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Full Research Project Final Report

- This report must be a stand-alone report, *i.e.*, must be complete in and of itself. Scientific articles or other publications cannot be substituted for the report.
- One electronic copy and one signed original copy are to be forwarded to the lead funding agency on or before the due date as per the investment agreement.
- A detailed, signed income and expenditure statement incurred during the entire funding period of the project must be submitted along with this report. Revenues should be identified by funder, if applicable. Expenditures should be classified into the following categories: personnel; travel; capital assets; supplies; communication, dissemination and linkage; and overhead (if applicable).
- For any questions regarding the preparation and submission of this report, please contact ACIDF

Section A: Project overview

1. Project number: 2013F111R
2. Project title: Supporting continued development of clubroot resistant canola and early detection of clubroot outbreaks
3. Research team leader: Michael Harding
4. Research team leader's organisation: Alberta Agriculture and Forestry
5. Project start date (yyyy/mm/dd): 2013/04/01
6. Project completion date (yyyy/mm/dd): 2017/12/31
7. Project final report date (yyyy/mm/dd): 2017/12/01

Section B: Non-technical summary (max 1 page)

In 2007, an irrigated canola crop in southern Alberta (Newell County) was discovered to have a severe infestation of clubroot caused by *Plasmodiophora brassicae* Wor. From 2008 to 2016 the infested field has provided anopportunity for clubroot research, extension and demonstration / training in southern Alberta. The site allowed for a naturally-occurring clubroot disease nursery in southern Alberta where hybrid canola seed companies could screen for clubroot resistance to Williams pathotype 5, which is predominant in that field. The pathotype 5 and sandy brown soil, with neutral to alkaline pH, provided a testing site unlike any other in Canada. In fact, it was the only large-scale clubroot nursery in Canada in 2012. Over 60 canola lines, varieties and cultivars were evaluated at the nursery over the 4 years of this project, some of which have gone on to become registered, commercially available, clubroot-resistant cultivars.

Clubroot continues to be found in new fields and new counties in Alberta each year. Early detection and proactive management are required for successful prevention and control of clubroot. Surveillance can provide early warning/detection of new outbreaks. Clubroot surveillance during this project was done in conjunction with Dr. Stephen Strelkov's Provincial survey for clubroot and followed Dr. Strelkov's standard survey protocol. The results were rolled into the Provincial clubroot survey results and reports. Over 200 fields were sampled in southern Alberta each year as part of this project (~900 fields total between 2013 and 2016). No new clubroot-positive fields were detected in southern Alberta, however three un-confirmed positive fields were reported by retail agronomists in the County of Newell in 2015-2016. Additionally, one positive field in Mountain View County was discovered by the local agricultural services personnel.

This clubroot nursery in Newell County provided many opportunities for extension and training such as the "Canola Galla", and informal tours by canola industry representatives, agriculture service board personnel and other specialists, which were held in 2012, 2013, and 2014 and had over 300 attendees learning more about clubroot scouting and management over the 3 years.

Section C: Project details

1. Project team (max ½ page)

Describe the contribution of each member of the R&D team to the functioning of the project. Also describe any changes to the team which occurred over the course of the project.

Dr. Michael Harding, Alberta Agriculture and Forestry, was the Principal Investigator. Dr. Harding supervised the field work and surveillance and performed most of the extension activities.

Mr. Greg Daniels, Innovotech, was responsible for the field site arrangements in 2012, but when Innovotech suspended all operations in Brooks Mr. Daniels was hired by Alberta Agriculture and Forestry. Mr. Daniels is now the Senior Technologist in the Plant Pathology program at the Crop Diversification Centre South. He organized and managed the field work and surveillance under Dr. Harding's supervision.

Dr. Stephen Strelkov, University of Alberta, is the Provincial lead for the clubroot survey in canola. Dr. Strelkov provided the survey protocol and expertise on surveillance techniques.

Mr. Dan Orchard, Canola Council of Canada, is a canola agronomist, and clubroot lead, with extensive experience detecting and managing clubroot on canola. His involvement helped to target extension activities to help deliver the right message at the right time to the right people. He, along with other colleagues at the Canola Council of Canada, assisted with surveillance.

Dr. Ron Howard, Alberta Agriculture and Forestry, was the Plant Pathology program leader at the Crop Diversification Centre South until April 1st, 2013. He trained Dr. Harding, as part of a succession plan. Part of this training involved assistance in preparing the proposal and establishing the clubroot nursery and surveillance activities going prior to his retirement. He also participated with extension activities. Dr. Howard's involvement was reduced beginning in June of 2014 upon retirement from Alberta Agriculture and Forestry.

Background (max 1 page)

Describe the project background and include the related scientific and development work that has been completed to date by your team and/or others.

