their living plant collections. The University of British Columbia also conducted a preliminary analysis of CWR growing in Canadian botanical gardens. Interpretation of the analysis indicated that 10 botanical gardens across Canada maintain about 2164 accessions of CWR with documented collection sites in Canada.

Many botanical gardens have food gardens and provide programming on food and agriculture for education purposes such as the UBC Botanical Garden in Vancouver. Many botanical gardens conserve selections of garden plants in systematic collections, maintain collections of species in jeopardy, and/or are studying their biology and cultivation. The majority of the accessions in the Royal Botanical Garden's collections in Burlington, Ontario are ornamental horticultural cultivars. Some gardens manage nature reserves or help coordinate the restoration of degraded habitats.

PGRC preserves seeds of native Canadian material as black box collections for some Canadian botanical gardens. These seeds are not tested for viability or researched in any other way by PGRC.

Other *ex situ* germplasm collections within Canada

Working collections of fruit germplasm native to Canada exist at some universities and at AAFC Research Centres for research purposes. However, many fruit breeding programs have ceased. The University of Saskatchewan collection contains some fruit germplasm that it has gathered from a variety of sources. This collection contains material of species such as blue honeysuckle (*Lonicera caerulea* L.), currant (*Ribes* spp.), raspberry (*Rubus idaeus* L.) and highbush cranberry (*Viburnum trilobum* Marsh.) (University of Saskatchewan 2016).

Between 1902 and 2013, the AAFC Agro-Forestry Development Centre in Indian Head Saskatchewan maintained a farmstead and field shelterbelt program for Western Canada. AAFC ended the program with some of the genetic resources being retained in Indian Head including a working collection of the sea buckthorn (*Hippophae rhamnoides* L.) and native buffalo berry (*Shepherdia canadensis* (L.) Nutt.). Other accessions were transferred to the University of Saskatchewan at Saskatoon (University of Saskatchewan 2021). For native Canadian shrubs and trees see also Appendix 5.

The AAFC Morden Research and Development Centre, Manitoba, maintains an arboretum, the Morden Arboretum Research Station, with about 2500 entries that have been assembled over more than 100 years.

The CFIA laboratory at the location Sidney, British Columbia, has both grapevine and tree fruit repositories which are used for CFIA's export certification program; they keep material on site as a service for Industry (industry pays to keep them there) as it pertains to specific regulated and non-regulated viruses. These materials are designated "Generation 1"; once they leave the site they are no longer under quarantine, and they become "Generation 2".

Investments in capacity building for *ex situ* conservations in other countries

Canada regularly contributes to the Consultative Group on International Agricultural Research (CGIAR), which is implementing a 5-year research program for managing and sustaining crop genebank collections at the International Agricultural Research Centres. Internationally, Canada supported developing country partners through many initiatives related to PGRFA. In October 2009, with the unveiling of its food security strategy, Canada announced a CAD 32.5 million contribution to the Consultative Group on International Agricultural Research (CGIAR) over three years to address micronutrient deficiencies and boost the nutritional status of vulnerable populations through improvements to the quality of staple foods that are consumed on a daily basis. This funding, in part, fulfilled Canada's 2009 G-8 commitment under the L'Aquila Initiative on Global Food Security. Canada provided CAD 10 million from 2003 to 2013 for the operational resources to help establish the Global Crop Diversity Trust.

Gaps and needs

The CNPGS genebanks' needs are connected to its clients – plant breeding, research and education. Cooperative research is an on-going priority for all three CNPGS genebanks. Enhanced connections with AAFC research projects as well as research at Universities, CSOs and Industry needs to be a future focus. Continued collaboration with taxonomists at AAFC and Universities is critical for collection management at CNPGS.

Capacities for long term seed storage at PGRC need to be expanded to ensure the facilities remain operationally efficient and capacities are adequate for additions to the collections. The conservation of native Canadian germplasm including fruits and berries need attention.

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Priority Activity 7. Regenerating and multiplying *ex situ* accessions

Regeneration is a key activity for active genebanks such as PGRC, CPGR and CCGB. The current FAO Genebank Standards (FAO 2014) are in fact used as guidelines rather than standards. Regeneration is usually done as soon as possible after receiving a new entry to the collection, maintaining its genetic integrity, and to ensure that basic characterization data can be collected. The species identity and the homogeneity of the accession also need to be assessed. The regeneration plots often allow to detect germplasm with useful traits that warrant further evaluation. Highly skilled personnel is required for this. Technical seed mixtures must be avoided.

CNPGS uses a variety of regeneration techniques based on germplasm requirements:

- PGRC uses fields, greenhouses and growth chambers to regenerate seed germplasm
- CPGR uses *in vitro* conservation (laboratory) and field regeneration
- CCGB uses field nurseries (field planting) and greenhouses to multiply and preserve clones vegetatively

Suggested regeneration procedures such as the number of plants to be grown, isolation requirements, special cultural practices (e.g., tissue culture) and the descriptors to be assessed have been recommended at the international level (FAO 2014). These practices have been customized to accommodate PGRC environments, physical layout resource availability and other special conditions. Isolation techniques vary with species or crop (i.e., greenhouse, screen house, field cage and field layout). Maintaining some of the specialized collections as disease free as possible is an on-going challenge, often requiring input from the disease and pest specialists.

Isolation measures must be observed to avoid cross pollination among accessions that compromises the genetic integrity of the material. Insect rearing is required for some species. Infestation by diseases and pests requires attention to ensure the success of a regeneration cycle but also to ensure that material is not infected with seed borne diseases. Single plants that show such disease are rogued. During each regeneration cycle each accession is verified by cross referencing phenotypes and any “off types” are rogued out.

Exchange of know-how with curators at others genebanks (including USDA, NCPGRU, VIR, IPK, Nordgen, PROCINORTE) is important, and procedures must be adapted to the Canadian environment. For most crop groups, standard operation protocols for regeneration and characterization have been developed over recent years at PGRC. Germplasm regeneration is one of the most labour intensive and critical steps in the operation of the CNPGS genebanks.

PGRC annually plants about 3000 accessions in the field, in greenhouses and occasionally in growth chambers for regeneration. Most of the cereal germplasm has been regenerated. Cereal CWR that were recently regenerated now usually have sufficient seed supplies for distribution and long-term preservation. Protocols for regeneration of a special collection of male sterile barley mutant lines have been developed and are used at PGRC. In cross pollinated species as well as biennial, perennial, and insect pollinated germplasm there is a considerable backlog in germplasm regeneration. These more challenging groups need greater attention to avoid loss of germplasm and genetic integrity. Compared to the early years of PGRC (1970 to 1998), major progress has been made in germplasm regeneration, but efforts must continue and, in some groups, efforts must be enhanced.

In 2013 in collaboration with Bioversity International and the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), PGRC identified 294 *Pennisetum* accessions that were globally distinct in the PGRC collection. Samples were sent to ICRISAT for multiplication. Over 200 accessions were successfully regenerated and are now available from the active collection at ICRISAT while PGRC continues to keep security back-up samples of these.

CPGR at Fredericton preserves an *in vitro* potato collection and each year plants some samples in fields to verify the genotypic integrity of the accessions. Micro-tubers of each accession are stored as security backup by PGRC. CPGR refreshes the micro-tuber collection regularly.

Many species of fruit germplasm at the CCGB are maintained in a field genebank or in greenhouses. The apple germplasm has two similar nurseries at the Harrow Research Center. One is grafted onto traditional rootstocks and an additional nursery on dwarf rootstocks to facilitate easier maintenance. Virus free *in vitro* strawberry germplasm (plantlets) is used to preserve and increase any material that is needed.

PGRC actively participated in the process to develop the FAO Genebank Standards (FAO 2014) and also in processes by the CGRFA to develop practical guidelines how to implement these standards in 2018. These standards are followed as guiding principles by all CNPGS genebanks. For all core activities at PGRC, internal documents for standard operational procedures have been developed by PGRC staff and are continuously updated. While FAO genebank standards are often used as starting points, locally developed practises are used due to constraints. This ensure resources are used most efficiently while maximizing the conservation of genetic diversity. This means that detailed characterizations and evaluations of germplasm are second in priority to urgent measures to preserve as much diversity as possible. Also, standards suggested for germination and viability testing are adapted to available facilities and capacities.

Staff of the CNPGS regularly participate in meetings of the United States National Plant Germplasm Curator and the Plant Germplasm Operation Committee, which allows staff to exchange information with American colleagues about practical genebank issues.

Gaps and needs

PGRC will need to continue adapting existing and developing new internal standard operational procedures using the FAO genebank standard (FAO 2014) and other information sources such as UPOV variety description procedures (UPOV 2011) as guidelines and points of reference. Backlogs in germplasm regeneration of challenging groups need attention.

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Chapter 3. Sustainable use of PGRFA

Priority Activity 8. Expanding the characterization, evaluation and further development of specific collection subsets to facilitate use

When CNPGS germplasm is regenerated this is often combined with in-depth characterization or evaluation using standardized descriptor lists such as those published by Bioversity International, UPOV, or used by other genebanks such as the National Plant Germplasm System (NPGS) at the USDA, the IPK Gatersleben (Germany) or the N.I. Vavilov Institute for Plant Genetic Resources (VIR) St. Petersburg (Russia). Adaptations to the needs of Canadian plant breeders are made to ensure the relevance of the collected data for Canadian genebank users. Generating such characterisation and evaluations data at field locations of the CNPGS in Canada makes this information in particular relevant for Canadian genebank clients. It also adds to information gained on accessions in the CNPGS genebanks that are duplicated in other genebanks internationally.

Detailed evaluations are done in cooperation with plant breeders and researchers. Climate change challenges may require traits to withstand drought, higher temperatures and new insect pests and diseases. Changing environments are a never-ending challenge for plant breeders but if they have access to suitable genetic resources, they can face these challenges head on. Germplasm from the CNPGS genebanks, as well as germplasm from other regions of the world, will be needed to meet new challenges.

Each year, PGRC conducts germplasm evaluation and characterization during the growing season in field plots interspersed with replications of standard cultivars planted to ensure data reliability. In cooperation with plant pathologists, evaluations for disease resistance are often conducted during the growing season as well. More detailed projects during the review period have included pea (*Pisum sativum*), flax *(Linum* spp.*)*, wheat (*Triticum* spp.) oat (Avena spp.), buckwheat (*Fagopyrum* spp.), triticale (x*Triticoseale*) sunflower (*Helianthus* spp.) and several Brassicaceae germplasm. For example, the PGRC pea germplasm collection was recently assessed for *Mycosphaerella* blight resistance, nutritional profiles and nitrogen fixation capacity. In addition, forages such as alfalfa (*Medicago*), sweet clover (*Trifolium* spp.), *Astragalus* spp. and many perennial grasses are planted on a regular basis. Special research projects are often conducted in conjunction with crop specialists (e.g., buckwheat (*Fagopyrum esculentum* Moench), coriander (*Coriandrum sativum* L.) and caraway (*Carum carvi* L.).

Based on previous research, a flax core collection was created (Diederichsen et al 2013) that has been used extensively by PGRC clients for molecular and agronomic studies has been integrated into the flax breeding program at the University of Saskatchewan. Follow up studies were initiated in 2019 to investigate cadmium affinity in diverse flax germplasm and associate such phenotypes with sequence-based data.

CNPGS research, germplasm characterization and evaluation

PGRC is a partner in several research projects to enhance the understanding of crop diversity, its utilization and conservation. AAFC and Canadian university scientists conducting major research with data flow back to PGRC during the review period included:

- Sabine Banniza, University of Saskatchewan: disease resistance evaluation in pulse crops, coriander, and caraway.

- Helen Booker, University of Saskatchewan: disease resistance evaluation in flax
- Sylvie Cloutier, AAFC Ottawa: molecular diversity analyses in flax and wheat
- Yong-Bi Fu, AAFC Saskatoon: molecular diversity analyses in several species
- Randy Kutcher, University of Saskatchewan: disease resistance evaluation in oats wheat and flax.
- Karsten Liber, University of Saskatchewan: seed quality evaluation in flax
- Monika Lulsdorf, University of Saskatchewan: disease resistance in chickpea
- Isobel Parkin, AAFC Saskatoon: molecular diversity characterization in several species.
- Stephen Robinson, AAFC Saskatoon: pre-breeding in Brassicaceae family
- Nicholas Tinker, AAFC Ottawa: molecular diversity analysis in oat
- James Tucker, AAFC Lacombe: disease resistance evaluation in barley
- Tom Warkentin, University of Saskatchewan: disease resistance and quality evaluation in pea and soybean
- Rong Zhou, AAFC Saskatoon: chemical evaluation of oilseeds

Screening PGRC germplasm for resistance to fungal diseases

PGRC has established collaborative projects with plant pathologists and breeders at the University of Saskatchewan (e.g., Randy Kutcher) to screen PGRC germplasm for resistance to fungal diseases. They are examining wheat (stem rust, leaf rust, leaf spot, *Fusarium* head blight), oat (crown rust, wilt) and flax (*pasmo*). With over 14,000 samples of wheat, 28,000 samples of oats and 3,500 samples of flax in the PGRC genebank collection, the team has started an enormous effort.

The PGRC genebank collection of *Camelina sativa,* a potential new commercial crop for Prairie Canada, was characterized and used in plant breeding (Eynck et Falk 2013). Lentil, chickpea and canola cultivars with improved resistance to important fungal pathogens (e.g., *Ascochyta* blight, clubroot) were developed by providing plant breeders with resistant germplasm lines and molecular markers linked to resistance genes.

Oat – *Avena*

The PGRC collection has more than 27,000 accessions of 29 *Avena* species; it is the largest oat collection in the world. During recent years, PGRC has focused on regeneration and characterization of *Avena* material to ensure that seeds and information about the material are available. Passport data has been improved and geo-referenced for producing distribution maps. Recent research at PGRC was focused on molecular, morphological and seed quality diversity to better understand the structure of the genepool (Diederichsen 2008, Bekele et al. 2018, Yan et al. 2016). A set of 350 world *Avena* cultivars was added from collaboration with Nicholas Tinker, a research scientist of AAFC Ottawa Research and Development Centre. Between 2012 and 2019 PGRC distributed a total of 13,763 *Avena* accessions of all species to 10 countries in the world. *Avena* germplasm belongs to the group of accessions with most requests made to PGRC. Disease resistance screening *of Avena* germplasm by the University of Saskatchewan is on-going. Large germplasm requests have been received from Poland, the US and the Russian Federation.

The flax story – Molecular characterization of PGRC material

Genome Canada and several stakeholders in the flax industry in Canada including provincial governments, the Flax Council of Canada, and producer organizations, funded the TUFGEN (Total Utilization Flax GENomics) project (2009-2014) in part to assess the genotypic and phenotypic diversity of the flax collection held by PGRC as it pertained to characterization, conservation, breeding and genetic improvement. The reference sequence of the flax genome published in 2012 was, at the time, the 12th plant genome sequenced worldwide but the first to be sequenced by a Canadian team. Subsequently, a core collection of 400 accessions representing most of the genetic variability of the 3,000+ accessions of flax maintained by PGRC was sequenced and phenotyped for agronomic, disease and quality traits at multiple locations for 4-5 years. The 1.7M single nucleotide polymorphisms generated clearly illustrated the breadth of the genetic diversity of the collection. Accessions from the Ethiopian, Indian and Pakistani regions harboured the greatest amount of diversity, suggesting to conservationists to undertake broader geographic sampling in order to capture the full extent of diversity. Several genome-wide association analyses were conducted and identified variants associated with 27 important traits including yield, seed size, straw strength and disease resistance. More than 125 scientific articles and book chapters were published by the TUFGEN team during that time and at least 50 additional contributions stemming from the research data have been published since, including a gold standard revision of the reference genome sequence into its 15 chromosomes.

A database housing pedigree information and all genotypic and phenotypic data currently fuels flax research and breeding activities. Canadian breeders have benefited greatly from the outcome of TUFGEN and have now implemented marker-assisted and genomic selections in their programs.

Finding peas that fix more nitrogen

Peas (*Pisum sativum* L) are an ancient, cultivated pulse that can be traced back to about 8,000 BC in the Middle East. They were introduced to Canada by immigrants and are now an important pulse crop widely grown on the Canadian Prairies.

Canada has become a world leader in pulse production and in sales. The Canadian pulse and special crop industry had an export value of more than CAD 4.4 billion in 2015. PGRC genebank staff and scientists from around the world cooperate to characterize and evaluate this material and to expand Canada's collection. Pulse crops, in combination with symbiotic soil bacteria, have the ability to assimilate or "fix" nitrogen from the air, use it to enrich their growth, and make it available in the soil for crops to use the following year. Scientists at the University of Saskatchewan recently compared peas with high root nodulation, obtained from international genebanks, to commercial pea cultivars grown in Canada. Scientists from the University of Saskatchewan and California State University evaluated the pea lines for their ability to assimilate nitrogen under local environmental conditions in western Canada. The research showed that environmental factors and the cultivar are both important factors when it comes to nitrogen fixation (Yang et al. 2017). This research will help farmers choose a pea cultivar with increased ability to fixate nitrogen, which will help them reduce nitrogen fertilizer costs.

Molecular characterization of PGRC material – Genetic sequence data (GSD)

Staring about 2010, genetic sequence data (GSD) on PGRC accessions has been generated annually on subsets of germplasm of oat (including wild oat species), barley (including wild barley species), wheat, flax, maize, soybean, and oilseed *Brassica* species. The number of PGRC accessions analyzed ranged from 200 to 600 accessions of pre-selected subsamples that represent the diversity in the species. The purpose was in all cases to better characterize the genetic diversity in order to enhance *ex situ* germplasm management, or in order to clarify phylogenetic relationships within the taxa considered. In wild oat, wild barley, wild emmer, crested wheatgrass and northern wheatgrass larger samples have been analyzed to assess genetic diversity for conservation purposes including *in situ* conservation (Fu 2015, Fu et al. 2019, Soto-Cerda et al. 2014).

