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Crop Profile for Potato in Canada, 2011

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Canada

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Preface

National crop profiles are developed under the Pesticide Risk Reduction Program (PRRP), a joint program of Agriculture and Agri-Food Canada (AAFC) and the Pest Management Regulatory Agency (PMRA). The national crop profiles provide baseline information on crop production and pest management practices and document the pest management needs and issues faced by growers. This information is developed through extensive consultation with stakeholders.

Information on pest management practices and pesticides is provided for information purposes only. No endorsement of any pesticide or pest control technique, discussed, is implied. Product names may be included and are meant as an aid for the reader, to facilitate the identification of pesticides in general use. The use of product names does not imply endorsement of a particular product by the authors or any of the organizations represented in this publication.

For detailed information on growing potato, the reader is referred to provincial crop production guides and provincial ministry websites listed in the Resources Section at the end of the profile.

Every effort has been made to ensure that the information in this publication is complete and accurate. Agriculture and Agri-Food Canada does not assume liability for errors, omissions, or representations, expressed or implied, contained in any written or oral communication associated with this publication. Errors brought to the attention of the authors will be corrected in subsequent updates.

Agriculture and Agri-Food Canada gratefully acknowledges the contributions of provincial crop specialists, industry specialists and growers in the gathering of information for this publication.

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The potato (*Solanum tuberosum*) is a member of the Solanaceae or nightshade family, which includes other horticulturally important members such as tomato, pepper, eggplant and tobacco, as well as weeds such as the nightshades and ground cherry. Potatoes originated in the Andes Mountains of Peru and Bolivia and have been cultivated for over 2000 years. They were introduced into Europe in the sixteenth century and into Canada in 1623 when a supply of potatoes was delivered to Annapolis Royal, Nova Scotia. New potato stock, of a variety of potato called "Royal Purple Chili", was introduced into eastern North America in 1851.

Since 2006, the Pesticide Risk Reduction Program has been working with the potato industry to identify priority pest management issues and develop a risk reduction strategy for potatoes. Wireworms have been identified as a key priority issue. A strategy has been developed to address sustainable management of wireworms in potato.

Crop Production

Industry Overview

Today, potatoes are consumed widely and are ranked fourth in world production, after corn, wheat and rice. Potato is the most important vegetable crop in Canada, accounting for 59% of all vegetable farm cash receipts in 2011 (Statistics Canada, CANSIM database, Tables 001-0013 and 001-0014).

Canada is recognized internationally as a leader in seed potato production, producing about 150 registered seed potato varieties.

General production information is presented in Table 1.

Table 1. General production information

Canadian production (2010)[1]	4.4 million tonnes 140,917 hectares	
Farm gate value (2010)[1]	$ 1,076 million	
Domestic consumption (2010)[2]	13.57 kg/person	
Exports (2010 - 11)3	$179 million (fresh)	
	$39 (seed)	
	$800 (frozen)	
	$83 million (processed)[4]	
Imports (2010 - 11)3	$113 million (fresh)	
	$ 4 million (seed)	
	$141 million (processed)[4]	
	$109 million (frozen)	

[1]Source: Statistics Canada, Table 001-0014 - Area, production and farm value of potatoes, annual CANSIM (database)(http://cansim2.statcan.ca)

[2]Source: Statistics Canada (Food Available for Consumption Data Series)

[3]Source: Statistical Overview of Canadian Horticulture 2010-2011. AAFC. Catalogue No. A71-23/2011E-PDF (Available at: www.agr.gc.ca/horticulture_e)

[4] Includes: Chips, dried, starch, canned and potato salad

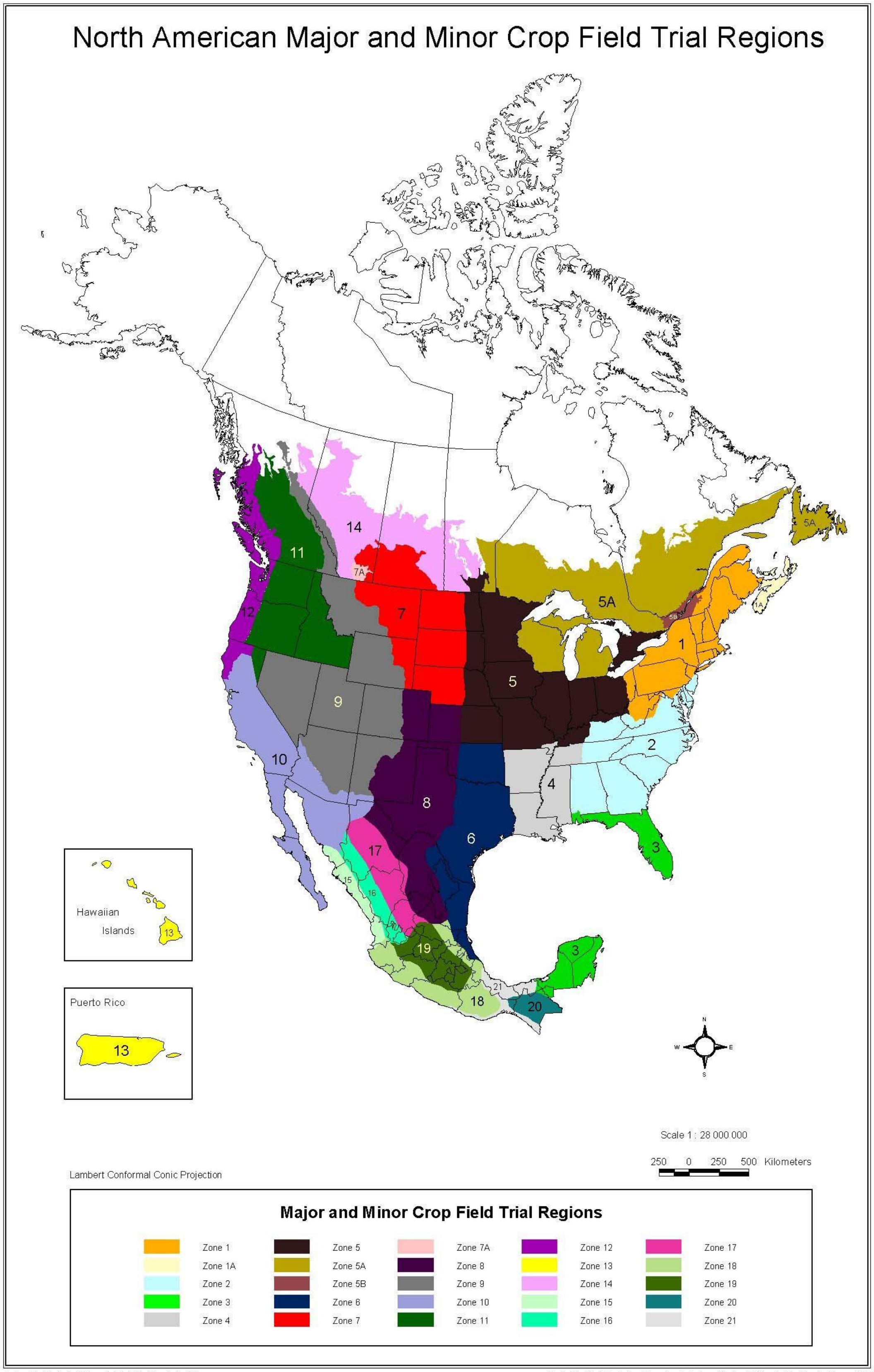
Production Regions

Potatoes are commercially produced in every province in Canada with main production concentrated in Prince Edward Island, Manitoba, Alberta, Quebec and New Brunswick. The percentage of the total Canadian production in each province is presented in Table 2.