Clubroot, caused by *Plasmodiophora brassicae* Woronin, is an important disease of plants in the Brassica family. In Canada, clubroot has mainly been a problem in cruciferous vegetables in the traditional production areas of Ontario, Quebec, British Columbia and the Atlantic Provinces. In the Prairie Provinces, clubroot has been reported sporadically in a few home gardens and commercial fields in Alberta and Manitoba since 1970 (Howard et al., 2010); however, this situation changed dramatically with the discovery of 12 infected canola (*Brassica napus* L.) fields in Sturgeon County northwest of Edmonton, Alberta in 2003 (Tewari et al., 2005). Annual surveys carried out since 2003 have revealed that clubroot is a much more widespread and serious disease in Alberta than initially thought. Cumulatively through 2016, it has been detected over 1500 canola, mustard and vegetable fields more than 30 counties (Strelkov et al., 2017). The disease has been detected in a few fields with pH ratings >7.5, although it has been more prevalent in crops grown on acidic soils (Strelkov et al., 2007). The predominant pathotype in most fields has been Williams pathotype 3 (Howard et al., 2010; Strelkov et al., 2007), although pathotypes 2, 5, 6 and 8 have also been detected.

In 2007, an irrigated canola crop west of Brooks, Alberta was discovered to have a severe infestation of clubroot caused by *P. brassicae*. Interestingly, the field near Brooks was in the brown soil zone with pH closer to neutral, and the predominant pathotype was Williams pathotype 5 (S.E. Strelkov, unpublished). Since 2008, the infested field has been used each year for clubroot research, extension, demonstration and/or crop scout training.

The primary goal of this proposed project was to maintain a clubroot nursery in southern Alberta to allow the consistent testing, and continued development, of clubroot resistant canola lines/varieties/cultivars. The site was also used in canola-related extension, training and demonstrations, and as an information resource for producers and industry representatives involved in the production of cruciferous vegetables, mustard, camelina and other crops that are susceptible to clubroot.

Due to the fact that clubroot continues to be found in new counties in Alberta each year (Strelkov et al., 2017), early detection and proactive management are required for successful prevention and control of clubroot. Surveillance in southern Alberta will provide early warning/detection of any new outbreaks and will allow rapid response to help contain new outbreaks. Since most fields in southern Alberta are currently free of clubroot, surveillance will allow early detection of any new infestations.

Objectives and deliverables (max 1 page)

State what the original objective(s) and expected deliverable(s) of the project were. Also describe any modifications to the objective(s) and deliverable(s) which occurred over the course of the project.

1. Maintenance of a clubroot nursery in a naturally-infested, irrigated commercial field in Southern Alberta where canola lines and varieties can be evaluated for clubroot resistance.
2. Enhance clubroot surveillance in southern Alberta to allow early detection of new infestations south of Highway #1.

2. Research design and methodology (max 4 pages)

Describe and summarise the project design, methodology and methods of laboratory and statistical analysis that were actually used to carry out the project. Please provide sufficient detail to determine the experimental and statistical validity of the work and give reference to relevant literature where appropriate. For ease of evaluation, please structure this section according to the objectives cited above.

The evaluations of clubroot-resistant lines were done in randomized complete block experimental designs, with four to six replicates. Plots were seeded with a 1-row, or 4-row, cone seeder in 6- to 8-m long rows at 30-cm spacing with standard agronomic practices for canola production (https://www.canolacouncil.org/crop-production/canola-grower's-manual-contents). All field work involved strict biosecurity and sanitation protocols to ensure that contaminated soil did not leave the field, especially on vehicles and plot equipment. The field was irrigated with an overhead low pressure pivot system, according to the grower`s own program. Weather data for the site was collected from the closest available weather station. Disease ratings for clubroot incidence and severity were recorded prior to maturity (August) and required destructive sampling. Root tissue was collected for each variety by loosening the soil with a potato fork and gently removing the plants from the soil to ensure galls were not inadvertently broken off or lost. Roots were removed from the plants using secateurs approximately one inch above the soil line and collected into plastic bags to contain infected soil and moisture during transport. Roots were taken to a contained laboratory at the Crop Diversification Centre South in Brooks, AB where they were rinsed to remove soil and blotted dry to enable visual rating of galls. The washed roots were rated using a 0-3 scale of disease severity (Kuginuki et al. 1999; Xue et al. 2008). Ratings were performed on the following basis:
0 – no clubbing of roots; 1 – slight clubbing (small galls on less than 1/3 of roots); 2 – moderate clubbing (small to medium galls on 1/3 to 2/3 of roots); 3 – severe clubbing (medium to large galls on more than 2/3 of roots). Any disposable materials collected (roots, soil, bags, etc.) were autoclaved before disposing in a landfill. Any reusable equipment or tools were thoroughly washed and sanitized to eliminate the risk of clubroot spread. Some plots could have been arranged so yield data could also be collected, but companies did not require additional yield data, so only clubroot incidence and severity were assessed.

