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CANADIAN FIELD CROP RESEARCH ALLIANCE

ALLIANCE DE RECHERCHE SUR LES CULTURES COMMERCIALES DU CANADA

CFCRA Research Report (2018-2023)

Soybean Cluster Oat Project Corn Project

CANADIAN AGRICULTURAL PARTNERSHIP

Canada



Executive Summary

Canadian agriculture relies on research to drive innovation and address the needs of farmers across the country and provide them with tools and technologies needed to keep the industry competitive in domestic and global markets.

Between 2018 and 2023, the Canadian Field Crop Research Alliance (CFCRA) supported 13 projects addressing soybean and corn research across Canada, and oat research in eastern Canada. These research activities made up the **Soybean Cluster**, **Oat Project**, and **Corn Project**, funded in part by the Government of Canada under the *Canadian Agricultural Partnership (CAP)* AgriScience Program, with additional funding support from industry partners.

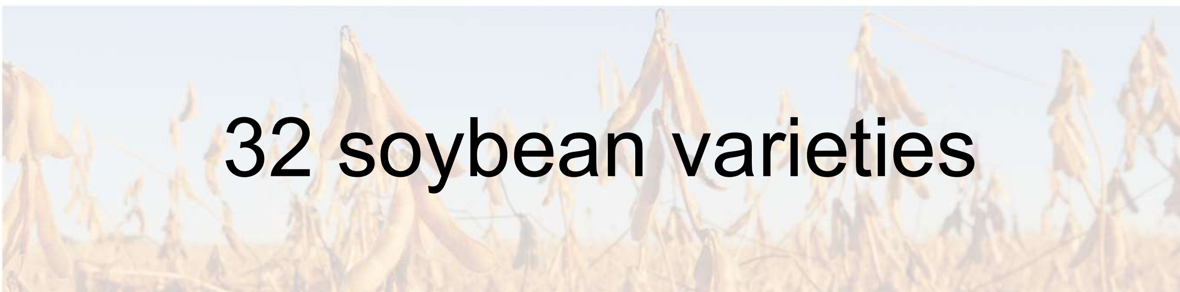
The projects brought together researchers from across the country to advance the economic and environmental sustainability of field crops in Canada. The goal of this five-year, $14.2 million cumulative research investment was to develop and release more resilient, productive, and high-quality soybean varieties; high yielding, disease resistant oat varieties; and corn germplasm with resistance to key diseases adapted to cooler growing regions of Canada. Other objectives included improving agronomic tools and practices needed to effectively grow soybeans in a sustainable manner, developing nitrogen management and seeding rate recommendations to better grow oats in eastern Canada, and developing advanced nitrogen management strategies for farmers growing grain corn, to enhance their productivity and environmental performance.

This research report summarizes the highlights and key achievements for each individual activity under the Soybean Cluster, Oat Project, and Corn Project.

Across the five-year period from 2018 to 2023, every project has expanded the opportunities available to Canadian farmers for soybean, oat, and corn.



Research efforts of the CFCRA Soybean Cluster, Oat Project, and Corn Project have resulted in 32 new soybean varieties, 16 new oat varieties, and 21 new corn inbreds with improved disease resistance, quality, and higher yields for Canadian farmers and the value chains they supply



These new varieties and genetics are now available to the Canadian industry, delivering value to producers who will gain access to new genetics and market opportunities to help keep the sector responsive and competitive.

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Table of Contents: Research Activity Summaries

Soybean Cluster - Activity 2

Title: Short season soybean breeding

Lead Researchers: Elroy Cober (Agriculture and Agri-Food Canada), Tom Warkentin (University of Saskatchewan) & Louise O’Donoughue (CÉROM)

Background

This research activity aimed to develop new non-genetically modified (non-GM) high yielding, very early maturing soybean cultivars (Maturity Group (MG) 00 and 000) for production in short season growing regions and validate early maturity gene performance to improve the breeding process.

The research activity integrated three separate breeding programs under one single collaboration. Dr. Elroy Cober at the Ottawa Research & Development Centre, Agriculture & Agri-Food Canada emphasized the development of cultivars for MG 00 growing areas and testing of end-use qualities such as tofu texture. Dr. Tom Warkentin at the Crop Development Centre at the University of Saskatchewan emphasized adaptation to MG 000 areas. Dr. Louise O’Donoughue at CÉROM emphasized the development of cultivars for MG 00 and applied molecular biology tools to understand genotype x environment (GxE) aspects of early maturity.

Research Goals

1. To develop short season soybean cultivars adapted to MG 00 and 000 growing regions of Canada
2. To consider end-use composition and function, specifically developing soybeans that are high in protein with good qualities for end-use markets such as tofu markets
3. To consider disease resistance to key diseases such as Phytophthora root rot, soybean cyst nematode (SCN), and white mold in new varieties
4. To validate newly identified maturity genes and assess their performance in various locations across Canada

Research Highlights (2018-2023)

Six* new soybean varieties were developed and released for the non-GM food grade soybean market, including:

AAC Dale (*licensed to SeCan*) has grey pubescence and yellow hilum. It is an early MG 00 variety adapted to regions of Manitoba, Ontario and Quebec

OT16-06 (*licensed to Agri Magic*) has grey pubescence and yellow hilum. It is a late MG 00 variety adapted to regions of Manitoba, Ontario and Quebec

OT18-16 (*licensed to CanGro Genetics*) has brown pubescence, an imperfect yellow hilum, and moderately higher seed protein and seed size. It is an early MG 0 variety adapted to regions of Ontario & Quebec

