Blackleg Strategic Plan in Canada

January 2019

Prepared by the Blackleg Steering Group

Canola Council of Canada
Manitoba Canola Growers Association
SaskCanola
Alberta Canola Producers Commission
Manitoba Agriculture
Saskatchewan Ministry of Agriculture
Alberta Agriculture and Forestry
Agriculture and Agri-Food Canada
Canadian Food Inspection Agency
University of Manitoba
University of Alberta
Alberta Innovates Technology Futures
Pathology Sub-Committee of the Western Canadian Canola/Rapeseed Recommending Committee

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1.0 SUMMARY

Blackleg continues to be a concern for canola production in Western Canada. Survey results over the past decade show that that blackleg incidence is on the rise (although the most recent survey indicates that trend may be starting to reverse), and this disease has become a trade barrier to canola markets that are sensitive to *Leptoshaeria maculans*. This strategic plan details the necessary research and extension efforts that are needed to allow the Canadian canola industry to effectively manage and stay ahead of the disease into the future. The authors of this plan, Blackleg Steering group, will update the Blackleg Strategic Plan every three years.

The canola industry in the past has relied on blackleg resistance (especially a single gene conferring resistance) as the principle method for controlling this disease. But due to the blackleg issues listed above, sole reliance on disease resistance may not provide durable control into the future. To stay ahead of blackleg, the canola industry needs to engage in a collaborative approach to manage this disease, to develop new tools for control, and to develop consistent messaging for management for canola growers. Through multiple venues, targets for research and disease extension messaging have been developed.

Priority Areas of Research are:

1. Identify effective R-gene rotations to increase the durability of resistant cultivars;
2. Developing a system to effectively screen/assess for quantitative resistance in commercial canola lines;
3. Identify the critical window of infection from blackleg to better steward agronomic practices;
4. Find new sources of blackleg resistance.

In addition to setting research priorities for blackleg research, priorities for extending information on blackleg control have been evaluated. Communication vehicles have to be developed for encouraging growers to take a risk analysis approach to managing blackleg and be developed for best management practices to control blackleg.

2.0 BACKGROUND

2.1 Purpose

This blackleg strategic plan was developed as the result of consultations with the canola industry which indicated that a coordinated and collaborative approach is needed to ensure the high priority blackleg research is conducted in the most competent and efficient manner as possible. With new understanding of the host pathogen interactions of blackleg, outbreaks in Australian and France, and a trade issue related to blackleg infected canola seed and dockage with China has brought this disease to the forefront of canola related disease concerns in Canada. To build this plan, the Blackleg Steering Group was formed composed of public and private plant pathologists, grower group representatives, and provincial extension staff in November of 2011. The function of this group is to offer guidance on blackleg research and to make extension recommendations based on the most current understanding of this disease.

Blackleg Steering Group Membership:

Plant Pathologists
Hossein Borhan (AAFC Saskatoon)
Dilantha Fernando (University of Manitoba)
Ralph Lange (AITF)
Gary Peng (AAFC Saskatoon)
Stephen Strelkov (University of Alberta)
Igor Falak (Corteva)
Yu Chen (Cargill)

Advisory Role
Clinton Jurke (CCC)
Rajesh Ramarathnam (CFIA)
Curtis Rempel (CCC)

Chair
Justine Cornelsen (CCC)

Grower Groups
Vacant (SaskCanola)
Delaney Ross (Manitoba Canola Growers)
Ward Toma (Alberta Canola)

Provincial Extension
Dane Froese (Manitoba Agriculture)
Barb Ziesman (WCC/RRC & SK MoA)
Murray Hartman (AAF)

2.2 Blackleg in Canadian Canola Production

Canola’s total contribution to the Canadian economy has been projected at $26.7 billion. Most of Canada’s canola is produced in the prairie provinces of Alberta, Saskatchewan and Manitoba, where canola is seen as a cash crop for farmers. In 2018, farmers harvested 22,535,200 acres of canola making it the largest field crop grown in Canada surpassing wheat acres. The amount of canola produced has doubled over the last ten years with the 5-year average yield of 40 bushels per acre being achieved.

Blackleg is one of the most serious diseases of canola in Canada. It has caused moderate to severe damage in many grower fields in the recent past, and accounted for yield losses, reduced sustainability of canola production and trade issues, particularly with China. The main reason for the increased disease impact is from the rise in both frequency and quantity of canola grown on tight rotations, along with the breakdown of resistance (R-genes) by new races of the blackleg pathogen on canola varieties grown across the prairies.

The Canadian canola industry, led by the Canola Council of Canada, have undertaken blackleg risk mitigation measures for canola pre-planting and canola production, and have placed great emphasis on training, education and research to change awareness and behavior around blackleg mitigation.

Risk mitigation measures of blackleg during pre-planting of canola:

- Identify new sources of blackleg resistance
- Identify and survey races of *Leptoshaeria maculans* in Canada for avirulence genes in order; to measure and monitor their distribution over time
- Identify major resistance genes in commercial cultivars

Risk mitigation measures of blackleg in canola production:

- Use of scouting for blackleg disease symptoms during the canola growing season
- Monitoring: Annual blackleg disease surveys
- Quick in-field diagnostics to identify *L. maculans* avirulence genes present in the field

2.3 Canadian Blackleg Workshop - 2018

Blackleg Workshops and Summits are held in Canada every three or four years to review the latest in blackleg research and to develop extension and future research priorities for the canola industry. These workshops, organized by the Canola Council of Canada and SaskCanola were held in 2011, 2015, and most recently in 2018.

This report on the 2018 Blackleg Workshop was originally published in Canola Digest – November 2018 Issue: https://canoladigest.ca/september-2018/blackleg-summit-shares-new-management-approaches/

What are the key new research discoveries on blackleg? Blackleg management can get lost among the 50 other important decisions that need to be made to grow just one canola crop, but with the Growing Forward 2 SaskCanola Agri-Science Project: 'Canola Disease Management Tools for the Prairies – Blackleg and Sclerotinia' coming to an end, this is a great time to share key findings with producers, agronomists and industry members. The Blackleg Summit held in Saskatoon earlier this year provided an opportunity to review the Agri-Science Project research and help Ag extension staff get this information into the hands of farmers.

KEY MESSAGES PRESENTED AT THE BLACKLEG SUMMIT

1. Rapid field test of canola stubble helps with variety selection. Hossein Borhan's lab at Agriculture and Agri-Food Canada (AAFC) Saskatoon worked to develop a rapid field diagnostics test for blackleg disease. The test identifies blackleg races present on the canola stubble. Genetic biomarkers developed as part of this project were shared with public and private pathology labs across western Canada. Four labs now have the markers for commercial evaluation. When growers detect significant amounts of blackleg in their field, they can now send stubble samples to diagnostic labs for genetic testing. This enables canola growers to make informed decisions about choosing the appropriate blackleg resistance in their canola variety that best matches the profile of the blackleg strain in the field.
2. Survey shows blackleg pathogen population across the Prairies. A collaborative effort was taken across the Prairies to survey and identify the blackleg pathogen population. This effort, led by the labs of Dilantha Fernando (University of Manitoba), Gary Peng (AAFC Saskatoon) and Ralph Lange (Alberta Innovates), will help determine where to deploy specific genetics to match the population, increasing the durability of resistance genes and better managing the pathogen.
3. Researchers find new sources and genes for blackleg resistance. More than 1,100 *B. napus* and *B. rapa* accessions were characterized for the profile of known R genes (resistance to blackleg). Several novel blackleg resistance genes were identified, which seed companies can use to improve their genetic base. 58 lines with quantitative (adult plant) resistance to blackleg disease were identified and the presence of adult plant resistance (APR) was confirmed. APR is a durable form of resistance and protects canola against the blackleg infection.
4. Canadian canola industry adopts resistance-gene labels. Producers can now choose varieties with 'R' genes that are durable to the specific blackleg races in their fields. This will play a significant role in reducing blackleg in the field in Canada.

PERSPECTIVE ON BLACKLEG FROM AUSTRALIA

Australian researchers, Dr.'s Angela Van de Wouw and Steve Marcroft participated in the Summit to share their knowledge and experience from working with blackleg in the canola growing regions of Australia. Van de Wouw and Marcroft are part of an approach called 'Genome to Paddock' to monitor pathogen populations, field disease pressure, and fungicide resistance. They also aided in the formation of blackleg resistance groups captured in Australia's extensive Blackleg Management Guide.