Table 2. Distribution of potato production in Canada (2010)

Production Regions	Seeded area (hectares)	Harvested area (hectares)	Percent national production
British Columbia	2,630	2,550	2%
Alberta	20,436	20,437	15%
Saskatchewan	3,035	2,833	2%
Manitoba	28,328	28,329	20%
Ontario	15,580	14,772	10%
Quebec	17,806	16,795	12%
New Brunswick	20,841	19,628	14%
Nova Scotia	809	769	1%
Prince Edward Island	34,601	34,602	25%
Newfoundland and Labrador	202	202	0.1%
Canada	144,270	140,917	100%

[1]Source: Statistics Canada, Table 001-0014 - Area, production and farm value of potatoes, annual CANSIM (database) (accessed November 1, 2012)



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Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, Februrary, 2001.

Figure 1. Common zone map: North American major and minor field trial regions

The major and minor crop field trial regions were developed following stakeholder consultation and are used by the Pest Management Regulatory Agency (PMRA) and the Environmental Protection Agency of the USA to identify the regions where residue chemistry crop field trials are required to support the registration of new pesticide uses. The regions are based on a number of parameters, including soil type and climate but they do not correspond to plant hardiness zones. For additional information, please consult the PMRA Regulatory Directive 2010-05 Revisions to the Residue Chemistry Crop field Trial Requirements (www.hc-sc.gc.ca/cps-spc/pubs/pest/_pol-guide/dir2010-05/index-eng.php).

Cultural Practices

The best sites for planting potatoes have deep, well-drained sandy or silt loam soils. The soil pH should be between 5.5 to over 7.5 for best crop growth, however growing on soils with lower pH can reduce the incidence of scab. Crusting soils are undesirable because heavy spring rains may seal the surface, trapping the sprouts below. Potato crops can have a negative impact on soil quality and fertility if not managed properly.

Crop rotation is important for soil conservation and overall crop health. Good crop rotations involve planting cereals, corn, forage and/or canola in sequence with potatoes. Rotations result in greater rooting depth, higher yields and improved soil organic matter. Rotations can help in weed control and reduce the incidence of disease and insects in potato by breaking the life cycle of the pests.

The cultivated potato is grown from vegetative tuber seed pieces that are planted several inches deep in rows and hilled up as they grow. Soil temperature at planting should be at least 10°C. Rows are typically 75 to 95 cm apart and seed pieces are placed 20 to 45 cm apart in the row, depending on the cultivar and end use of the crop.

There are over 140 cultivars of potato seed grown for sale in Canada by nearly 800 seed growers, on more than 30,000 ha. Important cultivars produced include Russet Burbank, Shepody, Umatilla and Ranger Russet for French fries; Atlantic, Conestoga, Dakota Pearl and Snowden for chips; and Superior, Russet Norkotah, Chieftain, Yukon Gold, Kennebec, Norland and Red Pontiac for table cultivars. The cultivar Goldrush is becoming more popular on the domestic market and is being used in restaurants. Production of specific varieties as gourmet potato tubers continues to grow as does the use of private varieties for fresh consumption.

Irrigation is used to supply the crop with adequate amounts of water throughout the growing season. In Alberta, Manitoba and Saskatchewan, up to 70% of the crop is irrigated, while in Prince Edward Island, only 3% is irrigated in order to protect ground water.

At harvest, tuber pulp temperatures should be 10 – 18 °C. At cool temperatures, tubers are more prone to bruising. It is important that harvesting machinery be serviced and well prepared in advance of the harvest season. Adjusting machinery so that bruising is reduced can result in considerable financial savings. When pulp temperatures at harvest are warm (above 18°C), tubers are susceptible to breakdown in storage.

Before being placed in storage, the skin of potatoes must be hardened (set) to ensure proper storage. In storage, temperatures below 3°C and above 15°C cause dramatic increases in respiration and should be avoided. Air movement must include both through the pile ventilation and recirculation of air in the storage. Relative humidity should be maintained at 92 to 97% for dry healthy potatoes and 85 to 90% for potatoes that are wet or diseased. Tubers should be kept in complete darkness to prevent greening and sprout inhibitors can be used on table and processing potatoes. Good warehouse and equipment sanitation is essential for controlling a number of postharvest diseases.

Table 3. Potato production and pest management schedule in Canada

Time of Year	Activity	Action
April – May	Plant care	Planting; hilling is often performed after planting and before emergence (AB).
	Soil care	Fertilization
	Disease management	Sanitation of seed cutting and planting equipment; seed piece treatment and in-furrow treatment.
	Insect and mite management	In furrow treatment
	Weed management	Pre emergence spray
June	Plant care	Hilling, irrigation (where used)
	Soil care	Conservation tillage (dammer diker) and topdressing carried out (AB).
	Disease management	Monitor for disease; begin fungicide program.
	Insect and mite management	Monitoring and spraying where necessary
	Weed management	Hilling and post emergence spray
July	Plant care	Monitoring, irrigation (where used)
	Soil care	Topdressing, if required
	Disease management	Monitor for disease, apply fungicide when necessary.
	Insect and mite management	Monitoring and spraying where necessary
	Weed management	Limited
August	Plant care	Monitoring, irrigation (where used); harvest of early varieties (Shepody, Atlantic and others) in late July and early August (AB).
	Soil care	None
	Disease management	Monitor for disease, apply fungicide when necessary.
	Insect and mite management	Monitoring and spraying where necessary
	Weed management	Limited
September	Plant care	Harvest
	Soil care	None
	Disease management	Monitor for disease, apply fungicide when necessary. Sanitation of harvest equipment and storage facilities before use.
	Insect and mite management	Limited so late in the season
	Weed management	Limited so late in the season
October	Plant care	
	Soil care	Soil analysis
	Disease management	Limited
	Insect and mite management	Limited
	Weed management	Limited

Abiotic Factors Limiting Production

Wind

Strong winds can result in foliar abrasion. Leaves that have been damaged by wind turn brown and leaf margins may be torn. Wind damaged leaves are dry and develop a leathery texture. Symptoms are more extensive when strong winds occur in hot, dry weather. Wind damage can be confused with many foliar diseases, so a correct diagnosis is important to prevent unnecessary pesticide treatments.

Tipburn

Tipburn occurs when excessive moisture is lost during hot, dry, windy conditions. The incidence of tipburn increases when roots have been damaged or pruned by cultivation. Tipburn symptoms are seen on leaf tips and margins as yellow to brown to black discoloration. Leaves may roll upward, become brittle and eventually die. Symptoms of tipburn can be confused with potato leafroll virus, late blight or insect damage.