OT18-09 (*licensed to SeCan*) has grey pubescence, yellow hilum, and larger than average seed size. It is an early MG 00 variety adapted to regions of Manitoba, Ontario and Quebec. It was rated semi-tolerant to iron deficiency chlorosis in Manitoba provincial trials

OT18-15 (*licensed to SeCan*) has brown pubescence and an imperfect yellow hilum. It is an early MG 0 variety adapted to regions of Ontario and Quebec

OT18-01 (*licensed to CanGro Genetics*) has grey pubescence, yellow hilum, and larger than average seed size. It is a late MG 00 variety adapted to regions of Manitoba, Ontario and Quebec

In addition to the development of six new soybean varieties, a new white mold nursery was established in Harrington, PE to screen new breeding material for resistance to *Sclerotinia sclerotiorum* (white mold)

* Three additional lines will be considered for licensing through the AAFC variety request for proposal process in March 2023. Company interest in licensing will not be known until after this report has been finalized

Soybean Cluster - Activity 3

Title: Meeting the soybean protein meal standard in Western Canada
Lead Researcher: Elroy Cober, Agriculture and Agri-Food Canada

Background

Typically, soybeans grown in Western Canada are lower in protein compared to those grown in Eastern Canada. This can result in lower prices for Western Canadian soybeans.

This research activity examined the seed protein differences of soybeans across Canada to determine the seed protein / yield relationship within a protein range high enough to meet meal standards in Western Canada.

Research Goals and Approaches

Low seed protein content in soybean grown in Western Canada can result in soybean meal which does not meet the necessary protein meal standard. The objectives of this study were to quantify agronomy and seed composition differences between Eastern and Western Canada grown soybean and to determine the yield cost of raising Western soybean protein.

Agronomy trials were conducted on a series of 20 low to high protein soybean lines grown across multiple locations across multiple years in eastern and western Canada. Seed protein and yield was measured to assess environmental effects on protein levels.

A non-nodulating soybean line was included as a control to allow for the determination of how much nitrogen from soil alone contributes to seed protein levels, since all nitrogen taken up by that line and turned into protein would come only from the soil.

Additionally, a genomics study was conducted on 10 lines to determine gene expression differences for genes that are associated with seed protein development. Gene ontology is being used to examine seed composition networks and identify the most differentially expressed genes involved in seed protein biosynthesis.

Research Highlights (2018-2023)

Seed protein quality, quantified with the 11S:7S ratio, was higher in Western Canada (2.72) compared to Eastern Canada (2.51). Average seed protein was significantly higher in Eastern Canada (41.6%) compared to Eastern Prairie (39.3%) and Prairie sites (39.7%) measured on a dry-matter basis. Separate east-west mega-environments were not found for seed protein in Canada; a high protein genotype is high protein across Canada. With an increase of seed protein by 1%, seed yield dropped by 45.3 kg/ha in Eastern Canada, 53.1 kg/ha in the Eastern Prairie and 78.4 kg/ha in Prairie sites. Growers and plant breeders may need to select higher protein genotypes, at the cost of lower yield, if the soybean industry is unable to exploit the protein quality advantage in Western Canada.

To understand the discrepancy in seed protein content between eastern- and western-grown soybeans, RNA-seq and differential gene expression analysis for sugar transport genes was used since a sugar transport gene is responsible for a major protein QTL. Thirty-four differentially expressed sugar transport genes (GmSWEETs), including GmSWEET29 and GmSWEET34 were consistently upregulated across all ten genotypes in each of the western locations over three years. Sugar transport genes GmSWEET29 and GmSWEET34 are likely candidates underlying the lower seed protein content of western soybeans. GmSWEET20 was somewhat downregulated in the western locations and may also play a role in lower seed protein content. Differential gene expression analysis was also performed on the top three high and low total protein soybean varieties and high and low 11S soybean varieties. The top 15 most upregulated and the 15 most downregulated genes were extracted from each site-year’s expression dataset (n=10) and cross-examined to create shortlists of the most consistently differentially expressed genes. Shortlisted genes were assessed for gene ontology to gain a global appreciation of the common differentially expressed genes. Genes with roles in the lipid metabolic pathway and carbohydrate metabolic pathway were differentially expressed in high total protein and high 11S soybeans in comparison to their low total protein and low 11S counterparts. Expression differences were consistent between East and West locations with the exception of one, Glyma.03G054100.

Soybean Cluster - Activity 4

Title: Supporting western and northern expansion of soybean in Canada
Lead Researcher: Leonid Savitch, Agriculture and Agri-Food Canada

Background

Western and northern expansion of soybeans in Canada leads to frequent and extended exposure of plants to cool temperatures. Exposure of soybean plants to cool nights and day/night temperatures, particularly at flowering time, can result in floral sterility, reduced pod and seed formation, delayed maturity, altered seed composition, and can drastically affect crop productivity.

This research activity aimed to characterize and evaluate soybean lines for their suitability to western and northern expansion, particularly in Saskatchewan. The output of this work was the fundamental knowledge of the mechanisms and regulation of soybean photosynthetic cold stress tolerance and acclimation, mechanisms and regulation of cold-induced delay in reproductive development, and cold-induced regulation of carbon metabolism and carbon partitioning.