Marcroft presented new work on upper canopy infection, which damages pods and results in the most yield loss for Australian canola growers. Later blackleg infection can be minimized with effective R genes and by a fungicide application during reproductive growth stages. Extended crop rotation is still the best practice to minimize the amount of infected stubble within the field. In Australia, they found that with inter-row sowing, horizontal stubble produces significantly higher quantities of spores and vertical stubble produces spores later in the growing season. Information like this will help in the development of new cultural practices to manage blackleg disease pressure.

The Blackleg Summit created the opportunity to learn about research from both Canada and Australia. This information transfer will help in further development of a holistic approach to managing blackleg.

IN SUMMARY

New information discussed at the summit will help us adopt more effective and more sustainable practices for an integrated pest management approach. With new genetic technology, the advances we have been making on understanding the resistance tools and the pathogens within the field have been vast. It's amazing to see how this type of information can help farmers make decisions back on the farm.

Agenda from the 2018 Canadian Blackleg Workshop can be found in Appendix 1.

2.4 Research Priorities

The canola industry has develops a list of priorities that is needed for blackleg research every three or four years. The most recent prioritisation was done over the Blackleg Workshop in February 2018 in Saskatoon and through discussions between the Blackleg Steering Group members in the fall of 2018.

These are the top blackleg research priorities for 2018:

1. Identify effective R-gene rotations to increase the durability of resistant cultivars
2. Developing a system to effectively screen/assess for quantitative resistance in commercial canola lines
3. Identify the critical window of infection from blackleg to better steward agronomic practices
4. Find new sources of blackleg resistance

Other projects listed as important are:

5. Correlation between plant infection and yield loss
6. Exploring the combination of mixing foliar fungicides and insecticides to reduce blackleg and flea beetle damage
7. Measure durability of each resistance gene
8. Understand how to best use quantitative resistance with major gene resistance
9. Crop rotation's impact on *L. maculans* population structure.
10. Agronomic practices to reduce blackleg
11. Develop differential isolates of *L. maculans*
12. Post-registration blackleg resistance durability measured in commercial canola cultivars

2.5 Current Blackleg Research

Blackleg projects currently being undertaken in Canada are:

Current grower-funded blackleg research projects in Canada

Project		Researchers		Date		Funding
Number	Title	Lead	Collaborating	Established	Complete (estimated)	Source
GF2 ASP Activity 2	Improving canola resistance against blackleg disease through incorporation of novel resistance genes source from B. napus, B. rapa, and B. oleracea	Hossein Borhan, AAFC	Dilantha Fernando	2013	5 years	AAFC, SaskCanola, ACPC
GF2 ASP Activity 3	Identifying novel resistance genes from canola relatives and developing canola germplasm with multiple resistance genes sourced from B. nigra, B. juncea, and B. carinata	Genyi Li, U of M	Dilantha Fernando	2013	5 years	AAFC, SaskCanola, ACPC
GF2 ASP Activity 4	Genome-wide association mapping of quantitative resistance against blackleg disease	Hossein Borhan, AAFC	Isobel Parkin, Steve Robinson, Sally Vail	2013	5 years	AAFC, SaskCanola, ACPC
GF2 ASP Activity 5	Transcriptomic analysis of the *Leptosphaeria maculans*-(blackleg-canola) interaction to identify resistance genes in canola and *avirulence* factors in *L. maculans*	Richard Belanger, U of Laval	Dilantha Fernando	2013	5 years	AAFC, SaskCanola, ACPC
GF2 ASP Activity 6	Durable blackleg resistance stewardship through knowledge of blackleg pathogen population, resistance genes and crop sequence towards the development of a cultivar rotation program in the Prairie Provinces	Dilantha Fernando, U of M	Gary Peng, Ralph Lange	2013	5 years	AAFC, SaskCanola, ACPC
GF2 ASP Activity 7	Investigating the Resistance (R-gene) durability of canola cultivars and emergence of virulent blackleg isolates in farmers' fields.	Dilantha Fernando, U of M	Hossein Borhan	2013	5 years	AAFC, SaskCanola, ACPC
GF2 ASP Activity 8	Quick field diagnostics of the *Leptosphaeria maculans* (the causal agent of blackleg) races through identification and marker development for avirulence genes in this pathogen	Hossein Borhan, AAFC	Dilantha Fernando	2013	5 years	AAFC, SaskCanola, ACPC
GF2 ASP Activity 9	Development of a blackleg yield loss model and assessment of fungicide resistance in western Canadian populations of *Leptosphaeria maculans.*	Stephen Strelkov, U of A	Gary Peng, Sheau-Feng Hwang, Ralph Lange	2013	April 2017	AAFC, SaskCanola, ACPC
CARP CCC 2015-12	Understanding the mechanisms for race-specific and non-specific resistance for effective use of cultivar resistance against blackleg of canola in western Canada	Peng, Garry AAFC	Fengqun Yu, Xunjian Liu, Zhai, Chun	2014	4 years	AAFC, CARP (SaskCanola, ACPC, MCGA)
CGDP ADF 2016-158	Mapping and introgression of the highly effective Brassica rapa blackleg resistance gene Rlm 11 into spring-type Brassica napus	Hossein Borhan, AAFC	Nicholas Larkan	2016	4 years	ADF, SaskCanola, WGRF

Continued research project listing:						
CGDP 2017-7	Identification and genetic mapping of novel genes for resistance to blackleg in Chinese and Canadian Brassica napus varieties	Dilantha Fernando, U of M	Gary Peng, Fengqun Yu	2017	4 years	SaskCanola
CARP CCC 2017-27	Monitoring the race dynamics of *Leptosphaeria maculans* for effective deployment and rotation of resistance genes for sustainable management of blackleg of canola in western Canada	Gary Peng, AAFC	Fenqun Yu	2017	5 years	Life science companies, AAFC, CARP (SaskCanola, ACPC, MCGA)
Pending funding through the Canadian Agricultural Partnership (CAP) Program:						
CAP ASP Activity 2	Developing a robust system for efficient assessment of Quantitative Resistance (QR) in commercial canola lines and varieties for blackleg management	Gary Peng, AAFC	Debra McLaren	2018	5 years	AAFC, SaskCanola
CAP ASP Activity 3 & 4	Developing tools for the rapid screening of canola germplasm for QR to blackleg disease	Hossein Borhan, AAFC	Ralph Lange	2018	5 years	AAFC, SaskCanola
CAP ASP Activity 5	Understanding the critical infection window that causes blackleg of canola in western Canada	Gary Peng, AAFC		2018	5 years	AAFC, SaskCanola
CAP ASP Activity 6 & 7	Fine tuning of the blackleg yield loss model in canola	Stephen Strelkov, U of A	Sheau-Feng Hwang, Klein-Gebbinick, Gary Peng	2018	5 years	AAFC, SaskCanola
CAP ASP Activity 8	Fungicide sensitivity in Lm: evaluation of the present situation	Stephen Strelkov, U of A	Sheau-Feng Hwang, Rudolph Fredua-Agyeman	2018	5 years	AAFC, SaskCanola
CAP ASP Activity 9 & 10	Improving management of blackleg on canola via better flea-beetle control and effective fungicide seed treatment in W Canada	Gary Peng, AAFC	Dilantha Fernando, Debra McLaren	2018	5 years	AAFC, SaskCanola
CAP ASP Activity 11 & 12	Improving blackleg durability through R-gene rotation in commercial canola fields on the Canadian prairies - a science based stewardship program	Dilantha Fernando, U of M	Gary Peng, Ralph Lange	2018	5 years	AAFC, SaskCanola
CAP ASP Activity 13 & 14	Genetic dissection of the Rlm 3-4-7-9 blackleg R gene cluster and KASP marker improvement	Hossein Borhan, AAFC	Nick Larkan, Isobel Parkin, Ralph Lange	2018	5 years	AAFC, SaskCanola
CAP ASP 2018	Blackleg and Verticillium CAP ASP Extension	Errin Willenborg SaskCanola		2018	5 years	AAFC, SaskCanola

2.6 Blackleg Publication Listing

The Canadian blackleg research community has very good capacity to conduct blackleg research. More than 50 people are involved in blackleg research, most of which are near full time status working on canola pathology and blackleg in particular. Field level research is excellent with more than 27 blackleg nurseries across the Prairies. Our researchers are also well networked within Canada and with the global research community with collaborations in China, UK, Poland, France, United States and Australia. Canada has the expertise, capacity and technologies to lead the world in blackleg research.

