1AgriScience Program - Projects Component

Annual Performance Report

Name of Recipient: Canadian Field Crop Research Alliance (CFCRA)	
Project Title: Breeding, genomics and agronomy research to improve oat yield and quality	
Project Number: ASP-001	**Period Covered by the Report**: 2019/04/01 to 2020/03/31
Project Start Date: 2018/04/01	**Project End Date**: 2023/03/31

1. Performance Measures – Project Level

In the performance measures table below, please provide the results and achievements that were finalized during the reporting period, that combines all the CA and CRDA activities. Do not include results that are not final or that will continue to be developed. It is quite possible that in the first year or two, there may not be any results to report. Please see Annex A for a description of each performance measure.

Performance Measure		Results Achieved	Provide a brief description of each final result achieved during the reporting period.
1.	Number of highly qualified personnel (HQP) working on funded activities (HQP refers exclusively to current Master and PhD students)		
2.	Training/knowledge transfer events		
	2.1 Number of training/knowledge transfer events organized by the recipient	1	The Ottawa Oat Day, July 18, 2019
	2.2 Number of presentations made in training/knowledge transfer events	7	• Bruce Roskens, Grain Millers, Inc.: “Challenges of oat variety development in the 2020’s” • Susan Tosh, University of Ottawa: “The top ten reasons to eat oats” • Weikai Yan: “Overview of the CFCRA Oat project and update on new oat cultivars” • Nick Tinker and Wubishet Bekele: “Genomics-assisted breeding of oat at Ottawa RDC” • Charlene Wight: “Oat data management: Back in the POOL and mapping the way forward”

Performance Measure		Results Achieved	Provide a brief description of each final result achieved during the reporting period.
			• Bao-Luo Ma: "Economic Optimum Rates of N: Site-specific Responses of Oat cultivars and Crop Lodging" • Allen Xue: "Prevalence and severity of oat diseases in Ontario, 2009-2018"
3.	Number of participants at training/knowledge transfer events	50	• 50 attended the Ottawa Oat day – July 18, 2019
4.	Number of new knowledge transfer products developed		
5.	Number of papers published in peer reviewed journals	12	1. WA Bekele, A Itaya, B Boyle, W Yan, JM Fetch, NA Tinker. 2020. A targeted genotyping-by-sequencing tool (Rapture) for genomics-assisted breeding in oat. Theoretical and Applied Genetics 133 (2), 653-664 2. Blake, V.C., Woodhouse, M.R., Lazo, G.R., Odell, S.G., Wight, C.P., Tinker, N.A., Wang, Y., Gu, Y.Q., Birkett, C.L., Jannink, J.-L., Matthews, D.E., Hane, D.L., Michel, S.L., Yao, E., Sen, T.Z. (2019). GrainGenes: centralized small grain resources and digital platform for geneticists and breeders, 2019 http://dx.doi.org/10.1093/database/baz065 3. Menzies, J.G., Xue, A.G., Gruenke, J., Dueck, B., Deceuninck, S., and Chen, Y. 2019. Virulence of Puccinia coronata var avenae f. sp. avenae (oat crown rust) in Canada during 2010 to 2015. Can. J. .Plant Pathol. 41: 379–391. 4. Song, X., Zhou, G., Ma, B.-L., Wu, W., Ahmad, I., Zhu, G., Yan, W., Jiao, X. (2019). Nitrogen application improved photosynthetic productivity, chlorophyll fluorescence, yield and yield components of two oat genotypes under saline conditions, 9(3), http://dx.doi.org/10.3390/agronomy9030115 5. Sunstrum, F.G., Bekele, W.A., Wight, C.P., Yan, W., Chen, Y., Tinker, N.A. (2019). A genetic linkage map in southern-by-spring oat identifies multiple quantitative trait loci for adaptation and rust resistance, 138(1), 82-94. http://dx.doi.org/10.1111/pbr.12666 6. Wu, W., Ma, B.-L. (2019). Erect–leaf posture promotes lodging resistance in oat plants under high