The surveillance activities were done in collaboration with Dr. Stephen Strelkov (University of Alberta), who coordinates the provincial survey for clubroot on canola each year in Alberta. A representative number of fields in each southern Alberta county were surveyed in late summer or early fall according to Dr. Strelkov`s survey methodology. Generally, 10 fields per county were surveyed, but in perimeter counties (counties bordering a municipality with confirmed clubroot) it was common to visit 20 or more fields. Briefly, 75 to 100 roots were examined within a $20m^2$ area at the main field entrance. If no clubroot was found at the entrance, the ratings were recorded and no further assessment was performed. If clubroot was found at the entrance, then the roots of all plants within a 1 m^2 area at each of 9 additional locations along the arms of a 'W' sampling pattern were dug from the soil and examined for the presence of galls, which are taken as an indication of *P. brassicae* infection. The severity of root infection on each sampled plant was assessed on a scale of 0 to 3, adapted from Kuginuki et al. (1999) where 0 = no galling, 1 = a few small galls, 2 = moderate galling and 3 = severe galling. The individual ratings were then used to calculate an index of disease (ID) for each field, according to the method of Horiuchi and Hori (1980) as modified by Cao et al. (2007). All necessary biosecurity and sanitation protocols were strictly enforced to avoid human transmission of infested soil.

3. Results, discussion and conclusions (max 8 pages)

Present the project results and discuss their implications. Discuss any variance between expected targets and those achieved. Highlight the innovative, unique nature of the new knowledge generated. Describe implications of this knowledge for the advancement of agricultural science. For ease of evaluation, please structure this section according to the objectives cited above.

NB: Tables, graphs, manuscripts, etc., may be included as appendices to this report.

Results for Objectives:

1. Maintenance of a clubroot nursery in a naturally-infested, irrigated commercial field in Southern Alberta where canola lines and varieties can be evaluated for clubroot resistance.
    a. In 2013 there were 4 canola lines evaluated for clubroot resistance.
    b. In 2014 there were 21 canola lines evaluated for clubroot resistance.
    c. In 2015 there were 14 canola lines evaluated for clubroot resistance.
    d. In 2016 there were 11 canola lines evaluated for clubroot resistance.

2. Enhance clubroot surveillance in southern Alberta to allow early detection of new infestations south of Highway #1.
    a. 2013: 220 fields visited and assessed for clubroot symptoms in S. Alberta
    b. 2014: 210 fields visited and assessed for clubroot symptoms in S. Alberta.
    c. 2015: 300 fields visited and assessed for clubroot symptoms in S. Alberta.
    d. 2016: 217 fields visited and assessed for clubroot symptoms in S. Alberta.

Results for Deliverables:

1. Clubroot resistance evaluations for hybrid canola seed companies
    a. In 2013 there were 2/4 lines showed significant resistance to clubroot pathotype 5.
    b. In 2014 there were 20/21 lines with resistance to clubroot pathotype 5.
    c. In 2015 there were 4/21 lines with resistance to clubroot and 10 with intermediate resistance.
    d. In 2016 there were 0/11 lines with resistance and 1/11 with intermediate resistance to clubroot pathotype 5.
2. Comprehensive clubroot surveillance and early detection in southern Alberta.
    a. In 2013 there were no new clubroot-infested fields found in any of the 220 fields assessed in southern Alberta (Strelkov et al., 2014).
    b. In 2014 there were no new clubroot-infested fields discovered in any of the 210 fields assessed in southern Alberta (Strelkov et al., 2015).
    c. In 2015 there were no new clubroot-infested fields discovered in any of the 300 fields visited, however, a confirmed field in Mountain View County was reported by the local Agricultural Service Board Fieldman (Strelkov et al., 2016). Additionally, a new pathotype that was virulent on clubroot-resistant canola cultivars was discovered at a naturally infested field in the County of Newell.
    d. In 2016 there was a second field in Mountain View County reported (Strelkov et al., 2017).
3. Opportunities for training and education of producers, industry agronomists, Ag. Service Board staff and other stakeholders on important canola production topics – especially clubroot.
    a. “Canola Galla” in Brooks in 2013 had over 100 attendees.
    b. “Canola Galla” in Brooks in 2014 had over 100 attendees.
    c. “Canola Galla” in Lethbridge and Red Deer in 2015 had over 100 attendees.
    d. “Canola Galla” in Red Deer in 2016 (attendance unknown but estimated at 50)

4. Literature cited

Provide complete reference information for all literature cited throughout the report.