Canadian blackleg researchers have been prolific in publishing in peer reviewed journals their findings, with more than 75 publications in recent years and over 20 within the last 3 years. Substantial blackleg research findings from the Canola Agronomic Research Program (CARP), a provincial canola producer group research program, and through Growing Forward 2, a federal government research program, have contributed to the management of blackleg within Canada.

Many publications were directly related to the 2015 Blackleg Strategic Plan research priorities:

1. Find new sources of blackleg resistance
2. Identify and survey races/avirulence genes in *L. maculans* in Canada to measure and monitor their distribution over time
3. Identify major resistance genes in commercial cultivars of B. napus
4. Quick field diagnostics to identify *L. maculans* avirulence genes present in the field
5. Correlation between plant infection and yield loss
6. Measure durability of each resistance gene
7. Understand how to best use quantitative resistance with major gene resistance
8. Sequence resistance genes
9. Identify and characterise quantitative resistance
10. Agronomic practices to reduce blackleg
11. Develop differential isolates of *L. maculans*

A summary of journal publications in 2016 to 2018 from Canadian institutes can be found in Appendix 2.

2.7 Key Research Findings from 2013 Growing Forward 2 Research Program

Key findings coming out of the SaskCanola & Alberta Canola Agri-Science Project on "canola disease management tools for the prairies – blackleg and sclerotinia". This research will provide significant economic return to Canada's canola industry by reducing crop loss. The outcomes are as follows:

1. Rapid field diagnostics test for blackleg disease. Canada developed a rapid "in-field" test to identify blackleg races present on the canola stubble. The PCR biomarkers which were developed as part of this project were shared with public and private pathology labs across western Canada. Four labs now have the markers for commercial evaluation. When growers detect significant amounts of blackleg in their field they may now send stubble samples to pathology labs for genetic testing. The pathology lab will then provide the grower with information on the specific races of blackleg in their field. This will enable canola growers to make informed decisions about choosing the appropriate blackleg resistance in their canola variety that best matches the profile of the blackleg strain in the field. This is an important tool for managing blackleg in the field.

2. Surveillance and Identification of blackleg pathogen population in Western Canada. A stronger understanding of blackleg pathogen population across Western Canada was gained which will help determine where to deploy specific varieties and R-genes to match the population. This will help to increase the durability of resistance genes and better manage the disease. This also addresses a concern of a major trading partner.

3. Identification of new sources and genes for blackleg resistance. More than 1,100 B. napus and B. rapa accessions are characterized for the profile of known Rlm genes (resistance to blackleg). Several novel blackleg resistance genes were identified which can be used by private seed companies to improve their genetic base. Preliminary mapping conducted on one of these lines support presence of a novel broad spectrum R gene against blackleg disease. 58 lines with quantitative (adult plant) resistance to blackleg disease were identified and presence of adult plant resistance (APR) was confirmed. APR against blackleg disease of canola is a durable form of resistance and protects canola against the blackleg infection.

4. Development of Blackleg resistance gene labels. The durability of some R genes used within commercial cultivars is now understood. This helped form the foundation for major gene resistance labels now used in blackleg resistance identification. Producers can now choose varieties with R genes that are durable to the specific blackleg races. Australia and Europe have used these labels to enable producers to choose the best gene that is most effective against the blackleg race present in their field. This will play a significant role in reducing blackleg in the field in Canada.

5. Development of a blackleg yield loss model. Producers can now estimate the amount of yield lost from blackleg in their canola fields. This is a key model that highlights the negative impacts of the disease and the economic constraints it can place on a crop. Being able to show the economic and agronomic impact of the disease to producers helps further showcase why blackleg is an important disease to manage on farm.

Using the yield loss model on the blackleg infested canola acres in western Canada shows that producers and industry have lost $500 million in revenue annually in the past several years. Return on investment for this research is significant if you consider direct loss to industry and potential economic impact to Canada if canola trade with China is halted.

Key knowledge and technology transfer (KTT) tools include the western Canadian blackleg survey, the Blackleg Scouting Video, www.blackleg.ca, and the development of the Blackleg Steering Group.

3.0 STRATEGIC PLAN

3.1 Research Priority 1: Identify effective R-gene rotations to increase the durability of resistant cultivars

This is the top priority for the canola industry, since the success of controlling blackleg depends on resistance genes that will be effective for growers in the long term. Recent knowledge gained of what blackleg major resistance genes exist in current commercial canola cultivars has provided producers with more information to select a cultivar to meet their field's need. This priority looks to preserve the durability of the resistant cultivars deployed in Canada. With several major resistance genes incorporated into cultivars and many other genes that could be adopted in Canadian cultivars there is a need to identify effective rotations to increase the durability of cultivars. Knowing how to effectively rotate major resistance genes will prevent blackleg from increasing in producer's fields and help prevent the selective loss of avirulence genes from *Leptosphaeria maculans* populations. This knowledge should prevent the selection of races with increased virulence or the creation of populations with few avirulence genes.

Possible research projects:

1. What are the most effective R-gene rotation strategies?
2. Do stacks of resistance genes select for more virulent races of *L. maculans*?
3. Identify resistance genes and sources of resistance at greatest risk of being lost. Are there differences in selective pressure applied by different resistance genes?
4. Develop markers for all current resistance genes in canola cultivars for quick identification.
5. What is the impact of disease pressure with different rotation sequence of crop species?
6. Exploration of novel R genes in B genome and R genomes.
7. Can R gene rotation be as effective as a 3 or 4 year rotation?

Time Frame:
Starting immediately and complete by 2023.

Current projects directed towards this priority:

- CARP CCC 2015-12
- CGDP ADF 2016-158
- CGDP 2017-7
- CARP CCC 2017-27
- CAP ASP Activity 11 & 12
- CAP ASP Activity 13 & 14

3.2 Research Priority 2: Developing a system to effectively screen/assess for quantitative resistance in commercial canola lines

Genetic diversity in resistance is a major step in providing resistance options for plant breeders and ultimately for canola producers. With research investments into understanding major resistance genes within Canadian cultivars the focus has moved over onto understanding how quantitative resistance works within canola cultivars. It is believed that quantitative resistance has been the backbone to cultivars by keeping low incidence and severity rates of blackleg across western Canada.

Possible research projects:

1. Developing a robust system for efficient assessment of Quantitative Resistance (QR) in commercial canola cultivars
2. Developing tools for the rapid screening of canola germplasm for QR to blackleg disease
3. Understand how to best use quantitative resistance with major gene resistance
4. Examining techniques to create new sources of resistance/immunity to blackleg
5. Sequencing and cloning novel sources of resistance to aid in incorporation in canola quality lines
6. Are there different resistance interactions to ascospores and pycnidiospores infections? How does this reflect on major gene and QR resistance?

Time frame:
Starting immediately and complete by 2023.

Current projects directed towards the priority:

- CAP ASP Activity 2
- CAP ASP Activity 3 & 4

3.3 Research Priority 3: Identify the critical window of infection from blackleg to better steward agronomic practices

In Canada, a short growing season and favorable spring conditions for *L. maculans* development, contribute to belief that cotyledon infection is the main pathway to stem infection, basal stem cankering or girdling and yield loss if host-pathogen interaction and environment are favorable for this occurrence. It is not known if cotyledon infection is the only avenue for *L. maculans* to enter into the stem and cause stem cankering. Identifying the critical window of infection from *L. maculans* will help steward agronomic practices to protect canola plants during peak infection time. Understanding when *L. maculans* infects canola plants will help in the development of protocols to test resistance, create chemical control options, and development of new agronomic best management practices.

Possible research projects:

1. What is the potential for blackleg root infection pathway in western Canada?
2. Exploration of the use or in-furrow fungicide to reduce blackleg infections under western Canada conditions
3. Can fluquinconazole (Jockey) seed or in furrow treatment be similarly effective as an early application of strobilurin fungicides
4. Efficacy of new seed or in-furrow treatment chemistry coming down the pipeline for efficacy against root and early foliar infections
5. Exploring the combination of mixing foliar fungicides and insecticides to reduce blackleg and flea beetle damage with the phase out of insecticide seed treatments for flea beetle management
6. Can blackleg be prevented effectively in tight crop rotations with cultivar resistance, seed/in-furrow fungicide treatment and/or early strobilurin fungicide application?
7. Can seed or furrow fungicides improve the durability of resistance genes (both major and minor)?

Time frame:
Starting immediately and complete by 2023.