Research Goals

1. Identify the mechanisms associated with superior photosynthetic cold stress tolerance and limited cold-induced delay in maturity
2. Characterize conventional early maturity soybean varieties (MG 00-000) with differential tolerance to the low night temperature induced feedback-limited photosynthesis, differential carbon partitioning and export, starch mobilization and differential low temperature induced delay in reproductive development, maturity and productivity
3. Develop, design and evaluate efficient screening tests for photosynthetic soybean cold stress tolerance and low temperature insensitive flowering and maturity phenotypes
4. Identify soybean germplasm with enhanced cold stress tolerance suitable for cultivation in Saskatchewan and Manitoba

Research Highlights (2018-2023)

- 19 early maturity soybean varieties were grown in controlled environments under long day conditions and were evaluated for their response to cold night stress and acclimation to low night temperatures (cold nights from V1 to maturity). Measurements included:
    - Rates of photosynthesis, respiration, transpiration, water use efficiency, redox state of the chloroplast, linear electron transport, and stomatal conductance at growth conditions, light saturated conditions and light and CO_2 saturated conditions
    - Daytime leaf starch accumulation and nighttime starch degradation
    - Daytime retention of leaf soluble sugars and nighttime export of soluble sugars in fully developed donor leaves at R3

- Results indicated that nighttime leaf starch degradation and export of carbohydrates is suppressed by low night temperatures, and photosynthetic performance and yield of starch accumulators and nighttime exporters of carbohydrates is affected by low night temperatures

- Cold acclimation of soybean varieties from early stages of plant development (V1 growth stage to maturity) grown under long day conditions led to the differentiation of germplasm according to growth phenotype, the days to maturity, reproductive development, and seed composition. The superior cold stress tolerance of early maturity soybean varieties was associated with minimal changes in days to maturity, number of pods, yield, seed weight and increased seed protein content.

- Differentiation of soybean germplasm was only possible when night temperatures dropped to 10°C or lower. Otherwise, all varieties maintained the same maturity and growth phenotypes

- Growth under short day conditions was found to diminish the negative effects of cold acclimation to low night temperatures when grown under long day conditions. Thus, indicating the interactive nature of cold acclimation and photoperiod on maturity, plant phenotype, and seed composition.

Soybean Cluster - Activity 5

Title: Northern latitude soybean – physiology of yield formation and beating the cold

Lead Researcher: Rosalind Bueckert, University of Saskatchewan

Background

Early Maturity Group (MG) 00 and 000 soybean cultivars are available from industry, many with herbicide resistance or identity preserved traits, but growing the crop remains a challenge in cool or dry years. Western Canada is a semi arid environment lacking three important environmental factors: warm days, warm nights, and water. This project focused on describing growth and yield performance of three groups of soybean, Early 00 (late MG 00), Ultra Early 00 (early MG 00) and Super Ultra Early 000 (MG 000).

This project evaluated cool temperature and abiotic stress on yield formation processes in a range of soybean varieties suited to very short seasons, including the best short season material from the short season soybean breeding programs of Dr. Tom Warkentin at the Crop Development Centre at the University of Saskatchewan, and Dr. Elroy Cober at the Ottawa Research and Development Centre at Agriculture and Agri-Food Canada.

The goal of this work was to assess the effects of cool temperature and stress on yield formation in the field, to identify key traits for varietal improvement so northern latitude soybean production can beat the cold.

Research Approach

- The development of early soybean varieties was tracked through the growing season using crop heat units and water availability, and physiological performance of soybeans in northern Saskatchewan was determined across multiple growing seasons (2018-2023)

- The progression of reproductive growth was monitored, reproductive limitations were identified, and yield components were measured

Research Findings (2018-2023)

- Soybean progression in response to heat is characterized using corn heat units (CHU). A lack of moisture (less than 100 mm cumulative rainfall by R1) can delay plant progression through reproduction. In some cases, delays in dry years of almost 1000 CHU can occur. Usually, soybean in western Canada requires between 2250 to 2500 CHU to reach maturity, with Saskatchewan closer to 2300 CHU by R8 (maturity). This study found that 900-920 CHU are needed to reach flowering or R1.

- The three subgroups, Early 00, Ultra Early 00 and Super Ultra Early 000 were found to have similar node and branch performance, although Ultra Early and Super Ultra Early varieties were more lush, with more branches. Yields were often similar for the three subgroups in reasonable rain years.

- Branches were found to carry additional yield in 000 and 00 cultivars, but in drought years, drought was found to compromise yield, and plants were found to have fewer branches and fewer pods per branch.

- MG 000 soybean cultivars yielded more than MG 00 in drought because most MG 000 cultivars mature earlier and therefore avoid the peak of the drought. While smaller in appearance, 000 cultivars yielded better. Indeterminate MG00 cultivars may do better in years where rainfall returns in August.

- **Recommendation for growing soybeans in cooler or drier regions**: Consider starting with MG 000 cultivars. As confidence, experience and rainfall years improve, farmers may consider introducing later MG 00 cultivars. While the protein concentrations in earlier soybean varieties can be lower, plant breeders are working toward making improvements in this space.

Soybean Cluster - Activity 6

Title: Breeding for soybean cyst nematode (SCN) resistance using marker assisted selection

Lead Researcher: Louise O'Donoughue, CÉROM

Background

Soybean cyst nematode (SCN) is a major soybean pest. It was first reported in Ontario in 1988 and has since been reported in Quebec and Manitoba. Though there are SCN-resistant soybean varieties available in North America, most of these have been bred for later maturities, so there are not as many varieties available for the target maturity zones that exist in Canada (especially in Manitoba and Quebec). More alarmingly, 90% of the SCN-resistant varieties have been developed from a single source of resistance to SCN, namely, PI88788, and some SCN populations are overcoming that source of resistance.