Cao, T., Tewari, J. and Strelkov, S.E., 2007. Molecular detection of Plasmodiophora brassicae, causal agent of clubroot of crucifers, in plant and soil. *Plant disease*, *91*(1), pp.80-87.

Evenson, R.E., 2001. Economic impacts of agricultural research and extension. *Handbook of agricultural economics*, *1*, pp.573-628.

Horiuchi, S. and Hori, M., 1980. A simple greenhouse technique for obtaining high levels of clubroot incidence. *Bulletin of the Chugoku National Agricultural Experiment Station, E*, (17), pp.33-55.

Howard, R.J., Strelkov, S.E. and Harding, M.W., 2010. Clubroot of cruciferous crops–new perspectives on an old disease. *Canadian Journal of Plant Pathology*, *32*(1), pp.43-57.

Kuginuki, Y., Yoshikawa, H. and Hirai, M., 1999. Variation in virulence of Plasmodiophora brassicae in Japan tested with clubroot-resistant cultivars of Chinese cabbage (Brassica rapa L. ssp. pekinensis). *European Journal of Plant Pathology*, *105*(4), pp.327-332.

Strelkov, S.E., Manolii, V.P., Cao, T., Xue, S. and Hwang, S.F., 2007. Pathotype classification of *Plasmodiophora brassicae* and its occurrence in *Brassica napus* in Alberta, Canada. *Journal of Phytopathology*, *155*(11-12), pp.706-712.

Strelkov, S.E., Hwang, S.F., Manolii, V.P., Cao, T. and Feindel, D., 2016. Emergence of new virulence phenotypes of *Plasmodiophora brassicae* on canola (Brassica napus) in Alberta, Canada. *European Journal of Plant Pathology*, *145*(3), pp.517-529.

Strelkov, S.E., Manolii, V.P., Harding, M.W., Hwang, S.F., Manolii, E., Zuzak, K., Rennie, D.C., Feng, J., Raham, M., Daniels, G.C., Burke, D.A., Hill, T.B., Zhar K. and Feindel D. (2017). Occurrence and spread of clubroot on canola in Alberta in 2016. *Canadian Plant Disease Survey*, 97:164-167.

S.E. Strelkov, V.P. Manolii, M.W. Harding, G. Sieusahai, S.F. Hwang, Y. Shi, A. Lawson, J. Fisher, J. Cornelsen, G.C. Daniels, and D. Feindel. 2016. Occurrence and spread of clubroot on canola in Alberta in 2015. *Canadian Plant Disease Survey*, 96: 163-168.

S.E. Strelkov, V.P. Manolii, M.W. Harding, S.F. Hwang, W. Fei, S. Rong, D.A. Burke, C.A. Pugh, J.M. Nielson, A. Barnes, C. Jacobsen, M. Vadnais and D. Feindel. 2015. The spread of clubroot on canola in Alberta in 2014. *Canadian Plant Disease Survey*, 95: 155-158.

S.E. Strelkov, V.P. Manolii, M.W. Harding, S.F. Hwang, N. Poscente, S.L.I. Lisowski, C.A. Pugh and D.A. Burke. 2014. The occurrence of clubroot on canola in Alberta in 2013. *Canadian Plant Disease Survey*, 94: 158-161.

Tewari, J.P., Strelkov, S.E., Orchard, D., Hartman, M., Lange, R.M. and Turkington, T.K., 2005. Identification of clubroot of crucifers on canola (*Brassica napus*) in Alberta. *Canadian journal of plant pathology*, *27*(1), pp.143-144.

Xue, S., Cao, T., Howard, R.J., Hwang, S.F. and Strelkov, S.E., 2008. Isolation and variation in virulence of single-spore isolates of Plasmodiophora brassicae from Canada. *Plant Disease*, *92*(3), pp.456-462.

5. Benefits to the industry (max 1 page; respond to sections *a)* and *b)* separately)

a) Describe the impact of the project results on Alberta's agriculture and food industry (results achieved and potential short-term, medium-term and long-term outcomes).

Clubroot is currently one the greatest disease threats to canola in western Canada. Potential losses to clubroot in Alberta would be extreme without resistant cultivars. For example, losses of up to 100% have been reported in a few fields. In addition to the direct yield losses, there are indirect economic losses due to the need for long rotations to help manage the disease. Taking fields out of canola is often a financial hardship for producers, particularly when canola prices are high. Supporting the development of resistant cultivars is a foundational principle in staying ahead of clubroot. The main benefit of this project is assistance with the continued development and testing of clubroot resistance in new canola lines and varieties against *P. brassicae* pathotype 5 in southern Alberta brown soil. This work supported the continued development of hybrid canola cultivars that are adapted to Alberta constraints, such as clubroot.