Performance Measure		Results Achieved	Provide a brief description of each final result achieved during the reporting period.
			plant population, 103 175-187. http://dx.doi.org/10.1016/j.eja.2018.12.010 7. Xue, A.G., and Chen, Y. 2019. Diseases of oat in central and eastern Ontario in 2018. Can. J. Plant Pathol. 41 (Suppl.): 87-88. https://doi.10.1080/07060661.2019.1619270 8. Xue, A.G., Chen, Y., Seifert, K. Guo, W., Blackwell, B.A., Harris, L.J. , and Overy, D. 2019. Prevalence of Fusarium species causing head blight of spring wheat, barley and oat in Ontario during 2001–2017. Can. J. .Plant Pathol. 41: 392–402. 9. Xue, A.G., Menzies, J., Chen, Y., Yan, W., Ma, B.L., Guo, W., Gao, F., Liu, J., and Ren, C. 2020. Reactions of Eastern Canada oat genotypes to Puccinia coronata f. sp. avenae. Can J Plant Sci. In press. https://doi.org/10.1139/CJPS-2019-0146 10. Yan W, Fregeau-Reid J, Mountain N, Kobler J. Genotype and management evaluation based on Genotype by Yield*Trait (GYT) analysis. Crop Breed Genet Genom. 2019;1:e190002. https://doi.org/10.20900/cbgg20190002 11. Yan W, Tinker NA, Bekele WA, Mitchell-Fetch J, Fregeau-Reid J. Theoretical Unification and Practical Integration of Conventional Methods and Genomic Selection in Plant Breeding. Crop Breed Genet Genom. 2019;1:e190003. https://doi.org/10.20900/cbgg20190003 12. Theory and practice to unify and integrate genomic selection and conventional breeding (Yan et al. 2019) Crop Breeding, Genetics and Genomics 2019;1:e190003. https://doi.org/10.20900/cbgg20190003. Published May 20, 2019.
6.	Number of new technologies (new products, practices, processes and systems) that are developed		
7.	Number of new technologies (new products, practices, processes and systems) that are assessed under		

Performance Measure		Results Achieved	Provide a brief description of each final result achieved during the reporting period.
	research conditions		
8.	Number of new technologies (new products, practices, processes and systems) that are demonstrated on-farm or in-plant		
9.	Number of new technologies (new products, practices, processes and systems) that attain Intellectual Property (IP) protection.	2	• OA1854-3 supported for full registration by RGCQ and tendered by SeCan • OA1894-1 supported for full registration by RGCQ and tendered by SeCan
10.	Number of new technologies (new products, practices, processes and systems) that are utilized		

2. Activity-level Information

In this section, please complete one table for each activity. For activities with both a CA and CRDA component, please integrate the results into one table.

CA Activity Number: 1B / CRDA Activity Number: 1A
Name(s) of Activity: Breeding, genomics and agronomy research to improve oat yield and quality
Principal Investigator: Weikai Yan
Summary of Activity Please provide a high-level summary of this activity that includes an introduction, objectives, methodology, deliverables, results and discussion. Technical language can be used in this section.

INTRODUCTION

Oat is an important, multi-purpose cereal in Canada that is grown for grain, straw, forage, or land cover. Oat grain is regarded as a healthy human food, largely due to the presence of beta-glucan (BGL) and other soluble fibers in the oat groat, which have been implicated in reduced risk of heart disease, lowered blood pressure, and lowered risk of type-II diabetes. Grain yield, groat content (i.e. milling yield), and BGL content are key targets for improvement. Protein, test weight, and kernel weight are considered secondary targets for improvement. Additionally, oat millers require a groat oil content of less than 8% to meet the FDA healthy food labeling requirements. To achieve high and stable yield and quality, lodging resistance is required under high-yielding environments, and resistance to crown rust is required in some production regions. Our nation-wide multi-disciplinary research team proposes to improve these characters through breeding, genomics, and agronomy. There are seven objectives in this proposed project: 1) developing new oat cultivars with improved grain yield and quality; 2) identifying optimal agronomic practices to achieve high and stable grain yield and quality; 3) enhancing the current oat breeding procedures in both the Ottawa and Brandon programs with genomic selection; 4) improving the ability to deploy appropriate rust resistance genes through a survey of Pc gene profiles in existing cultivars, and Pc gene effectiveness in western and eastern Canada; 5) enhancing genetic diversity in North American oat breeding programs through a joint testing and genotyping network that promotes germplasm exchange and provides information about adaptation; and 6) developing a multi-faceted approach to data and knowledge management that enhances all objectives of this project and benefits world-wide pre-competitive oat research. Collectively, these six objectives have an ultimate goal, which is to improve Canadian oat grain yield and quality. The expected impacts on the Canadian field crop sector include: 1) increased income for Canadian oat growers, 2) increased profit of Canadian/American oat processors, 3) increased health of oat consumers, 4) increased resilience of Canadian agriculture against biotic and abiotic stresses and adaptation to climate change, and 5) enhanced Canadian soil and environmental conservation due to the planting of more oats in rotation with other crops. Through these outcomes, this project addresses the following AAFC priorities: 1) to enhance Canadian environmental sustainability in the face of climate change, and 2) to enhance knowledge and technology transfer activities and thereby the resiliency and productivity of the agriculture.