Air pollution

Air pollution injury occurs when there is a high concentration of pollutants in the air for several hours or days around a potato crop. Injury often occurs when weather conditions are hot and humid on cloudy days with little wind. Symptoms vary depending on the particular pollutant, concentration of the pollutant in the air, weather conditions, duration of exposure, crop growth stage and varietal susceptibility. Black flecking or pepper like spots on the underside of leaves is often visible. Severe damage appears as necrotic or chlorotic spots on the underside and top of leaves, bronze leaf color and early plant death. Symptoms normally develop on the lower leaves first and can progress up the plant to younger leaves. Yield losses can be high if the injury causes plants to die early. Diagnosis of air pollution injury can be difficult, but observing other highly susceptible plants (alfalfa, soybean, ragweed) nearby, can help confirm this disorder.

Lightning injury

Lightning injury occurs when lightning strikes an area in a potato field. Symptoms appear in 2 to 24 hours of the strike. Affected plants usually occur in a well-defined circular or oval pattern. Leaves may remain green for some time but stems collapse, become water soaked and turn brown to black and eventually tan/white. A characteristic sign of lightning injury is a ladder-like appearance of internal stem tissue. Damaged tubers display brown to black necrosis and cracks on the tuber skin. Severely damaged tubers will appear cooked with internal tissue collapsed, creating a hole in the tuber. Affected tubers are highly susceptible to secondary disease infection and are normally completely decayed before harvest.

Aerial tubers

Aerial tubers are commonly found on potato plants growing along stems. They are small, green to purple in colour and have odd shapes. One or several tubers may grow at a single point on the plant. Aerial tubers usually appear later in the season when plants are actively sending energy down to tubers. They appear at points along stems because of a buildup of carbohydrate, which is moving from leaves down to the tubers. The build-up of carbohydrate results from a blockage or restriction within the stem due to disease, mechanical injury or waterlogged soils. Aerial tubers commonly form when plants are infected with rhizoctonia, blackleg or other disease that block the stem vascular tissue.

Bruising

Bruising is caused by mechanical injury during handling of tubers. Most bruising occurs during windrowing, harvesting, conveyor drops and bin piling. Bruising not only reduces quality of the tubers, but the resulting breaks in the skin provide entry points for some diseases.

Blackspot

Blackspot is internal discoloration of a tuber where mechanical injury has occurred. The skin remains intact with no sign of injury, but below the skin, the tissue will appear blue-gray, brown or black. Some cultivars are more susceptible to blackspot than others.

Shatter bruising

Shatter bruising appears as splitting or cracking of the tuber skin that may extend deep into the tissue. Bruising of this type can occur from blunt mechanical impact or excessive vertical drops. Very large tubers and tubers with high specific gravity are more prone to shatter bruising.

Pressure bruising

Pressure bruising occurs when the tuber surface is under pressure from other tubers while in storage. It is more severe when tubers are dehydrated due to low moisture in the field before harvest or inadequate humidity during storage. Symptoms include a depression or flattening of the tuber surface with tissue becoming dehydrated as the tissue moisture is displaced.

Skinning

Skinning occurs when the skin is rubbed off by mechanical injury. It is more prevalent on immature tubers. The skin may peel back or slough off and the tissue below will turn black over time. Russet skinned cultivars are less prone to skinning than red or white skinned cultivars.

Low temperature and freezing injury

Low temperature and freezing injury can occur in tubers when they are exposed to cold temperatures in the field or in storage. In the field, tubers may be exposed to cold temperatures or freezing before late season harvest. In storage, if temperatures fall below 3^{o}C, injury can occur. Symptoms include darkening of the inside of the tuber followed by a soft, wet rot of affected tissue. Tissue damaged by freezing in storage, is often infected by bacteria, which further break down the tubers.

Blackheart

Blackheart can develop in the field, transport containers or storage, when internal tuber tissues do not receive sufficient oxygen. In waterlogged fields, water physically fills up air spaces in the soil, preventing oxygen from reaching the tuber. Problems resulting from low oxygen are more severe under higher soil temperatures which also increase the tuber respiration rate. During transport or storage, low oxygen levels can result from poor ventilation. Symptoms appear as dark grey, purple or black, oddly shaped discoloration in the center of the tuber with distinct lines between healthy and affected tissue.

Hollow heart and brown center

Hollow heart and brown center are two phases of the same disorder. These disorders often occur following periods of rapid growth and/or moisture, fertility and temperature stresses. The exact cause of hollow heart and brown center are not known. Brown center may be induced when soil temperatures are below 13°C for 5 to 7 days around tuber initiation. Brown center normally occurs early in the season when tubers are very small. Symptoms appear as a brown discoloration in the center of the tuber near the stem end. If growth is slow following brown center development, the dead brown cells may become dispersed with healthy cells and the brown color will dissipate before harvest. If growth is rapid, affected cells will split apart creating a cavity resulting in hollow heart. Hollow heart normally occurs late in the season. Symptoms appear as longitudinal cracks that vary in size and shape developing in the center, bud end or stem end of the tuber. The cavity walls of hollow heart develop a tan to brown layer resembling skin, which creates a distinct line between the cavity and healthy tissue.

Tuber surface cracks

Surface cracks include growth cracks and thumbnail cracks. Both conditions are affected by moisture in the soil and make table-stock tubers unmarketable. Growth cracks occur from irregular moisture patterns in the field. They often develop when a heavy rainfall or irrigation occurs after a dry period or with the application of fertilizer. Rapid growth causes excessive pressure on the tuber skin, resulting in cracks. Thumbnail cracks occur when waterlogged tubers are exposed to the air or drying conditions. Thumbnail cracks appear as small, shallow cracks resembling a thumbnail dent in the tuber skin. At harvest, the excessive pressure on tuber skin will cause small cracks when exposed to dry air.

Malformed tubers

There are several types of tuber malformations (knobby, dumbbell, pointed end and bottle neck) that vary in their timing of development and shape. These malformations develop when a disruption in growth occurs due to inadequate moisture and fertility, followed by regular growth. Periods of high temperature, plants with few stems or tubers, rhizoctonia, pruning and excessive vine growth can cause malformed tubers as well. Using cultivars that are less susceptible can reduce the incidence of malformed tubers. Round or oblong cultivars are less prone to malformations.

Tuber greening

Tuber greening occurs when tubers are exposed to light from the sun or artificial sources, resulting in excessive chlorophyll production. Tubers that develop close to the soil surface, that have been planted too shallowly or are hilled poorly or are exposed by erosion or ground cracks, are prone to greening. Tuber greening is a quality and health issue. The production of chlorophyll in the tuber skin also increases levels of glycoalkaloids, such as solanine, a saponin, which are mildly toxic to humans and results in a bitter tasting potato. Most of the glycoalkaloids can be removed when the skin is peeled off.

Internal sprouting

Internal sprouting occurs in storage when sprouts (buds) are damaged or the pressure from adjacent tubers does not allow sprouts to grow outward. Sprouts can penetrate directly through the skin or enter an adjacent tuber usually in a depression or deep eye. Internal sprouting can cause tubers to split or form small tubers internally.