The annual survey of for clubroot in southern Alberta provides early detection of any new outbreaks and allows proactive management responses. The survey has also helped identify fields with new virulent pathotypes of clubroot.

Finally, the clubroot nursery site has been a valuable staging point for demonstration plots used in extension and training activities. These activities have improved the awareness of and scouting for clubroot in southern Alberta. This is evidenced by the number of clubroot positive fields discovered in southern Alberta by local authorities and retail agronomists – many of whom were trained at this site.

b) Quantify the potential economic impact of the project results (e.g., cost-benefit analysis, potential size of market, improvement in efficiency, etc.).

Clubroot is now confirmed in almost 3000 fields in Alberta (Strelkov et al., 2017). A conservative estimate of potential damage to clubroot is 10% loss in those 3000 fields. If an average field is 100 ac and average yield is 35 bu/ac and price estimate is $11/bu, then clubroot losses would equal over $11 million annually. Assuming that clubroot resistance testing at the S. Alberta nursery contributes 1% to 5% to the total value, this equals a return on investment of between $100,000 and $½ million each year for as long as the resistant cultivars are deployed in infested fields.

The value of the surveillance and extension is more difficult to monetize. An estimate of return on investment of 40% for agricultural research and extension has been corroborated by Evenson (2001). If even half this value is true (20%) then extension and surveillance funded by this project will provide an annual return of $26,500 per year. This means that the investment in this project has been worthwhile to the canola industry

It is important to note that surveillance activities have also been instrumental in the discovery and characterization of new pathotypes of *P. brassicae* that are virulent on previously resistant canola cultivars (Strelkov et al., 2016).

6. Contribution to training of highly qualified personnel (max ½ page)

Specify the number of highly qualified personnel (e.g., students, post-doctoral fellows, technicians, research associates, etc.) who were involved in the project.

Technicians and summer students at Alberta Agriculture and Forestry (Crop Diversification Centre South):
Greg Daniels, Sherry Lisowski, Dustin Burke, Carol Pugh, Blake Hill, Jon Nielson, Arvind Gill, Jennifer Reid, Kristy Gibb, Logan Vaughan, Vivian Gietz, Jackson Hill, Allan Alfano.

7. Knowledge transfer/technology transfer/commercialisation (max 1 page)

Describe how the project results were communicated to the scientific community, to industry stakeholders, and to the general public. Organise according to the following categories as applicable:

a) Scientific publications (*e.g.*, scientific journals); attach copies of any publications as an appendix to this final report

S.E. Strelkov, V.P. Manolii, M.W. Harding, S.F. Hwang, E. Manolii, K. Zuzak, D.C. Rennie, J. Feng, M. Raham, G.C. Daniels, D.A. Burke, T.B. Hill, K. Zhar and D. Feindel. 2017. Occurrence and spread of clubroot on canola in Alberta in 2016. Canadian Plant Disease Survey, 97: 164-167.

S.E. Strelkov, V.P. Manolii, M.W. Harding, G. Sieusahai, S.F. Hwang, Y. Shi, A. Lawson, J. Fisher, J. Cornelsen, G.C. Daniels, and D. Feindel. 2016. Occurrence and spread of clubroot on canola in Alberta in 2015. Canadian Plant Disease Survey, 96: 163-168

S.E. Strelkov, V.P. Manolii, M.W. Harding, S.F. Hwang, W. Fei, S. Rong, D.A. Burke, C.A. Pugh, J.M. Nielson, A. Barnes, C. Jacobsen, M. Vadnais and D. Feindel. 2015. The spread of clubroot on canola in Alberta in 2014. Canadian Plant Disease Survey, 95: 155-158.

S.E. Strelkov, V.P. Manolii, M.W. Harding, S.F. Hwang, N. Poscente, S.L.I. Lisowski, C.A. Pugh and D.A. Burke. 2014. The occurrence of clubroot on canola in Alberta in 2013. Canadian Plant Disease Survey, 94: 158-161.

Howard, R. J., D. A. Burke, S. E. Strelkov, D. C. Rennie, C. A. Pugh, S. L. I. Lisowski, M. W. Harding**,** and G. C. Daniels. (2014). Evaluation of methods for cleaning and disinfesting equipment contaminated with clubroot. Can. J. Plant Pathol. 36(2): 266-266. (Abstract)

Stephen E. Strelkov, Sheau-Fang Hwang, Michael W. Harding, and T. Kelly Turkington. 2014. Occurrence, spread and management of clubroot on canola (*Brassica napus*) in Canada. 11th Conference of the European Foundation for Plant Pathology, Krakow, Poland September 12, 2014.