The goal of this research activity was to develop early maturing SCN-resistant varieties adapted to Canadian environments (MG 1-00) using marker assisted selection.

Research Highlights (2018-2023)

- Since 2018, 156 advanced soybean lines have been tested against 2 types of SCN populations, and SCN-resistance has been confirmed in 37 of those lines. These lines were derived from first generation crosses, using very exotic material with poor agronomics
- The promising SCN-resistant lines are then used in second generation crosses to develop more agronomically favorable material
- Between 2018 and 2023, 67 new second generation crosses have been made, and the material is in various stages of development
- Concurrently, material is being genotyped with markers for two main resistance genes (*Rhg1* and *Rhg4*), as well as maturity genes, to increase the allelic frequency of the desired genes and eliminate any plants that are lacking the appropriate maturity or resistance genes
- Through this process, approximately 16,800 plants have been screened, and marker assisted selection has narrowed the pool down to about 3,766 plants that are predicted to have SCN resistance

Soybean Cluster - Activity 7

Title: Breeding of high yielding resistance & value-added soybean using elite and exotic germplasm

Lead Researcher: Istvan Rajcan, University of Guelph

Background

This research activity aimed to develop non-genetically modified (non-GM) food grade soybean varieties with increased yields, disease resistance, and desired market traits for maturity group (MG) 1-00. More specifically, new soybean varieties developed under this activity were targeted to have the following characteristics:

1. High yields, enhanced by incorporating new alleles from elite Canadian and exotic sources such as elite and modern Chinese varieties

2. Enhanced value and market opportunities for value-added markets, including improved tofu and soymilk properties, high sucrose content, saponin, isoflavones, and modified oil profiles for healthy food and bioproduct markets

3. Improved resistance to white mold

Research Highlights (2018-2023)

- Between 2018 and 2023, **19 new soybean cultivars** were developed and registered as certified food grade soybean varieties with Canadian Seed Growers Association (CSGA).

- These varieties, and variety descriptions, are summarized in the table on the following page.

Variety	Licensed to	RM*	Description
OAC Rush	SeCan	1.0	SCN resistant food grade variety with very strong yield levels for its maturity
OAC Kamran	SeCan	0.6	Food grade variety with imperfect yellow hilum, excellent standability, SCN resistance, and moderately tolerant rating to Phytophthora root rot. Competitive combination of yield and protein levels for growers and IP exporters
OAC Aberdeen	Huron Commodities	1.6	High yielding food grade variety with imperfect yellow hilum and SCN resistance
OAC Attika	CanGro Genetics	0.4	High yielding food grade variety with imperfect yellow hilum
OAC Almond	CanGro Genetics	0.1	High yielding food grade variety with imperfect yellow hilum
OAC Bryce	SeCan	0.8	Food grade variety with imperfect yellow hilum and strong yield levels for lower protein, non-GMO markets
OAC Hastings	SeCan	0.5	Food grade variety with imperfect yellow hilum and slightly later maturity than OAC Strive
OAC Shine	SeCan	0.5	Food grade variety with strong seed protein levels (44.3%)
OAC Dawn	SeCan	0.8	Light brown hilum conventional soybean with strong protein content and competitive yield levels
OAC Casey	SeCan	0.9	Food grade variety with imperfect yellow hilum and good field tolerance to Phytophthora root rot
OAC Malory	SeCan	1.0	Yellow hilum food grade variety with SCN resistance. Slightly shorter maturing than OAC Avatar with higher protein levels and comparable seed size
OAC Elevation	SeCan	1.3	Imperfect yellow hilum food grade variety with large seed size, strong yields and high protein levels (44%)
OAC Cooper	CanGro Genetics	00.7	High yielding food grade variety with yellow hilum
OAC Bounty	CanGro Genetics	0.7	High yielding food grade variety with imperfect yellow hilum, and resistance to Phytophthora root rot
OAC Acclaim	CanGro Genetics	0.5	High yielding food grade variety with imperfect yellow hilum, high resistance to Phytophthora root rot, and above average protein content
OAC Ambrose	SeCan	0.7	Food grade variety with yellow hilum, good standability and very competitive yield levels
OAC Carson	SeCan	0.4	Food grade variety with imperfect yellow hilum, good field tolerance to Phytophthora root rot, and comparable maturity and protein levels to OAC Strive (with slightly smaller seed size)
OAC Bruno	SeCan	0.6	High yielding, imperfect yellow hilum food grade variety with SCN resistance for the lower protein, non-GMO market
OAC Moria	CanGro Genetics	0.5	Imperfect yellow hilum food grade variety with excellent lodging resistance and good tolerance to Phytophthora root rot

* RM = relative maturity

Soybean Cluster - Activity 8

Title: Breeding food grade soybean varieties or germplasm for high yield, better quality or pest resistance

Lead Researchers: Owen Wally, Agriculture and Agri-Food Canada & Kangfu Yu *(retired),* Agriculture and Agri-Food Canada

Background

This research activity targeted the development of food grade non-GM soybean varieties with increased yields and SCN resistance for maturity group 2-2.5.

This research activity also targeted the development of food grade soybean germplasm with unique qualities for niche markets, such as low or null lipoxygenase traits for soymilk and/or soy beverages and unique protein profiles for specific food and processing uses.