OBJECTIVES

Objective #1: Cultivar development

• By 2023, to release at least one new cultivar for subregion1, with ≥11% higher grain yield than the mean of check cultivars AAC Bullet and AAC Roskens while keeping the groat level of the check cultivars (≥72%) (High b-glucan is not required for oat grain not used for milling).

• By 2023, to release at least one new cultivar for subregion2, with ≥11% higher yield than the mean of check cultivars AC Rigodon, Dieter, and Synextra while keeping the beta-glucan (≥4.2%) and groat (≥72%) levels of the check cultivars.

• By 2023, to release at least one cultivar for subregion2, with ≥5.0% beta-glucan while keeping the yield and groat levels of the check cultivars AC Rigodon, Dieter, and Synextra.

Objective #2: Agronomic research to develop oat production guide

• Cultivar and region specific production guide on N rate and method and planting density if there are genotype by treatment and region by treatment interactions.

• Scientific manuscripts reporting the researches

Objective #3: Genomic selection

• GS derived lines from this project are at an advanced stage of performance testing, and GS

lines from the GFII project could be recommended as varieties.
• Scientific report on the relative efficiency of GS vs. visual selection.
• Recommendation on the use of GS in future oat breeding within Ottawa and Brandon oat breeding programs.
• Genotype and phenotype database, and highly predictive GS models for ongoing use.

Objective #4: Pyramiding crown rust resistance using gene markers

• 2018: data on crown rust response of two populations (10W60 and 15F082)
• 2018: Genotype data of the two populations
• 2019: Selectable markers for PcTX, Pc59, and/or Pc61.
• By 2022, >10 crown rust resistant lines
• By 2022, >1 oat line carrying ≥3 Pc genes

Objective #5: Crown rust pathogen virulence and host resistance gene survey

• Report on the crown rust rating of the oat crown rust differential lines tested in Ottawa and Morden (Yan, Menzies)
• Survey report of oat field in eastern Canada and western Canada and publish the annual survey report (Menzies and Xue)
• Report of reactions of newly released oat cultivars and promising lines to different crown rust races (Menzies)

Objective #6: North American joint oat breeding and testing

Yearly data of grain yield, agronomic traits, grain quality, any diseases, and compositional quality for c. 240 new breeding lines from 4 breeding programs at 5 locations (Ottawa, Brandon, Saskatoon, Lacombe, and Fargo) (Yan, Mitchell Fetch, Beattie, and McMullen)

Objective #7: Oat Data and Knowledge Management

All interim database deliverables were populated and enhanced until project completion. An overall project report describing project accomplishments in knowledge management is published.

MILESTONES

Objective #1: Cultivar development (yearly)

1) About 50 new crosses
2) About 300 F4:5 or F6:7 lines, to be tested in next year's Home Test.
3) Yield and quality data of c. 400 breeding lines from Home Test.
4) Yield and quality results of c. 60 breeding lines tested in the Preliminary Test.
5) Yield and quality data of c. 30 breeding lines tested in the registration test.
6) Up to 2 oat lines supported for registration

Objective #2: Agronomic research to develop oat production guide

2018/2019: Data and summary of the 1st year Exp1.
2019/2020: 2nd year data pf Exp1 and summary across two years for Exp1
2020/2021: 3rd year data for Exp1, summary across years, crop guide on optimal N.
2021/2022: first year data of for Exp2 and Exp3
2022/2023: 2nd year data for Exp2&3 and final summary, production guide on N application and planting density.