Stem-end browning

Symptoms of stem end browning appear as an internal tan, red or brown discoloration of vascular tissue at the stem end of the tuber. The discoloration may be apparent shortly after harvest or may develop over the first month or two in storage. The disorder occurs when immature vines are killed rapidly. The symptoms of stem-end browning are very similar to tubers with necrosis caused by potato leaf roll virus or verticillium wilt.

Enlarged lenticels

Enlarged lenticels develop when tubers are in contact with excessive moisture in the field or in storage. Enlarged lenticels can also develop under dry conditions in compacted soil. Lenticels are small pores in the tuber skin responsible for gas exchange. In waterlogged soils and in storage with excessive free moisture, lenticels will swell. With prolonged exposure to these conditions, lenticels will further enlarge and burst the suberin layer, forming raised masses over the tuber skin. The rupture of the suberin layer opens up tubers to infection by many diseases.

Diseases

Key Issues

- Resistance to fungicides is an on-going problem for diseases including: late blight and pink rot to metalaxyl, early blight to several fungicides, fusarium dry rot to thiabendazole and fludioxonil and metalaxyl-m in some areas; and seed piece decay to fludioxonil and thiophanate-methyl. The monitoring of resistant populations and improved resistance management strategies should be implemented.
- There is a need for alternative, reduced risk products, to be used in rotation, for the management of diseases such as pink rot, fusarium dry rot and powdery scab.
- Research is needed to gain understanding of how new strains of *Phytophthora infestans* “behave” under Canadian conditions.
- An effective control strategy is needed for seed borne late blight.
- Currently available varieties of potatoes are not resistant to all strains of late blight.
- Some genetically modified cultivars do have resistance to late blight however there is a lack of acceptance in the market place of genetically modified potato cultivars.
- An improved system for forecasting diseases such as early blight and late blight is required.
- There is insufficient knowledge on the economic thresholds for early blight and brown spot. It is not known whether there is a need at the field level to distinguish between these diseases.
- There is limited understanding of the biology of silver scurf and how the disease is transferred to daughter tubers.
- Pink eye is a serious issue in localized areas each year. Research is needed to better understand the interaction between field conditions, plant health and subsequent physiological changes that result in pink eye.
- There are very limited control methods available for diseases such as verticillium wilt, common scab and silver scurf. IPM strategies that include rotational crops, soil amendments and other novel approaches need to be developed.
- There is a need for a survey to establish the fusarium species causing dry rot in Canada.
- *Fusarium graminearum* has been identified as the predominant dry rot pathogen in some parts of Canada. Information is needed to better understand the potential for mycotoxin production by this pathogen in potato.
- The incidence of blackleg is increasing in some areas and in some varieties. Biological control strategies (bacterial phage) and biopesticides (eg.Serenade) should be evaluated for efficacy against this disease.
- Common scab resistance should be included in breeding programs as a priority trait.
- Mancozeb is the only broad spectrum seed piece treatment available. With the concerns of resistance to fludioxonil and thiophanate-methyl, the importance of mancozeb as a seed piece treatment has increased.

- Powdery scab is becoming more important given its role as a vector for Potato Mop-Top Virus. There is insufficient information available on varieties susceptibility to this disease. Chemical controls are insufficient.
- Testing for golden nematode is an export requirement for many Canadian seed potato producers. Cost effective field sampling and lab testing services for this pest are needed.
- There is insufficient information on nematode species causing problems in different areas and their economic thresholds.
- The impact of green manures and crop rotation on nematode populations is not well understood.
- Improved diagnostic services for nematodes are needed.
- National phyto-sanitary guidelines and reduced risk storage sanitation options for potato storages are not available. Current products for sanitizing potato storages are insufficient.
- There is a need to ensure harmonization of pesticide registrations and pre-harvest intervals (PHI) between Canada and the US.
- Economic thresholds for black dot have not been determined.
- There are no biological controls available for silver scurf on potato seed pieces both in storage and in the field.

Table 4. Occurrence of diseases in potato production in Canada

Disease	British Columbia	Alberta	Saskatchewan	Manitoba	Ontario	Quebec	New Brunswick	Prince Edward Island
Bacterial ring rot								
Bacterial soft rot								
Blackleg								
Pink eye								
Common scab								
Black dot								
Brown spot								
Early blight								
Fusarium dry rot								
Fusarium wilt								
Grey mould								
Late blight								
Pink rot								
Powdery scab								
Pythium leak								
Rhizoctonia canker and black scurf								
Seed piece decay								
Silver scurf								
Verticillium wilt								
Aster yellows phytoplasma								
Mosaic and latent viruses								
Potato leafroll virus								
Potato mop top virus								
Witch's broom phytoplasma								
Nematodes								

Widespread yearly occurrence with high pest pressure
Widespread yearly occurrence with moderate pest pressure, OR localized yearly occurrence with moderate pest pressure OR widespread sporadic occurrence with high pest pressure
Widespread yearly occurrence with low to moderate pest pressure OR widespread sporadic occurrence with moderate pressure OR sporadic localized occurrence with moderate pressure.
Localized yearly occurrence with low to moderate pest pressure OR widespread sporadic occurrence with low pressure OR localized sporadic occurrence with low to moderate pest pressure.
Pest is present and of concern, however little is known of its distribution, frequency and importance.
Pest not present
Data not reported

[1]Source: Potato stakeholders in reporting provinces.

[2]Please refer to the colour key (above) and Appendix 1, for a detailed explanation of colour coding of occurrence data.

Table 5. Adoption of disease management practices in potato production in Canada

Practice / Pest		Common Scab	Early blight	Fusarium Dry Rot	Late blight	Rhizoctonia canker and black scurf	Verticillium wilt	Viruses (General)	Nematodes (General)
Avoidance	resistant varieties								
	planting / harvest date adjustment								
	crop rotation								
	choice of planting site								
	optimizing fertilization								
	reducing mechanical damage or insect damage								
	thinning / pruning								
	use of disease-free seed, transplants								
Prevention	equipment sanitation								
	mowing / mulching / flaming								
	modification of plant density (row or plant spacing; seeding rate)								
	seeding / planting depth								
	water / irrigation management								
	end of season crop residue removal / management								
	pruning out / elimination of infected crop residues								
	tillage / cultivation								
	removal of other hosts (weeds / volunteers / wild plants)								

	Practice / Pest	Common Scab	Early blight	Fusarium Dry Rot	Late blight	Rhizoctonia canker and black scurf	Verticillium wilt	Viruses (General)	Nematodes (General)
Monitoring	scouting - trapping	green	green	green	green	green	green	green	green
	records to track diseases	green	green	green	green	green	green	green	green
	soil analysis	green	red	green	white	green	green	red	green
	weather monitoring for disease forecasting	red	green	red	green	red	red	green	white
	grading out infected produce	green	green	green	green	green	green	green	green
Decision making tools	economic threshold	green	green	green	green	green	green	green	green
	weather / weather-based forecast / predictive model	red	green	red	green	red	red	green	white
	recommendation from crop specialist	green	green	green	green	green	green	green	green
	first appearance of pest or pest life stage	red	green	green	green	red	red	green	white
	observed crop damage	green	green	green	green	green	green	green	green
	crop stage	green	green	green	green	green	green	green	green
	calendar spray	green	green	red	green	red	green	green	white
Suppression	pesticide rotation for resistance management	white	green	green	green	green	red	green	red
	soil amendments	green	red	green	red	green	green	red	green
	biological pesticides	red	green	red	green	red	red	red	red
	controlled atmosphere storage	green	red	green	green	red	red	white	red

green	**This practice is used to manage this pest by at least some growers in the province.**
red	**This practice is not used by growers in the province to manage this pest.**
white	**This practice is not applicable for the management of this pest**
grey	**Information regarding the practice for this pest is unknown.**

[1]**Source: Potato stakeholders in reporting provinces (Alberta, Manitoba, Ontario, Quebec, New Brunswick and Prince Edward Island).**

Table 6. Fungicides registered for disease management in potatoes in Canada.