Applied RNA-sequencing technology has been used to identify differentially expressed genes for traits of the breeding target late maturity in crested wheatgrass and sainfoin germplasm in collaboration with a Canadian public breeding program. GSD has been used to screen 600 soybean accessions to support public breeding for early maturity. Upon completion of a project generating and analyzing GSD, all generated sequence data and some derived sequence data were deposited in public databases such as the National Centre for Biotechnology Information (NCBI) and Figshare (https://figshare.com/) which are universally accessible.

Enhancing capacity building in GSD by AAFC

AAFC regularly establishes training programs for students, including visitors from many countries. Some key issues addressed include analyzing and applying GSD on PGRFA for usage in conservation and plant breeding. The laboratory headed by Yong-Bi Fu at Saskatoon used PGRC germplasm and specifically provided training to foreign scientists from Chile, China, Columbia Ethiopia, Mexico, Nigeria and Pakistan. These training efforts have helped to develop expertise for foreign visitors from developing countries in generating GSD and characterizing plant germplasm.

Generating genetic sequence data (GSD) capture in AAFC collections

On March 22, 2016, the Government of Canada announced an investment in AAFC of CAD 30 million over 6 years, starting in 2016-2017 to accelerate the DNA analysis and digital recording of the department's collections of over 19 million specimens of insects, plants, fungi, bacteria and nematodes. This initiative also includes generating GSD for germplasm accessions held by the Canadian national gene bank Plant Gene Resources of Canada (PGRC), in addition to improving digital passport data records. This project has already collected sequence data for 20,000 PGRC accessions and will hopefully reach almost 35,000 by the end of the project in 2022. In some instances, this will provide sequence data for all accessions of a particular species or even genus in the collection. For species and relatives of the cereals which make up a large proportion of the PGRC collection, the selection of lines for sequencing has been in concert with researchers focused on a particular species to generate data of immediate value to the community.

Use of GSD generated on CNPGS material has been downloaded by the public. For on-going projects generating GSD data, the database structures to provide public access to GSD are presently being developed within AAFC. The GRIN-Global genebank information system (https://pgrc-rpc.agr.gc.ca/gringlobal/landing) used by CNPGS does not have the capacity to hold GSD data. The CNPGS accession numbers will be used to point to various highly sophisticated databases that can hold GSD on CNPGS listings.

Research in genomics-based characterization of PGRC germplasm collections has involved several research projects associated with collections of wheat, oat, barley, flax, yellow mustard, Jerusalem artichoke and four native grass species. These research efforts have generated many innovative characterization tools, advanced knowledge of crop genetic diversity, molecular make-up of genepools and contribute to germplasm conservation and utilization. Such research has strengthened PGRC germplasm collection and utilization through germplasm acquisition and filling gaps in the collections and contributed to Canada's commitments in capacity building through training foreign scientists in several AAFC laboratories. Research has positioned PGRC well among international genebanks which carry out molecular germplasm characterization (Baral et al., 2011, Bekele et al. 2018a, Bekele et al 2018b, Fu and Horbach 2012; Peterson et al. 2014; Fu et al. 2019, Soto-Cerda et al. 2014, Yan et al. 2016). The following are two highlights of such activity by AAFC using PGRC germplasm:

(1). Development of several protocols for "next generation" sequencing based on genotyping-by-sequencing (GBS) for analysis of plant genetic diversity. These GBS protocols enable scientists to characterize and explore useful genetic variants from huge *ex situ* germplasm collections for plant breeding.

(2) Development of effective genetic-based strategies for conserving and utilizing four native Canadian grass species: side-oats grama (*Bouteloua curtipendula* (Michx.) Torr.), Nuttall's salt-meadow grass (*Puccinellia nuttalliana* (Schult.) Hitchc.), crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) and northern wheatgrass (*Agropyron lanceolatum* Scribn. & J. G. Sm.).

This research not only advanced efforts to effectively conserve and utilize native grasses in the Canadian Prairie for habitat restoration and high-quality forage development, but also helped to demonstrate the outreach contribution of AAFC research to native grass germplasm utilization for forage breeding (Barak et al. 2018).

Improved characterization and evaluation using a wide range of methods is essential for more efficient conservation and use of genebank collections. Basic characterization using agro-botanical characteristics (descriptors) of high heritability traits is essential for true to type verification of germplasm. Ideally, collaborative projects with various user communities can be identified. This helps to ensure data collection is on target and meets the needs of the user communities while sharing costs.

Gaps and needs

Standardization of characterization and evaluation of germplasm including molecular methods, sequencing and phenotyping is required to ensure better interoperability of databases and facilitating exchange of information. It will be necessary for CNPGS staff to communicate with a variety of users to ensure that information generated on CNPGS germplasm holdings is linked to the physical germplasm and that both the physical germplasm and the associated information can be shared. The genebank information system GRIN-Global-CA will need to be linked to other databases maintaining such information.

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Priority Activity 9. Supporting plant breeding, genetic enhancement and base-broadening efforts

Plant genetic resources have been used in Canada for many decades. Benefits from their use have accrued through genetic improvements that have contributed to major increases in productivity and resistance to pests, diseases and adverse growing conditions as well as improvements in earliness, harvestability and market value. Canadian grain yields have steadily increased over the past decades and the improved quality of our products has contributed to greater sales on world markets. Almost all innovative plant breeding in Canada is carried out by the private sector and public institutions (AAFC and universities).

A primary role of genebanks is to provide raw material to the plant breeding community for the development of improved varieties to meet the needs of growers, consumers and requirements of various production systems. Breeding goals are usually determined by market demand (including export markets) as well as regional requirements. Environmental adaptation is essential as well as key quality characteristics like resistance to diseases and pests. These objectives can only be achieved by using appropriate germplasm. Genebanks in Canada or elsewhere in the world are often one of the only sources of such genetic materials.

Canadian Field Crop Research Alliance

Canadian field crop farmers are working hard to ensure the sector remains vibrant and strong. The crop sector is a key contributor to Canada's economy, representing CAD 25 billion in farm gate receipts, CAD 21 billion in exports and supporting thousands of jobs across the country while expanding markets for the sector's safe, high-quality products.

The Canadian Minister of Agriculture and Agri-Food announced (2019) an investment of up to CAD 39.3 million to four science clusters including barley, wheat, diverse field crops and soybean under the Canadian Agricultural Partnership. These investments include an additional CAD 28.4 million in contributions from industry, for a total investment of CAD 67.7 million. These new Clusters will drive innovation and discovery in the Canadian field crops sector over the next five years:

- The Barley Cluster (CAD 6.3 million) aims to improve productivity in the science and technology of using barley for food and increase disease resistance. The Cluster will be led by the Barley Council of Canada.
- The Diverse Field Crop Cluster (CAD 13.7 million) focusses on variety development, crop protection, production agronomy and value-added practices to support diverse crop growth. The Cluster will be led by Ag-West Bio Inc.
- The Wheat Cluster (CAD 13.9 million) aims to deliver higher-yielding wheat varieties to producers, and to develop the next generation of *Fusarium* Head Blight resistant varieties. The Cluster will be led by the Canadian Wheat Research Coalition.
- The Soybean Cluster (CAD 5.4 million) will help Canadian soybean crops become more resilient and productive, increase the geographic range for growing crops and benefit the environment. The Cluster will be led by the Canadian Field Crop Research Alliance.

Wheat Breeding in Canada

Canada is a vast country with many different crop production environments. Over 90% of the area devoted to wheat cultivation is in the western provinces of Alberta, Saskatchewan and Manitoba, where agricultural production is often on the fringes of crop adaptation. Hard red spring wheat (*Triticum aestivum* L.) and durum wheat (*T. durum* Desf., syn. *T. turgidum* L. subsp. *durum* (Desf.) van Slageren) predominate in the western provinces whereas soft winter wheats (*T. aestivum* L.) predominate in Ontario and Quebec. In western Canada, limitations imposed by requirements for early maturity, tolerance to drought and other regional abiotic stresses, and stringent end-use quality parameters that define top wheat classifications (particularly Canadian Western Red Spring (CWRS) and Canadian Western Amber Durum (CWAD) severely restrict the germplasm base directly useful for cultivar development. In winter wheat, the requirement for high levels of cold tolerance is a limitation in most regions.

Over the past century, in addition to increasing grain yield, a major impetus for incorporating genetic diversity into Canadian wheat from global primary to tertiary gene pools has been a necessity to maintain and improve resistance to existing and emerging disease and insect threats. These threats include *Fusarium* head blight (FHB), stem rust, leaf rust, stripe rust, common bunt, leaf spotting diseases, powdery mildew (primarily in eastern regions), orange wheat blossom midge (OWBM), and wheat stem sawfly. Over the past decade, the production of OWBM tolerant cultivars has become commonplace and there has been a large increase in the number and production of FHB and stripe rust resistant cultivars in all market classes. These cultivars have had high rates of adoption due to simultaneous improvements in productivity, reduction in height and lodging, and resistance to traditional disease threats such as stem and leaf rust, and common bunt. For example, from 2012 to 2019 the area of hard red spring (CWRS) wheat seeded to cultivars with intermediate or better FHB resistance increased from 32% to 83%. In durum, improvement in the rate of progress for FHB resistance has been hindered by a lack of readily usable sources of resistance. *Triticum turgidum* subsp. *durum* relatives or their derivatives, and international accessions have been used. In 2021, the first Canadian durum wheat with intermediate resistance to FHB was approved for registration. In the future, drivers for incorporating genetic diversity will include existing objectives and increased emphasis on physiological traits to mitigate the effects of climatic variability such as harvest integrity, heat and drought tolerance, and nutrient use efficiency. For these traits to gain prominence in cultivars, appropriate germplasm and tools to facilitate rapid, efficient, and effective incorporation and selection will be required.

The majority of wheat improvement efforts in Canada are concentrated in the public sector and sharing of improved germplasm is generally quite open. International ties and collaborations with the International Wheat Yield Partnership and Wheat Initiative have become increasingly important. As exotic germplasm is introduced to breeding programs through these and other international collaborations, longer term pre-breeding activities are increasingly important for building new parents, which can have a much longer development period. This is illustrated by the recent interest in hybrid wheat development and the extension of timelines to commercialization. If successful, the introduction of hybrids is also likely to increase Canadian wheat genetic diversity. As genomic information continues to increase, the ability to store, process and transfer vast amounts of information may become a greater limitation and a future predictor of breeding program commercial success.

Pre-breeding in cereals

Introversions of disease resistances to stem rust and crown rust from CWR in *Avena* have been a successful strategy in Canadian oat breeding since the 1960s and all modern Canadian oat cultivars have in their pedigree's alleles from *A. sterilis* (Diederichsen 2016). To enhance resistance to *Fusarium* head blight, wide intergeneric crosses with several CWR with promising results were made by Fedak et al. (2019).

Farmer-funded and farmer-directed non-profit organization investing in agricultural research – the Western Wheat and Barley Breeding Core Support Agreement

The Western Grains Research Foundation (WGRF) benefiting western Canadian farmers has existed since 1995. WGRF and Agriculture and Agri-Food Canada (AAFC) have collaborated on western wheat and barley cultivar development, through a series of collaborative agreements stating contributions of the parties and shared goals. The objective is to provide mutual financial and technical support and to facilitate the development of wheat and barley cultivars for western Canadian farmers with higher yields, improved agronomic traits, end use properties, and better disease and insect resistance.

The investment of WGRF relies on "check-off" payments from Prairie grain farmers on wheat and barley sold by them. This money is reinvested in the development of new wheat and barley cultivars. Farmers are part of the decision-making committee responsible to identify the needs for new cultivars and traits creating economic, social and/or environmental benefits. Key new wheat and barley cultivars that are adapted to various agro-ecological zones have been released – 150 new cultivars since 1996 (see also Table 9.1).

Barley Breeding

The National Barley Cluster is a component of Agriculture and Agri-Food Canada's AgriScience program under the Canadian Agricultural Partnership. The National Barley Research Cluster brings together twelve research activities from across Canada. The overall goals of the research are to ensure that barley production remains competitive with other major crops in Canada and to improve the quality traits of Canadian barley to satisfy the diverse and evolving needs of our customers. Research areas within the cluster include variety development, agronomic productivity, disease resistance, quality and performance, and sustainability (Barley Council of Canada 2021).

Oilseed Crop breeding

The work started by public plant breeding to change the oil quality of rapeseed to develop what is marketed today as canola exemplifies Canada's significant contribution to enriching the crop diversity of *Brassicas*. PGRC houses 1900 accessions of the genus *Brassica* including genetic resources relevant for canola/rapeseed (*Brassica napus* L.) breeding.

***Brassica* oilseeds and mustards** – The breeding of canola was very actively pursued after World War II at the University of Manitoba and at AAFC Saskatoon, where AAFC is still a world leader in work on these crops. Rapeseed (*Brassica napus* L.) that has low erucic acid content and is free from glycosinolates was developed in Canada and has been marketed as canola since the 1970s. *B. napus* canola became the dominant oilseed in Canada and has had major impact on-farm income in Canada and globally. Other *Brassica* oilseeds (*B. rapa* L., *B. juncea* (L.) Czern. and *B. carinata* A. Braun) with canola quality have also been developed in Canada. Germplasm introductions from Europe (*B. rapa, B. napus*), Ethiopia (*B. carinata*) and India (*B. juncea*) have been instrumental for these developments. Today private breeding dominates B. *napus* breeding in Canada and makes major investments in research and development of canola. Nearly all canola cultivars planted today in Canada are F_1 hybrids and have herbicide tolerance.

Pre-breeding using CWR in for improving rapeseed/canola – AAFC public sector research supports strategic objectives that benefit the continued adaption of rapeseed to the Prairie environment. This pre-breeding effort contributes to genetic enhancement and base-broadening utilizing PGRC resources and material from other genebanks of crop wild relatives of *B. napus* by 1) developing methods to directly access alleles in crop wild relatives aiding pre-breeding objectives; and 2) determining the diversity in underlying adaptive mechanisms that have evolved in related genera to develop a greater understanding of physiological processes. On-going research at AAFC in Saskatoon develops innovations to enhance the process of gene introgression through interspecific hybridization and uses the PRGR collection to investigate variation in stress physiology among diverse genera including *Isatis tinctoria* L., *Cochlearia officinalis* L., *Pringlea antiscorbutica* R. Br. *ex* Hook. F., *Armoracia rusticana* G. Gaertn. *et al*., and *Hesperis matronalis* L.

Flax – Another major breeding effort was seen in flax (*Linum usitatissimum* L.). Historically flax was one of Canada's important oilseed crops, but Canadian production has fallen significantly in recent years. PGRC houses 3500 accessions of *Linum* germplasm which is one of the largest flax collections in the world. Canadian flax breeding programs have released 46 cultivars from 1981-2015. A Canadian flax core collection was developed by PGRC to support the Genome Canada Project TUFGEN project. Subsequently these accessions have been widely used in flax breeding and research in Canada and internationally in Chile, France and India.

Soybean – Genome Canada supported soybean breeding research at Laval University in Quebec City. AAFC soybean breeding programs at Ottawa and Harrow develops short-season soybean cultivars for areas in Canada requiring early maturing soybeans with a focus on specialty types for food, feed and tolerance to stresses breeding objectives include:

- Develop food grade soybean varieties with high yield, pest resistance and good processing quality for Canadian soybean growers
- Development of food grade soybean germplasm with special food quality traits for national and international niche markets
- Development and application of novel technologies to improve selection efficiency in soybean variety development

Research connections – collaboration and partnerships

Expanded AAFC Canadian field crop breeding and research programs

A wide range of research efforts are underway that focus on national and regional and local programs with which CNPGS has collaborated or contributed to conserved plant germplasm such as:

- Enhancing wheat breeding capacity through private sector involvement and technology adoption
- Sustainable production and genetic enhancement of small fruit crops with improved market-oriented quality attributes
- Development of premium quality western Canadian winter wheat

- Enhancing the stability of recent yield advances in western Canadian winter wheat
- Characterization and selection of improved quality attributes (postharvest physiological properties) in Canadian tree fruit, berry, and wine grape germplasm
- Integrated genomics, plant pathology and breeding research for improvement of *Fusarium* Head Blight resistance in Canadian cereals
- Precision breeding in wheat mediated by engineered haploid inducers
- Integrating quantitative proteomics, redox metabolomics and proteo-genomics approaches to identify sources of pre-harvest sprouting resistance in Canadian wheat
- Mining the soybean germplasm collection through genotyping-by-sequencing and phenotyping to enhance germplasm utilization
- Assessing genotypic diversity and environmental impact on cadmium concentration in flax seed in support of enhanced plant breeding
- Expanding the genetic biodiversity of wheat by pre-breeding
- Identifying resistance to tan spot disease in winter and durum wheat
- Developing durable clubroot resistance against pathotype 5X based on the action modes and deployment of resistance genes
- Gene-for-gene mediated resistance to midge in canola and wheat
- Identifying new genes in domesticated intermediate wheatgrass to improve biotic stress resistance
- Filling gaps in wheat cultivar development with translational research
- A systems biology approach for durable *Fusarium* Head Blight / Deoxynivalenol resistance in wheat
- Advanced genomics strategies to capture novel genetic diversity for oilseed crop improvement
- Impact of genome ploidy on the plant's response to stress
- Genetic characterization of ergot resistant germplasm to reduce ergot contamination of grain for human and animal consumption
- Integrated genomics, plant pathology and breeding research for improvement of *Fusarium* Head Blight resistance in Canadian cereals
- Tissue culture techniques for the rapid multiplication, selection and improvement of blueberry plants
- High throughput “omics” approaches for effective breeding selection of durum wheat quality

University contributions are many and varied

The University of Saskatchewan and the Crop Development Center (CDC) are located in the College of Agriculture and Bioresources. Due in part to the close proximity to PGRC, CDC is an important research partner. The Center provides important links to develop crops for food and feed (e.g., spring wheat, durum wheat, spelt wheat, canary seed, barley, oat, soybean flax, pea, lentil, chickpea, dry bean, and faba bean). CDC has focused on plant breeding and pathology to improve existing crops and developing new crops. Many other universities have breeding efforts using PGRC germplasm to support agricultural development in their region:

University of Manitoba, Winnipeg, Manitoba
University of Alberta, Edmonton, Alberta
University of Guelph, Guelph, Ontario
McGill University, Quebec, Quebec
Dalhousie University, Halifax, Nova Scotia

Genebank – plant breeding linkage in potato development: The AAFC Potato Accelerated Release Program

AAFC initiated the accelerated release program in 1998. It is a two-phase process to fast track the release of promising potato selections developed at the Fredericton (New Brunswick) and Lethbridge Research and Development Centres (Alberta) of AAFC to the producer. Seed potato producers and potato processors across Canada joined forces in a collaborative effort to develop better potato cultivars for the Canadian industry and facilitate faster field-testing and cultivar registration process. Approximately seventy stakeholders have participated in the program since 1998. Potato growers' trial new potato selections earlier in their development in their own fields under their own growing conditions.