Objective #3: Genomic selection

Each year starting from year 1 (2018/19):
-GBS markers for about 2000 new breeding lines (about 1000 from each of Ottawa and Brandon);
-900 lines from training population genotypes and phenotyped, added to database, and used to update GS predictions for both breeding programs.
-80 lines from each of Ottawa and Brandon selected based on GS and increased in New Zealand

Each year starting from year 2 (2019/20):
-80 GS-selected lines from each breeding program are tested in performance tests together with selections from regular breeding streams.
-Evaluation of the performance of GS breeding streams, and overall performance of breeding programs relative to common checks.

Objective #4: Pyramiding crown rust resistance using gene markers
2018/19: Selectable markers for PcTX.
2018/19: Crosses combining Pc genes (91, 94, 59, 61, TX).
2019/20: selectable markers for Pc59 and/or Pc61; Three-way or four-way crosses segregating for 3+ Pc genes.
2020/2021: 2 populations of 400 F4:5 lines segregating for 3+ Pc genes.
2021/2022: crown rust data from 2 populations (Yan, Menzies).
2022/2023: resistant breeding lines with 3 or 4 effective Pc genes.

Objective #5: Crown rust survey (annually)
• Report on the crown rust rating of the oat crown rust differential lines tested in Ottawa and Morden
• Report Survey results of oat field in eastern Canada and western Canada
• Report of reactions of key oat cultivars and promising lines to different crown rust races

Objective #6: North American joint oat breeding and testing
• Yearly data of grain yield, agronomic traits, grain quality traits, and diseases for c. 240 new breeding lines from 4 breeding programs at 5 locations and compositional quality from at least one location.
• Genotypes and phenotypes of ENCORE incorporated to train and evaluate GS.

Objective #7: Oat Data and Knowledge Management
• 2018: Formal linkages and curational arrangements with T3/Oat, GrainGenes, ORI, and POOL.
• 2019: POOL is up-to-date with recent germplasm from major North American programs and queries in POOL provide a gateway to relevant data in T3/Oat and GrainGenes.
• 2020: Rust gene nomenclature is up-to-date and QTL survey is complete.
• 2021: Rust genes and QTL can be queried on the oat genome sequence to find candidate genes or develop better markers.
• 2022: Simple or advanced queries available for in-depth knowledge on Canadian oat varieties.
• 2023: Useful queries are available for breeders to interrogate germplasm from crop wild relatives.

RESULTS

Executive Summary

The project has run smoothly and the objectives of all three major research areas have been fulfilled or surpassed. 1) For cultivar development, two new oat lines, OA1584-3 and OA1594-1, were supported for full registration by RGCQ (Quebec) on Jan 29, 2020 and were claimed by SeCan under the CRCRA framework. These lines have yielded 14% and 12% higher than control cultivars over 2017 to 2019 across Quebec. Two crown rust resistant oat lines released a year earlier, OA1453-2 (AAC Caliber) and OA1444-4 (AAC Reid), also claimed by SeCan, yielded 36% and 30% higher than trial means in southern Ontario. 2) In genomic selection, a comprehensive theoretical framework and a pragmatic strategy were formally published and validated with yield trial data. Among 40 2017-genomic predicted lines, OA1652-3GS, OA1662-1GS, and OA1675-1GS yielded among the best in the 2019 Preliminary trials. Some 2018 genomic predicted lines also yielded well in the 2019 Home Test. 3) In the agronomic study, two years of N fertilizer rate study (3 oat cultivars with 6 N rates) at 8 locations across Canada were completed and useful results have been obtained for developing best management strategies. Preliminary analysis of the results showed that yields responded positively to N rates at most sites in both years. This allowed us to calculate the most economic rate of N (MERN) rates on the sites that showed positive responses. The MERN values varied from 120 to 161 kg N ha^{-1}, depending on the location. The estimated yield at MERN ranged from 4902 kg ha^{-1} at Beaverlodge AB to 7187 kg ha^{-1} at Lacombe AB.