Active Ingredient[1,2]	Classification[3]	Mode of Action[3]	Target Site[3]	Resistance Group[3]	Re-valuation status[4]	Targeted pests[5]
Seed Treatment						
fludioxonil	phenylpyrrole	E2: signal transduction	MAP/Histidine- Kinase in osmotic signal transduction (os-2, HOG1)	12	R	black scurf (*Rhizoctonia solani*), silver scurf (*Helminthosporium solani*), dry rot (*Fusarium* spp.)
fludioxonil + mancozeb	phenylpyrroles + dithio-carbamates and relatives	E2: signal transduction + multi-site activity	MAP/Histidine- Kinase in osmotic signal transduction (os-2, HOG1)	12 + M3	R + RE	black scurf (*Rhizoctonia solani*), silver scurf (*Helminthosporium solani*), dry rot (*Fusarium* spp.)
iprodione	dicarboximide	E3: signal transduction	MAP/Histidine- Kinase in osmotic signal transduction (os-1, Daf1)	2	RE	seed- borne rhizoctonia stem and stolon canker *(Rhizoctonia solani*); silver scurf (suppression)
mancozeb	dithio-carbamates and relatives	multi-site contact activity	multi-site contact activity	M3	RE	fusarium seed piece decay
metiram	dithio-carbamates and relatives	multi-site contact activity	multi-site contact activity	M3	RE	seed-borne common scab, fusarium seed piece decay
thiophanate-methyl	thiophanate	B1: mitosis and cell division	ß-tubuline assembly in mitosis	1	RE	verticillium wilt, fusarium rot, silver scurf, seed piece decay, blackleg
In furrow						
metalaxyl-M + azoxystrobin	acylalanine	A1: nucleic acids synthesis	RNA polymerase I	4	R + R	rhizoctonia stem and stolon canker, black scurf (*Rhizoctonia solani*); pink rot (*Phytophthora erythroseptica*)(suppression)

Active Ingredient[1,2]	Classification[3]	Mode of Action[3]	Target Site[3]	Resistance Group[3]	Re-valuation status[4]	Targeted pests[5]
Foliar application						
ametoctradin + dimethomorph	triazolo-pyrimidylamine + cinnamic acid derivatives	C8: respiration + F:5 lipid synthesis and membrane integrity	C8: complex III: cytochrome bc1 (ubiquinone reductase) at Q x (unknown) site + phospholipid biosynthesis and cell wall deposition (proposed)	45 + 40	R + R	late blight, reduces tuber blight
azoxystrobin	methoxy-acrylate	C3. respiration	complex III: cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene)	11	R	early blight (*Alternaria solani*), late blight (*Phytophthora infestans*), black dot (*Colletotrichum coccodes*)
azoxystrobin + chlorothalonil	methoxy-acrylates + chlorornitriles (phthalonitriles)	C3. respiration + multi-site contact activity	complex III: cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene) + multi-site contact activity	11 + M5	R + RE	early blight (*Alternaria solani*)
Bacillus subtilis	*Bacillus subtilis* and the fungicidal lipopeptides they produce	F6: lipids and membrane synthesis	microbial disrupters of pathogen cell membranes	44	R	early blight (*Alternaria solani*) (suppression), white mould (*Sclerotinia sclerotiorum*) (suppression)
boscalid	pyridine carboxamide	C2. respiration	complex II: succinate-dehydro-genase	7	R	early blight (*Alternaria solani*)

Active Ingredient[1,2]	Classification[3]	Mode of Action[3]	Target Site[3]	Resistance Group[3]	Re-valuation status[4]	Targeted pests[5]
captan	phthalimide	multi-site contact activity	multi-site contact activity	M4	RE	early blight (*Alternaria solani*), late blight (*Phytophthora infestans*) , black dot (Colletotrichum coccodes)
chlorothalonil	chloronitrile (phthalonitrile)	multi-site contact activity	multi-site contact activity	M5	RE	early blight (*Alternaria solani*), late blight (*Phytophthora infestans*), botrytis vine rot
copper (different salts)	inorganic	multi-site contact activity	multi-site contact activity	M1	R	early blight, late blight, botrytis vine rot
cyazofamid	cyano- imidazole	C4. respiration	complex III: cytochrome bc1(ubiquino-ne reductase) at Qi site	21	R	late blight
cymoxanil + mancozeb	cyanoacetamide-oxime + dithio-carbamates and relatives	Unknown mode of action + multi-site contact activity	multi-site contact activity	27 + M3	R + RE	late blight
dimethomorph + chlorothalonil	cinnamic acid amides + chloronitriles (phthalonitriles)	F5: lipid synthesis and membrane integrity + multi-site contact activity	phospholipid biosynthesis and cell wall deposition (proposed) + multi-site contact activity	40 + M5	R + RE	late blight, reduces tuber blight

Active Ingredient[1,2]	Classification[3]	Mode of Action[3]	Target Site[3]	Resistance Group[3]	Re-valuation status[4]	Targeted pests[5]
dimethomorph + mancozeb	cinnamic acid amides + dithiocarbamates and relatives	F5: lipid synthesis and membrane integrity + multi-site contact activity	phospholipid biosynthesis and cell wall deposition (proposed) + multi-site contact activity	40 + M3	R + RE	late blight, reduces tuber blight
dimethomorph + metiram	cinnamic acid amides + dithiocarbamates and relatives	F5: lipid synthesis and membrane integrity + multi-site contact activity	phospholipid biosynthesis and cell wall deposition (proposed) + multi-site contact activity	40 + M3	R + RE	late blight, reduces tuber blight
fenamidone + mancozeb	imidazolinones + dithio-carbamates and relatives	C3. respiration + multisite contact activity	complex III: cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene) + multi-site contact activity	11 + M3	R + RE	early blight, late blight
fenamidone + chlorothalonil	imidazolinones + chloronitriles (phtalonitriles)	C3. respiration + multi-site contact activity	complex III: cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene) + multi-site contact activity	11 + M5	R + RE	early blight, late blight
famoxadone + cymoxanil	oxazolidine-diones + cyanoacetamide-oxime	C3. respiration + unknown mode of action	complex III: cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene)	11 + 27	R + R	early blight, late blight
fluazinam	2,6-dinitroaniline	C5. respiration	uncouplers of oxidative phos-phorylation	29	R	late blight