An example of setting priorities for developing new cultivars

Most if not all plant breeding programs work in close conjunction with the crop producers and/or processors to help ensure the new cultivars fit both the growing environment and the end users' needs. A wide variety of strategies are employed to help accelerate new developments such as increasing demand for high-quality, plant-based protein ingredients. The Prairie Grain Development Committee (PGDC) is a forum for the exchange of information relevant to the development of improved cultivars of grain crops for the western Canadian prairies.

An example is the Prairie Recommending Committee on Oilseeds (PRCO) which provides oversight for among others, flax cultivar registration in Canada. Candidate lines are evaluated in multi-location, multi-year trials across Western Canada. The purpose of the trial is to collect agronomic performance and seed quality data for consideration in the Committee's decision regarding their support for registration of a candidate line as cultivar for production in Canada. This group agrees by consensus on candidate lines to test based on provisional datasets presented by the developer and the disposition of lines in registration trials. The PRCO also makes decisions with regards to the standards (check cultivars) and protocols to be followed. A similar process applies to all main agricultural crops grown in Canada: wheat, rye, triticale, oat, barley, pulses, and special crops (where official registration is required). The following crop specific registration recommending committees operating in a similar way exist in Canada (CFIA 2021):

- Atlantic Recommending Committee for Cereal Crops (ARCCC)
- Ontario Cereal Crops Committee (OCCC)
- Ontario Canola Recommending Committee (OCRC)
- Ontario Pulse Crop Committee (OPCC)
- Ontario Recommending Committee for Flue-Cured Tobacco (ORCFCT)
- Prairie Recommending Committee for Oat and Barley (PRCOB)
- Prairie Recommending Committee for Oilseeds (PRCO)
- Prairie Recommending Committee for Pulses and Special Crops (PRCPSC)
- Prairie Recommending Committee for Wheat, Rye and Triticale (PRCWRT)
- Quebec Recommending Committee for Cereal (QRCC)
- Quebec Recommending Committee for Oilseed and Protein Crops (QRCOPC)
- Western Canada Canola/Rapeseed Recommending Committee (WCCRRC)

Programs and research projects managed by the federal government, provincial government, universities and private sector are too diverse to identify all the key achievements. The reader is directed to the publicly available databases where a wide variety of queries can be made that focus on agricultural research. (e.g., https://www.agr.gc.ca/eng/about-our-department/planning-and-reporting/research-projects/?id=1208366237788) Prairie Grain Development Committee: http://www.pgdc.ca/index.html

Participation of producers in decision-making processes regarding the Plant Breeders' Rights intellectual property regime in Canada

Under the Canadian Plant Breeders' Rights Act (https://lois-laws.justice.gc.ca/eng/acts/P-14.6/) which was enacted in 1991, section 73 requires that the Minister of Agriculture and Agri-Food forms an Advisory Committee consisting of representatives of various associations and enterprises involved in the value chain (e.g. plant breeders, horticulturists, seed dealers, farmers, and other individual or stakeholders the Minister considers appropriate). The measure is intended to involve the farming community, as well as other representatives, in the administration of the Canadian intellectual property regime for the protection of new plant varieties/cultivars. It thus ensures that legislative, policy, and procedural decisions surrounding the administration of the Plant Breeders' Rights Act, are made respecting interests of all value chain members, including farmers, and benefits the value chain as a whole. The advice from the Advisory Committee comes in various forms; it could be communicated to the Plant Breeders' Rights Commissioner via an annual face-to-face meeting or in written format. The outcome of this practice is reflected in the impacts of the decisions taken by the Advisory Committee, or the policies implemented; for example, improved access to new plant varieties and cultivars for Canadian farmers.

The farming community, as well as other representatives in the different crop specific value chains, are involved in the administration of the Canadian Plant Breeders Rights intellectual property regime. By involving farmers in the decision-making process, it ensures their views and interests are taken into consideration with respect to plant genetic resources. The effectiveness of the Advisory Committee is assessed by the impact and outcomes of the decisions taken, or policies implemented, that improve farmers' access to innovative new plant cultivars. Implementing partners included:

- Canadian Federation of Agriculture
- Canadian Horticulture Council
- Canadian Organic Trade Association
- Canadian Ornamental Horticulture Alliance
- Canadian Potato Council
- Canadian Seed Growers Association
- Canadian Seed Trade Association (Seed Canada)
- Canterra Seeds, Grain Growers of Canada
- Producteurs de Grains du Québec
- Syngenta Canada
- University of Saskatchewan, Crop Development Centre
- Agriculture and Agri-Food Canada

Crop development priorities established for the next decade

AAFC Research priorities are generally established and reviewed with producers, partners and user groups on a regular basis. Since the crops grown in Canada are very diverse, there is no fixed model for all crops. Each commodity or crop group works out their own direction for the research, and progress is reviewed on a regular basis. Some examples of project priorities established include:

- Evaluation and Field-Testing Agreement (EFTA) for strawberry (*Fragaria*) selections
- Dry bean cultivars for southern Alberta and Saskatchewan (2012-17): Development of pinto bean and yellow bean cultivars with high yield and seed quality
- Novel sainfoin cultivars for enhancing production efficiencies of pasture and beef cattle and building capacity in forage breeding
- Breeding malting and food barley cultivars for western Canada at Agriculture and Agri-Food Canada's Brandon Research and Development Centre assisted by new technologies
- Development of improved cultivars of *Camelina* for the Canadian Prairies
- Germplasm and cultivar development of condiment mustard for improved yield and quality
- Collection and characterization of species of *Berberis* in Brazil, Argentina, Chile, Ecuador, and Uruguay
- Organic Science Cluster: Theme A. Field crops: Optimizing productivity and competitiveness through adaptable systems for field crops (Dalhousie University 2021)

Calls for proposals are open to Canadian researchers and breeders on a fairly regular basis. Some examples of the Federal government funding opportunities include:

- Agricultural Clean Technology Program
- AgriAssurance Program: National Industry Association
- AgriInnovate Program
- AgriRisk Initiatives – Microgrants
- Coordinated Agriculture Policy Research Initiative
- Agricultural Living Laboratories Initiative: Collaborative Program
- Saint-Hyacinthe Research and Development Centre's Industrial Program
- Technology Transfer and Licensing
- Agri-Science Program – Projects and Clusters
    - The Agri-Science Program is a program under the Canadian Agricultural Partnership, which in part aims to accelerate the pace of innovation by providing funding and support for pre-commercial science activities and cutting-edge research that benefits the agriculture and agri-food sector, and Canadians.
    - There are two components:
        - AgriScience – Cluster component: Proposals are intended to mobilize industry, government and academia through partnerships, and address priority themes and horizontal issues that are national in scope.
        - AgriScience – Project component: A single project or a smaller set of projects that would be less comprehensive than a Cluster.

In summary, plant breeding remains an active sector in Canada. Due to historical development public plant breeding by the federal government (AAFC) and public breeders at Canadian Universities supported by the Provinces are still important in Canada. In recent years a shift to more engagement of the private sector in plant breeding has occurred while the public sector focuses more on germplasm development.

Canadian Food Inspection Agency (CFIA) and cultivar registration

Since Canada adopted UPOV-91 (Feb 27, 2015), the Plant Breeders' Rights (PBR) Office of AAFC – CFIA - has recorded a significant increase in applications for protection of new varieties/cultivars. This helps to ensure that Canadian plant breeders can protect innovations they have developed and ultimately producers can have access to new and innovative cultivars, supporting their competitiveness in a global marketplace. The PBR Office also has experienced an increase in the number of non-resident agriculture variety applications for protection in the Canadian marketplace.

CFIA is responsible for cultivar registration of major crop species in Canada. The purpose of cultivar registration is to provide government oversight to ensure that health and safety requirements are met, and that information related to the identity of the cultivar is available to regulators to prevent fraud. It also facilitates seed certification, the international trade of seed and the tracking and tracing of cultivars in commercial channels. Not all crops have their new cultivars registered. During the years 2012 to 2019 at total of 1782 cultivars were registered in Canada. Soybean (733), potato (248), rapeseed/canola (117) and alfalfa (91) dominated in this list (Table 9.1). Cultivars that are protected by Plant Breeders Rights can be used by plant breeders for further breeding purposes (Canadian Intellectual Property Office 2021).

Table 9.1. Cultivars registered in Canada between 2012 and 2019 by crop kind. (CFIA 2021)

Crop kind	Number of cultivars
ALFALFA	91
ALFALFA, HYBRID	2
BARLEY, SIX-ROW, SPRING	19
BARLEY, SIX-ROW, SPRING, FORAGE TYPE	1
BARLEY, SIX-ROW, SPRING, HULLESS	2
BARLEY, TWO-ROW, SPRING	28
BARLEY, TWO-ROW, SPRING, HULLESS	3
BARLEY, TWO-ROW, WAXY, HULLESS	1
BEAN, FIELD, Yellow type	3
BEAN, FIELD, BLACK TYPE	8
BEAN, FIELD, CRANBERRY TYPE	6
BEAN, FIELD, FLOR DE JUNIO TYPE	1
BEAN, FIELD, GREAT NORTHERN TYPE	4
BEAN, FIELD, PEA (NAVY) TYPE	15
BEAN, FIELD, PINK TYPE	1
BEAN, FIELD, PINTO TYPE	11
BEAN, FIELD, RED KIDNEY TYPE	3
BEAN, FIELD, RED MEXICAN TYPE	3
BEAN, FIELD, WHITE KIDNEY TYPE	2
BIRD'S-FOOT TREFOIL	1
BROMEGRASS, MEADOW	2
BROMEGRASS, SMOOTH	3
BUCKWHEAT	2
CANARYGRASS, ANNUAL	2
Canola quality Brassica juncea, hybrid	2
CLOVER, RED, DOUBLE CUT	15

CLOVER, WHITE, LOW-GROWING	3
CLOVER, WHITE, TALL GROWING	3
FABABEAN	9
FESCUE, MEADOW, FORAGE TYPE	5
FESCUE, TALL, FORAGE TYPE	14
FLAX, OILSEED	17
LENTIL	29
MUSTARD, BRASSICA JUNCEA L., INDIAN	3
MUSTARD, BRASSICA JUNCEA L., ORIENTAL	1
MUSTARD, SINAPIS ALBA L., WHITE	1
OAT, SPRING	40
OAT, SPRING, HULLESS	3
ORCHARDGRASS	19
PEA, FIELD, GREEN	8
PEA, FIELD, YELLOW	19
POTATO	248
RAPE, OILSEED, SPRING, BRASSICA NAPUS, CANOLA	7
RAPE, OILSEED, SPRING, BRASSICA NAPUS, HYBRID CANOLA	117
RAPE, OILSEED, SPRING, BRASSICA NAPUS, RAPESEED	4
RYE, WINTER	1
RYE, WINTER, HYBRID	5
RYEGRASS, ANNUAL	19
RYEGRASS, PERENNIAL, FORAGE TYPE	14
SOYBEAN, OILSEED	733
SUNFLOWER, HYBRID, NON-OILSEED	4
SUNFLOWER, HYBRID, OILSEED	12
TIMOTHY	16
TOBACCO, FLUE-CURED HYBRID	2
TRITICALE, SPRING	6
WHEAT, DURUM	22
WHEAT, SPELT	2
WHEAT, SPRING	120
WHEAT, WINTER	43
WHEATGRASS, CRESTED	2
Total	**1782**

Gaps and needs

Historically many breeders deposited a sample of new any cultivar with CNPGS genebanks. CNPGS hopes that this voluntary action will continue. It is important to ensure the CNPGS genebanks can serve as a comprehensive archive of crop breeding and development efforts in Canada.

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Priority Activity 10. Promoting diversification of crop production and broadening crop diversity for sustainable agriculture

Promoting diversification of crop production and broadening crop diversity for sustainable agriculture is a key element for AAFC, Canadian Universities and in the private sector. The AAFC Science and Technology Branch (STB) has developed nine sector strategies (AAFC 2016). Some of these are particularly relevant for plant breeding research. Canada is also among the 14 member countries of the global Wheat Initiative (2021).

Wheat research background

Canada is one of the world's top five wheat exporters with an average of CAD 7 billion exported annually. Canada produces an average of 30 million tonnes of wheat each year and is the world's largest producer of high protein milling wheat.

Innovation plays a significant role in the agriculture industry and Canada's economy. It is estimated that every dollar invested in wheat research delivers a net return to producers of twenty dollars. On July 21st, 2017, federal, provincial and territorial ministers reached agreement on the Canadian Agricultural Partnership, which is a 5-year, CAD 3 billion agreement that came into effect April 1, 2018. This agreement is strengthening the agriculture, agri-food and agri-based products sector, ensuring continued innovation, growth and prosperity and together, with federal investments in science and innovation, trade, the environment and value-added industries. It helps our agricultural sector reach its full potential.

Wheat research priorities were developed as a national collaboration of farmers, federal and provincial governments, public research institutions, exporters and processors in an effort led by Cereals Canada and Agriculture and Agri-Food Canada. The report outlines priority areas of research that public, private and producer groups should focus on for the next five years in order to ensure this CAD 7 billion wheat industry remains strong and grows in the future.

This is the first time the industry has come together to establish such research priorities. The priorities were:

- Improving wheat yield and reliability
- Increasing sustainability
- Improving food safety for example by reducing mycotoxins
- Being able to respond to consumer needs by developing a feedback mechanism from purchasers to researchers

Ultimately a strong wheat sector means greater opportunities for all Canadians. The process will be on-going, allowing the value chain to measure work against established goals and refine objectives for success. In early 2020 "The Canadian Wheat Research Priorities 2020 through 2022" was released. This updated the earlier release about priorities. National wheat research priorities were developed through national collaboration of farmers, federal and provincial governments, public research institutions, exporters and processors, led by Cereals Canada and Agriculture and Agri-Food Canada. The five research priorities are:

- Improving wheat yield
- Improving wheat yield reliability

- Increasing sustainability
- Improving food safety
- Increasing our ability to respond to consumer needs, both internationally and domestically, by enhancing the feedback mechanisms between purchasers, researchers, and producers

The report lays innovation opportunities for public and private researchers, farmer-led organizations funding innovation, and governments who continue to invest in wheat research and development. The report also provides a first picture of where research dollars are spent, allowing the value chain to measure work against established goals and refine objectives for success that the public, private and producer groups should focus on for the next two years in order to ensure that the CAD 7 billion wheat industry provides growing and sustainable profitability into the future. Stakeholders in every region of the country can use this document to better understand where efforts and funding should be focused in order to achieve greater success for Canada's important wheat sector.

Pulse crops in Canada – changes and trends since January 2012

Pulse crops in Canada are growing in importance. Pulse Canada, a producer led organization, has developed a centralized database on pulse crop research funded via the producer organizations and Agriculture and Agri-Food Canada.

In 2017, Pulse Canada developed and launched the Pulse Research Database. This is a centralized list of previous and on-going pulse research in nutrition, health, environmental sustainability, quality, functionality, processing and applications.

Many of the projects in the database have been funded by producer organizations – the members of Pulse Canada (Alberta Pulse Growers, Saskatchewan Pulse Growers, Manitoba Pulse and Soybean Growers, Ontario Bean Growers) and the Canadian government (Agriculture and Agri-Food Canada). The database was developed by Pulse Canada as a tool for the pulse research community and is currently co-managed by Pulse Canada, the USA Dry Pea and Lentil Council and the American Pulse Association.

The database provides the following benefits for scientists, research funders and pulse industry stakeholders:

- Access to non-confidential information on pulse research projects for which results may not be published, as well as projects that are currently underway for which public information would not be widely available
- Eliminates the need to search multiple websites of pulse research funding organizations and public databases for information on pulse research projects
- Includes only research on pulses, therefore eliminates the need to enter names of all pulse types and formats when conducting a search, unless deliberately limiting the search to research on a specific pulse type or ingredient format

The AAFC Oilseeds Science Strategy

The AAFC Oilseeds Science Strategy considers Research Development and Technology Transfer (RDT) needs and capacity as it relates to oilseed crop production, particularly for food and feed end uses, up to and including storage of harvested material. The crop types considered within this strategy include canola, rapeseed, mustard, soybeans (oilseed and food-grade), flax, sunflower, hemp and safflower.

There is a wide range of capacity in the different oilseed crop sectors to support corresponding RDT. However, most oilseed crop sectors have developed national and/or regional RDT strategies or priorities and have been successful in obtaining funding through industry-led Growing Forward programming.

AAFC's current RDT capacity encompasses integrated production systems (agronomy, crop protection and biology), genetic improvement and germplasm development (including genomics) depending on the use of genetic resources, and variety finishing/regional testing for crop adaptation. The STB is particularly active in upstream research using genomics and molecular biology to better understand disease and insect interactions with plants and to identify genes conferring desirable traits in order to mitigate impacts. This work also increases understanding of the genetic basis of quality and anti-nutritional seed traits, and plant responses to abiotic stresses. Other RDT activities include optimizing crop production practices through plant nutrition, effective rotations, and insect, disease and weed management in order to respond to climate change impacts and producer needs.

AAFC science to increase productivity and improve attributes for food and non-food uses of oilseeds will focus on:

- using genetic improvement, germplasm development, the creation of new breeding tools, variety development and enhanced production methods to increase the yield potential of oilseed crops, mitigate the impacts of abiotic stress factors, and respond to market demands and requirements for specific oilseed crop quality traits; and
- supporting the development of a range of effective and efficient integrated production systems involving oilseeds by taking into account agronomy, crop protection, biology, and early-generation and variety testing for crop adaptation to regional conditions, in order to decrease the yield gap for oilseed crops.