Summary by objective

Objective #1: Cultivar development

- Two lines, OA1584-3 and OA1594-1, tested from 2017 to 2019 in the Quebec provincial oat registration trials, were supported for full registration by RGCQ on Jan 29, 2020. In 30 trials across Quebec these lines have yielded 14% and 12% higher, respectively, and have higher beta-glucan content, than official control cultivars. Both lines showed slightly higher yield and beta-glucan levels than AAC Nicolas, currently the highest yielding cultivar in Quebec.
- 33 lines were tested in the ORDC registration trials. Some superior lines were identified, including OA1623-4, OA1623-5, and OA1644-13, which will be tested again. One line, OA1439-1 was tested in the Western Cooperative Oat Registration Test (WCORT) and showed high yield and beta-glucan and was invited for a 2^{nd} year test in 2020. Another line, OA1627-1, which was tested in 2018 ENCORE and 2019 ORDC Registration Test, showed superior yields in western locations and will be entered in WCORT in 2020 as well.
- 55 lines, including 5 GS-2017 lines, were tested in the Preliminary Test in conjunction with ENCORE. Based on the data, 18 lines, including 3 GS-2017 lines, will be advanced to the registration trials. The 3 GS-2017 lines will be tested in Quebec because they showed superior yield in the non-rust regions.
- 432 lines were tested in 2019 Home Test at three locations (Ottawa, New Liskeard, and Normandin). This test serves multiple purposes: to identify superior oat genotypes for release as new cultivars, to generate phenotypic data for GS model development, and to study the relative selection efficiency of GS versus visual selection. The Home Test assessed 60 visually selected lines from 2018 hills (VS), 60 genomics predicted high yielding lines (GS), and 20 genomics predicted low yielding (GC) from the same selected crosses. Based on the data, 14 GS lines, 2 GC lines, and 13 VS lines, along lines from the regular breeding stream, will be advanced to the 2020 Preliminary trials.
- 1350 observation plots were planted and visual selection was conducted.
- 11800 hills were grown and visually assessed.
- 58 new crosses were made to incorporate the best new lines identified from various yield trials. These include 10 naked*covered crosses, with the intention of developing superior lines of both covered and naked oats. The latter is a new priority to meet emerging needs of oat growers and industry.
- Greenhouse advance of new crosses was conducted year-round as usual
- Breeder Seed for OA1453-2 (AAC Caliber), OA1415-2 (AAC Excellence), OA1426-2 (AAC Clyde), OA1436-1 (AAC Roberval), and OA1444-4 (AAC Reid) were produced. Pre-Breeder Seed for OA1568-6 (AAC Chandler) was produced.

Objective #2: Agronomic research to develop oat production guide

The N rate study

- A 2nd year N-study was conducted at 8 locations across Canada (Ottawa ON, New Liskeard ON, Normandin QC, Melfort SK, Winnipeg MB, Yonkton SK, Beaverlodge AB, and Lacombe AB) and useful results were obtained. Lacombe did not run the experiment in 2018 due to bad weather conditions and late approval of the project. The Yorkton SK was newly added in 2019. Data on yield and agronomic traits have been collected. Data from the Winnipeg site (run by Richardson) from both years have yet to be received.
- Results from preliminary analysis of the data showed the following trends: 1) oat grain yield responded positively to increasing N rates at 7 site-years ($p \le .001$); 2) there is strong positive correlation between yield and plant height for 5 of the 7 locations in 2019 ($p \le .001$). 3) the estimated most economic rates of N (MERN) for Ottawa, Melfort, Yorkton, Lacombe and Beaverlodge were 142, 161, 131, 120 and 152 kg N ha^{-1}, respectively, for preplant application of urea. The estimated yield at MERN was 6327 kg ha^{-1} (Ottawa), 6896 kg ha^{-1} (Melfort), 5644 kg ha^{-1} (Yorkton), 7187 kg ha^{-1} (Lacombe), and 4902 kg ha^{-1} (Beaverlodge). No response was observed at New Liskeard and Normandin in either year.