Research Highlights (2018-2023)

Seven new soybean cultivars were developed and registered as certified food grade soybean varieties with the Canadian Seed Growers Association (CSGA), summarized in the table on the following page.

In addition to the development of new soybean varieties, specialty soybean germplasm was also developed and registered to Plant Gene Resources of Canada. This specialty soybean germplasm provides valuable genetic material for use by other public and private soybean breeders to incorporate traits of interest into their breeding programs, and further supports growth in the Canadian soybean industry.

Variety	Relative Maturity	Description
AAC Wigle	2.2	A high yielding, high-protein, large-seeded, SCN resistant food grade variety with yellow hilum and acceptable processing quality for foreign and domestic tofu, soymilk, and miso markets. It is well adapted to areas of southwestern Ontario with 3200 or more crop heat units, and has a protein content of 45.8%
AAC Big Ben	2.3	A high yielding, SCN resistant food grade variety with yellow hilum and acceptable processing quality for foreign and domestic tofu, soymilk and miso markets. It is adapted to areas of southwestern Ontario with 3300 or more CHUs
AAC McRae	2.2	A high yielding food grade soybean with yellow hilum, high protein concentration, and acceptable processing quality for foreign and domestic tofu, soymilk, and miso markets. It has excellent SCN and soybean sudden death syndrome (SDS) resistance. It is adapted to areas of southwestern Ontario with 3100 or more CHUs
AAC Nancy	2.5	A high yielding, high protein, large seeded yellow hilum food grade cultivar with excellent levels of resistance to SCN and SDS
AAC Richard	2.3	A food grade cultivar with yellow hilum, high protein concentration, and good processing quality for foreign and domestic soymilk, tofu, and miso markets. It has resistance to soybean cyst nematode (SCN) and is adapted to areas of southwest Ontario with 3100 or more CHUs
OX-221*	2.5	A high yielding food grade soybean with imperfect yellow hilum and good field resistance to SCN for the tofu and soymilk markets
OX-222*	2.5	A high yielding, food grade soybean cultivar with yellow hilum and resistance to SCN for the tofu and soymilk markets

*OX-221 and OX-222 will be considered for licensing through the AAFC variety request for proposal process in March 2023. Company interest in licensing will not be known until after this report has been finalized.

Soybean Cluster - Activity 9

Title: Strategies for effective and durable management of *Phytophthora* and root rot complexes of soybeans

Lead Researchers: Yong Min Kim, Agriculture and Agri-Food Canada; Stephen Strelkov, University of Alberta; and Debbie McLaren (*retired*), Agriculture and Agri-Food Canada

Background

This research activity aimed to expand coordinated surveys for current and emerging soybean root pathogens across Canada, thereby enhancing knowledge and technology transfer activities to help farmers and industry adopt innovative disease management strategies.

Research Goals and Approaches

1. Survey for current and emerging soybean root pathogens and soybean cyst nematode (SCN) in Canada

2. Monitor the spread of sudden death syndrome (SDS) in Ontario and establish a nursery to screen for SDS tolerance

3. Utilize advanced PCR analysis for root rot pathogens to enable precise quantification of target DNA

Research Highlights (2018-2023)

- Coordinated surveys were carried out annually from 160 fields across Canada (Alberta, Saskatchewan, Manitoba, Ontario, Quebec and Prince Edward Island)

- Root rot was confirmed in 100% of the fields assessed

Research Highlights (2018-2023) continued

- Results indicated that root rot was caused primarily by *Fusarium* species (*F. oxysporum*, *F. redolens*, *F. graminearum*, *F. solani*, *F. avenaceum*, and *F. acuminatum*) and the newly identified *Macrophomina phaseolina*

- The pathogenicity of these main species was assessed on a suite of 20 soybean cultivars. The level of resistance varied, suggesting the feasibility of a gene pyramiding approach for resistance to Fusarium root rot and wilt on soybean

- SCN was not identified at quantifiable levels in any of the field samples submitted from outside of Ontario (55 total), indicating slow expansion of SCN in new soybean producing areas

- SDS disease screening nurseries were established at AAFC Harrow, and in an infested field near Chatham, Ontario. A number of lines were tested at these locations from 2020-2022 (57,110 and 127 varieties), with varying levels of tolerance

- An advanced molecular diagnostics technique based on droplet digital PCR (ddPCR) was developed for the predominant *Fusarium* spp., enabling precise quantification of the pathogen in fields, indicating expansion

- Overall, the findings from this research activity provided a deeper understanding of the incidence and spread of root rot diseases associated with the *Fusarium* spp. complex and other emerging pathogens, and can be used to develop management strategies for these diseases affecting soybean across Canada

Soybean Cluster - Activity 10

Title: A new method for precise and reproducible phenotyping of *Phytophthora sojae* isolates in soybean
Lead Researcher: Richard Bélanger, Université Laval

Background

Phytophthora root rot, caused by *Phytophthora sojae,* is one of the most devastating diseases of soybean in Canada.

The current method of phenotyping *Phytophthora sojae* to identify the virulence profile, the hypocotyl assay, is hampered by several limitations.

This research activity proposed to overcome those limitations by developing the first comprehensive phenotyping of *Phytophthora sojae* isolates present in Canadian soybean fields based on a novel reproducible hydroponic bioassay and molecular tools.