AAFC's RDT will also improve environmental performance of the sector by:

- enhancing sustainable oilseed production practices
- improving nutrient and water use efficiency
- developing sustainability metrics for oilseed crop production

New knowledge and tools developed by AAFC will also help mitigate factors that threaten the oilseed value chains, including new and emerging biotic stresses.

The AAFC Bioproducts Science Strategy

The AAFC Bioproducts Science Strategy concentrates on RDT needs related to agri-based feedstocks for non-food and non-feed industrial bioproducts. This includes multi-purpose commodities whose end use is industrial (e.g., flax for fibre); purpose-grown crops (e.g., *Brassica carinata* A. Braun and *Camelina sativa* (L.) Crantz); animal and food waste; woody species (agroforestry); and biopesticides.

This is a diverse emerging sector with yet-to-be fully developed supply chains. Non-traditional partnerships and collaborations are devoting efforts to numerous manufacturing sectors, and industry leadership continues to emerge. Genetic resources for this strategy are accessed outside the Multilateral System of the International Treaty on Plant Genetic Resources. The AAFC STB is best positioned to focus on the upstream feedstuffs for the supply chain and address gaps in the innovation continuum that cannot be addressed solely by industry or other RDT organizations. AAFC's RDT will focus on identifying components and properties in existing crops and livestock for value added industrial applications, and develop new purpose grown biomass crops. This includes discovery-type research in:

- plant and animal biology, biochemistry
- plant-made industrial, pharmaceutical and vaccine products
- biopesticides
- total plant utilization and co-product development

AAFC will also focus RDT on increasing sustainability of feedstock production and developing quantitative measures to support industry in the development of sustainability metrics. The final focus area for this strategy is mitigating emerging biotic and abiotic threats to bioproduct feedstocks.

The AAFC Horticulture Science Strategy

The AAFC Horticulture Science Strategy considers the RDT needs and research capacity from a crop production perspective including production, post-harvest treatment, storage, and distribution of fresh and minimally processed produce. The crops covered in this strategy include potatoes, greenhouse and field vegetables, small fruits, tree fruits, floriculture, nursery, Christmas trees, sod, maple, honey, and herbs and spices.

With over 120 different horticultural crops produced in Canada, there is a wide diversity in both the types of crops grown and the growing conditions between regions. RDT efforts, therefore, encompass a variety of eco-zones. With such a diverse sector, a wide range of capacity exists in the horticultural crop sectors for corresponding RDT activities and limited capacity to set national priorities and raise funds.

AAFC's current capacity in horticulture includes integrated production systems (agronomy, crop protection and biology; environmentally sustainable production systems; post-harvest handling and storage; germplasm development (use of genetic resources) to improve productivity and tolerance to biotic and abiotic stresses for some horticultural crops (potato, tree fruit and berry crops); and generation of field and greenhouse data (efficacy, residue and crop tolerance) in support of minor use pesticide registration.

AAFC's RDT will focus on:

- developing integrated crop production and management systems and the development of knowledge and predictive tools to minimize losses due to existing and emerging biotic and abiotic stresses on horticultural crop production
- using genetic resources, genetic information, germplasm development and integrated production systems to improve yield potential and tolerance to biotic and abiotic stresses for some major horticultural crops
- improving the efficiency of nutrient, water and energy utilization and reducing the environmental impact of horticulture crop production through practices such as integrated pest management and integrated crop production
- addressing market demands for consistent composition and quality traits through crop management techniques; and
- using genetic information and germplasm development to improve crop attributes for some major horticultural crops

New knowledge, tools and genebank germplasm developed by AAFC will also help to mitigate factors that threaten the horticulture value chains, including predictive capacity to anticipate emerging biotic stresses, and enhance the safety and marketability that are particular to horticultural products from production, post-harvest handling, storage, and distribution systems.

Important factors regarding diversification

Present day agricultural production systems depend on relatively few crop species. There is a growing desire to introduce new crops and species into production systems to better support agricultural sustainability. Diversification has positive environmental effects. Diversified crop rotations enhance resilience and provide ecosystem services. However, public research and producers' choices have continued to narrow the scope of species that are being worked on compared to the situation 50 years ago. New crops to Canada can emerge, or old crops make a "comeback". Underutilized and neglected crops are often only preserved in genebanks. For example, hemp (*Cannabis sativa* L.) is a crop that is making a comeback as an oilseed crop, for human nutrition, and more recently its medicinal and recreational use. On October 17, 2019, the production and sale of edible cannabis, cannabis extracts and cannabis topicals became legal in Canada under the Cannabis Act. The development of Hemp (fibre, oilseed, cannabidiol forms) in Canada is under the guidance of Health Canada, advised by a Hemp Interdepartmental Committee that authorizes cultivars for cultivation in Canada and periodically produces an updated List of Approved Cultivars.

There is a trend towards greater crop diversification in Canada as evidenced by the increasing number of species and cultivars available to producers (see Priority Activity 9). The majority of the Canadian agricultural sector is oriented towards export markets. Niche markets for local production, albeit limited in economic impact, are however emerging in Canada, which will further the diversification.

Taxonomy has a fundamental role for structuring genebank collections and utilizing gene pools. Staff at the Vascular Plant Herbarium (DAO) maintained by AAFC in Ottawa made major contributions to better understand the gene pool of alfalfa (*Medicago*) (Small 2011) or describing underutilized native fruit crops (Lorion and Small 2021), while PGRC contributed to describing the gene pool of coriander (*Coriandrum sativum* L.) from a plant breeders' perspective (Diederichsen et al. 2020)

The private sector has also contributed to crop diversification in Canada. Agriculture Environmental Renewal Canada (AERC) Inc. (https://agriculture-environmental-renewal-canada.myshopify.com/) bred cultivars of pearl millet and sorghum, crops that are mostly confined to dryland tropics. These varieties adapted to Canada are now being grown for seed, including for export. Climate changes may result in the introduction of other crops to Canada.

The success story of *Camelina* is another example of a success story for oilseed farmers in Prairie Canada. Through international collaboration, PGRC obtained most of its genetic material for *Camelina* from genebanks in the USA, Germany (IPK), Russia (VIR) and Ukraine (NCPGRU). This crop requires less water and fertilizer than rapeseed/canola, matures relatively early and can grow in short growing seasons. *Camelina* is also a good feedstock (ingredient) for bio-products such as bioplastics in packaging and can serve as a food for humans, or a nutritious, protein-rich feed for cattle, poultry and /or fish. Canada is emerging as a *Camelina* leader thanks to the work of many researchers at AAFC. AAFC scientists are using these genetic resources to develop new *Camelina* cultivars for Canadian agriculture. AAC 10CS0048 ('Midas') was released in 2013 as the first cultivar developed by AAFC. To help with future breeding of *Camelina*, AAFC scientists also led a public-private research team, which sequenced the *Camelina* genome in 2014 (Kagale et al. 2014)

Public and NGO involvement in programs promoting diversity

Prior to 2012, CSOs' involvement in PGRFA conservation was often informal and difficult to measure. SeedChange's program (formerly the USC program) is a key player. Its mission is to build food sovereignty by working with civil society partners to enhance biodiversity, promote ecological food systems, and counter inequity. In 2013, SeedChange launched *The Bauta Family Initiative on Canadian Seed Security* ("Bauta Initiative"), to build a Canadian seed system that promotes food security and is resilient in the face of climate change. There are three key elements to the work of the Bauta Initiative:

i) Conserving agriculturally significant seed diversity,
ii) Adapting seeds to regional environments, and
iii) Breeding crops for sustainable farming.

The Bauta Initiative leads participatory on-farm research and education programs on seed conservation and plant breeding to increase the quality, quantity, and diversity of regionally adapted seed for low-input, ecological farming conditions. There is a formal national collaboration among a number of organizations to support participatory plant breeding, variety/cultivar selection, seed production, and seed conversation across the country. Significant improvements in collection standards, storage, documentation, and inter-agency sharing of both seeds and information have been made. Thanks in part to the support of SeedChange, the Canadian CSO seed conservation sector has improved significantly in the quantity, quality, and diversity of its efforts to collect and document domestic PGRFA. Today over 5700 samples of 86 species and just under 3000 cultivars are currently listed in their catalogues.

The CSO SeedChange depicts its role in this overview:

"We work with 35,000 farmers around the world to grow a better future, one seed at a time. The struggles farmers' face are global. SeedChange supports small-scale farmers around the world in their fight for justice, health and sustainability. We partner with like-minded local non-profits to help keep seeds in

farmers' hands, protect farmers' rights, and change the way we grow our food. Local partners always deliver our programs. They know their regions and farming communities best. We contribute in five ways.
– We are ***facilitators****, sharing knowledge and connecting people working to seed change in different parts of the food system.*
– We are ***funders*** *for our partners' work in promoting sustainable agriculture and food sovereignty.*
– We are ***trainers****, supporting farmers who preserve seed diversity, farm sustainably and bring healthy food to markets.*
– We are ***incubators*** *for innovative ideas. We document successes from the field to help agro-ecological practices spread.*
– We are ***influencers****, encouraging policies that support small-scale farmers, protect seed diversity and prioritize sustainable agriculture.*

We believe in local seeds, local knowledge, and communities empowering themselves. Every SeedChange project is shaped by farmers' needs and ideas and designed collaboratively with the local partners who deliver it. Projects we support include farmer-to-farmer knowledge exchanges, community seed banks, farmer-led research and plant breeding, and co-ops through which farmers can improve their incomes by bringing healthy food to local markets. Ecologically sound farming techniques that preserve and enhance biodiversity are at the core of all of our work. Our guiding principles are food sovereignty and agro-ecology – two transformative concepts put forward by farmers' movements to build a just and sustainable world.

Seeds of Survival pioneered our award-winning approach, while working with the Ethiopian Biodiversity Institute to help farmers rebuild after droughts and famine in the late 1980s. We've been building our expertise by collaborating with farmers, researchers and partners around the world, including Canada, ever since.

Seeds of Survival Scale-Up Program (2015-2020) digs into the publications, methods and results from our most recent five-year program, the Seeds of Survival Scale-Up Program. It was a CAD 19.5 million climate resilience and food security program funded through SeedChange donors and Global Affairs Canada."

Gaps and needs

To enhance the mobilization of germplasm in the CNPGS genebank collections for the use in research and breeding, evaluation and characterization are very important. Pre-breeding activities to adapt wild genotypes or old landraces material in the genebank collections could be an important tool to help assemble the genetic diversity harboured in the genebanks for applied plant breeding. Local markets may hold options for landraces of underutilized and neglected crops in genebanks or preserved on-farm and new approaches to plant breeding by CSOs have potential.

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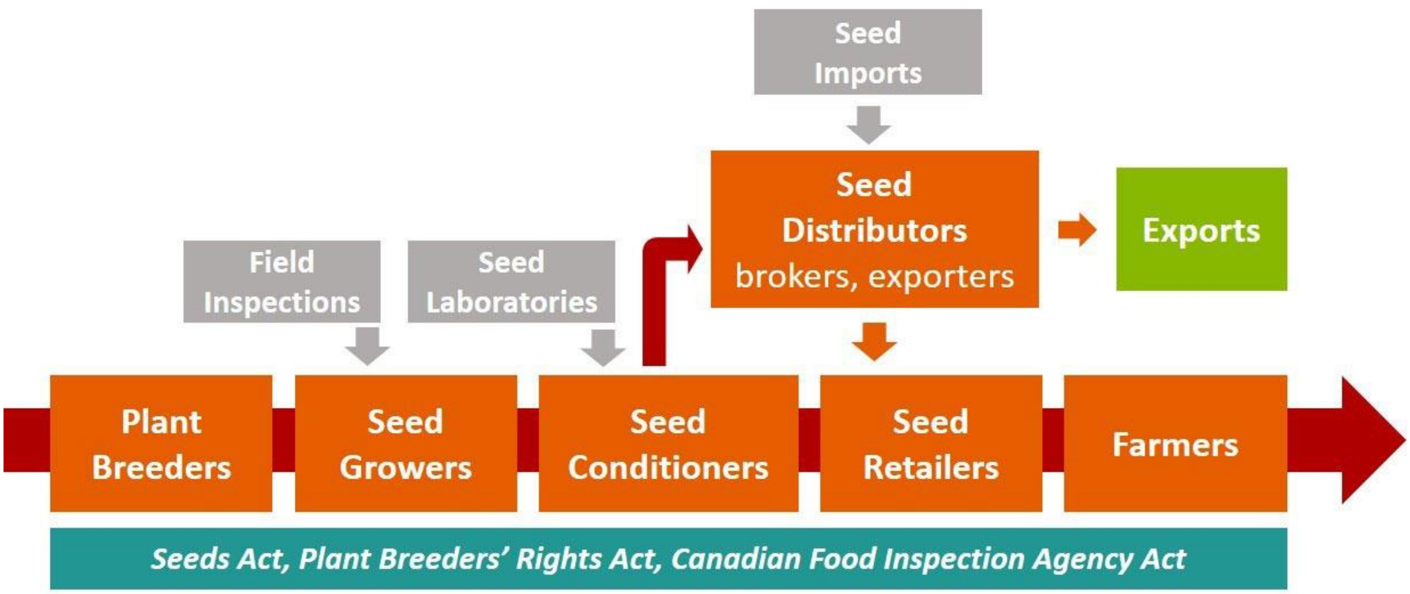
Priority Activity 11. Promoting development and commercialization of all varieties (cultivars), primarily farmers' varieties/landraces and underutilized species

The Canadian seed sector develops and commercializes plant innovation/new cultivars. It has many players in both the public and private sectors. The seed sector has a long history in Canada and has served the Canadian agricultural sector very well. The seed sector is comprised of a variety of specialists performing key functions: plant research and variety development; seed growing; seed processing; seed testing; and seed marketing. Figure 11.1 provides an overview of what the system looks like, the key pieces of enabling legislation, and who the players are In Canada (Seed Synergy Partner Organisations 2018). The roles of public and private plant breeding are elaborated under Priority Activities 9 and 10.

Figure 11.1: Structure of the Canadian seed sector (Adapted from: Seed Sector Value Chain Roundtable 2014).



List of the major players involved in industry and regulation of seed sector:

Research Plant Breeding

- Private Companies
  - 135 scientists
  - 227 Technicians
  - 100 Support staff
  - 155 Summer staff
- Universities (McGill, Guelph, Manitoba, Saskatchewan, Alberta)
- Agriculture and Agri-Food Canada
- Provincial Agriculture Departments

Seed Growers

- 3,500 Pedigree seed growers
- 1,800 Forage seed growers *
- 400 Seed corn growers
- 370 Potato seed growers

* includes pedigree and common seed growers

Seed Conditioners and Seed Labs

- Registered Seed Establishments (RSEs)
  - 574 Approved Conditioners (AC)
  - 851 Bulk Storage Facilities (BSF) Technicians
- 33 Accredited seed labs

Distributors, Brokers and Exporters

- Private Companies

Seed Imports

- 84 Authorized importers (AI)

The involvement of farmers is important for the Canadian seed sector because they help to define breeding objectives for plant breeders and many breeding programs at Universities in Canada are funded by producer organisations.

Participatory plant breeding in Canada

Over the past decade there has been an increased involvement of farmers in plant breeding. This ensures that new varieties and cultivars are adapted to the wide spectrum of growing conditions while also meeting new niche market opportunities. The Canadian Organic Vegetable Improvement Project (CANOVI) is a partnership between the Bauta Initiative and the University of British Columbia supported by the Organic Science Cluster 3 (OSC3) (2018-2023). The program has two components: i) building a national variety trial network to identify vegetable varieties that are the best candidates for regional open-pollinated (OP) seed production; and ii) building a national PPB network to develop new varieties of OP vegetables. Germplasm for this project is provided by Canadian vegetable farmers and seed producers, UBC, Cornell University, and the University of Wisconsin–Madison. The program currently works with 65 farmers across Canada to manage 150 PPB and PVS projects on pepper, carrot, rutabaga, radicchio, winter squash, and lettuce.

Some additional examples of participatory approaches:

- Farmer participation in plant breeding for Canadian organic crop production: implications for adaptation to climate uncertainty: https://www.umanitoba.ca/outreach/naturalagriculture/ppb.html
- Farmer participation in Potato breeding and selection: http://www.fao.org/3/ca7839en/ca7839en.pdf
- Plant Breeders' Rights Advisory Committee: https://www.fao.org/3/ca7837en/ca7837en.pdf
- Agriculture and Agri-Food Potato Accelerated Release Program: https://agriculture.canada.ca/en/agricultural-science-and-innovation/technology-transfer-and-licensing-agriculture/licensing-opportunities-agriculture/accelerated-release-program-new-potato-selections-french-fries-chips-and-fresh-market/about-accelerated-release-program

Changes and trends since January 2012

According to the 2011 Census of Agriculture (Statistics Canada, https://www.statcan.gc.ca/en/ca2011/index), pulses represented approximately 6% of the field crop area in Canada in 2011, while wheat and canola accounted for almost 50%. Pulse area and production in Canada has therefore greatly increased, making the country one of the leading producers and exporters of pulses worldwide. Pulse seeded areas were at 2.2 million hectares in 2011. This was a jump of more than 11 times the area planted in 1981. As well, the number of farms reporting pulses almost doubled from 6,392 in 1981 to 12,110 in 2011. The development and expansion of the pulse industry was closely tied to its profitability, research into new cultivars that resist lodging and disease or have a shorter growing season, and the growth of processing facilities. The majority of pulse variety and cultivar registrations in Canada have been developed in public breeding programs, funded through private-public-producer check-offs in exchange for royalty-free access to the new cultivars developed. Agriculture and Agri-Food Canada and both the University of Saskatchewan (the Crop Development Centre) and the University of Guelph developed the majority of new pulse cultivars.

Organic production is growing in Canada**.** In meeting the public's desire for access to organic products the Government of Canada created regulations in order to formalize and protect the concept of "organic" within a legal framework. This has created new market opportunities for farmers to produce and sell value added products that are protected by national regulations (Government of Canada 2021).

Gaps and needs

Development and commercialization of new cultivars, as well as the maintenance of a resilient seed system in Canada need to include all stakeholders.