Howard, R. J., D. A. Burke, S. L. I. Lisowski, S. E. Strelkov, D. C. Rennie, S. F. Hwang, G. D. Turnbull, L. M. Kawchuk, and M. W. Harding. (2013). Assessing the potential for

clubroot spore contamination of field pea seed. Can. J. Plant Sci. 91(2): 389-389. (Abstract)

b) Industry-oriented publications (*e.g.*, agribusiness trade press, popular press, etc.) attach copies of any publications as an appendix to this final report

Mac Olsen. 2017. Information session provided for clubroot awareness. Smoky River Express, September 6, 2017.

Zoe Todd. 2017. Plant fungus creeping northwest, infecting Alberta fields. CBC News, September 12, 2017.

Normand Boulet and Sheila Kaus. 2017. The Fieldman's Files – Clubroot Update. The South Peace News, September 14, 2017.

Gord Gilmour. 2015. 2015 crop disease outlook. Country Guide, January 2, 2015.
Also in: AGCanada, January 2, 2015

Ken Blackley. Helping Prevent Crop Disease. Call of the Land. January 28, 2015

Barb Glen. Alberta's 2015 crop forecast: watch for clubroot, barley scald. The Western Producer. January 29, 2015

Plant Diseases to look for in 2014, Alberta Farmer Express, Feb 18, 2014

Crop disease a concern for growers in 2014, Lethbridge Herald, Jan 22, 2014 and in Prairie Post West, Feb 28, 2014.

Loads of info in Peace Agronomy Update, Fairview Post, Jan 24, 2014

Agri-News. 2014. Increase in Clubroot infected fields in 2013. This Week in Agriculture. February 3, 2014.

Coles, K., R. Lange, M.W. Harding, R.J. Howard. 2014. Canola diseases. Farming Smarter. https://www.youtube.com/watch?v=fr06P6n0pyA

Harley Richards. 2014. New strain of clubroot can infect resistant canola. Red Deer Advocate, July 9, 2014.

Agri-News. 2014. Crop disease update. This Week in Agriculture, July 14, 2014.

Agri-News. 2014. Managing clubroot. This Week in Agriculture, July 21, 2014.

Richard Kamchen. 2014. Scouting in full swing. Ag Knowledge – FCC, July 25, 2014

Dan Singleton. 2014. New clubroot strain identified near Edmonton. The Mountain View Gazette, July 29, 2014.

Adam Deitrich. 2014. Woodlands investigates clubroot in area farms. Whitecourt Star. September 24, 2014.
Also in: The Mayerthorpe Freelancer, September 24, 2014.

Helen McMenamin. 2014. New strain of clubroot beats resistance genes. Farming Smarter Magazine. Fall 2014 Edition.

Barb Glen. 2014. Crop disease levels 'concerning'. The Western Producer. December 11, 2014.

Barb Glen. 2013. New canolas help calm clubroot fear. The Western Producer. August 15, 2013.

c) Scientific presentations (*e.g.*, posters, talks, seminars, workshops, etc.)

Harding, M.W., R.J. Howard and D.A. Burke. 2016. Farm biosecurity and equipment sanitization. Natural Resources Program, Portage College, Lac La Biche, AB April 5, 2016

Harding, M.W., Howard, R.J. and Burke, D.A. 2015. Farm biosecurity and equipment sanitation. Natural Resources Program. Portage College, Lac La Biche Campus.Lac La Biche, AB March 9, 2015.

Howard, R. J., D. A. Burke, S. E. Strelkov, D. C. Rennie, C. A. Pugh, S. L. I. Lisowski, M. W. Harding, and G. C. Daniels. (2014). Evaluation of methods for cleaning and disinfesting equipment contaminated with clubroot.

Stephen E. Strelkov, Sheau-Fang Hwang, Michael W. Harding, and T. Kelly Turkington. 2014. Occurrence, spread and management of clubroot on canola (*Brassica napus*) in Canada.

Howard, R. J., D. A. Burke, S. L. I. Lisowski, S. E. Strelkov, D. C. Rennie, S. F. Hwang, G. D. Turnbull, L. M. Kawchuk, and M. W. Harding. (2013). Assessing the potential for clubroot spore contamination of field pea seed.

d) Industry-oriented presentations (*e.g.*, posters, talks, seminars, workshops, etc.)

Strelkov, S.E., S.F. Hwang, M.W. Harding, M. Vadnais and D. Feindel. 2015. Status of clubroot and new strains of the pathogen. FarmTech 2015, Edmonton, AB. January 27-29, 2015.

Harding, MW. 2015. Crop disease update for 2014. Agronomy Update Conference. Lethbridge Lodge Hotel, Lethbridge, Alberta, Canada, January 20, 2015.

Harding, MW. 2015. Crop disease update. Agro Plus Grower Meeting. Foremost Community Hall, Foremost, Alberta, Canada, March 11, 2015.