Current projects directed towards this priority:

- CAP ASP Activity 5
- CAP ASP Activity 6 & 7
- CAP ASP Activity 8
- CAP ASP Activity 9 & 10

3.4 Research Priority 4: Find new sources of blackleg resistance

Genetic diversity in resistance is a major step in providing resistance options for plant breeders and ultimately for canola growers. This priority is a long term commitment since new sources of resistance are unlikely to be readily available. It may require moving these sources from distant relatives of canola or creating the resistance needed in the lab. With new technology becoming more readily available this opens options to effectively transfer resistance genes.

Possible research projects:

1. Identify novel resistance in current canola germplasm
2. Surveying and moving novel resistance from the A, B, and C genomes into canola quality material
3. Surveying and moving novel resistance from other brassica relatives into canola quality material
4. Examining techniques to create new sources of resistance/immunity to blackleg
5. Sequencing and cloning novel sources of resistance to aid in incorporation in canola quality lines
6. Exploration of novel R genes in B genome and R genomes.
7. Using novel technologies that transfer R genes from B or R genome efficiently into *B. napus*

Time frame:
Starting immediately and complete by 2023.

Current projects directed towards this priority:

- CGDP ADF 2016-158
- CGDP 2017-7
- CAP ASP Activity 13 & 14

3.5 Other Research Needed

3.5.1 - Correlation between plant infection and yield loss

Refining the yield loss model: blackleg infection with current canola cultivars. Understanding the impact that blackleg infection actually poses to canola growers is needed to better communicate the need to control disease.

Current projects directed towards this priority:

- CAP ASP Activity 6 & 7

3.6 Extension Delivery

The information generated by current and future research projects will appropriate vehicles to deliver these messages in an effective manner. As an example: how should information on the gene for gene relationship between *B. napus* and *L. maculans* be presented to agronomists and canola growers so that the best choices for cultivar selection are made. The Blackleg Steering Group is in the best position to develop the key extension messages. This body represents both private and public researchers, extension staff and canola growers, and has the expertise to craft the key messages from blackleg research in Canada and elsewhere. Representation by funding groups will also help to decide what the best methods to deliver these messages are.

Tools that may be used are:

- The Canola Watch – the Canola Council of Canada's weekly agronomic email service
- Blackleg.ca - A comprehensive website for blackleg information
- Articles dedicated to blackleg through Western Canadian magazines and newspapers
- Engaging agronomists to disseminate messaging directly to canola growers
- Video(s) on blackleg management, identification, and the nature of the disease
- Development of literature or brochures on blackleg disease management for growers

3.7 Key Extension Messages

Immediate key messaging topics are:

1. List of best management practices and relate these to blackleg risk reduction/enhancement
2. Encourage the need for diversity when growing canola – diversity of crops, blackleg resistance, fungicide usage, etc.
3. Blackleg identification in the field: how to scout for and rate the disease
4. Blackleg lifecycle: how the pathogen works in Canadian prairie environment
5. Blackleg yield loss tool to identify potential losses in crop
6. Value of resistant varieties for managing blackleg; differences between major gene resistance and quantitative resistance

Examples of key messaging extension material can be found in Appendix 3.

3.8 Key Extension Messages to Develop

Extension messaging to develop as blackleg research is completed:

1. Blackleg resistance classification and recommendations on how resistance selection can prevent blackleg infection and resistance breakdown
2. Proper timing and application method for fungicide products on minimizing blackleg infection
3. Encourage adoption of new agronomic practices if the research suggests changes needed

APPENDIX 1

2018 Blackleg Workshop Agenda

2018 Blackleg Workshop
Research Results and Future Directions
Hosted by SaskCanola & Canola Council of Canada

9:00 am Understanding blackleg in western Canada
Justine Cornelsen, Canola Council of Canada

Understanding blackleg in Australia
Dr. Steve Marcroft, Marcroft Grains Pathology

Navigating R-gene rotation stewardship through research with grower participation
Dr. Dilantha Fernando, University of Manitoba

Performance of canola cultivars against mixed *L. maculans* populations and the case for routine standardized monitoring of pathogen genetics
Ralph Lange, Alberta Innovates

Tolerance to fluquinconazole
Dr. Angela Van de Wouw, University of Melbourne

A new tool for the identification of blackleg and race characterization
Sandy Junek, Discovery Seed Labs

12:10 pm Lunch
1:10 pm Genomics tools and resources for better management of blackleg disease of canola
Dr. Hossein Borhan, Agriculture & Agri-Food Canada

An overview of identified resistance genes and gene interactions in the canola growing regions of Australia
Dr. Angela Van de Wouw, University of Melbourne

Developing genetic resources for control of canola blackleg disease
Dr. Fengqun Yu, Agriculture & Agri-Food Canada

Optimizing canola resistance to blackleg through silicon absorption
Dr. Richard Bélanger, University of Laval

Industry Perspectives
Dr. Xuehua Zhang, Monsanto Canada
Dr. Igor Falak, DuPont Pioneer

APPENDIX 2

2016-2018 Canadian Blackleg Research

Becker M, Zhang X, Belmonte M, Fernando WGD. 2017. Transcriptome analysis of the *Brassica napus-Leptosphaeria maculans* pathosystem identifies receptor signaling and structural genes underlying plant resistance. ***The Plant Journal***. (*in press*) DOI: 10.1111/tpj.13514. IF=5.47

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APPENDIX 3

Key Extension Messages / Materials

Figure 1: Top 5 best management practices for blackleg (SaskCanola/Alberta Canola GF2 ASP).

Figure 2: Description of top 5 best management practices for blackleg (SaskCanola/Alberta Canola GF2 ASP) .

Figure 3: *Leptospaeria maculans* lifecycle under Canadian environmental conditions (SaskCanola/Alberta Canola GF2 ASP).

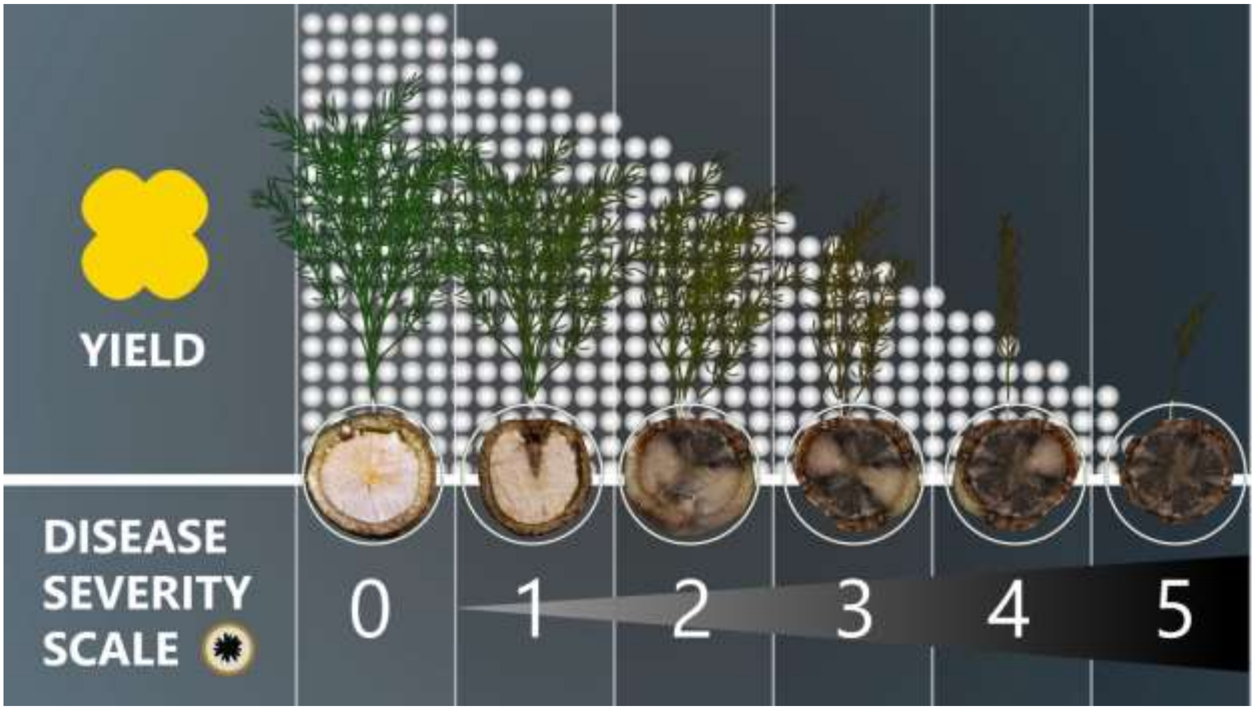


Figure 4: Blackleg yield loss model: every unit increase in disease severity results in roughly 20% yield loss (SaskCanola/Alberta Canola GF2 ASP).