Research Highlights (2018-2023)

- A novel hydroponic assay was developed to assess soybean response to *Phytophthora sojae* with better accuracy and reproducibility for both vertical (Rps genes) and horizontal resistance genes
- A direct link was established between genomic signatures and phenotypes of *P. sojae* isolates to quickly and accurately identify virulence patterns against Rps genes

Research Highlights (2018-2023) continued

- A molecular tool was developed to allow the simultaneous diagnosis of six avirulence genes in each *P. sojae* isolate matching the most common Rps genes (1a, 1b,1c, 1k, 3a, 6)

- Comprehensive surveys of *P. sojae* presence in soybean fields were conducted across Alberta, Saskatchewan, Manitoba, Ontario, Quebec, and Atlantic Canada in 2018, 2019, 2020, and 2021

- The application of the molecular diagnostics tool was made available for the first time in a commercial context in 2022, to diagnose *P. sojae* pathotypes in soybean fields

- A comprehensive map of distribution and characteristics (virulence patterns) of *P. sojae* isolates throughout soybean-producing regions in Canada was produced

Soybean Cluster - Activity 11

Title: Ultra early herbicide tolerant soybean

Lead Researcher: Elroy Cober, Agriculture and Agri-Food Canada

Background

This research activity focused on developing early maturity soybean cultivars for Western Canada and identifying and validating early maturity genes useful to breeders to improve yield. This activity aimed to deliver herbicide-tolerant (HT) genetically modified (GM) cultivars adapted to the very short season areas of Canada (maturity groups 00-000)

Research Goals and Approaches

The goal of this activity was the development of ultra early soybean cultivars that have herbicide tolerance. This activity used a combination of breeding and genomics approaches, where potential parental lines were genotyped for early maturity. Subsequently, traditional breeding approaches were to be used to introgress the Roundup Ready 2 Xtend® (RR2X) trait into the early maturing material.

Research Highlights (2018-2023)

Prolonged negotiations to access the RR2X technology caused delays and prevented the release of new ultra early, herbicide tolerant soybean varieties during this five-year time period from 2018 to 2023. Nevertheless, significant progress was made using applied genomics to identify suitable material and markers for early maturity. A number of candidate genes were identified for maturity loci E7 & E8, and diagnostic KASP markers were developed and tested for these candidate genes.

The genomics approach referred to as the “Maturity Diagnostic Toolbox” was developed and used to genotype over 250 cultivars and potential new parent lines for time of flowering and maturity loci/genes, growth habit, and soybean cyst nematode (SCN) resistance.

Oat Project - Activity 1

Title: Breeding, genomics and agronomy research to improve oat yield and quality

Lead Researchers: Weikai Yan, Wubishet Bekele, Baoluo Ma & Nick Tinker (retired), Agriculture and Agri-Food Canada

Background

This research project aimed to improve Canadian oat grain yield and quality through a comprehensive set of objectives that would develop new oat cultivars, enhance genomic selection processes in breeding programs, and develop crown rust resistant germplasm for oats. This activity also explored agronomic practices to achieve high and stable grain yields and quality across the entire country.

Research Objectives and Approaches

This research project had three distinct components, breeding; genomic selection; and agronomy, with the following objectives:

1. To develop new oat cultivars for eastern Canada with improved grain yield and milling quality for end users

2. To improve the selection accuracy in the oat breeding programs at Agriculture & Agri-Food Canada in Ottawa, ON and Brandon, MB using modern genomic tools and approaches

3. To identify optimum nitrogen amounts and application methods, as well as optimum planting density for oat production in different oat growing regions of Canada

Research Highlights (2018-2023)

Breeding efforts resulted in **16 new oat cultivars** developed and released between 2018 and 2023. Among these were five for mega-environment (ME) 1 (southern and eastern Ontario) , eight for ME2 (northern Ontario, Quebec, and Maritimes), and three for ME3 (Canadian Prairies). The four cultivars released in 2019 have already shown significant impact on oat production in Ontario and Quebec. Specifically, AAC Excellence has shown superior yield, grain quality, and β-glucan levels and was listed as the top variety on the 2023 Quebec oat recommendation list. AAC Reid showed 25% higher yield than OCCC trial mean in ME1, superior grain and compositional quality, lodging resistance, and resistance to multiple diseases (crown rust, barley yellow dwarf virus, and powdery mildew). AAC Chandler was one of the top yielders in northern Ontario (ME2). The newer cultivars, which are expected to be better still, are yet to show their impact, but are expected to perform very well in the coming years.

Genomic selection (GS) was introduced into the breeding program at AAFC Ottawa and AAFC Brandon to complement traditional breeding by visual selection. GS was shown to be effective in selecting yield and β-glucan. Two of the 16 cultivars developed under this activity were among the 60 lines selected through genomic prediction in 2017 in the observation nursery. While OA1655-1 was also selected visually, OA1675-1GS was discarded by visual selection for its tall plant height.

Agronomy studies on optimum nitrogen fertilization rates revealed that the maximum economic rate of nitrogen (MERN) in Canada averaged **127 kg/ha** at market prices* and varied by location and years. Estimated yields from MERN fertilization were **5560 kg/ha in western Canada** and **6240 kg/ha** in **eastern Canada.** MERN is lowered as the cost of nitrogen fertilizer increases. Split use nitrogen was also found to improve nitrogen use efficiency. Plant density studies revealed that the **optimum seeding rate for oats was 420 seeds/m^2 for eastern Canada**, which is considerably higher than the OMAFRA-recommended seeding rate of 200-300 in seeds/m^2 in Ontario.

*Cost of grain and N used in economic calculations for the agronomy studies varied by year: 2018-2019: grain @ $246/tonne & N @ $750/tonne; 2020-2023: grain @ $400/tonne & N @ $2200/tonne.