Active Ingredient[1,2]	Classification[3]	Mode of Action[3]	Target Site[3]	Resistance Group[3]	Re-valuation status[4]	Targeted pests[5]
fludioxonil + mancozeb	phenylpyrroles + dithio-carbamates and relatives	E2: signal transduction + multi-site contact activity	MAP/Histidine- Kinase in osmotic signal transduction (os-2, HOG1)	12 + M3	R + RE	black scurf (*Rhizoctonia solani*), silver scurf (*Helminthosporium solani*), dry rot (*Fusarium* spp.)
mancozeb	dithio-carbamates and relatives	multi-site contact activity	multi-site contact activity	M3	RE	early blight, late blight
mandipropamid	mandelic acid amide	F5: lipid synthesis and membrane integrity	phospholipid biosynthesis and cell wall deposition (proposed)	40	R	late blight
maneb	dithio-carbamates and relatives	multi-site contact activity	multi-site contact activity	M3	DI (last date of use Dec 31, 2013)	early blight, late blight
metalaxyl-M + chlorothalonil	acylalanines + chloronitriles (phthalonitriles)	A1: nucleic acids synthesis + multi-site contact activity	RNA polymerase I + multi-site contact activity	4 + M5	R + RE	early blight, botrytis vine rot, pythium leak (suppression in storage), pink rot (suppression in storage)
metalaxyl-M + mancozeb	acylalanines + dithio-carbamates and relatives	A1: nucleic acids synthesis + multi-site contact activity	RNA polymerase I	4 + M3	R + RE	early blight, late blight, pythium leak (suppression), pink rot (suppression)
metiram	dithio-carbamates and relatives	multi-site contact activity	multi-site contact activity	M3	RE	early blight, late blight
pyraclostrobin	methoxy-carbamate	C3. respiration	complex III: cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene)	11	R	early blight, late blight

Active Ingredient[1,2]	Classification[3]	Mode of Action[3]	Target Site[3]	Resistance Group[3]	Re-valuation status[4]	Targeted pests[5]
pyraclostrobin + metiram	methoxy-carbamates + dithio-carbamates and relatives	C3. respiration = multi-site activity	complex III: cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene)	11 + M3	R + RE	early blight, late blight
propamocarb	carbamate	F4: lipid synthesis and membrane integrity	cell membrane permeability, fatty acids (proposed)	28	R	late blight
propamocarb + chlorothalonil	carbamates + chloronitriles (phthalonitriles)	F4: lipid synthesis and membrane integrity + multi-site contact activity	cell membrane permeability, fatty acids (proposed) + multi-site contact activity	28 + M5	R + RE	late blight
propamocarb + mancozeb	carbamates + dithio-carbamates and relatives	F4: lipid synthesis and membrane integrity + multi-site contact activity	cell membrane permeability, fatty acids (proposed)	28 +M3	R + RE	late blight
pyraclostrobin + chlorothalonil	methoxy-carbamates = choronitriles (phthalonitriles)	C3 respiration + multi-site contact activity	complex III: cytochrome bc1 (ubiquinol oxidase) at Qo site (cyt b gene) + multi-site contact activity	11 + M5	R + RE	early blight, late blight
pyrimethanil + chlorothalonil	anilino-pyrimidines + chloronitriles (phthalonitriles)	D1: amino acids and protein synthesis + multi-site contact activity	methionine biosynthesis (proposed) (cgs gene) + multi-site contact activity	9 + M5	R + RE	early blight
zoxamide + mancozeb	toluamides + dithio-carbamates and relatives	B3: mitosis and cell division + multi-site contact activity	ß-tubulin assembly in mitosis	22 + M3	R + RE	early blight, late blight

Active Ingredient[1,2]	Classification[3]	Mode of Action[3]	Target Site[3]	Resistance Group[3]	Re-valuation status[4]	Targeted pests[5]
Post-harvest						
hydrogen peroxide					R	fusarium tuber rot, bacterial soft rot, silver scurf
Bacillus subtilis	*Bacillus subtilis* and the fungicidal lipopeptides they produce	F6: lipid synthesis and membrane integrity	microbial disrupters of pathogen cell membranes	44	R	early blight (*Alternaria solani*) (suppression), white mould (*Sclerotinia sclerotiorum*) (suppression)
thiabendazole	benzimidazole	B1: mitosis and cell division	ß-tubuline assembly in mitosis	1	R	storage rots caused by *Fusarium* spp., *Phoma* spp., *Helminthosporium* spp., *Oospora* spp. and *Rhizoctonia* spp.
Pseudomonas syringae Strain ESC-10					R	suppression of decay caused by dry rot (*Fusarium sambucinum*) and silver scurf on both seed and storage potatoes

[1]Registrations confirmed on the PMRA Registered Products Database (www.hc-sc.gc.ca/cps-spc/pest/index-eng.php) July 30, 2012.

[2] Not all end use products containing this active ingredient may be registered for use on this crop. The information in these tables should not be relied upon for pesticide application decisions. Individual product labels must be consulted for up to date, accurate information concerning the use of these pesticides and specific registration details.

[3]Source: FRAC Code List: Fungicides sorted by mode of action (including FRAC code numbering) published by the Fungicide Resistance Action Committee (March 2012) (www.frac.info/frac/index.htm).

[4]PMRA re-evaluation status as of **October 31, 2012**: R – full registration, RE (yellow) – under re-evaluation, DI (red) – discontinued by registrant, PO (red) – being phased out as a result of re-evaluation.

[5] Please consult the pesticide label for a detailed listing of pests controlled by products containing each active ingredient. Information on registered pesticide uses is also available from the PMRA Registered Products Database (www.hc-sc.gc.ca/cps-spc/pest/index-eng.php).

Seed Piece Decay *(Rhizoctonia solani, Fusarium* spp.*, Erwinia carotovora,Pythium* spp.*)*

Pest information

Damage: Seed piece decay is caused by a number of pathogens, occurring alone or in combination and results in misses, poor emergence and stunted growth. Spots on seed pieces turn black and watery as they are colonized by bacteria and the seed pieces eventually completely rot.

Life Cycle: Fusarium is the principle cause of seed piece decay, as it is present in almost all soils, in storage and on handling equipment. Seed pieces can be affected when the soil is too dry or too wet. Seed cutting allows for a point of entry for the pathogens that cause the disease. The entry of fusarium allows other pathogens, such as erwinia, to gain a foot hold.

Pest Management

Cultural Controls: Only certified, disease-free seed should be planted. Seed cutting equipment must be cleaned and disinfected regularly. Avoid planting into cool, wet, poorly drained soil and ensure seed is not planted too deep.

Resistant Cultivars: None available.

Chemical Controls: Seed piece treatments can be effective in reducing the incidence of this disease.

Issues for Seed Piece Decay

1. Mancozeb is the only broad spectrum seed piece treatment option available. With the concerns with resistance to fludioxonil and thiophanate-methyl, the importance of mancozeb as a seed piece treatment has increased.