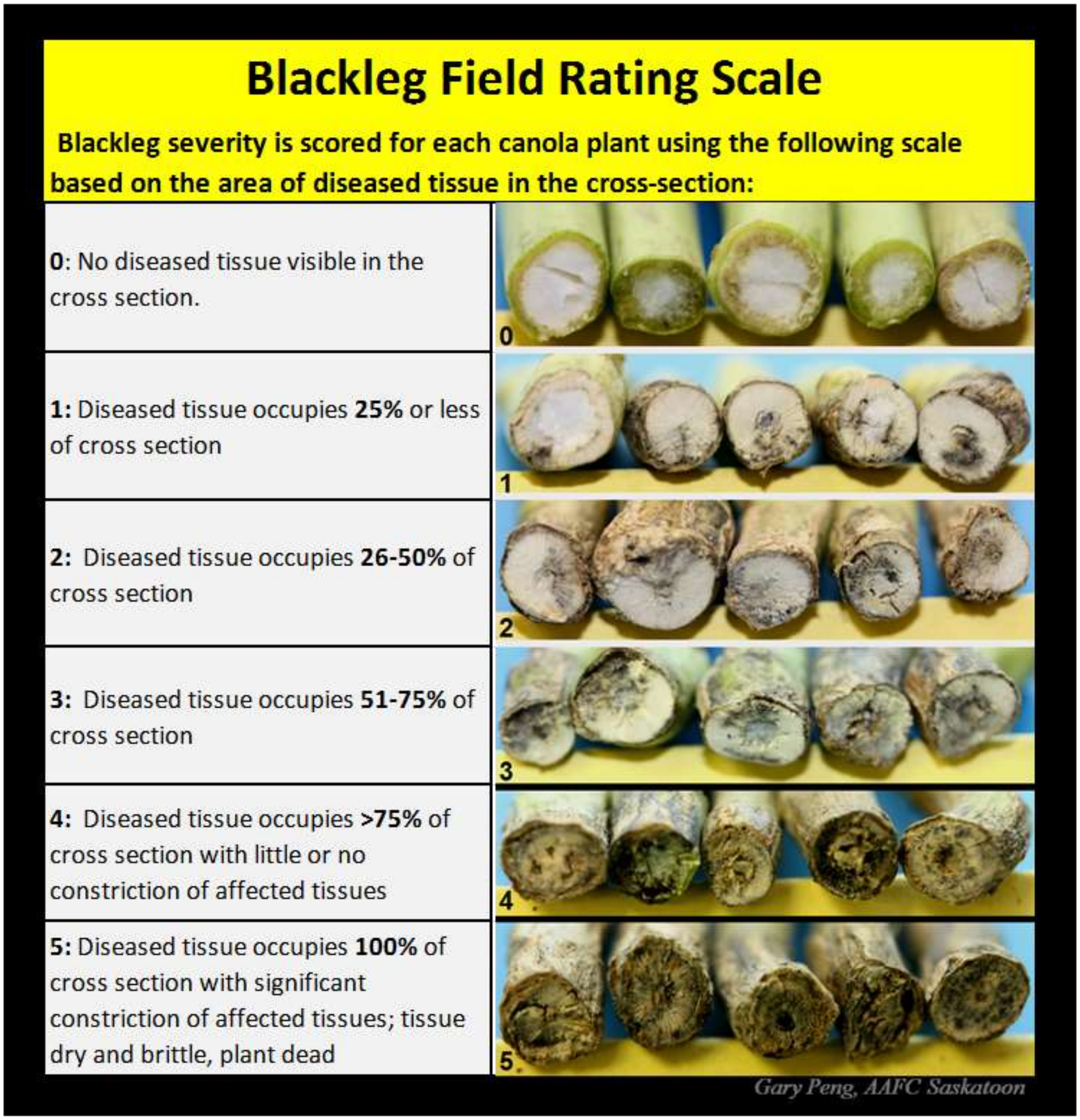


Figure 5: Blackleg disease severity rating scale.

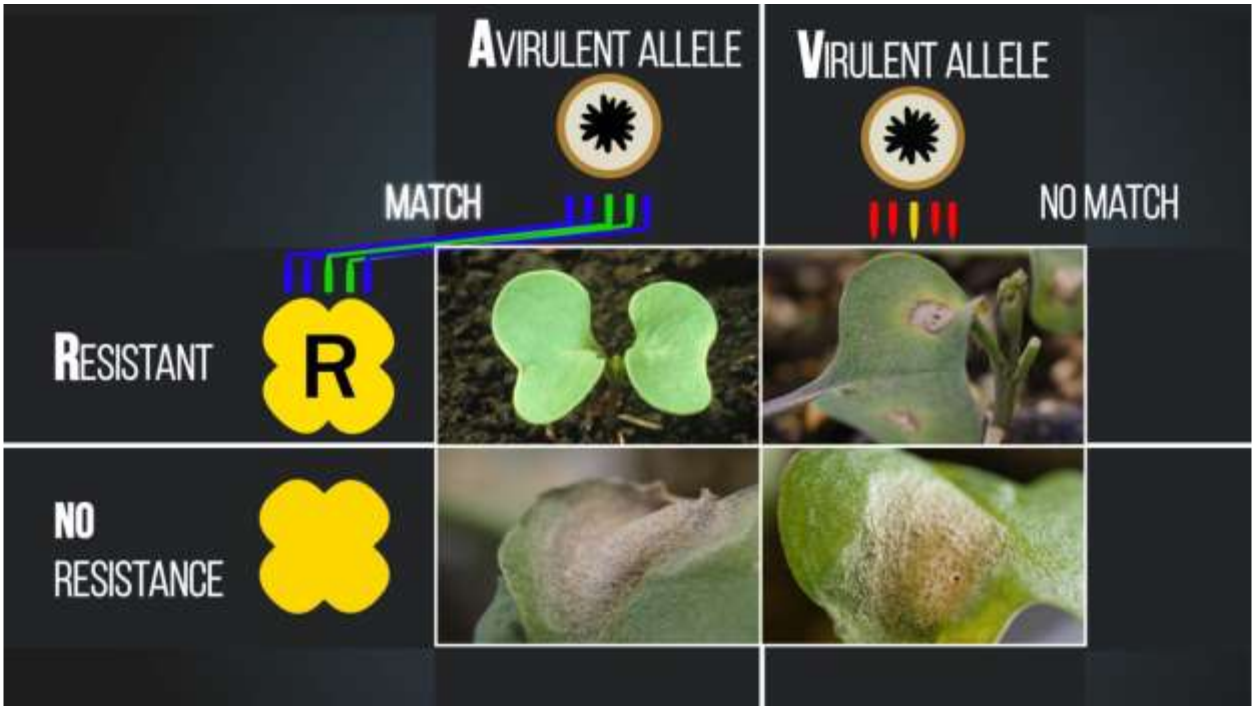


Figure 6: Major gene interactions with avirulent and virulent alleles on susceptible and resistance cultivars.