Participatory approaches in plant breeding could be expanded. Utilizing germplasm from the PGRC genebank could help create value added crops that can be grown for niche market communities. Intellectual property protection of these value-added cultivars could be utilized to capture the economic value helping to ensure commercial success. This would help secure funding for continued participatory breeding thereby promoting future breeding work and diversification.

There is a need for effectiveness of the policies and legal framework in promoting landraces/farmers' varieties and underutilized species and specific requirements for the commercialization of varieties for these crops.

Seed regulations **–** Depending on type of PGRFA and the market, landraces/farmer's varieties may be subject to regulatory requirements under the Canadian Seeds Act and Regulations. The Seeds Act and Regulations are federally passed laws and regulations in place to ensure health and safety requirements are met and that information related to the identity of the variety is available to regulators to prevent fraud. It also facilitates seed certification, the international trade of seed and the tracking and tracing of varieties in commercial channels.

In ensuring commercial success of all agricultural plant genetic resources, outreach efforts should be made to enhance understanding of legal framework for using commercial varieties/cultivars.

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Priority Activity 12. Supporting seed production and distribution

Effective seed systems are in in place in Canada to ensure that farmers adopt suitable cultivars and use seed and planting materials in adequate quantity and quality, in a timely manner and at reasonable cost (see also Priority Activity 11). Integrated approaches that strengthen existing seed systems are needed to produce and make available quality seed of crop varieties that are useful for diverse farming systems. New markets with more focus on local production are emerging in Canada and will need regulations that can support seed systems and plant breeding addressing these emerging needs.

Private investment in Canada's seed sector

A survey by the Canadian Seed Trade Association (CSTA) (2018) found that three crops – corn, canola and soybeans – made up 89% of private research investment in Canada. Canola alone was 64% of industry expenditure. This survey is conducted every five years and is the most comprehensive snapshot of private seed sector research and development in Canada. The data provides insights into research investment today, projections into the future, barriers to innovation and demonstrates the effect of policy and market changes on investment decisions. Compared to 2012 the survey found greater diversification, as private research investment in wheat and pulses had increased substantially. These two crops combined made up almost 20% of the private research investment in Canada.

Overall private research expenditures have grown significantly over the five years 2012-2018. In 2012 the sector spent CAD 101M on private research, and CSTA forecasted modest growth of 1% by 2017. However, the latest data shows that private research expenditures have grown to CAD 171M in 2017, a 56% increase over five years ago. Research Investment total CAD 171 million in 2017.

Survey respondents reported that their companies employed over 2,300 people in Canada, with 54% of those positions involved directly in research.

CSTA a national trade association that brings together more than 130 company and association members engaged in all aspects of seed research, production, and marketing and trade, both domestically and internationally. CSTA members are important contributors to Canada's economy. CSTA members develop and provide seeds produced through various production methods, including organic, conventional and biotechnology, and range from small, family owned and operated companies, to large multi-national firms.

Seeds Canada – 2020

In 2020, the group Seeds Canada was formed; it is based on four partner organizations; the Canadian Plant Technology Agency (CPTA); the Commercial Seed Analysts Association of Canada (CSAAC); the Canadian Seed Institute (CSI); and the Canadian Seed Trade Association (CSTA). These organizations amalgamated to become one new, national seed association called Seeds Canada. Seeds Canada will be the leading voice of the Canadian seed sector, helping seed industry members succeed domestically and internationally.

References

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Chapter 4. Building sustainable national and international networks

Priority Activity 13. Building and strengthening national programs

The Canadian National Plant Germplasm System (CNPGS) is a network of centres and personnel dedicated to preserving and providing access to the biodiversity of crop plants and their wild relatives (see also Priority Activity 6). The CNPGS plays a significant part in Canada's commitments to the FAO and its CGRFA, the ITPGRFA, to the CBD and to the UN SDGs. The responsibility of managing the Canadian national *ex situ* PGRFA genebank collections is shared among three Agriculture and Agri-Food Canada (AAFC) Research and Development Centres:

- **Plant Gene Resources of Canada (PGRC)** preserves and distributes seed germplasm (especially wheat, barley and oat and their crop wild relatives (CWR)) as well as some clonal germplasm (e.g., Jerusalem artichoke, rhubarb). PGRC also maintains the Genetic Resource Information Network – Canadian Version (GRIN-CA) database management system for all germplasm holdings in the CNPGS.

- **Canadian Potato Genetic Resources (CPGR)** CPGR preserves and distributes disease free potato germplasm.

- **Canadian Clonal Genebank (CCGB)** CCGB preserves and distributes tree and small fruit germplasm.

The mandate of the CNPGS is to acquire, preserve and evaluate the genetic diversity of crops and their wild relatives with focus on germplasm of economic importance or potential for Canada. The main deliverables of the CNPGS are:

- Viable disease-free germplasm of cultivated plants and crop wild relatives (CWR) important to Canada.
- Providing and generating relevant information on its germplasm holdings
- Contributing to conservation and utilization of PGRFA on a national and global level by cooperation; and
- Representing Canada and Canadian agricultural interests in global fora related to PGRFA.

The three CNPGS gene banks belong to AAFC's the Science and Technology Branch and are guided by AAFC's Biodiversity and Bioresources Science Strategy.

AAFC's Biodiversity and Bioresources Science Strategy

The Biodiversity and Bioresources Science Strategy focuses on the research and development on biodiversity and bioresources, as they relate to agriculture, agri-food, and agri-based industries. It covers the protection of Canada's biodiversity and agricultural value chain from pests and invasive species, through knowledge generation, and the development of mitigation strategies using beneficial organisms. Activities include biological surveys, monitoring as well as observation of environmental perturbations to assess their impact on organisms relevant to agriculture leading to baseline inventories and identification of established and emerging threats. In addition, it also covers related scientific activities related to the management of bioresource collections and the preservation of organisms and genetic material of interest to the sector. Main objectives addressed by the Strategy are:

Increased Agricultural Productivity

- Enhance, maintain, and conserve crop and farm animal genetic diversity and provide sources of genetic variability and knowledge about genes and traits of interest of accessions in bioresources collections for genetic improvement to ensure agri-food security and mitigation of genetic erosion
- Understand gene flow and plant reproductive systems affecting crop productivity
- Understand beneficial organisms (biocontrol agents, symbionts, pollinators, etc.), biotic competitors, and established pests that affect established commodity-based system productive capacity
- Provide authoritative identification of species for established pests as well as beneficial organisms for established commodity-based production systems

Enhanced Environmental Performance

- Understand the impact of environmental perturbations (e.g., climate change) on biodiversity and organisms relevant to agriculture (crops, farm animals, pests, insects, fungi and bacteria and weeds, native or and invasive species)
- Characterize the ecological and evolutionary processes of plant parasitism and symbiosis, invasive species, and beneficial organisms that enhance the environmental performance of production systems
- Provide baseline inventories of the agricultural biota through surveys, identify bio-indicators, and monitor the effect of agricultural practices and environmental changes on organisms and production systems
- Model digitized information in biological collections and area-wide survey data to identify emerging IAS and develop IAS risk assessment parameters (invasion pathways, eco-climatic index) and develop risk parameters (habitat complexity loss, climate extreme tolerances, etc.)

Improve food and non-food attributes

- Provide research, knowledge of traits of interests for accessions in biological collections (e.g., genomics and phenotypes) to improve attributes of Canada’s agricultural commodities and to support new opportunities for food and non-food uses
- Collect and provide information on the incidence and movement of new pests, toxigenic microorganisms, and invasive species that threaten Canada's agriculture, common to multiple commodities
- Develop and enhance knowledge of existing and emerging invasive species, pests and their hosts for current risk identification, in anticipation of threats to agriculture and to support the development of diagnostic tests
- Provide authoritative identification of species for new and emerging pests, diseases, and invasive alien species.
- Provide science and develop and implement risk reduction strategies to mitigate the impact of pests, diseases, and invasive species on agricultural production

Researchers involved in the above AAFC Science Sector Strategies use the diverse collection in the CNPGS genebanks.

Gaps and needs

From 1995 to 2005 the Expert Committee on Plant and Microbial Genetic Resources provided valuable input for the CNPGS genebanks on plant genetic resource policies and activities. The committee had representation from Canadian Federal and Provincial governments, Universities, industry, scientific societies, and non-government organizations. It would be valuable to re-establish a revised committee particularly in light of the intensity of international discussions on PGRFA that take place at FAO and the ITPGRFA and other international organizations. Also, the complementary and recently strengthened aspects of *in situ* and on-farm conservation could be addressed by such a committee.

Priority Activity 14. Promoting and strengthening networks for plant genetic resources for food and agriculture

Canada participates in a number of national, regional and international networks. These include thematic networks, crop networks and research networks.

NORGEN Task Force on Genetic Resources under the IICA

Regional cooperation was enhanced in 1998 with the Cooperative Program in Research and Technology for the Northern Region (PROCINORTE) of the Inter-American Institute for Cooperation on Agriculture (IICA). It is a trilateral network of federal agricultural, agri-food and food system research bodies in Canada, Mexico, and the USA. It aims to promote cooperation in research and technology in the Northern Region of the Americas through exchanges and partnerships for competitive and sustainable agricultural development by incorporating science, technology, innovation, and knowledge-sharing in areas of trilateral relevance. This program is under the auspices of IICA which acts as Executive Secretariat.

Agriculture and Agri-Food Canada, the USDA Agricultural Research Service, and the Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias participate in the PROCINORTE Task Force on Genetic Resources for Food and Agriculture (NORGEN). NORGEN has the following objectives:

(1) encourage the communication and collaboration among personnel involved in National Genetic Resource Systems,
(2) identify and address training and educational needs,
(3) integrate with other genetic resources networks in the Americas and around the world,
(4) develop projects of interest to the three countries,
(5) encourage reciprocal participation of national experts in each country's operational and advisory genetic resources committees,
(6) establish contact with other task forces of PROCINORTE, and
(7) support the development of an Integrated Genetic Resources System in Mexico.

Some of the major NORGEN achievements include leading (Canada) the development of hemispheric efforts to develop a comprehensive PGRFA conservation strategy under the auspices of the Global Crop Diversity Trust. Between 2004 and 2007, with funding provided in part by the GCDT, a series of hemisphere wide meetings were held to gather information and ideas concerning PGRFA conservation.

As identified in the Strategy document, the Americas existed in virtual isolation, both culturally and floristically, from the rest of the world until Columbus' arrival, about 500 years ago (Davidson 2008). Dubbed the "New World" by early European visitors, the Americas are in fact a region where agriculture and civilization arose thousands of years ago. As prehistoric cradles of civilization, the Mesoamerican and Andean regions prospered as a result of the independent discovery and development of agriculture by Native Americans. With the spread of agriculture throughout the hemisphere, crop species also spread, evolving and adapting according to the conditions and needs of different cultures and climates. The resulting agro-biodiversity, which includes crop landraces, their wild relatives and progenitor species, represents a vast storehouse of genetic resources.

Many crops of global importance were first domesticated in the Americas, including maize, potato, tomato, cotton, cassava, tobacco, beans, squashes, vanilla, cacao, peanut and peppers. Dozens of other crop species were domesticated in the Americas; many of these were important and widespread at the time of European contact but have since been neglected or displaced by introduced crops.

The outcome was the development of the Americas Strategy with a goal to foster the development of cooperation and collaboration amongst all members of the Americas, to strive for the conservation and sustainable utilization of all crop's genetic diversity in the Americas and to foster the development of a rational and efficient long-term development plan for conservation and sustainable use of PGRFA (Davidson 2008).

The strategy document was developed by all the regional plant genetic resources networks in the Americas, namely the Caribbean Plant Genetic Resources Network (CAPGERNet), the Plant Genetic Resources Network for North America (NORGEN), the Andean Network on Plant Genetic Resources (REDARFIT), PROCISUR's Sub-program for Plant Genetic Resources (REGENSUR), the Mesoamerican Network on Plant Genetic Resources (REMERFI) and the Amazonian Network on Plant Genetic Resources (TROPIGEN). Lack of capacity and coordination to rationally conserve and optimally use these resources weakens all efforts toward food security and sustainable development in the Americas. In view of these constraints, PGRFA national programs and networks were created in most American countries aiming at the conservation and utilization of PGRFA for improved crop varieties and food security. The agreed objectives of the Hemispheric Strategy were as follows:

1. A PGRFA Hemispheric Information System (PGR-HIS) with diversity characterized and rationalized – To foster cooperation at the hemispheric level while recognizing sub-regional and national needs, i.e., supporting national collections through an information platform in the context of the hemispheric strategy.
2. The safe storage and exchange of germplasm – To foster the development of national and regional capacity for safe storage and exchange of germplasm through national, regional and hemispheric efforts and networks.
3. Conservation of PGRFA in perpetuity - To furnish high priority to the safeguarding of unique and valuable diversity comprised in ex situ collections of PGRFA in the Americas.
4. Promoting PGRFA use – To foster innovation by promoting the identification of useful materials for direct use, enhancement or plant breeding programs.

Additional projects include training of genebank staff on the GRIN-Global genebank database management system (https://pgrc-rpc.agr.gc.ca/gringlobal/landing), exchange of information on the impact of genetically modified plants on genebank operations, a planning session on training future genebank managers, and presentations on crop wild relatives in all three countries in 2019. All NORGEN members participate in the regular Plant Germplasm Operating Committee Meetings and the Curator Workshops held by the USDA/ARS National Plant Germplasm System at various locations.

The IICA – PROCINORTE – NORGEN umbrella brought together Canada, Mexico and USA representatives in a workshop entitled Plant Genetic Resources: Challenges, Tools and Perspectives Sharing: Canadian, Mexican and American Experiences (February 2015).

The NORGEN Taskforce on Genetic Resources held another workshop entitled "First Nations and Agro-biodiversity" in November 2015. AAFC researchers leading the "Three Sisters Project," participated in this meeting. For this session the PROCINORTE Secretary contacted the Legal Research Chair in Food Diversity and Security of Laval University, Quebec City, to help plan and organize a joint workshop on "Genetic resources, food security, and agricultural economic and legal aspects". A special effort was also made to ensure representation from Indigenous Peoples at the workshop since their ancestors developed, and in many cases also preserved, traditional genetic resources and associated knowledge for the benefit of future generations (see also Priority Activity 4).

In October 2015 the NORGEN Genetic Resources meeting was held in Brazil in conjunction with SIRGEALC – PROCINORTE for IICA. Canada, Mexico and the USA took advantage of the meeting to hold their annual discussion.

International Cooperation – USDA

Cooperation with USDA and its National Plant Germplasm System (NPGS) is highly valued by Canada and the staff of CNPGS. Most crops grown in Canada are also important in the USA. Both countries have seen the introduction of cultivated plant species from other locations. The exchange of germplasm between the two countries has been significant. Curators of the USDA and AAFC genebanks interact regularly to enhance coordination of efforts. Staff from CPGS Fredericton participate in the technical advisory committee of USDA–ARS potato germplasm project.

The GRIN-CA database system was provided to the CNPGS by the USDA and has been operational since 1999. It has critically supported all genebank functions. The GRIN taxonomy provided a solid well-researched taxonomic structure. Close cooperation with the USDA for implementing GRIN-Global has been on-going for many years and continues during the upgrade to GRIN-Global-CA (https://pgrc-rpc.agr.gc.ca/gringlobal/landing) at PGRC.

Also in the global context, such as at meetings of the ITPGRFA and of the FAO-CGRFA, the USA and Canada cooperate closely as members of the North American Region. Officials often work together to present a regional position.

International Cooperation – Other genebank cooperation

PGRC has an on-going cooperative project with the National Plant Genetic Resource Centre of Ukraine (NCPGRU) in Kharkiv. Two joint collecting missions with focus on CWR were conducted in cooperation between NCPGRU and PGRC. During the review period 2012 to 2019 this cooperation involved exchanging germplasm. CPGR has a longstanding collaboration with CIP – the International Potato Centre, in Peru.

In the circumpolar region, the genebanks of the five Nordic Countries Denmark, Finland, Iceland, Norway and Sweden (Nordgen) headquartered at Alnarp in Sweden, as well as the N.I. Vavilov Institute for Plant Genetic Resources (VIR) at St. Petersburg in Russia, are important cooperators with PGRC due to sharing similar eco-geographic conditions to Canada. Germplasm and information exchange with these national genebanks is on-going.

The global context

Canada has a long history of being involved in the FAO (FAO was founded in Quebec City in 1945), the CGRFA, and ITPGRFA. ITPGRFA, adopted in 2001, was signed and ratified by Canada on 10 June 2002. AAFC was the lead national Department for the Government of Canada in negotiations as well as in the implementation of the Treaty (Fraleigh and Harvey 2011). Canada is very much aware of international interdependencies for global and national food security, and of the fact that the international exchange of genetic resources for cultivated plants is critical for sustainability both nationally and globally. Canada also supports the fair and equitable sharing of benefits arising from the use of plant genetic resources which motivates the strong engagement of Canada in the ITPGRFA.

Canada signed and ratified the Convention on Biological Diversity (CBD) agreed upon in Rio de Janeiro in 1992 and ratified it the same year. The Secretariat of the CBD is located in Montreal, Quebec, Canada (Environment and Climate Change Canada 2020).

Canada participated in the development of global crop genetic resources strategies at the initiative of the Global Crop Diversity Trust (Crop Trust 2021). Canadian CNPGS staff and scientists/breeders at universities contributed to the strategies for oat, barley, wheat, chickpea, faba bean, lentil, oats, potato, lentil and strawberry.

Gaps and needs

The AAFC/CNPGS specialists will continue to engage in global efforts to conserve and utilize PGRFA. Technical cooperation and sharing of capacities nationally and internationally will enhance efficiencies. Issues related to benefit-sharing for PGRFA, and associated information have become more contentious. This requires developing better procedures in order to reach agreements with various stakeholders within Canada and with all international partners in FAO – CGRFA, the ITPGRFA and CBD.

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Priority Activity 15. Constructing and strengthening comprehensive information systems for plant genetic resources for food and agriculture

Canada makes all germplasm and associated information held by the three genebanks that form the CNPGS accessible to the public for research, breeding and education. This includes seed or propagation materials (small quantities only) passport data, characterization data and evaluation data. Information about the collections complies with Canada's open government policy (https://open.canada.ca/en/about-open-government) as well as meeting the needs of user groups and international obligations.