Between 2018-2023, **16 new oat cultivars** were developed & released for eastern Canada

Variety	Licensed to	Adapted To	Description
AAC Excellence	Eastern Grains	ME2	Superior yield, grain quality, and β-glucan levels. Top listed oat cultivar on the 2023 Quebec recommendation list
AAC Reid	SeCan	ME1	Superior yield, grain quality, β-glucan content, resistance to lodging and multiple diseases, yielded 25% > OCCC trial means in Areas 2 & 3 in Ontario
AAC Stature	SeCan	ME1	Good yield grain quality, great ease of threshing and cleaning, yielded 20% higher than OCCC trial means in Areas 2 and 3 in Ontario
AAC Chandler	SeCan	ME2	Superior yield, β-glucan content, lodging resistance, one of the highest yielding in Area 5 in Ontario
AAC Zip	SeCan	ME2	Superior yield and exceptionally good lodging resistance
AAC Wallace	William Houde	ME2	Superior yield & grain quality, lodging resistance, one of the highest yielding cultivars in Quebec
AAC Wight	SeCan	ME2	Superior yield & β-glucan content
AAC Hunt	SeCan	ME3	Superior yield & grain quality
AAC Dehaan	SeCan	ME1&3	Superior yield, grain and compositional quality, Quaker preferred variety
OA1444-5-19 (registered name TBD)	SeCan	ME1	Superior yield, grain quality, β-glucan content, lodging and rust resistance
OA1609-7 (registered name TBD)	SeCan	ME2	Same yield as AAC Nicolas in Quebec with slightly improved grain and compositional quality
AAC Fedak	To be tendered	ME3	Superior yield, grain & compositional quality, rust resistance, likely to be approved by Quaker as a preferred milling oat in March 2023
AAC Molnar	To be tendered	ME2	Same yield as AAC Nicolas in Quebec, superior grain and compositional quality
OA1634-1 (registered name TBD)	To be tendered	ME3	Superior yield, grain and compositional quality
OA1655-1 (registered name TBD)	To be tendered	ME1	Superior yield, grain and compositional quality
OA1658-1 (registered name TBD)	To be tendered	ME2	Superior yield & grain quality, likely to be approved by Quaker as a preferred milling oat in March 2023

* Oat growing regions in Canada are divided into three mega-environments (MEs). ME1 includes southern and eastern Ontario; ME2 consists of northern Ontario, Quebec and the Maritimes; and ME3 consists of the Canadian Prairies

Corn Project - Activity 1

Title: Development of short season, cold tolerant, disease resistant corn inbreds

Lead Researchers: Aida Kebede, Agriculture and Agri-Food Canada and Lana Reid (*retired*), Agriculture and Agri-Food Canada

Background

This research activity used conventional corn breeding methodologies enhanced by double haploid (DH) inbred production, and specialized screening techniques for cold tolerance and disease resistance, to develop early-maturing cold-tolerant corn inbreds and inbreds with improved disease resistance to Gibberella ear rot (GER), northern corn leaf blight (NCLB), Goss's wilt, common rust and eyespot.

Research Approaches

- Multiple yield trials were conducted annually in Alberta, Manitoba, Quebec, Ontario and PEI to assess performance of advanced genetic material
- Disease nurseries for GER, NCLB, common rust and eyespot were conducted in Ottawa, and one new disease nursery for Goss's wilt was established in Manitoba, to assess the susceptibility of material to key corn diseases
- Annual surveys for current and emerging diseases were also conducted to continue to guide the inbred development program on which diseases to put more resources into and to scout for new/emerging diseases

Research Highlights (2018-2023)

- **21 new elite corn inbreds** were released to the corn industry, summarized in the table on the following page
- The first Canadian public disease screening nursery for Goss's wilt was established in Carberry, MB, and protocols for screening for Goss's wilt were published
- Annual surveys were completed to monitor current and emerging diseases, guiding Agriculture and Agri-Food Canada and the Canadian corn seed industry on which diseases to focus their corn germplasm development efforts on
- A double haploid (DH) breeding approach was developed and established for inbred development

Summary of corn inbreds developed and released between 2018 and 2023

Inbred	Year Released	Gibberella ear rot	Common rust	NCLB[1]	Eyespot	Other notes
CO465	2018				Resistant	Early maturing[2]
CO466	2018				Resistant	
CO467	2018					Early maturing
CO468	2018					
CO469	2018					
CO470	2018				Resistant	
CO471	2018		Resistant	Resistant	Resistant	
CO472	2018		Resistant	Resistant		
CO473	2018		Resistant	Resistant		
CO474	2019		Resistant		Resistant	Early maturing
CO475	2019	Resistant				
CO476	2019	Resistant				
CO477	2020					Sugarcorn
CO478	2020		Resistant			Sugarcorn
CO479	2020					Sugarcorn
CO480	2020		Resistant			Sugarcorn
CO481	2022	Resistant				Early maturing
CO482	2022		Resistant			Early maturing
CO483	2022	Resistant				Early maturing
CO484	2023	Resistant				Early maturing
CO485	2023	Resistant				Early maturing

1. NCLB – Northern corn leaf blight

2. Early maturing means suitable for the 2200-2500 CHU regions of Canada, especially Manitoba

Corn Project - Activity 2

Title: Cross-Canada agronomic & environmental benefit of advanced 4R nitrogen management of grain corn

Lead Researchers: Mario Tenuta, University of Manitoba; Craig Drury, Agriculture and Agri-Food Canada (AAFC); David Hooker, University of Guelph, Joann Whalen, McGill University; Gaétan Parent, AAFC and Curtis Cavers, AAFC

Background

This research activity aimed to develop advanced 4R (Right Source, Right Rate, Right Time, and Right Place) nitrogen management strategies for Canadian corn producers that enhance productivity and environmental performance (nutrient leaching and GHG emissions) for nitrogen-intensive corn production.