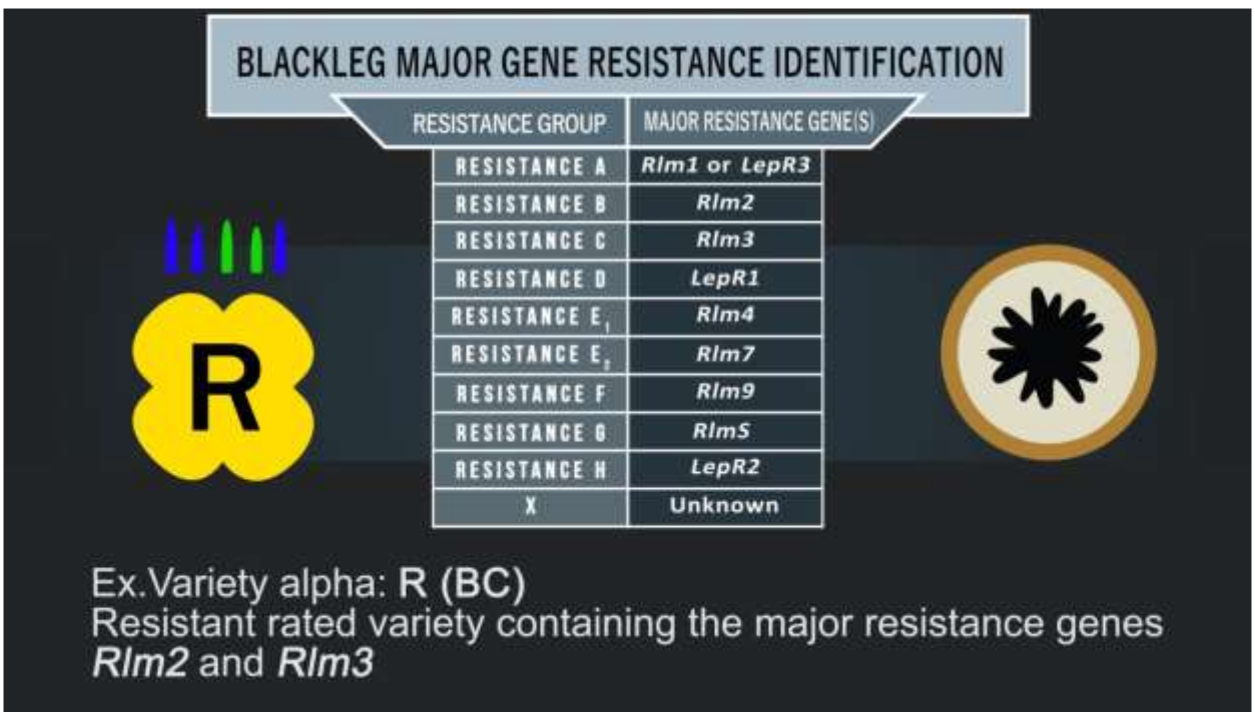
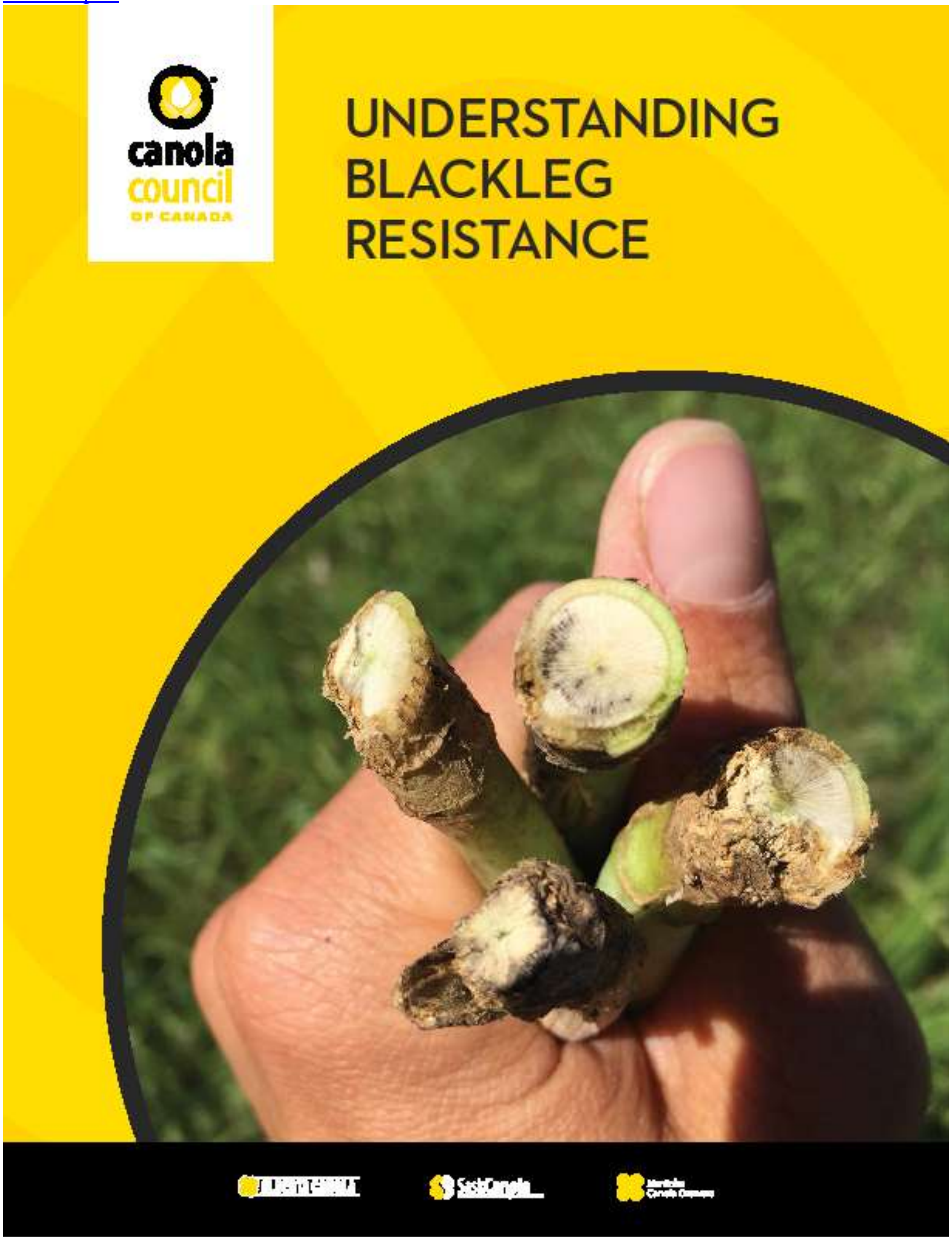


Figure 7: Canadian blackleg major gene resistance identification system.

Brochure: Understanding Blackleg Resistance funded by Alberta Canola, SaskCanola and Manitoba Canola Growers.
https://www.canolacouncil.org/media/597865/18CCC9862_Understanding-Blackleg-Resistance-WEB1.pdf



BLACKLEG RESISTANCE AND CLASSIFICATION

Blackleg resistant canola varieties have been a key tool to help manage this disease since their introduction in the early 1990s. However, blackleg pathogens continue to evolve and, in some areas, are overcoming the effectiveness of current blackleg resistance genes.

New resistance genes and two-part labels will help growers identify which resistance groups may be best suited for the current pathogen population in each of their fields - improving the ability to manage blackleg and increasing the longevity of blackleg resistance.

Blackleg resistance is a valuable resource that must be used judiciously in an integrated management approach, which includes practicing a diverse crop rotation with at least two years between canola crops, effectively managing weeds, and proper scouting/identification of canola diseases.

WHAT SHOULD YOU DO?

For proper management, an integrated management approach **MUST** be incorporated.

To prevent or manage canola fields severely infected by blackleg (resulting in yield loss), the following management practices should be strongly considered:

- Practice a diverse crop rotation with at least two years between canola crops
- Scout for the disease across fields
- Grow canola varieties with a Resistant (R) or Moderately Resistant (MR) field rating
- Use a different resistance group or source to target the blackleg races within the field
- Consider an early season fungicide application
- Manage Brassica weeds and volunteer canola, which can host the pathogen

WHAT TO LOOK FOR?

blackleg.ca

BLACKLEG RESISTANCE CLASSIFICATION

FIELD RESISTANCE RATING

Individual canola breeding companies substantiate their blackleg resistance claims to the Canadian Food Inspection Agency through standard testing procedures outlined by the Western Canada Canola/Rapeseed Recommending Committee guidelines to obtain blackleg resistance field ratings.

Varieties are compared to the susceptible check variety (Westar) for blackleg infection and are assigned ratings as follows:

FIELD RESISTANCE RATING	% DISEASE SEVERITY OF WESTAR
R (Resistant)	0-29.9
MR (Moderately Resistant)	30-49.9
MS (Moderately Susceptible)	50-69.9
S (Susceptible)	70-100

MAJOR GENE RESISTANCE IDENTIFICATION

Major gene resistance labels are also being introduced for more detailed blackleg resistance identification. These labels are voluntary for seed developers to apply to their varieties. Major gene resistance has been categorized into alphabetized groups based on their interactions with the pathogen and other major genes. Ten resistance groups have been created to provide growers with additional information when deciding on their next variety to use while managing severe blackleg fields.

RESISTANCE GROUP	MAJOR RESISTANCE GENE*
A	Rlm1 or LepR3
B	Rlm2
C	Rlm3
D	LepR1
E_1	Rlm4
E_2	Rlm7
F	Rlm9
G	RlmS
H	LepR2
X	unknown

* Major resistance gene groups are subject to change.

EXAMPLE OF A BLACKLEG RESISTANCE TWO-PART LABEL

FORMS OF BLACKLEG RESISTANCE WITHIN VARIETIES

There are two main forms of blackleg resistance found within Canadian canola varieties:

- **Major Gene Resistance:** the major resistance gene, in the plant, needs to match with specific genes in the race of *Leptosphaeria maculans* for the defense response in the plant to be induced. It is a less stable form of resistance if there are many races, but it allows for complete blackleg control when matched with a specific *L. maculans* race.
- **Minor Gene (Quantitative) Resistance:** the resistance genes in the plant help to reduce the severity of infection of all *L. maculans* races within the field by slowing the pathogen as it moves into or down the plant stem. It is a stable form of resistance but does not provide complete blackleg control.