Since 2001, all three CNPGS genebanks have been using a version of the USDA GRIN genebank database management system adapted to Canadian needs (GRIN-CA). The database management system manages the key functions for the operation of PGRC on an operational basis and for searching and ordering of germplasm by users:

(1) Handling the management data associated with germplasm holdings at PGRC for the operation of the Canadian genebanks of the CNPGS.
(2) Facilitating the communication of germplasm holdings and associated information to genebank clients.
(3) Allowing genebank clients to order germplasm from PGRC and allowing PGRC managing these orders; and
(4) Supporting efficient communication of information about PGRC germplasm holdings and requests to global stakeholders.

In 2010, PGRC started a process to implement GRIN-Global which has been developed in a joint effort by the Global Crop Diversity Trust, Bioversity International, and the Agricultural Research Service of the United States Department of Agriculture (USDA). This genetic resources data management specialized software program was the first priority identified in the Global Crop Diversity Trust hemispheric strategy for the Americas led by Canada. Grin-Global will go a long way towards meeting the top priority for the hemispheric strategy developed with the assistance of the Global Crop Diversity Trust (See Priority Activity 14).

In 2014, PGRC hosted a three-day workshop to train curators from Mexico and Canada on GRIN-Global, with support from the Cooperative Program in Agricultural Research and Technology for the Northern Region (PROCINORTE) of the Inter-American Institute for Cooperation in Agriculture (IICA). The objective was to contribute to preparation of the Third Report on the State of the World's Plant Genetic Resources for Food and Agriculture. The adaptation of GRIN-Global to specific Canadian needs is still on-going. The Canadian adaptation was implemented as GRIN-Global-CA (https://pgrc-rpc.agr.gc.ca/gringlobal/landing) in 2021.

It is important that the implementation of GRIN-Global at PGRC be completed since it will facilitate more efficient communication with other databases that hold similar type information. Linkage between the physical germplasm (accessions) and various types of data (e.g., genetic sequence data and other similar molecular information) generated by genebank clients needs to be facilitated. Standardization of data collection is important for all CNPGS genebanks. For example, taxonomic treatments of many genera are in steady flux as review by crop experts take place, as well as new techniques and information become available. Keeping abreast of these types of development is key to ensuring the information remains dynamic and useful to a variety of clients.

For PGRC accessions such links were established between passport entries in the GRIN-CA database and for all oat (*Avena sativa*) accessions that appear as cultivars or parental lines in the POOL Database for pedigrees of oat lines (https://triticeaetoolbox.org/POOL/). This demonstrates the usefulness of PGRC genebank accession numbers to link to external databases, which is a model for molecular data that are generated today in massive volumes.

Canada is committed to contributing to the FAO – CGRFA's work towards a Third Global Plan of Action for PGRFA. The information Canada provides to the FAO WIEWS database also serves for reporting on implementation of the Sustainable Development Goals of the United Nations, in particular goal no. 2 "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" with its specific target 2.5 on PGRFA.

Canada has been actively engaged in work of the Global Information System (GLIS) in furtherance of Article 17 of the ITPGRFA. Canada believes that decentralized databases need to be curated by those who are close to the data. GLIS should serve as a connecter among such databases. It is important that national genebanks are equipped with software and technical infrastructure to facilitate genebank management and data sharing.

AAFC supports the work of the Global Biodiversity Information Facility and is a voting participant in the GBIF network (GBIF 2021). AAFC also hosts the database of the Canadian Biodiversity Facility (CBIF), the Canadian node for GBIF. Related to that is the "Canadensys" database provided by a network including over 11 participating universities, five botanical gardens and two museums, which collectively house over 13 million specimens (Canadensys 2021). These databases are relevant for recording data on PGRFA, in particular crop wild relatives. They also hold data on many other organisms of relevance to biodiversity for food and agriculture and the agricultural sector, including biocontrol agents, weeds, pests and diseases.

Upon completion of projects analyzing genetic sequence data (e.g., projects by Yong-Bi Fu, Isobel Parkin, Nicholas Tinker, and Sylvie Cloutier; see Priority Activity 8) the results can be uploaded to public databases such as National Centre for Biotechnology Information (NCBI) and/or Figshare (https://figshare.com/). Figshare is an online open access repository where researchers can preserve and share their research outputs, including figures, datasets, images, and videos. It is free to upload content and free to access, in adherence to the principle of open data.

AAFC has been proactive in embracing this trend and in 2017 embarked on a project (Data Mobilization of AAFC Biological Collections – BIOMOB) to develop a DNA library and associated molecular catalogue for a significant proportion (40%) of the plant collection at PGRC. The DNA will be maintained as a resource for future projects and the molecular marker data, currently housed on local servers, will be made publicly available in a custom database. Ideally, these data will be linked with the GRIN-CA database, but this will require additional work. The project data has already been leveraged by public researchers, specifically to support research in target crops such as barley.

Gaps and needs

The standardization for data from the recent "omics" disciplines is an emerging issue for the genebank managers. This type of information must be linked to the physical material held by genebanks. The Global Information System for Plant Genetic Resources for Food and Agriculture (Article 17 of the ITPGRFA) is tasked to link databases that are maintained by various stakeholders such as GRIN-Global-CA (https://pgrc-rpc.agr.gc.ca/gringlobal/landing).

For the CNPGS the full implementation of GRIN-Global is key. This is needed in order to allow more efficient handling as users search for up-to-date information from relevant databases. This should include databases with molecular information (genetic sequence data) that is generated by many researchers and currently stored in a decentralized manner. If all goes well, the data can be linked back to the physical germplasm accessions of NCPGR genebank material. Interoperability of databases will be critical for this to happen.

Priority Activity 16. Developing and strengthening systems for monitoring and safeguarding genetic diversity and minimizing genetic erosion of plant genetic resources for food and agriculture

Monitoring and safeguarding genetic diversity and minimizing genetic erosion are essential. The ITPGRFA was established to conserve and utilize plant genetic resources for food and agriculture. However, long-term conservation of such a large volume of diverse germplasm remains a challenging mission (Fu 2017). Measures are being explored and developed to mitigate various threats to genebank sustainability and to secure a food supply for humanity for generations to come. Recently, a focus has been on molecular approaches which have pointed at changes in genepools over time (see also Priority Activity 7). The applications for collection management have been limited and new initiatives using sequencing technologies are on-going.

Tools for monitoring and assessing genetic diversity have moved from classical taxonomy and agri-botanical characterization to molecular assessments. However, for the day-to-day operation of a genebank and germplasm collecting in the field, classical tools based on morphology remain important. These methods are applied at the CNPGS genebanks and according to standard operation protocols that have been developed and improved on an on-going basis for each crop group (see also Priority Activity 8). A recent initiative to document seed (and plant) morphology by the CFIA has resulted in establishing the International Seed Morphology Association (ISMA 2021). PGRC has actively participated in this initiative and sees it as a new tool for species and or cultivar identification based on seed morphology features.

Gaps and needs

The management of diverse genebank collections with considerable inter- and intra-accession diversity is a challenge. Strategic decisions on acquisition of new material must be made to avoid loss of diversity which includes also diversity created by Canadian researchers and plant breeders. Monitoring and maintaining the diversity within genebank collections as well as the diversity of native wild plant relatives in *in situ* are important.

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Priority Activity 17. Building and strengthening human resource capacity

Staff numbers working at the three CNPGS locations have been fairly stable during the review period. The three CNPGS genebanks employ 18 full-time staff including two research scientists, two professionals, 14 research assistants and an administrative assistant. Variable numbers of summer assistants are present pending various research programs and external funding.

All three CNPGS genebanks are located within AAFC Research and Development Centres and have access to considerable infrastructure and related technical and administrative support. This offers opportunities for genebank staff members to interact on a daily base with other staff including research scientists and professionals. This interaction results in profitable experiences in such areas as plant breeding, pathology, physiology, agronomy and molecular biology.

PGRC has the added advantage of being located on the campus of the University of Saskatchewan, facilitating more interactions. All staff participated regularly in training to ensure safety and well-being at the workplace. Staff at PGRC are able to obtain specific training as required by attending University classes on plant taxonomy, statistics, or IT technology. Close cooperation with the CFIA at Saskatoon has helped to strengthen staff training.

Professional staff attend relevant national and international meetings and conferences as part of their professional development program. Staff regularly participate in relevant regional meetings with the USDA/ARS genebank staff. Remote participation using computer technology has enhanced these training opportunities and possibilities.

Gaps and needs

Training of future genebank staff is of great relevance and Canada is engaged in this through cooperation with the USDA and NORGEN (Volk et al. 2019). Training on PGRFA related issues at Canadian Universities needs attention.

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Priority Activity 18. Promoting and strengthening public awareness of the importance of plant genetic resources for food and agriculture

PGRC was established as Canada's national genebank for PGRFA by AAFC on October 1, 1970. It started in Ottawa and subsequently moved to Saskatoon in 1998. To mark the 50th anniversary, a virtual symposium with 16 invited speakers from national genebanks, research, plant breeding, non-governmental organizations, AAFC, FAO-CGRFA and ITPGRFA was organised by PGRC at Saskatoon. There were close to 400 participants from nearly 27 countries.

AAFC staff have actively contributed to establishing and teaching a class on plant genetic resources for food and agriculture at the University of Saskatchewan. This is the only Canadian university that offers a specialized module on plant genetic resources for food and agriculture.

CPGR staff in Fredericton produce a newsletter relating to Potato genetic resources as well as other PGRFA related issues in French and English languages (Government of Canada 2021). The annual newsletter has a broad distribution to all relevant stakeholders as well as posted on the genebank website.

Many CNPGS partners have important outreach programs. For example: Bob Wildfong, Executive Director of Seeds of Diversity recently explained:

"Biodiversity is the key to adapting our food system to changes in the 21st century. The problem is that we're losing food biodiversity every day. During the last hundred years, 75% of our food crop varieties became extinct. Today, only 10% of the remaining varieties are available from seed companies. Diversity of plants and animals is very important. It makes living things adaptable. It allows wild and domesticated species to withstand threats like diseases, climate changes, pests, and other unpredictable conditions. With enough variation in a group, there will always be some individuals that can survive under any changing situation. Food crop biodiversity is our single most crucial tool to adapt our food systems to changes.

- Seed Saving Resources – instructional handouts and how-to resources for experienced or aspiring seed savers
- Community Seed Libraries – a host of community-based seed library initiatives across the country
- Seedy Saturdays – hundreds of community-organized annual events hosting seed exchanges, workshops and vendors

Sow Canadian Ecologically produced Seed

- Canadian Seed Catalogue Index – list of seed companies in Canada, as well as the vegetable and fruit seed they've sold in recent years
- Ecological Seed Finder - a searchable database of ecological vegetable and grain seed sold in Canada

  Member Seed Directory – our own listing of over 3000 varieties (accessions) saved by our members and available for member-to-member exchange.

Seeds of Diversity maintains a collection of over 2900 regionally adapted and rare varieties/landraces, backing up the work of our member seed savers and Canadian heritage seed companies who help keep the seeds viable and available for future gardeners and farmers. We thank our volunteers and donors who:

- adopt seeds into the library, protecting them in perpetuity
- grow out seed and return freshly saved seed to us
- donate varieties from their own seed collections"

Gaps and Needs

Maintenance and enhancement of genetic diversity of PGRFA as one of the key components of biodiversity needs to be promoted. Awareness for plant genetic resources for food and agriculture has increased in Canada. It will be important to continue mobilizing the genetic diversity maintained by the CNPGS genebanks in Canada to meet challenges such as climate change, and to communicate this potential to the public.

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Conclusions

Chapter 1. *In situ* conservation

- Over 25% of Canada's wild plants are related at the genus level to economically valuable crop species. This is an immense opportunity for researchers to explore.
- A coordinated and inclusive approach involving all levels of government and other stakeholders for *ex situ* and *in situ* conservation of native plant genetic resources for food and agriculture (PGRFA) is required.
- Ideally, crop wild relatives and wild food plants should be conserved *in situ* where they can continue to evolve under natural conditions.
- Outreach to Civil Society Organizations (CSO), Botanical Gardens and Indigenous Peoples can help to achieve a coherent approach to *in situ* conservation.
- The CNPGS genebanks support *in situ* conservation by complementary *ex situ* conservation and could enhance this.
- International projects supported by Global Affairs Canada support on-farm, *ex situ* and sustainable use of PGRFA in many countries around the world.

Chapter 2. *Ex situ* conservation

- The Canadian National Plant Germplasm System (CNPGS) managed by Agriculture and Agri-Food Canada (AAFC) consists of three genebanks for PGRFA which are the most relevant for *ex situ* conservations of PGRFA: Plant Gene Resources of Canada, PGRC, (seed germplasm), Canadian Clonal Genebank, CCGB, (fruit germplasm), and Canadian Potato Gene Resources, CPGR, (potato germplasm).
- The CNPGS genebanks provide critical support to research and breeding efforts by distributions of PGRFA and associated information (75,000 samples during the review period from 2012 to 2019 to over 50 countries).
- The CNPGS genebanks require on-going investments in operational needs, infrastructure and personnel to maintain, explore and expand the genetic resources collection (over 110,000 accessions).
- Cooperation with plant breeders, research scientists, CSOs and other parties both inside and outside of AAFC is essential for the CNPGS to operate efficiently and effectively.
- Underutilized and neglected crops as well as native Canadian PGRFA require enhanced attention by the CNPGS genebanks to avoid loss of genetic diversity.

Chapter 3. Sustainable use of PGRFA

- The Canadian seed sector is built on innovations resulting from research and plant breeding in the public and private sectors over many years. Over 1780 cultivars were registered in Canada during the review period 2012-2019.
- Industry has become a leader in the development of finished cultivars. AAFC and Universities are critical assisting in pre-breeding and research including the use of germplasm from the CNPGS genebanks.

- The Canadian Food Inspection Agency (CFIA) has established inclusive processes for regulation of the seed sector and variety registration which are important to ensure continuous innovation.
- New approaches by CSOs and with support by AAFC to participatory plant breeding and on-farm development will add to the sustainable use of PGRFA.
- International projects supported by Global Affairs Canada (GAC) support sustainable use and conservation of PGRFA on-farm and *ex situ*.

Chapter 4. Building sustainable national and international networks

- The CNPGS genebanks take part in national and international networks to assure that the genetic diversity of PGRFA and the associated information are preserved and shared.
- The genebanks of the CNPGS are integrated in the AAFC Science and Technology Branch and, therefore, in a good position to connect PGRFA conservation with research and innovation to the benefit of all Canadians and of global food security.
- A national committee with representation from all Canadian stakeholders would support national and international coordination of PGRFA activities in Canada.
- Cooperation on PGRFA technical aspects and knowledge exchange is critical within the North America region and beyond.
- International fora including the ITPGRFA, the FAO Commission on Genetic Resources and the CBD impact the PGRFA activities and their sustainable use in Canada.

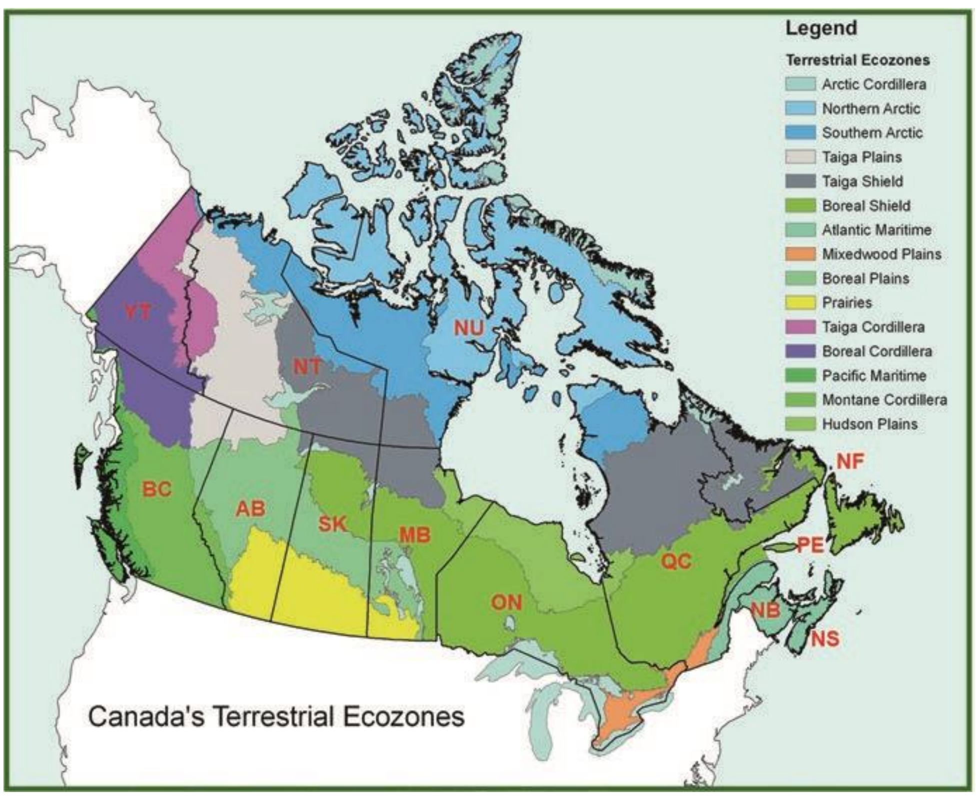
Appendices

Appendix 1. Canadian Geography – A short summary
(from Diederichsen and Schellenberg 2016)

Canada's land area amounts to approximately 9,984,670 km^2, which is about 7% of the terrestrial surface of the globe. The longest east - west distance is about 5514 km, and the longest north - south distance is 4634 km. The Arctic tundra in the North is vast stretch of cold permafrost, while the boreal forest stretches as a belt from the Pacific to the Atlantic coast. These two vegetation zones cover two thirds of the country, are sparsely settled, and have little or no agricultural production.