Objective #3: Genomic selection

- We have switched to a Rapture based oat genotyping assay which is performing as well or better than the previous GBS assay (see output Bekele et al, 2020).
- GBS-Rapture markers were assayed for 2500 new breeding lines (2000 from the Ottawa program and 450 from the Brandon program).
- 900 lines from training populations (HT test in the Ottawa Program and B-test in the Brandon program) were genotyped (for DNA markers) and phenotyped (yield trials), and data were added to the database to update GS predictions for both programs.
- 80 lines (60 GS-good and 20 GS-poor) were selected based on GS for each program and were increased in New Zealand. These will be tested in the 2020 yield trials.
- among the GS and the comparable VS lines tested in the 2019 Home Test, the highest yielder was a GS line. Among the GS lines and comparable lines from regular breeding streams tested in the 2019 Preliminary trials, the highest yielder was also a GS line (OA1652-3GS). Both GS lines had the smallest test weight and kernel weight in the respective trials, however.

Objective #4: This objective was removed from the original proposal due to reduced budget.

Objective #5: Crown rust test and survey (annually)

- 526 new oat lines tested in HT, Preliminary, and Registration trials were screened for crown rust resistance at Heckston ON and crown rust and smut resistance at Morden MB. Field survey for oat diseases were conducted as usual across east and west Canada.
- The crown rust survey was conducted during August 8th to August 16th in central and southwestern Manitoba and south eastern Saskatchewan in 2019. Fifty eight fields with wild oats and 57 fields of commercial oats were surveyed and generally, the incidence and severity of crown rust in the areas surveyed was lower than average in 2019. Thirty eight (33%) of wild oat fields and 21 (18%) of commercial oat fields had plants infected with crown rust. The incidence of crown rust in the commercial oat fields with infected plants ranged from 0 to 50%, with severities ranging from R to 10S. The incidence of crown rust in the 58 fields of wild oats ranged from R to 80%, with severities of 0 to 5S. The incidence and severity of crown rust was greater in Manitoba crop districts 01, 07, 08 and 09. Saskatchewan crop districts had very little crown rust at the time of our survey with SK 01 having the most.

- Twenty oat fields located in the major production areas in Ontario were surveyed for diseases in 2019. Of the 11 diseases surveyed, crown rust, halo blight, barley yellow dwarf, and loose smut were most prevalent, having moderate to severe levels of infection in 12, 4, 2, and 2 fields, respectively. Fusarium head blight (FHB) was observed in all surveyed fields with low severities. *Fusarium poae* and *F. sporotrichioides* were the predominant species isolated from the FHB infected kernels.

Objective #6: North American joint oat breeding and testing

- Data of grain yield, agronomic traits, grain quality traits, and diseases for 166 new breeding lines from 3 breeding programs (AAFC-Ottawa, AAFC-Brandon, and CDC Univ Saskatchewan) at 4 locations (Ottawa ON, Brandon MB, Lacombe AB, and Saskatoon SK) and compositional quality from three locations were obtained and shared to collaborators and the GS group.
- Data of genotypes and phenotypes of ENCORE were incorporated to develop and evaluate GS for both east and west Canada.

Objective #7: Oat Data and Knowledge Management

- Participation in weekly conference calls with the T3/Oat and GrainGenes teams (USDA-ARS) continues.
- 2306 lines were added to the Pedigree of Oat Lines (POOL) database. However, a new version of T3/Oat (using the BreeDBase platform) is in development, so further data entry is on hold.
- Sixty-eight classical and molecular genetic maps of oat were uploaded to GrainGenes.
- A document collating all of the information relating to the locations of rust genes in the oat genome was prepared in collaboration with Kathy Klos, USDA-ARS, Aberdeen, ID.