Due to the complexity of minor gene resistance there is no simple way to measure it (at this time), but its performance is captured within the field resistance rating. Major genes are readily identified within a variety and can be communicated using the major gene resistance label.

BE SURE TO DIFFERENTIATE BETWEEN THESE PLANT DISEASES:

Sclerotinia Stem Rot

Verticillium Stripe

Grey Stem

Blackleg

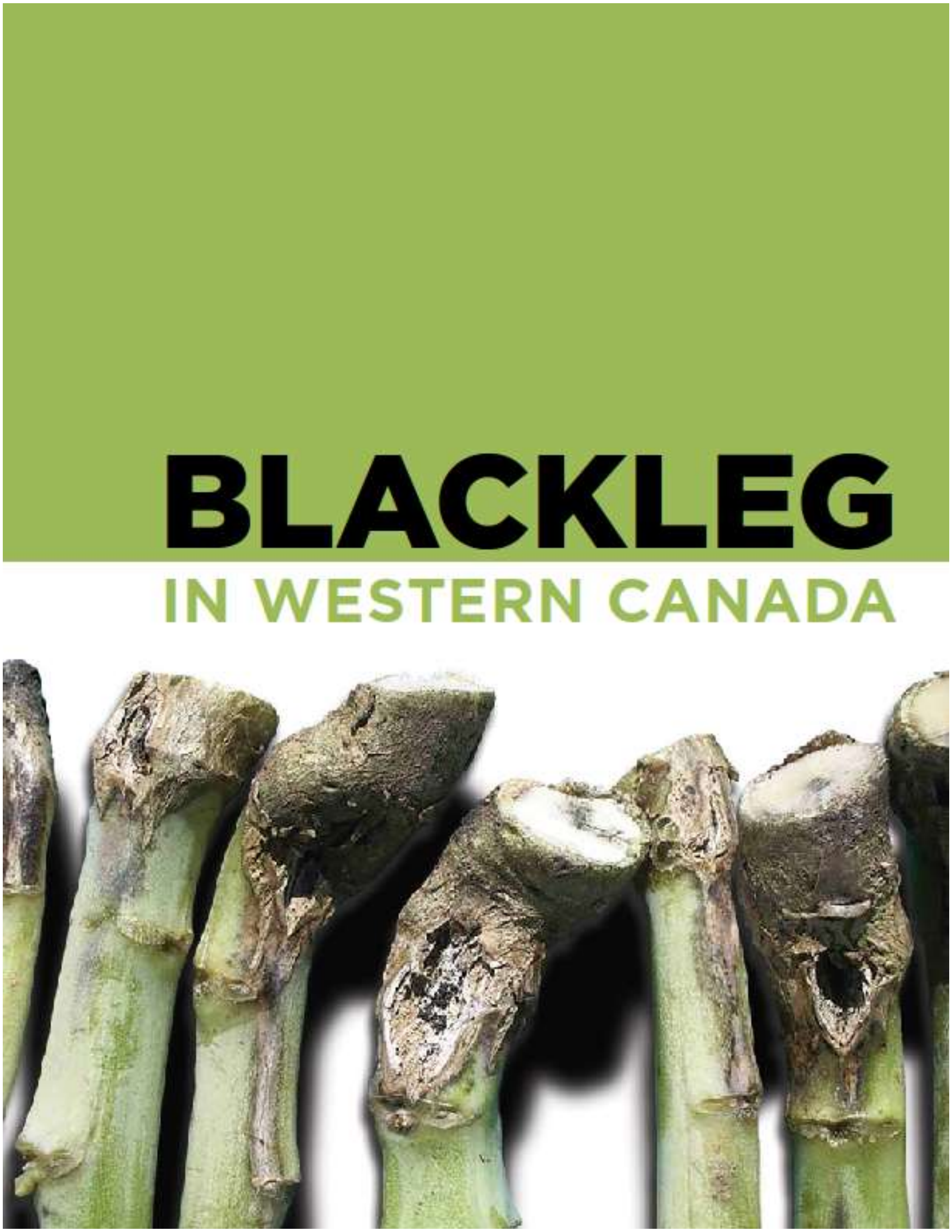
For more information on blackleg, such as prevention strategies and scouting, please go to **blackleg.ca**

canola council OF CANADA

To contact your local Canola Council of Canada agronomy specialist, visit **canolacouncil.org** or call **1-866-834-4378**.

2018

Brochure: Blackleg in Western Canada Pamphlet funded by Growing Forward 2.
https://www.saskcanola.com/quadrant/media/files/resource/pdfs/BLACKLEG-SP-Brochure.pdf



BLACKLEG OF CANOLA IN WESTERN CANADA

Introduction

Blackleg is a serious disease of canola, and other brassica crops, which can result in significant yield loss in susceptible varieties. It is caused by a complex of fungal species. Only the highly virulent species, *Leptosphaeria maculans* causes severe damage to canola in Canada, while the weakly virulent species, *L. biglobosa* generally does not cause serious infection or yield loss.

In heavily infested fields, a large percentage of plants may develop basal stem cankers. In most fields, however, the yield losses are minimal due to low disease levels, although yield losses of 50% or greater have been reported in western Canada. Blackleg-resistant varieties and good crop rotations helped minimize the disease impact in the 1990's and early 2000's. Recent increases in canola acres and short rotations, have the potential to increase blackleg inoculum levels and disease risk.

Key Points

- Blackleg is a fungal canola disease, which has increased in incidence and severity in western Canada in recent years.
- The pathogen population has been changing, which has made some major resistance (*R*) genes in current canola varieties ineffective in some fields.
- Learn to ID blackleg and scout for symptoms especially during or after swathing, to assess the risk for blackleg.
- Reduce blackleg risk by using resistant varieties, rotating resistance varieties and growing non-host crops (cereals or pulses) for 2-3 years between canola crops. Never plant canola on canola stubble.

Scouting for Blackleg Severity

Before swathing or immediately after, examine 10-20 plants at each of 5 sites along a "W" pattern in the field (50-100 total). Observe entire plant and look for grey leaf/stem/pod lesions with black pepper-like spots (pycnidia), or a basal canker or dry rot at the stem base. Clip the base of the stem in order to score diseased tissue in the cross section.

0	No diseased tissue visible in the cross section
1	Diseased tissue occupies 25% or less of cross section
2	Diseased tissue occupies 26-50% of cross section
3	Diseased tissue occupies 51-75% of cross section
4	Diseased tissue occupies >75% of cross section with little or no constriction of affected tissues
5	Diseased tissue occupies 100% of cross section with significant constriction of affected tissues; tissue dry

This factsheet was developed by the Canadian Blackleg Steering Committee, including members from: Agriculture & Agri-Food Canada, Alberta Agriculture & Rural Development, Alberta Innovates - Technology Futures, Canola Council of Canada, Manitoba Agriculture, Saskatchewan Ministry of Agriculture, and University of Manitoba.

Blackleg infections in western Canada are primarily initiated by spores (pycnidiospores and ascospores) produced on infected canola residue (rather than infected seed). Early infections can cause severe damage later in the season.

Asexual fungal fruiting bodies called pycnidia and sexual fruiting bodies, called pseudothecia, release microscopic spores that spread to canola crops.

Sexual "ascospores" (pictured above) **are airborne, resulting in a longer-distance disease dispersal.**

Asexual "pycnidiospores" (pictured above) **can be repeatedly spread through splashing water from rain or irrigation or by wind, contributing to secondary disease cycles.**

The earlier the infection occurs (on cotyledons, for example), the greater the likelihood of basal stem canker development and more severe yield loss. Infected residues may continue to produce pseudothecia for at least two years or until the residue breaks down.

Symptoms of the disease are often associated with wounds caused by hail damage or root maggot feeding.

Blackleg symptoms can be found on all above ground portions of the canola plant including cotyledons, leaves, stems and pods. Lesions reduce photosynthetic capacity and cause loss of water and nutrients to the plant, resulting in yield loss.

Field symptoms often appear as prematurely ripened, lodged, or dead patches. Foliar symptoms include gray lesions with or without dark borders and may contain the spore-producing pycnidia, which appear as pepper-like black spots.