Harding, M.W. 2015. Crop Disease Update. Smart Farming Workshop, Calmar, AB. March 12, 2015

Harding, M.W., S.E. Strelkov, S.F. Hwang. 2015. Disease Situation Update: Clubroot and verticillium on canola. 2015. Lacombe County Agricultural Service Board Meeting, Lacombe, AB. March 19, 2015

Harding, MW, Burke, DA, and Howard, RJ. 2015. Canola Galla: Clubroot Sanitization Demonstration. Penhold Community Centre, Penhold, Alberta, Canada, August 19, 2015.

Harding, MW. 2015. Pathology Research at CDCS. Lendrum Farm Tour, Brooks, Alberta, Canada, August 28, 2015.

Harding, MW. 2015. Update on Regulated Diseases. Lethbridge County Ag Service Board Meeting. September 10, 2015.

Harding, M.W. 2015. Canola School: Reporting New Clubroot Infestations in the Fight Against the Disease. Filmed in Lacombe, Alberta, Canada. Real Agriculture, October 14, 2015.
(https://www.youtube.com/watch?v=qnvKSADNVNY&index=20&list=PLpPFNpbxLGlJWmSIEu20jrLJQijCcxqKF)

Harding, MW. 2015. Canola School: Genetic Diversity and the Fight to Protect Clubroot Resistance. Filmed in Lacombe, Alberta, Canada. Real Agriculture, October 27, 2015.
(https://www.youtube.com/watch?v=4wTW6s3kmHc&index=21&list=PLpPFNpbxLGlJWmSIEu20jrLJQijCcxqKF

Harding, M.W. 2015. Cereal and canola disease update for 2015. Foremost Community Hall, Foremost, Alberta, Canada, November 25, 2015.

FarmTech-2014: provided disease outlook and forecast in Edmonton on January 29-30. The presentation included the current clubroot disease situation and survey results.

Canola 'Galla'-2014: field days in Brooks, AB and at the clubroot nursery (east of Bassano, AB) provided training and education for producers, agronomists, ag fieldmen and other stakeholders. Learning opportunities include: clubroot scouting and recognition, host range, clubroot management tools and practices. Additionally, sessions on weed identification and management, insect sweeping and identification and beneficial insects and pollinators were held on July 31st and August 1st, 2013. Over 100 attendees participated in the "Galla" in 2013.

Harding, M.W., R.J. Howard and J. Broatch. 2014. Clubroot: A recurring issue on canola. CanoLAB 2014. Olds, AB. February 29-31, 2014.

M.W. Harding, R. Howard, S. Chatterton, S.Strelkov, K. Turkington, K. Xi, N. Boulet, F. Sawchuk, S. Dutrisac, N. Paulovich. 2014. Crop disease update for 2013. Peace Agronomy Update-2014. Fairview, AB. January 16, 2014

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S.E. Strelkov, V.P. Manolii, M.W. Harding, S.F. Hwang, N. Poscente, S.L.I. Lisowski, C.A. Pugh, and D.A. Burke. 2014. The occurrence of clubroot on canola in Alberta in 2013. Pest Surveillance Branch Update Conferences Brooks AB. March 18, 2014, and Vegreville, AB. March 19, 2014.

Canola 'Galla'-2013: field days in Brooks, AB and at the clubroot nursery (east of Bassano, AB) provided training and education for producers, agronomists, ag fieldmen and other stakeholder. Learning opportunities include: clubroot scouting and recognition, host range, clubroot management tools and practices.

Howard, R.J., D.A. Burke, S.E. Strelkov, D.C. Rennie, C.A. Pugh, S.L.I. Lisowski, M.W. Harding, and G.C. Daniels. Evaluating methods for cleaning and disinfesting equipment contaminated with clubroot. International Clubroot Workshop, Edmonton, AB. June, 19-22, 2013.

Harding, M.W. and R.J. Howard. 2013. Important diseases of canola and pulses. MNP`s Farm Management Club, Lethbridge, AB. January 9th, 2013.

Harding, M.W., R.J. Howard, T.K. Turkington, H.R. Kutcher, P. Laflamme. 2013. Managing field crop diseases. Agronomy Update, Lethbridge, AB. January 16, 2013.

Orchard, D. and M.W. Harding. Canola diseases: blackleg, sclerotinia and clubroot. Lacombe County Diseases of Canola Information Meeting, Gilby, AB. February 11, 2013.

Canola 'Galla'-2012: field days in Brooks, AB and at the clubroot nursery (east of Bassano, AB) provided training and education for producers, agronomists, ag fieldmen and other stakeholders. Learning opportunities include: clubroot scouting and recognition, host range, clubroot management tools and practices.

e) Media activities (*e.g.*, radio, television, internet, etc.)