Lessons leaned

1. In the 2019 Home Test and the Preliminary trials, both GS and visual selection yielded some superior genotypes, which are from different crosses. This suggests that the two approach complement, rather than overlap, in cultivar development. It is important to explore why some GS predicted lines were not selected by visual selection and vice versa to further improve breeding efficiency.
2. Some GS predicted high yielding lines yielded indeed among the best. These lines, however, were poor in test weight, kernel weight, and/or maturity. It is common in plant breeding that the improvement of yield may lead to lowered levels for other breeding objectives. Therefore, multi-trait selection should be considered in next step genomic selection.

New opportunities

- There is an increasing interest in growing naked oat for food in both Canada and the US. Naked oat grain is also a potential export commodity. We have started some naked oat breeding (after long termination of Dr. Vern's work) a few years ago and have developed some new naked lines to be tested in 2020 for potential release. We have also made new crosses to combine the best genetics of Chinese naked oats and Canadian covered oat.

Issues

- Describe any challenges or concerns in achieving the results and deliverables of this activity during the reporting period. How were they overcome or how do you plan to overcome?
- Describe any potential changes to the work plan and the budget during the reporting period. How were or how will they be managed?

None

Key Achievements

A key achievement represents a significant achievement or tangible result that could potentially be applied either by farmers or industry or the science community. In one to three paragraphs, please provide key achievements that meet one of the following criteria:

1) The item has commercial potential (all testing and piloting has been completed);
2) The item has been commercialized; or
3) The item has been adopted by the sector.

Examples of tangible results could include increased sustainability (beneficial management practice), reduced costs, improved productivity or increased profitability. Please note that the information provided will be used for communication purposes only.

If no key achievements have been realized at this stage, please leave this section blank.

1. Two new oat lines: OA1584-3 and OA1594-1 were supported for registration and claimed by SeCan. Two crown rust resistant oat lines released, OA1444-4 and OA1453-2, yielded 136% and 130% of the mean of the trials in southern Ontario. A third line, OA1568-6 also yielded well and showed high beta-glucan content in Quebec.
2. Some GS predicted high yielding lines (OA1652-3GS, OA1662-1GS, and OA1675-1GS) proved to yield well in the 2019 Preliminary trials and will be further tested in Quebec for potential release as new oat cultivars.
3. A simplified and improved genotyping by sequencing (Rapture) was developed and used in genotyping oat breeding lines, which facilitated genomic selection (Output: Bekele et al. 2020).
4. A unified theoretical framework was proposed, under which genomic selection (GS) and conventional selections (including visual selection in the early stages and yield trials in the late selection stages) were unified with regard to dealing with genotype by environment interactions. This theoretical framework led to a pragmatic strategy for GS model development, evaluation, and implementation in the Ottawa oat breeding program (Output: Yan et al., 2019), which proves to work well. This strategy is now extended to oat and barley breeding programs in both eastern and western Canada (the "TUGBOAT" project).

Annex A

Performance Measures Table	
Performance Measures	**Description**
1. Number of highly qualified personnel (HQP) working on funded activities	This includes only individuals who are registered in Master or PhD programs and are working on activities that receive funding through the Canadian Agricultural Partnership. They are only counted in their first year working on projects. For each reported HQP, please provide the following: the name of the student, level of degree, field of study and name of the academic institution.
2. Training/knowledge transfer events	
2.1. Number of training/knowledge transfer events organized by the recipient	This includes events completed in the reporting year that were organized under the project to share results of the activities with audiences who may use that knowledge in the future. Examples could include training events, scientific meetings, symposia, conferences, workshops, industry meetings, field days or webinars. Annual General Meetings do not normally qualify for this category as they are considered to be part of normal day-to-day business. For each reported item, please provide the following: name of the event, name of the organizer and organization, location, and year/month/day.
2.2. Number of presentations made in training/knowledge transfer events	This includes oral presentations and poster presentations at events that are not organized by the recipient, for example, conferences, symposiums or training events. For each reported item, please provide the following: name of presenter, title of presentation, name of the event, location, and year/month/day.
3. Number of participants at training/knowledge transfer events	This includes individuals who attend the events listed and who may use that knowledge in the future.
4. Number of new knowledge transfer products developed	New knowledge could include, but is not limited to: 1) newly acquired knowledge that differs significantly from previously acquired knowledge; 2) existing knowledge that is enhanced to meet different requirements; 3) existing knowledge that is applied in different situations. These are knowledge transfer materials created under the project that have been disseminated to transfer information to audiences who may use that knowledge in the future. Examples could include brochures, factsheets, flyers, guides, articles in trade magazines, technical bulletins and social media items. Only the number of products developed should be reported, not the number of copies that were printed and disseminated. For each reported item, please provide the following: author(s), title of the item, type of the reported item (e.g. brochure), name of the trade