The tell-tale symptom of blackleg is a canker or dry rot at the stem base. Basal stem cankers consist of hard, dry, woody tissue that, when cut in cross section at the soil line, reveal blackening of the vascular ring and cortex. Severe stem girdling impedes transport of water and nutrients, and weakens the stem to cause lodging.

Management: Plant certified disease-free seed, and use a chemical seed treatment. Second, avoid planting canola into fields with infested canola stubble. Third, the use of resistant canola varieties is the cornerstone of blackleg management. Provincial Seed Guides can provide information on blackleg resistance in canola varieties. While the specific *R* genes carried in different canola cultivars are yet to be known, it may be possible avoid selection against specific *R* genes by rotating canola cultivars from different seed companies within the crop rotation. This may maximize the likelihood of genetic diversity in canola rotations.

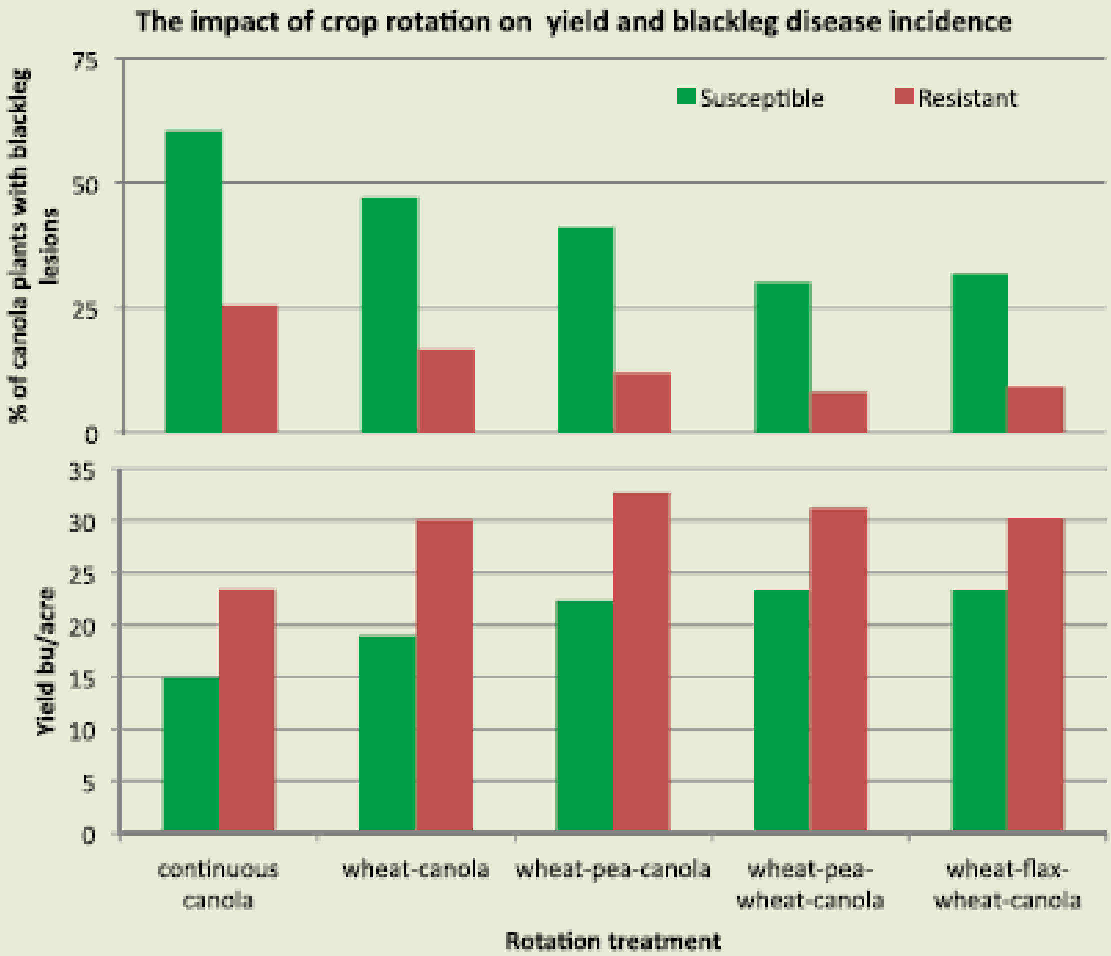
The canola industry is working towards the development of a *R* gene labeling system for canola varieties that will help producers in making informed variety selection and rotation decisions.

Due to the fact that the blackleg pathogen does not survive in soil, it only persists as long as the canola residue (approximately 2-3 years). Therefore, blackleg can be successfully managed by using adequate rotation away from susceptible crops. A one in four rotation is recommended and, when used with resistant varieties, the strategy will provide optimal management of blackleg in most years.

Research on burning or burying of stubble showed minor or no effect on blackleg.

Finally, a protective fungicide spray can reduce severity and prevent yield loss in situations where the variety has lost resistance and disease pressure is high. Fungicide application should be done as an early preventative treatment (2 to 6 leaf stage) in high risk fields with good yield potential.

Risk Factor	0–1 Low Risk	2–3 Medium	4–5 High Risk
Field History			
Scouting	Always	Sometimes	Rarely
Variety	Resistant (R)	MR or MS	Susceptible (S)
Crop Rotation	3-4 year break	2 year break	1 year break or less
Canola Rotation	Different Variety	Same Variety	Same Variety
Canola Buffer	>400 meters to next canola crop or stubble	100-400 m / 50-100 m to next canola crop or stubble	0 to 50 meters to next canola crop or stubble
Foliar Fungicide	Preventative fungicide application	None	None
Weather	Dry	Average	Wet
Other IPM	Good control of canola-related weeds, residue management practices	Poor control of canola-related weeds, reduced tillage, straw chopping	Volunteer canola and related weeds present, zero tillage, lots of residue



Data from Kutcher, H.R., Brandt, S.A., Smith, E.G., Ulrich, D., Malhi, S.S., and Johnston A.M. 2013. Blackleg disease of canola mitigated by resistant cultivars and 4-yr crop rotations in Western Canada. Canadian Journal of Plant Pathology. 25(2): 209-221. Figure used with the permission of the publisher Taylor & Francis Ltd. (www.tandfonline.com)

It is understood that the economics of canola production may, at times, entice producers to push rotations to canola every year or every second year. While this may seem wise for reasons of short-term profitability, it is important for canola producers to keep in mind the risks associated with short rotations, including:

- Reduction in canola yield.
- A rise in blackleg disease potential which can affect many fields or farms regionally.
- Selection for resistance-breaking races of the blackleg fungus, which can lead to erosion of resistance in commercial cultivars in as few as two or three seasons of continuous canola.
- Build-up of other plant diseases such as root rot complex, sclerotinia, and clubroot.
- An increased reliance on fungicides, which is more costly and carries associated risks of development of fungicide resistance in various pathogens.
- Other agronomic concerns including weed control and establishment of insect pests.
- **THE PURPOSE OF A GOOD CROP ROTATION IS TO MAINTAIN DIVERSITY IN THE CROPPING SYSTEM.**

Resistance to *L. maculans* in canola can be in the form of quantitative or adult plant resistance and qualitative or race-specific resistance. Plants and pathogens have co-existed throughout their evolution. Changes in pathogen virulence are continually balanced by changes in the resistance of the host (and vice versa). Therefore, when a resistant cultivar is introduced the pathogen population may change to overcome it. In nature this is a slow and gradual process. Plant breeding accelerated the development of resistance, but loss of resistance can also be accelerated without judicious use of these cultivars.

Research has indicated that many western Canadian canola cultivars carry a good level of adult-plant resistance; infected plants show slower infection development and reduced disease impact relative to susceptible varieties. This type of resistance can be more resilient to changes in a pathogen population.

In order for resistance genes to be effective in canola, they need to correspond to the avirulence genes present in the pathogen population. Preliminary research conducted in western Canada, shows that *Rlm3* is the major *R* gene found in canola cultivars, either on its own or in combination with other genes such as *Rlm1*. However, pathogen surveys indicate there is a high level of virulence towards *Rlm1* and *Rlm3* in the current pathogen population, meaning these specific *R* genes are no longer effective in western Canada. Additional *R* genes are being evaluated for uses in new canola varieties.

Canola	Pathogen (*L. maculans*)	
	Avirulent (*Avr*)	Virulent (*avr*)
Resistant (RR or Rr)	– (resistant)	+ (susceptible)
Susceptible (rr)	+ (susceptible)	+ (susceptible)

Resistance genes in canola will correspond only to the avirulence (*Avr*) genes in the pathogen.