Research Approaches

This research met an important need to increase the use efficiency of nitrogen fertilizers to hold or reduce nitrogen fertilizer rates in grain corn without decreasing yields. Specifically, the project explored the economic and environmental impacts of advanced 4R nitrogen management practices with grain corn, and examined whether in-season nitrogen testing and rate adjustments should be included in advanced 4R practices. Four high-efficiency fertilizers were compared to liquid urea ammonium nitrate fertilizer at planting: ESN, SuperU, Agrotain and Agrotain+ across sites in Ontario, Quebec and Manitoba.

Research Highlights (2018-2023)

Nitrogen application; source, timing and placement studies

Specifically in Ontario, single/double injection bands were compared with broadcast applications regarding nitrogen losses and grain yield.

In 2018, broadcast surface application of urea and SuperU without incorporation gave lower yields than single and double slot injection of UAN, with or without Agrotain+. SuperU provided yields on par with side-dressing of UAN at the highest rate.

Research Highlights (2018-2023) continued

In 2019, broadcast application of urea and SuperU outperformed injected UAN sources in terms of yield, and double slot injection of UAN sources was better than single-slot.

In 2020, yields were higher with an in-season application of UAN (either single or double slot injection) compared to broadcast application at planting.

With respect to emissions, in 2020, Agrotain+ reduced nitrous oxide (N_2O) more for double-slot than with single-slot injections. For ammonia emissions, SuperU reduced these with broadcast application at planting, but single or double injection of UAN was even more effective.

In Quebec, corn grain yield was greater across all three years (2018, 2019 and 2020) when the nitrogen fertilizer was split in two applications rather than broadcast on the field before planting. Split application delivered 25% of the recommended nitrogen fertilizer in the form of urea within 5 cm of the corn seed at planting. The remaining 75% of the required nitrogen was applied as a liquid urea ammonium nitrate solution when corn reached the V5-V6 growth stage. Corn grain yield was greater (2018) and tended to be higher (2019, 2020) when urea ammonium nitrate was injected at a depth under 5 cm compared to being dribbled on the soil surface, or injected at a depth deeper than 5 cm.

The urea and nitrification inhibitors in Agrotain and Agrotain+ were associated with more corn grain yield at higher N application rates in 2018 and 2019, but not in 2020 due to the weather conditions in Quebec.

In terms of application timing, in Manitoba, results showed that delaying split nitrogen applications (after V4 stage) did not improve corn yields compared to earlier split nitrogen applications. However, in Ontario and Quebec, a more positive response to later nitrogen application (V8 to V12) was observed, due to regional differences in climate.

Research Highlights (2018-2023) continued

Optimal nitrogen application rate for grain corn using in-field measurements

In Quebec, studies showed that the use of near infrared spectroscopy (NIRS), Greenseeker and other reflectance sensors prior to post-emergence application of nitrogen fertilizer did not improve the determination of the optimal nitrogen rate for corn.

The use of nitrogen nutrition index (NNI) alone also did not result in an effective determination of the optimum nitrogen rate for corn. Results suggest that a more effective diagnosis would need to consider the lower and upper parts of the corn plant in order to detect nitrogen deficiency in corn.

Optimal nitrogen application rate for grain corn using modeling

An optimal nitrogen application rate for grain corn can be determined using modelling at the V8 growth stage. The model incorporates many parameters, ranging from precipitation, light, soil pH, soil phosphorus, potassium, calcium, and aluminum content to corn plant nitrogen, corn aerial biomass, and soil carbon and sand. The model takes into account data from this study, as well as data from other ongoing projects. The relationship was found to be valid even when combining contrasting data from sites located in both Manitoba and Quebec, thereby potentially developing a predictive model for all of Canada. The model is currently being validated at the Quebec Research and Development Centre, Agriculture and Agri-Food Canada.

Overall, modeling analysis using traditional data related to soil, climate and plants was found to be more effective than using NIRS and light reflectance when predicting the optimum nitrogen rate for corn. This is likely due to the fact that a single parameter, whether NNI, soil nitrate content, or reflectance at a certain wavelength of foliage, rarely, if ever, directly determines the optimal nitrogen rate for corn production. It is more reliable for a multitude of parameters to be used together, simultaneously, and factors that maximize crop yields are multifactorial, comprising soil phosphorus concentration, soil pH, calcium, magnesium, and other vital elements.



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CANADIAN FIELD CROP RESEARCH ALLIANCE

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About the CFCRA

The CFCRA is a not-for-profit entity founded in 2010 with an interest in advancing the economic and environmental sustainability of field crops in Canada, particularly soybean, corn, wheat, barley and oat. The CFCRA is comprised of provincial producer organizations and industry partners, including: Atlantic Grains Council; Producteurs de grains du Québec; Grain Farmers of Ontario; Manitoba Crop Alliance; Manitoba Pulse & Soybean Growers; Saskatchewan Pulse Growers; Prairie Oat Growers Association; SeCan; and FP Genetics.

For more information on the CFCRA please visit
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