	magazine/publisher and page number(s) if applicable, and year/month/day.
5. Number of papers published in peer reviewed journals	This includes scientific papers that are published in peer reviewed journals. Papers that are not yet published (ex. manuscripts in preparation, under review or accepted) should not be reported. For each reported item, please provide the following: author(s), year of publication, article title, title of journal, volume (issue), and page number(s). If the item is a book or a book chapter, add name of publisher. If the item is an article for conference proceedings, add title of published proceedings, location, and year/month/day.
6. Number of new technologies (new products, practices, processes and systems) that are developed	A new technology could include, but is not limited to: 1) a newly created technology that differs significantly from existing technologies; 2) an existing technology that is modified to meet different requirements; 3) an existing technology that is tested in different situations. New products are goods and services that differ significantly in their characteristics or intended uses from products previously produced and used. Examples could include equipment, software, novel foods or consumer goods. New practices are new agronomic techniques or methods that can be applied directly by producers. New processes are the set of operations performed by equipment in which variables are monitored or controlled to produce an output in labs or processing facilities. New systems are the set of detailed methods, procedures and routines created to carry out a specific activity, perform a duty, or solve a problem. Development consists of the creation of a new product, the generation of a new practice, or the demonstration of utility of a new process or system. This category does not include new varieties. New varieties are only reported under 'Number of new technologies that attain Intellectual Property protection' and/or 'Number of new technologies that are utilized'. Gene sequences, breeding lines and populations are not eligible under this category. To avoid duplication, for any new technologies, only set a target that represents the last stage in the innovation process. For example, a new technology is either developed, or assessed, or demonstrated or utilized.
7. Number of new technologies (new products, practices, processes and systems) that are assessed under research conditions	See the definition of new technologies under #6. Are assessed: when new technologies are evaluated or tested under research conditions.

	This category does not include new varieties. New varieties are only reported under 'Number of new technologies that attain Intellectual Property protection' and/or 'Number of new technologies that are utilized'. Gene sequences, breeding lines and populations are not eligible under this category. To avoid duplication, for any new technologies, only set a target that represents the last stage in the innovation process. For example, a new technology is either developed, or assessed, or demonstrated or utilized
8. Number of new technologies (new products, practices, processes and systems) that are demonstrated on-farm or in-plant	See the definition of new technologies under #6. Are demonstrated: when new technologies are presented to the sector by experiments, prototypes, examples or pilot on-farm or in-plant. This category does not include new varieties. New varieties are only reported under 'Number of new technologies that attain Intellectual Property protection' and/or 'Number of new technologies that are utilized'. Gene sequences, breeding lines and populations are not eligible under this category. To avoid duplication, for any new technologies, only set a target that represents the last stage in the innovation process. For example, a new technology is either developed, or assessed, or demonstrated or utilized.
9. Number of new technologies (new products, practices, processes and systems) that attain Intellectual Property (IP) protection	See the definition of new technologies under #6. Examples for IP protection could include, but are not limited to: plant breeder rights, patents filed, registered trademarks and copyrights, and registered germplasms and released varieties (excluding breeding lines and gene sequences). For each new variety, please provide the registration number, the variety name, and year/month/date.
10. Number of new technologies (new products, practices, processes and systems) that are utilized	See the definition of new technologies under #6. Are utilized: when new technologies are adopted or implemented for use within the sector. Examples may include, but are not limited to: a signed license agreement, a signed letter of intent, a new product that is available on the market, and a new practice which is adopted by farmers. Gene sequences, breeding lines and populations are not eligible under this category. To avoid duplication, for any new technologies, only set a target that represents the last stage in the innovation process. For example, a new technology is either developed, or assessed, or demonstrated or utilized.