There are 15 terrestrial eco-zones generally recognized and these can be further subdivided into 53 eco-provinces with 194 eco-regions. Figure 1 shows the large-forested band that covers more than 40% of Canada's land surface and includes, from west to east, the Pacific Maritime, Boreal Cordillera, Montane Cordillera, Boreal Plains, Boreal Shield, Hudson Plains, and Atlantic Maritime eco-zones.

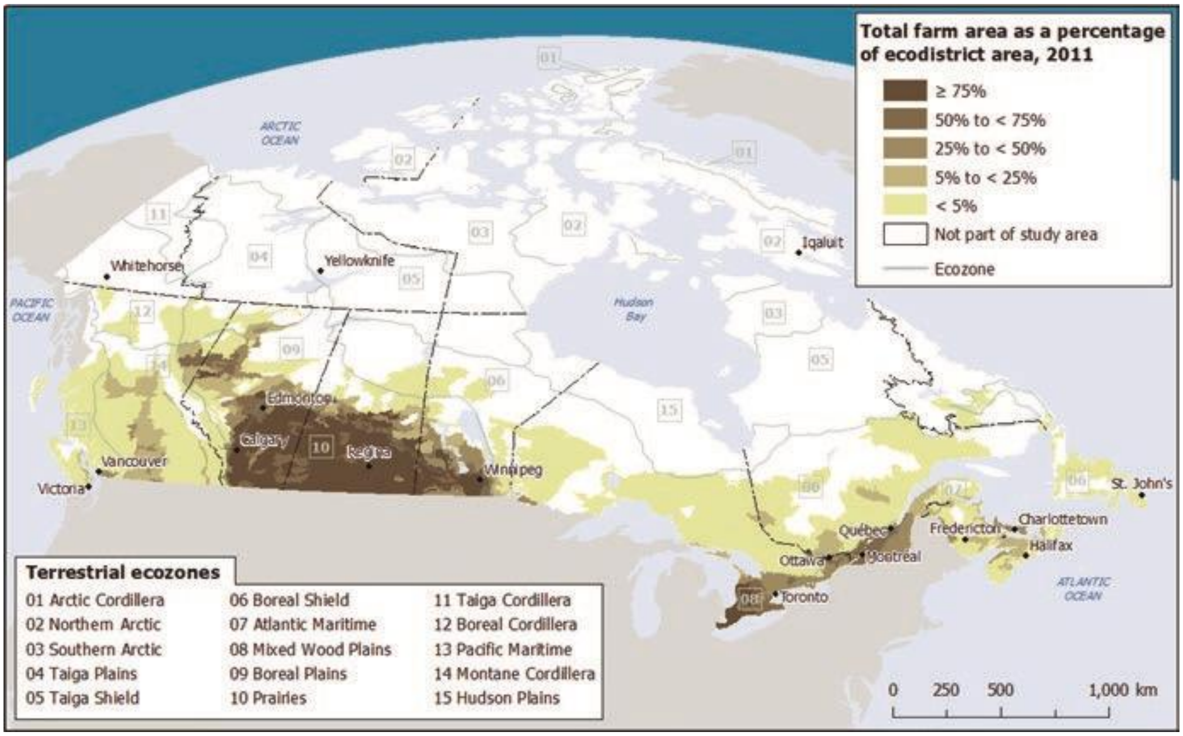
Figure 1. Canada's terrestrial eco-zones with borders of provinces (10) and territories (3) indicated (Natural Resources Canada 2017).



Abbreviations: AB Alberta, BC British Columbia, MB Manitoba, NB New Brunswick, NF Newfoundland and Labrador, NS Nova Scotia, NT Northwest Territories, NU Nunavut (territory), ON Ontario, PE Prince Edward Island, QC Quebec, SK Saskatchewan, YT Yukon (territory)

Politically, Canada is divided into ten provinces and three territories. Generally speaking, only the southern parts of the country are well suited to agricultural production and as well as having the majority of the larger population centers. These areas also have more diversified vegetation than the vast northern regions. For agriculture, the prairies of Western Canada are most important (Figure 2).

Figure 2. Farmland distribution in Canada. (Statistics Canada 2014)



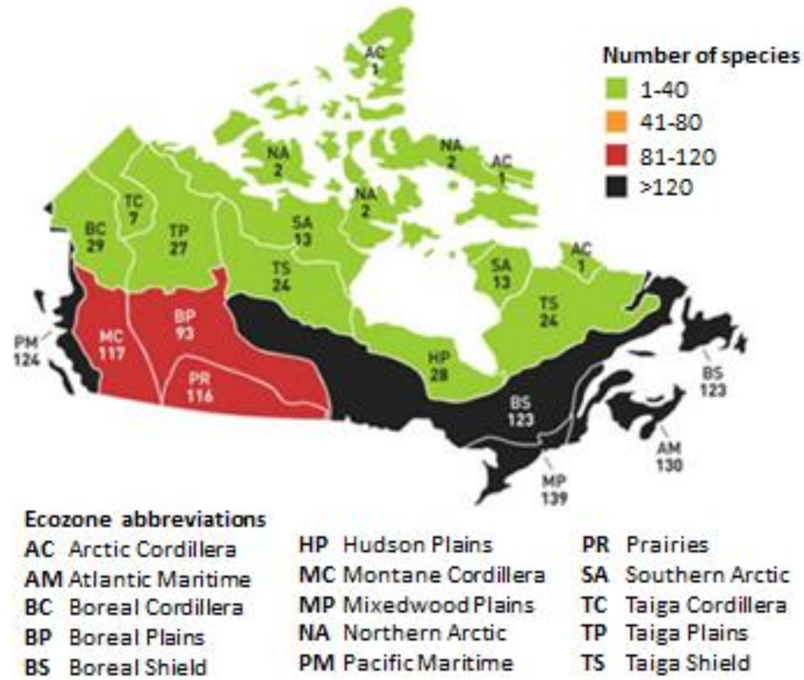
Flora of Canada

The number of higher plant species reported in Canada is 5087 (Canadian Food Inspection Agency 2008). Of these, 10 plant species are categorized as being endangered, 47 as threatened, and 46 as being of special concern (COSEWIC 2017). It is interesting that 1229 vascular plant species amounting to about 25% of the total Canadian flora, consist of alien species (Canadian Food Inspection Agency 2008).

Of the alien species, 483 are weedy or invasive, and more than half of these were introduced deliberately as crops, as ornamentals, or for other uses. Darbyshire (2003) provided an inventory of Canadian weeds listing 872 species in total, including the native weed species. Due to the size and ecological diversity of the country, 316 native Canadian species are considered to have been introduced in some parts of the country, and of these 69 are categorized as invasive.

The degree of impact anthropogenic activity has had on the Canadian flora is important. In the agricultural areas of the western provinces of Alberta, Saskatchewan, and Manitoba, there are relatively small "islands" of native plant habitats remaining. Figure 3 shows that the number of invasive species is particularly high in the more densely settled areas in the southern parts. Although alien species can be invasive and thereby threaten the native flora, it is important to remember that many alien species are crop plants and are critical to food production either for domestic utilization or the export trade.

Figure 3. Number of invasive alien plant species in Canada by ecozone (Note: Based on the 162 species for which distribution maps were available). (Canadian Food Inspection Agency 2008).



An excellent and regularly updated checklist for Canadian vascular plants with distribution maps is available on the Internet (Brouillet et al. 2010). Davidson (1995) reported that 364 native Canadian species have direct or potential use in crop development or breeding programs. He grouped these plant genetic resources into the following categories: forage and turf grasses (138 species); fruit crops (111 species); cereals, oilseeds, and other field crops (18 species); special and minor crops (86 species); and nut crops (11 species). In addition, Davidson (1995) listed 137 genera of native landscape plants and concluded that the potential of these remains untapped. Many species, particularly in the fruit crop grouping, could be identified as world resources (e.g., *Amelanchier*) with a major part of their distribution occurring on Canadian soil. That such a high number of native Canadian taxa are plant genetic resources of economic significance is striking, as Canada is not identified as one of the centers of diversity of cultivated plants first pointed out by Vavilov (1926). Nearly all important crops presently grown in Canada trace their evolutionary origin to other parts of the world.

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Appendix 2. A snapshot of Canadian Agriculture – 2016 Census of Agriculture (Statistics Canada)
(https://www150.statcan.gc.ca/n1/daily-quotidien/170510/dq170510a-cansim-eng.htm)

Agricultural production remains a critical component of the Canadian landscape from many perspectives. Agricultural data has been collected in Canada since 1666. The most recent survey in 2016 marks the 22nd Census of Agriculture since Confederation in 1867. The Census of Agriculture provides the only comprehensive and integrated profile of the physical, economic, social and environmental aspects of Canada's agriculture industry. It is conducted every five years. The data are needed to make informed decisions about business management strategies, agricultural policies, programs and services that directly affect farmers and rural communities.

Canadian producers have continually taken advantage of technological advances to more efficiently deliver a wider variety of agricultural products to Canadians and the world. Farming has evolved into an innovative career choice requiring knowledge of business management and technology, as well as the agricultural sciences.

While there are fewer agricultural operations and farm operators, agricultural operations are getting larger and using more of Canada's available agricultural land to grow crops. The area of cropland increased by 6.9% from 2011 to 93.4 million acres in 2016.

Some important statistics from the Census of Agriculture (2016):

- Land in crops (excluding Christmas trees): 93.4 million acres see the table below.
- The Census recorded 193,492 agricultural operations, down 5.9% from 2011, and 271,935 farm operators, a decline of 7.5%.
- Farms are on average larger and more area is devoted to crop production.
- In 2016 the average value of land and buildings was CAD 2,696 per acre, which is an increase of 38.8% from 2011 (in 2016 constant dollars).
- There were 271,935 farm operators in 2016 and almost three-quarters of them were male (71.3%). The proportion of female farm operators increased from 27.4% in 2011 to 28.7% in 2016.
- Farm operators are slightly older on the average.
- There were 193,492 agricultural operations covering 158.7 million acres in 2016, with an average farm size of 820 acres.
- In 1971, there were 366,110 agricultural operations covering 169.7 million acres, with an average farm size of 463 acres.
- From 1971 to 2016, the number of agricultural operations in Canada decreased by 47.1% and the total farm area decreased by 6.4%.
- Despite the decrease in total farm area, the total area of cropland increased from 68.8 million acres in 1971 to 93.4 million acres in 2016. This was the largest area of cropland on record for the Census of Agriculture.
- Cropland accounted for 58.8% of total farm area in 2016. The total area used for pasture (natural or seeded) declined by 4.4% as farmers switched from livestock production to crops.
- Increased use of no-till seeding technology, an important soil conservation practice, has been a major contributing factor to the reduced summer fallow area. No-till seeding allows the retention of stubble from the previous crop to trap winter snow, improve soil structure and reduce moisture loss during seeding.

- From 2011 to 2016, the total area of land seeded using no-till technology increased by 16.8% to 48.2 million acres.

Table 1. Agricultural land use comparisons 2011 to 2016

Land use	Unit of measure	2011	2016
Land in crops (excluding Christmas tree area)	Number of farms reporting	174,343	163,431
	Acres	87,352,431	93,382,638
	Hectares	35,350,270	37,790,608
Summerfallow land	Number of farms reporting	20,221	12,558
	Acres	5,152,632	2,209,071
	Hectares	2,085,196	893,979
Tame or seeded pasture	Number of farms reporting	64,949	54,092
	Acres	13,671,483	12,556,190
	Hectares	5,532,652	5,081,309
Natural land for pasture	Number of farms reporting	82,865	72,075
	Acres	36,332,724	35,240,524
	Hectares	14,703,330	14,261,332
Woodlands and wetlands	Number of farms reporting	102,744	95,563
	Acres	12,101,658	11,417,481
	Hectares	4,897,367	4,620,490
Area in Christmas trees, woodlands and wetlands	Number of farms reporting	103,528	96,214
	Acres	12,171,626	11,476,261
	Hectares	4,925,682	4,644,277
All other land*	Number of farms reporting	143,014	122,335
	Acres	5,474,852	3,858,408
	Hectares	2,215,594	1,561,442

* In 2011, in Alberta, Saskatchewan, and Manitoba, land that was reported as "too wet to seed" has been classified as "other land" instead of cropland or summerfallow

A Brief Overview of agricultural operations in Canada based on the Agricultural census of 2016

Some key elements

- Oilseed and grain farms account for the highest proportion of Canadian agricultural operations, in part due to the amount of arable land available on the Prairies.
    - In 2016, the number of oilseed and grain operations increased from 61,692 to 63,628, accounting for 32.9% of all agricultural operations in Canada.
    - Canola remains the biggest crop, accounting for more than one-fifth of all croplands.

- Beef and feedlot operations rank second (18.6%) with 36,013 agricultural operations—despite a 3.7% decline from 2011.
- While total farm area (Table 2) edged down from 2011, the area dedicated to cropland rose to 93.4 million acres in 2016.
    - Urbanization may reduce cropland available in some areas, a net increase in cropland is attributable to a shift in land use. Farmers have converted land formerly used as pasture, summerfallow or other less productive land into productive areas.
- The number of farm operators declined from 2011 while their average age continued to rise.
    - However, the proportion of operators under 35 years of age edged up for the first time since 1991.
- Primary agriculture accounted for 1.5% of national gross domestic product (agricultural gross domestic product) in 2013.
- Agricultural operations in Canada employed 280,315 people in 2015.
- From a trade perspective, agricultural goods accounted for 2.2% of Canada's total imports and 4.6% of total exports (CANSIM table 228-0059, accessed April 13, 2017).

Table 2. Farm area related to farm size, Canada, 2011 to 2016

Total number of farms classified by farm area	# farms 2011	# farms 2016
Farms under 10 acres	12,991	13,193
Farms 10 to 69 acres	32,705	32,036
Farms 70 to 129 acres	24,205	22,494
Farms 130 to 179 acres	21,705	20,148
Farms 180 to 239 acres	11,719	10,644
Farms 240 to 399 acres	24,974	22,986
Farms 400 to 559 acres	15,053	13,645
Farms 560 to 759 acres	11,781	10,792
Farms 760 to 1,119 acres	13,413	12,143
Farms 1,120 to 1,599 acres	10,831	9,640
Farms 1,600 to 2,239 acres	9,222	8,335
Farms 2,240 to 2,879 acres	5,230	4,982
Farms 2,880 to 3,519 acres	3,482	3,365
Farms 3,520 acres and over	8,419	9,089

Some general trends:

There are fewer farms, but the farms are larger.

- Total farm area decreased 0.9% from 160.2 million acres in 2011 to 158.7 million acres in 2016.
    - Farm size varied considerably based on region and farm type.

- The largest operations on average were found in Saskatchewan (1,784 acres), while the smallest on average were located in Newfoundland and Labrador (174 acres).
- Farm operators under 35 years of age accounted for an increasing share of total operators and their absolute numbers also rose from 24,120 in 2011 to 24,850 in 2016.
    - This was the first absolute increase in this category of operators since 1991.
    - Partnerships accounted for 22.9% of farms, while 22.5% were family corporations and 2.7% were non-family corporations.
    - The rate of incorporation among farm operations rose from 19.8% in 2011 to 25.1% in 2016
- There were 193,492 farms counted in 2016, down 5.9% from the previous census in 2011. However, this was the lowest rate of decline in 20 years.
    - While farm numbers declined, the average area per farm increased from 779 acres in 2011 to an average of 820 acres in 2016.
- Many farm operators also do off-farm work.
    - The Census identified that 44.4% of all farm operators did some off-farm work, usually as a means of supplementing their total income. Just over 3 in 10 (30.2%) operators worked an average of 30 hours a week or more off the farm.
- Corporations more likely to have succession plans.
    - The transfer of agricultural assets as farmers transition out of the sector can happen in a number of ways. Farm assets can be sold in whole or in part and the buyer can be a new entrant or someone looking to expand their existing operation.
    - Farm operations can also be transferred to other parties via a will or written succession plan.
- More oilseed and grain-type farms, increasing from 30.0% in 2011 to 32.9% in 2016.
    - Prairie farmers drive gains in field crop area.
    - In the Prairie Provinces, 46.3% of farms fell into this farm type.

References

Statistics Canada. Table 32-10-0406-01 Land Use DOI: https://doi.org/10.25318/3210040601-eng

Appendix 3. Changing diversity of crops on Canadian farms

Farm operators continued to diversify the crops they produce in response to changing market demands and improved crop varieties/cultivars.

- For example, lentils are now the third-largest crop in Saskatchewan following canola and spring wheat, as market demand increased from foreign buyers.
    - According to the FAO, Canada was the largest producer of lentils in the world in 2014.
- There has been an expansion of soybeans, corn for grain and corn for silage in the Prairie Provinces, the result of new cultivars suitable to the growing conditions of the region.
    - Soybean area in Manitoba more than doubled—from 705,032 acres in 2011 to 1,645,397 acres in 2016.
    - In Central Canada, corn and soybeans remained the largest field crops by area, while fodder crops and potatoes were the largest crop areas in Atlantic Canada.

Table 1. Change in acreage of major crops in Canada between 2011 and 2016

Crop	2011 (acres)	2016 (acres)
Canola (rapeseed)	3,471,547	20,606,778
Spring wheat (excluding durum)	25,748,008	15,693,427
Alfalfa and alfalfa mixtures	6,287,122	9,276,755
Barley	13,484,516	6,696,068
Durum wheat	4,207,429	6,062,953
Soybeans	699,095	5,615,864
Lentils	125,562	5,584,808
All other tame hay	6,353,498	4,851,167

Blueberries, cranberries, and greenhouse veggies are bright spots in the horticulture sector

- Fruits, berries, and nuts acreage rose 6.7% from 2011, mainly due to blueberries and cranberries.
- Blueberry area continued to expand in Quebec and Atlantic Canada (principally areas of managed low bush blueberries) and in British Columbia (where high bush blueberries dominate).
- Nationally, blueberry area has consistently increased over the past several censuses and now stands at 196,026 acres.
- Growing international demand largely drove the increase in blueberry area. Canada exported 94.8 million kilograms of frozen blueberries in 2016, up 33.7% from 2011. Meanwhile, exports of fresh blueberries rose 84.4% to 37.1 million kilograms.