Late Blight (*Phytophthora infestans*)

Pest information

Damage: Late blight is one of the most problematic and devastating potato diseases worldwide. Lesions develop on leaves and stems. Under favourable conditions, sporulation occurs in lesions resulting in thousands of new spores that spread to surrounding potato tissues. Late blight infection can lead to complete defoliation. Tubers that come into contact with late blight spores are susceptible to infection resulting in irregularly shaped lesions that penetrate up to 2 cm into the tuber. Late blight infected tubers are extremely susceptible to secondary rot pathogens.

Life Cycle: The fungus survives from season to season as mycelium in infected tubers in storage, cull piles and tubers left in harvested potato fields. The disease spreads when infected tubers are planted or infected volunteers develop. There are two mating types of the fungus, A1 and A2 and oospores may be produced when these two types occur together. Oospores are resistant structures that may contribute to the overwintering survival of the fungus in the absence of potato tissue and are of concern because of the potential development of new strains. Sporangia are produced in infected tissues and are spread by wind and rain. Tubers become infected late in the season and during harvest when spores in the soil come in contact with the tuber. Blight will spread in storage if free moisture is present.

Pest Management

Cultural Controls: Effective management of this disease requires an integrated approach. The most important management measures include the removal and destruction of cull piles, other sanitation practices and fertilization. Certified, disease free seed should be planted and if possible, resistant or tolerant cultivars used. Fields should be regularly monitored for the presence of the pathogen. Scouting should begin just before crop emergence, with weekly checks for the presence of spores or lesions on leaf tips and margins. The Blight Severity Index (BSI) method is available for forecasting late blight in many provinces. Alternative hosts, such as hairy nightshade should be controlled inside and outside the field. When possible, harvest should be delayed for at least two weeks following complete vine kill to allow time for any spores on the foliage to die. Ventilation is required for tubers that go into storage wet or damp, so that the tubers dry as quickly as possible. Tuber rot should be graded out and storages should be monitored.

Resistant Cultivars: There are no completely resistant cultivars. Less susceptible cultivars include 'Kennebec', 'Sebago', 'Nooksack' and 'Russet Burbank'.

Chemical Controls: Refer table 6. Volunteer potatoes are controlled using glyphosate. A protectant foliar fungicide spray may be needed every 5-10 days up to harvest, depending on the weather. Systemic fungicides provide some control of late blight already established in the plant.

Issues for Late Blight:

1. Current varieties of potatoes are not resistant to all strains of late blight.
2. Metalaxyl resistance has resulted in the loss of the only truly systemic fungicide that could be used to control a late blight infection. Growers must now rely on a more stringent program of repeated application of protectant fungicides.
3. There is a lack of acceptance in the market place of genetically modified potato cultivars that have been developed. Some genetically modified cultivars do have resistance to late blight.
4. The strains of *Phytophthora infestans* in Canada have changed in recent years. Research is needed to understand how these new strains "behave" under Canadian conditions.
5. Little is known about an effective control strategy for seed-borne late blight. Current recommendations often include a mancozeb-based seed treatment and the foliar application of cymoxanil at 80% emergence. However, little data exists to support this management approach.
6. An improved system of forecasting for this disease, including increasing the number of weather stations to generate data, is required to facilitate more accurately timed fungicide applications.

Early Blight (*Alternaria solani*) and Brown spot (*Alternaria alternata*)

Pest information

Damage: The pathogen attacks primarily senescing leaves and foliage on stressed plants and plants affected by verticillium wilt or other diseases. Yield losses can be serious when lesions cover large areas of the leaves. Tuber infection is possible, resulting in lesions, but is rarely a serious problem in Canada. In storage, infected tubers dry up and shrivel as the disease progresses. Early blight can also affect many different crops and weeds including tomatoes, peppers and eggplants. Brown spot results in infected leaves and stems developing small, round, dark brown spots that may coalesce into larger necrotic areas. Severely affected leaves dry up and drop off. Concentric rings may form in larger leaf lesions. The symptoms are very similar to early blight and the two diseases can be easily confused. The importance of brown spot may be underestimated.

Life Cycle: The pathogen overwinters in infected crop residue, soil, tubers and on other hosts, including tomato, pepper and Solanaceous weeds. Spores are produced in infected material and are spread by wind. Infection may also occur through foliar contact with infested soil. The disease may appear any time of the year, not only early in the season as its name suggests. Rapid early blight spread occurs during alternating wet and dry weather, as dry conditions aid in spore dispersal by wind. Plants with nitrogen and/ or phosphorous deficiencies are more prone to this disease. *Alternaria alternata* is a common saprophytic fungus on plant debris. Infection of leaves occurs directly or through stomata. Older leaves are more susceptible to infection.

Pest Management

Cultural Controls: Diseased potato vines should be destroyed to reduce overwintering inoculum. Plants should be kept healthy by adequate fertilization and the control of other diseases and stress factors. Scouting should begin just before crop emergence and include checking for overwintering inoculum, followed by weekly checks for foliar lesions. Late-maturing cultivars should be used when possible. The use of forecasting models would reduce the number of fungicide applications in a season.

Resistant Cultivars: Some cultivars do exhibit resistance to this disease, mostly ones needing long growing seasons.

Chemical Controls: Most fungicides that are used to control late blight also control early blight, however in recent years new fungicides have been developed that provide improved early blight control compared to those fungicides used primarily to protect against late blight. Applying fungicides only for early blight control may not be economically justified in all regions. There are no fungicides registered in Canada to control brown spot.

Issues for Early Blight and brown spot

1. The impact of early blight on yields is not understood.
2. Current forecasting models and the weather data inputs are not sufficient. An improved system of forecasting for this disease, including increasing the number of weather stations to generate data, would facilitate more accurately timed fungicide applications.
3. This pathogen has (and is) developing resistance to many of the fungicides currently available. Monitoring of resistant populations and improved resistance management strategies should be implemented.

4. There is a need for the harmonization of pesticide registrations with the US. Cantus WDG (boscalid) (is an example of a fungicide with a very long pre-harvest interval (PHI). In Canada, the PHI is 30 days. The PHI in the US is only 10 days.
5. The relative importance of brown spot and early blight in affected potato fields is often unknown. There is insufficient knowledge on the economic thresholds for each disease. It is not known whether there is a need at the field level to distinguish between brown spot and early blight.

Grey Mould *(Botrytis cinerea)*

Pest information

Damage: Grey mould rarely causes economic damage in potato. The fungus develops on flowers or lower leaves and stems as a dense grey-black fuzzy mould. Tuber infections are rare, but may occur at harvest when tubers are damaged.

Life Cycle: The fungus attacks a wide range of plants including ornamentals, vegetables and forest seedlings. The fungus sporulates profusely under cool, wet conditions. Spores are dispersed by wind and rain. The primary source of inoculum is crop residues left from the previous season.

Pest Management

Cultural Controls: Over fertilization should be avoided as it can produce a thick crop canopy that prolongs leaf wetness which is ideal for the fungus. Good crop rotations and the maintenance of a healthy crop with adequate fertility and water help prevent infection. Tuber damage should be avoided at harvest and tubers should be allowed to heal before being stored at low temperature.

Resistant Cultivars: None available.

Chemical Controls: Most protectant fungicides provide good control of grey mould, but once the disease becomes established, hot and dry periods are required to stop the spread of the disease.