Caitlynn Reesor. 2014. Increase in Clubroot infected fields in 2013. Call of the Land, February 3, 2014.

Caitlin Reesor. 2014. Canola Galla. Call of the Land. July 18, 2014.

f) Any commercialisation activities or patents – None.

N.B.: Any publications and/or presentations should acknowledge the contribution of each of the funders of the project.

Section D: Project resources

1. Statement of revenues and expenditures:

a) ***In a separate document certified by the organisation's accountant or other senior executive officer, provide a detailed listing of all cash revenues to the project and expenditures of project cash funds.*** *Revenues should be identified by funder, if applicable. Expenditures should be classified into the following categories: personnel; travel; capital assets; supplies; communication, dissemination and linkage; and overhead (if applicable).*

Please see the attached financial report

b) ***Provide a justification of project expenditures and discuss any major variance (i.e., ± 10%) from the budget approved by the funder(s).***

No major variances from the budget to report.

2. Resources:

Provide a list of all external cash and in-kind resources which were contributed to the project.

Total resources contributed to the project		
Source	**Amount**	**Percentage of total project cost**
Funders	$132,500	50.2%
Other government sources: Cash	$15,060.67	5.7%
Other government sources: In-kind	$81,698.07	31.0%
Industry: Cash	$22,500	8.6%
Industry: In-kind	$12,000	4.5%
Total Project Cost	**$263,758.74**	**100%**

External resources (additional rows may be added if necessary)		
Government sources		
Name (only approved abbreviations please)	Amount cash	Amount in-kind
Government of Saskatchewan	$1500	0
Saskatchewan Association of Rural Municipalities	$1500	0
Industry sources		
Name (only approved abbreviations please)	Amount cash	Amount in-kind
Heads Up Plant Protectants Inc.	$5000	0
CPS	$5500	0
Bayer CropScience	$7000	0
Monsanto	$5000	0

Section E: The next steps (max 2 pages)

Describe what further work if any needs to be done.

a) *Is new research required to deal with issues and opportunities that the project raised or discovered but were not dealt with within the current project?*

While all the research proposed was accomplished, the need for testing new resistance sources, and proactive clubroot surveillance, continues.

b) *Is there related work that needs to be undertaken to continue advancement of the project technology or practice?*

The work should continue in an effort to continue to support breeders bringing strong clubroot resistance to canola cultivars. The site in southern Alberta is unique (brown soil with neutral to alkaline pH and pathotype 5). It could potentially be location to continue to support resistance breeding.

c) *Did the project identify any new technology or practice that needs to be developed?*

Yes, and development and commercialization will be done by the seed companies that own the intellectual property.

d) *What suggestions do you have that increase commercial use of results by farmers and/or companies. These may be:*

Continued extension of key messages underpinning clubroot prevention and management.

Section F: Research Team Signatures and Employers' Approval

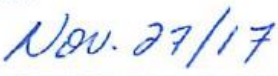
The team leader and an authorised representative from his/her organisation of employment MUST sign this form.

Research team members and an authorised representative from their organisation(s) of employment MUST also sign this form.

By signing as representatives of the research team leader's employing organisation and/or the research team member's(s') employing organisation(s), the undersigned hereby acknowledge submission of the information contained in this final report to the funder(s).

Team Leader's Organisation

Research Team Members (add more lines as needed)

Team Leader	
Name: Michael Harding	Title/Organisation: Research Scientist/Alberta Agriculture and Forestry
Signature: 	Date: 24-Nov-2017
Team Leader's Employer's Approval	
Name: David Feindel	Title/Organisation: Director, Pest Surveillance Section/Alberta Agriculture and Forestry
Signature: 	Date: 

2. Team Member	
Name: Dr. Stephen Strelkov	Title/Organisation: University of Alberta
Signature: 	Date: Dec. 5, 2017

3. Team Member	
Name: Mr. Greg Daniels	Title/Organisation: Alberta Agriculture and Forestry
Signature:	Date: Dec 5, 2017
Team Member's Employer's Approval	
Name: Dr. Michael Harding	Title/Organisation: Research Scientist/Alberta Ag & Forestry
Signature:	Date: Dec 5, 2017

4. Team Member	
Name: Mr. Dan Orchard	Title/Organisation: Canola Council of Canada
Signature:	Date: Dec. 6/17

5. Team Member	
Name: Dr. Ron Howard	Title/Organisation: RJH Ag Research Solutions Ltd., Brooks, AB
Signature: R.J. Howard	Date: December 6, 2017
Team Member's Employer's Approval	
Name: Dr. Ron Howard	Title/Organisation: RJH Ag Research Solutions Ltd., Brooks
Signature: R.J. Howard	Date: December 6, 2017