Table 2. Area of selected fruits and berries, Canada, 2011 and 2016

Area of selected fruits and berries in Canada – 2011 and 2016 acres (thousands)		
Fruit	**2011**	**2016**
Blueberries	175.1	196
Apples	45.1	43.6
Grapes	30	31.2
Cranberries	15.2	18.1
Strawberries	11.1	10.1
Peaches	7.8	6.6
Raspberries	7.4	5.6
Sweet cherries	4.8	5.4
Saskatoon	3	2.8
Sour cherries	2.8	2.6
Source(s): CANSIM table 004-0214.		

- Cranberry area increased from 15,191 acres in 2011 to 18,134 acres in 2016.
    - Exports of fresh cranberries also increased, rising 77.6% from 2011 to 63.5 million kilograms in 2016 (Statistics Canada. 2017.
    - Both blueberries and cranberries are now amenable to mechanized harvesting, allowing operators to increase the scale of their operation with a minimal increase in the number of employees.
- The area of strawberries and raspberries declined as the commodities faced disease outbreaks as well as labour and market challenges.
    - Raspberry area fell 23.7% from 2011 to 5,651 acres in 2016, while strawberry area decreased 8.4% to 10,155 acres.
- Apple orchard area continued to decline, with the largest decreases in Nova Scotia and Quebec.
    - Overall, the total acres dedicated to apple production fell 3.2% from 2011 to 43,631 acres in 2016.

Table 3. Area of selected field vegetables, Canada, 2011 and 2016

Area of selected field vegetables for the fresh market in Acres (thousands)			
Vegetable	**2011**	**2016**	
Sweet corn	57.3	47.6	
Green peas	29.6	31.7	
Carrots	23.4	22.3	
Beans	21	21	

Squash, zucchini and pumpkin	15.7	19.4	
Tomatoes	18.3	17.6	
Dry onions	14.6	14.2	
Cabbage (incl. Chinese)	13.2	13.2	
Broccoli	10.3	10.2	
Lettuce	8.3	8.3	
Source(s): CANSIM table 004-0215.			

The number of farms reporting field vegetables rose 10.3% from 2011 to 9,994 in 2016. However, most of the new farms reporting vegetables were small.

- Total field vegetable area in Canada increased 1.0% to 270,294. Despite a 16.9% decrease in sweet corn area since 2011, sweet corn remained the largest vegetable crop area in 2016.
- Greenhouse vegetable area rose 22.5% from 2011 to 165.4 million square feet in 2016.
- Ontario continued to lead the provinces, accounting for more than two-thirds of all greenhouse vegetable area.

Landscape plant, nursery, Christmas trees and sod area

Nursery operations reported 17.8% less area in 2016 (49,073 acres) from five years earlier, while Christmas tree area declined 16.0% to 58,780 acres and sod area fell 10.6% to 56,719 acres.

- Lower sod and nursery area were driven by a shift away from the construction of single-detached dwellings in favour of multi-dwelling type buildings (CANSIM table 027-0001, accessed April 13, 2017), and a move away from traditional landscaping practices towards hard-scaping.
- The decline in Christmas tree area was a result of increased demand for artificial Christmas trees (Statistics Canada. 2017. Special tabulation, based on *World Trade Atlas* Database, accessed April 13, 2017).
- One in eight farms sold food directly to consumers

Farmers harvest the sun for more than growing crops

In 2016, 5.3% of farms reported having a renewable energy-producing system on their operation.

- Of these farms, 85.0% had solar panels while 15.7% reported wind turbines.
- Ontario had the highest percentage of farms with renewable energy-producing systems on their operation at 10.4%. Of the 5,180 farms with renewable energy-producing systems in Ontario, 85.5% had solar panels and 17.5% had wind turbines.
- Prince Edward Island had the second-highest percentage of farms with renewable energy-producing systems at 5.8% and had the highest percentage of farms reporting renewable energy with wind turbines at 42.3%.

Larger and more valuable farms

Farms continued to grow in size, with average farm area reaching 820 acres per farm in 2016.

- The value of land and buildings used by agricultural operations increased 37.5%, from CAD 311.2 billion in 2011 to CAD 427.9 billion (in 2016 constant dollars) in 2016.
    - Land and building values varied across the country, ranging from an average of CAD 1,210 per acre in Saskatchewan to CAD 9,580 per acre in Ontario.
    - The national average value for land and buildings on-farms was CAD 2,696 per acre.
    - Total farm sales reached CAD 69.4 billion in 2015, as Canada remains one of the world leading exporters of agriculture products.

Appendix 4. Indigenous Peoples and agriculture in 2016: A portrait Extracted from Statistics Canada, Agriculture – Population Linkage Data, 2016.
(https://www150.statcan.gc.ca/n1/pub/96-325-x/2019001/article/00001-eng.htm**)**

Indigenous Peoples have a long history of agriculture production that goes back many centuries, long before the arrival of Europeans on the land that today includes Canada. Very little data, or for that matter analysis, on Indigenous Peoples and agriculture has been published. This article represents Statistics Canada's first attempt at filling this gap.

One of the key products from the 2016 Census of Agriculture is the Agriculture–Population Linkage Database, a rich source of information on the socioeconomic characteristics of the agricultural population, which is defined as all persons who live in agricultural households. By linking farm-level data from the Census of Agriculture to individuals in the Census of Population, a portrait emerges of Indigenous Peoples and agriculture. It should be noted that Indigenous history has been marked by government policies that affected Indigenous access to farmland, tools and market.

Strong growth in the number of Indigenous People in the agricultural population

In 2016, of the 592,975 people in the agricultural population:

- 15,765 individuals (2.7%) self-identified as Indigenous.
- By comparison, Indigenous People accounted for 4.9% of Canada's total population.
- Métis (10,960) represented the largest group of Indigenous People living in agricultural households in 2016, accounting for 69.5% of the total (Table 1).
- In addition, 4,135 First Nations People and
- 115 Inuit were part of the agricultural population.

Table 1: Indigenous identity categories

	Agricultural population (number)	Total population (number)	Agricultural population (%)	Total population (%)
Total Indigenous population	15,765	1,673,785	100.0	100.0
First Nations	4,135	977,230	26.2	58.4
Métis	10,960	587,545	69.5	35.1
Inuit	115	65,025	0.7	3.9
Multiple Indigenous identities	300	21,310	1.9	1.3
Indigenous identities not included elsewhere	255	22,670	1.6	1.4
Note: Totals may not equal 100% due to rounding.				

Nationally, the number of Indigenous People in the agricultural population in 2016 was 21.4% higher than in 1996, the first year in which comparable data were collected. During the same period, the total agricultural population fell 39.3%.

Several factors may have contributed to the increase in the number of Indigenous People in the agricultural population. One may be that greater numbers of Indigenous People chose agricultural careers.

Two other factors likely played a role as well. The first is relatively high natural growth in the Indigenous population, while the second is changes in self-reported identification. More people are newly identified as Indigenous on the Census of Population, continuing a trend over time.

Indigenous farm operators increase in number

In 2016, Indigenous agricultural operators represented 5,160 (1.9%) of the 270,720 agricultural operators in Canada. The number of Indigenous agricultural operators in 2016 increased 53.7% compared with 1996. In contrast, the total number of agricultural operators overall declined 30.1% over the same time period.

Of the 3,940 agricultural operators who self-identified as Métis, the largest number (965) farmed in Alberta, followed by those in Saskatchewan (820) and Manitoba (650). Métis made up more than half of Indigenous agricultural operators in all regions.

Among all agricultural operators surveyed, 1,060 self-identified as First Nations People. British Columbia had the largest number of First Nations agricultural operators (285), followed by Ontario (215) and Alberta (150). First Nations farm operators more likely to be women. Women made up 36.8% of First Nations agricultural operators, compared with 28.6% of non-Indigenous agricultural operators. English was reported as the first language by 79.4% of First Nations agricultural operators, followed by 14.5% who reported French and 4.2% who reported an Indigenous first language. Multiple first languages were reported by 2.0% of First Nations operators. Among the 960 agricultural operations managed by First Nations People, 'other crop farming', representing 22.7%, was the most common type of agriculture practised (Chart 2). Beef cattle production was the main activity of another 21.1%. Agricultural operations managed by First Nations People had a median area of 151 acres, or about two-thirds the size of operations managed by non-Indigenous persons. The median gross farm revenue of First Nations agricultural operations was CAD 18,000, or about one-quarter of the revenue of farms managed by non-Indigenous operators. These differences are partly explained by the concentration of First Nations agricultural operators in British Columbia, where it is more common to find small agricultural operations that focus on specialty crops, such as berries. It is notable, as well, that First Nations operators were more likely to be "part-time" farmers. In 2016, 60.8% of First Nations agricultural operators worked at an off-farm job or business.

Some important statistics:

The First Nations farm operators in 2016:

Average age:	52.3
Average total income:	CAD 45,111
Average household size:	2.9 persons
Highest level of education completed:	
High school	28.7%
College	20.8%
No diploma	20.1%
Trades qualification	14.2%
University	16.2%
Top three major fields of study:	
Business	14.4%
Mechanic/repair tech	9.8%
Health professions	9.6%
Employed off-farm:	60.8%
Registered or Treaty Indian:	50.9 %
Top two Indigenous mother tongues:	
Blackfoot	1.2%
Ojibwa	0.8%
Top three farm types:	
Other crop	22.7%
Beef cattle	20.8%
Oilseed and grain	16.4%

Conclusion

Indigenous People represented one of the few growing sectors of the agricultural population in 2016, posting large increases even as the total agricultural population declined. Compared with non-Aboriginal farm operators, Indigenous farm operators were more likely to be female, and were more likely to combine farming with off-farm paid employment. More research on Indigenous Peoples and agriculture remains to be done, particularly on the subject of Aboriginal access to agricultural land.

Appendix 5. National Tree Seed Centre Statement for Canada's Country Report for the Third Report on the State of the World's Plant Genetic Resources for Food and Agriculture

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Additional purposes & next Steps

1. Verify NTSC list of species and current taxonomy of interest to PGRC for opportunistic collections could make to report progress towards the next PGRFA report
2. Create a database column to make query recall for PGRFA easier and prevent duplication between FGR and PGRFA species.
3. Potentially work together with AAFC to survey CONFORGEN for particular woody species of interest to PGRFA for next report.

PRIORITY ACTION 5: Supporting targeted collecting of plant genetic resources for food and agriculture:

Imminent risk of loss, opportunities for use and gap filling of *ex situ* collections are the primary motivating forces to undertake targeted collecting of PGRFA. Although many major crops have generally been well collected, gaps still remain. Collections of crop wild relatives, wild food plants, regional, minor and underutilized crops are much less complete. Existing diversity of these plant groups can be particularly vulnerable to climate change even when adequately conserved and managed *in situ*/on-farm.

PRIORITY ACTIVITY 6: Sustaining and expanding *ex situ* conservation of germplasm:

Driven by an increasing demand for diversification, it is critical to expand *ex situ* conservation of underutilized crops, wild food species, forages and crop wild relatives, which are often more difficult to conserve *ex situ* than cereals or legumes. This Priority Activity aims to ensure the development of a rational, efficient, goal-oriented and sustainable system of *ex situ* conservation and use for both seed and vegetatively propagated species."

Background information from reviewing former reports and further discussion:

The reporting of plant genetic resources and forest genetic resources to FAO has been separated though in Canada, nearly all woody plant species have food, medicinal, fibre or cultural value documented by Indigenous Peoples (Uprety et al 2012; https://ethnobiomed.biomedcentral.com/articles/10.1186/1746-4269-8-7 and Additional File 1: https://static-content.springer.com/esm/art%3A10.1186%2F1746-4269-8-7/MediaObjects/13002_2011_262_MOESM1_ESM.DOC).

Non-timber forest products (NTFPs) make a significant contribution to the economy and are particularly important for private owners and First Nations People as a supplemental source of income. The production of Christmas trees and products from maple syrup are the principal NTFP commodities. Christmas trees generate over CAD 40 million and maple syrup products produce over CAD 350 million in annual sales (Natural Resources Canada 2011a). Other sources of income are derived from food-based plants, such as wild berries and mushrooms, and extracts from plants used for pharmaceuticals.

Background – The National Tree Seed Centre (NTSC) was established in 1967 with a mandate to store, test and distribute tree and shrub seed for scientific research, beginning with range-wide provenance tests for improved timber traits. It was formerly recognized as part of the National Forest Genetic Resources Centre (NFGRC) at the Petawawa National Forestry Institute (PNFI) in 1992 and contributed to the 1st Canadian Country Report on Plant Genetic Resources (1996).

The NFGRC lead five research projects that directly addressed forest gene conservation issues:

- **Forest Genetic Resources Services** maintains *ex situ* forest conservation plantations, a national information system on *ex situ* conservation needs, and the physical seed collection of the National Tree Seed Centre (NTSC) for domestic and international seed exchanges.
- **The Physiological Genetics and Plasticity Project** investigates eco-physiological responses to increased CO2 concentrations, drought, photoperiod, and temperature to quantify genetic variation in responses to anticipated climate changes.
- **The Seed Science and Reproductive Development Project** focuses on seed germination requirements, seed storage protocols, and reproductive biology, with special emphasis on protocols for longer-term storage of recalcitrant seed.
- **The Molecular Genetics and Tissue Culture Project** conducts basic research on gene regulation, gene expression, and genetic transformation of trees. This project also focuses directly on germplasm preservation through development of protocols for long-term germplasm storage through tissue cultures and maintains a cryopreservation facility for long-term storage of tissue cultures.
- **The Genetic Diversity and Reproductive Success Project** investigates the genetic and demographic effects of small population size with the aim of defining the minimum viable population (MVP) sizes required to maintain population viability (genetic diversity and reproductive success) in rare and declining native tree populations.

Researchers, projects and the NTSC were moved to the Atlantic Forestry Centre in 1996 when the Petawawa facility was closed. Researchers have continued to develop genetic resource knowledge as per above as funding and priorities permit; species priorities have expanded, determined by urgent native species' conservation issues. This is assessed by regularly surveying jurisdictions under the federal-provincial collaboration termed CONFORGEN (Conservation of Forest Genetic Resources) for each State of Canada's Forest Genetic Resources reports (2012); see also www.conforgen.ca. The majority of native woody plant species in Canada of interest to food and agriculture are not focal species to forestry due to their size less than 10 meters and taxonomic complexes of some genera. (https://cfs.nrcan.gc.ca/publications?id=10185&lang=en_CA).

The National Tree Seed Centre's collection and database is diverse, with 30,580 unique collections of 463 woody plant species accessioned since its inception; the majority being single-plant collections to support genetic research. 12,657 genetically distinct collections are currently stored. Over 27,000 seed testing records (moisture content, thousand seed weight, total seed weight, and viability by germination, tetrazolium or excised embryo tests) have also been undertaken to date.

Seed is still provided free of charge to the global research community, though more than 75% if requests are by Canadian researchers and institutions. The diversity of research needs has continued to grow as new socioeconomic and advanced genomic characteristic of native species and wild or improved populations are recognized, identified and incorporated into operational programs. NTSC maintains two core collections: a dedicated gene conservation freezer for representative base samples and federally listed Species at Risk, and an available active research collection of common and non-native species. Orthodox seed is stored at -20°C in glass Mason jars and routinely tested every 10 years for calculating potential seedlings for clients. Gene conservation collections are only tested if seed quantity permits, and collections are being repackaged from Mason jars to trifoliate aluminium foil packets in 2021. Short-lived orthodox seed may also be stored in liquid nitrogen if additional longevity is warranted. Recalcitrant seed was frequently re-collected for researchers 2012-2019. With the recent success of a protocol to conserve and establish butternut (*Juglans cinerea*) from embryonic axes (Williams et al 2019, https://cfs.nrcan.gc.ca/publications?id=39892), long-term cryogenic storage trials of other recalcitrant species like oaks (*Quercus* spp.) are underway.

When the Dominion Shelterbelt Program closed in 2013, remaining seed-lots from native and non-native woody plant species remaining were donated to the NTSC, though many were discarded due to resulting low germination retesting rates. Only good quality seedlots were kept and integrated into this report as species formerly prioritized in the Prairie provinces by AAFC. Even with the Dominion seed bank consolidation, the 2012-2018 period was a depressed period of collection activity and acquisition due to limited staffing and CFS program funding. Operations focus on maintaining routine seed testing and distribution, and priorities for urgent gene conservation issues to acquire seed ahead of invasive forest species and pathogens.

The table below summarizes *ex situ* collections thought to be of interest to food and agriculture, with exclusive columns for collections made prior to 2012 that were continually supported by NTSC, and new collections made, acquired and distributed in 2012-2019 by NTSC.

Report woody plant species of interest
(http://www.fao.org/fileadmin/templates/agphome/documents/PGR/SoW1/americas/CANADA.PDF)

Potential native gene pools	Target 5 – Supporting: Pre-2012 Collections Maintained and Available	Target 6 – Expanding: New NTSC Seed Collections made 2012-2019[2]	Target Number of Seedlot Requests 2012-2019
Shepherdia argentea	1	1	1
Prunus nigra	1	0	1
Prunus pensylvanica	91	4	44
Prunus pumila	1	0	
Prunus serotina	53	0	20
Prunus virginiana	406	15	60
Sambucus canadensis	11	1	7
Sambucus cerulea	0	0	
Sambucus racemosa	12	1	4
Viburnum acerifolium	1	1	0
Viburnum alnifolium	1	0	3
Viburnum cassinoides	7	0	2
Viburnum dentatum	1	1	0
Viburnum edule	1	1	0
Viburnum lentago	3	0	
Viburnum trilobum	14	3	5
Asimina triloba	0	2[3]	2

Castanea dentata	1	1 [3]	0
Corylus americana	0	0	
Corylus cornuta	1	1	1
Carya cordiformis	0 – short-term storage and use	4	4
Carya glabra	0	0	
Carya laciniosa	0 – short-term storage and use	2[3]	2
Carya ovalis	0 – short-term storage and use	2	2
Carya ovata	0 – short-term storage and use	2	2
Juglans cinerea	Embryonic axes preserved in liquid nitrogen; see		
Juglans nigra	0 – short-term storage and use	1	1
Juglans nigra	0 – short-term storage and use	1	1