Issues for Grey Mould

None identified.

Verticillium Wilt (*Verticillium albo-atrum* and *V. dahliae*)

Pest information

Damage: Verticillium causes early dying of leaves and stems of potato. The disease is often associated with other pathogens, including root lesion nematodes, giving rise to what is called “Potato Early Dying Syndrome”. Severe reduction in yield and tuber quality can occur. Fungal growth impedes the transport of water through the plant, causing wilting. The symptoms develop initially on lower leaves and may develop on individual stems or one side of a stem.

Life Cycle: Verticillium wilt is soil borne and can be spread by the movement of infested soil by wind or mechanical means. The disease can be introduced into new fields through the use of infected seed potatoes. Verticillium infects young plants through developing roots. Wounds are not required for infection. There is an increase in disease incidence and severity when verticillium and root lesion nematodes occur in the soil together. The fungus establishes itself in the xylem and moves upwards, infecting stems, petioles and leaves. Verticillium infects tubers, but does not spread easily or cause significant harm in storage.

Pest management

Cultural Controls: The disease becomes more of a problem when crop rotations are short. Crop rotations should be at least 5 years. Rotation crops such as red clover, sunflower and alfalfa should be avoided, while crops such as corn, onions and peas are beneficial. Complete burning of vines can reduce fungal levels. Although burning may be expensive, it is a good control strategy for heavily infected fields. Controlling weeds that are hosts to verticillium in and around the field can be a good method to control this disease.

Resistant Cultivars: Resistant cultivars include Rideau, Century, Russet and Atlantic.

Chemical Controls: Soil fumigation can reduce root lesion nematode populations and therefore reduce verticillium wilt incidence. Soil fumigation may not be cost effective and is not commonly used.

Issues for Verticillium Wilt

1. Research is required into new strategies that could include rotational crops, soil amendments and other novel strategies to reduce the impact of verticillium wilt.

Fusarium Wilt *(Fusarium oxysporum, F. avenaceum* and *F. solani)*

Pest information

Damage: Fusarium wilt can cause significant yield losses in some potato growing areas. Symptoms are similar to verticillium wilt, with the pathogen interfering with water transport, causing plants to become stunted, wilt and die.

Life Cycle: Infection occurs through developing roots and stolons that are wounded. Soilborne inoculum is the primary source of infection. The disease can be spread from one field to another by the movement of soil, tubers or other plant material.

Pest Management

Cultural Controls: Only certified disease free seed should be planted. Fields with a disease free history should be used and good sanitation practices must be practiced to reduce the transmission of the disease from infected fields.

Resistant Cultivars: None available.

Chemical Controls: Refer table 6. The use of registered seed treatment fungicides can control some fusarium species.

Issues for Fusarium Wilt

1. Research is required into new strategies that could include rotational crops, soil amendments and other novel strategies to reduce the impact of fusarium wilt.

Bacterial Ring Rot (BRR) (*Clavibacter michiganensis* subsp. *sepedonicus*)

Pest information

Damage: Symptoms of bacterial ring rot include wilted leaflets, yellowing of interveinal areas of leaves, dieback of individual stems and vascular discolouration in stems and affected tubers. Affected tubers may develop a decay of the vascular tissues and become prone to secondary rots. Damage was very serious until the early 1970s, after which continuous inspection and aggressive seed certification programs reduced outbreaks of the disease. There is a zero tolerance for the disease in seed lots.

Life Cycle: The pathogen overwinters in infected tubers in the field or in storage and can also survive for up to 5 years as dried slime on farm equipment and storage facility walls. The pathogen is spread on cutting knives and field equipment. Ideal conditions for spread are at planting when tubers are cut for seed. There are some insects that are also capable of spreading the disease.

Pest Management

Cultural Controls: The use of certified seed free of BRR and sanitation are the main methods for keeping this disease under control. Equipment bins, containers and storage areas must be disinfected. All machinery that comes in contact with potatoes that may be infected must be cleaned and disinfected with a registered product for ring rot. Infested fields should not be planted to potatoes for at least three years, during which time all volunteer potatoes must be killed and plant material removed. If disease develops, the crop should be left in the field as long as possible to allow the majority of infected tubers to rot in the field before harvest and the harvested tubers should be marketed immediately. If the pathogen is found in the field, a two year quarantine is established during which time potatoes cannot be grown in that field. Research is underway to identify highly effective disinfectants for use on planktonic and biofilm forms of this pathogen in storages.

Resistant Cultivars: The production of resistant cultivars results in potatoes that may be carriers of the disease but not show symptoms. Therefore, potatoes with resistance are of limited help in the control of the disease.

Chemical Controls: There is one registered disinfection product available for sanitation of equipment and storage facilities.

Issues for Bacterial Ring Rot

1. Storage sanitation practices need to be improved.
2. Current products for sanitizing potato storages are insufficient

Blackleg (*Erwinia carotovora* subsp*. atroseptica* and *E. carotovora* subsp. *carotovora)*

Pest information

Damage: Blackleg can cause significant yield loss, seed piece decay at planting, stunting of young plants and foliar yellowing and wilt of older plants. Black discolouration may develop on the lower stem. Tuber infection and decay may occur in the field and in storage.

Life Cycle: The disease is primarily seed borne although the pathogen can survive in other host grain crops and weeds. In the soil, the pathogen does not survive for long without a suitable host. Spread is primarily during planting, when seed pieces are cut. Warm soils favour wound healing, while cool and wet soils promote disease development and seed decay. Rotting seed pieces release large quantities of bacteria into the soil that infect daughter tubers. Immature tubers with thin skin are most likely to be infected. Lesions from fungal pathogens can create entry points for infection.

Pest Management

Cultural Controls: Tuber damage should be avoided and only certified, disease free seed should be planted. Fields should be well drained. Cleaning and disinfecting of seed cutters and other equipment should be done twice a day and between seed lots or fields. A three year crop rotation is recommended. Proper management of seed pieces and planting when soil temperatures are optimum is important in the management of this disease. Storage facilities should be well ventilated and held at temperatures of 10-13°C with 95% relative humidity for 10-14 days after harvest to allow wounds to heal. After curing, tubers should be stored in a cool storage facility to slow disease progress.

Resistant Cultivars: Resistant cultivars include ‘Cascade’, ‘Kennebec’ and ‘Russet Burbank’.

Chemical Controls: Registered fungicide seed treatments can control diseases that cause lesions that allow subsequent infections with the blackleg pathogen.

Issues for Blackleg

1. The incidence of blackleg is increasing in some areas and in some varieties. Biological control strategies (bacterial phage) and the biopesticide (Serenade) could be evaluated for efficacy.

Bacterial Soft Rot (*Erwinia carotovora subsp. carotovora, Bacillus spp., Clostridium spp., Flavobacterium spp., Pseudomonas spp.*)

Pest information

Damage: Potatoes may be affected in the field or in storage. Soft rot usually occurs in association with other diseases and results in a soft, watery, foul smelling decay.

Life Cycle: Infection can be through lenticels, wounds or as a result of chilling injury or bruising. The causal bacteria are spread by irrigation water and tuber handling.

Pest Management

Cultural Controls: Tuber wounding should be avoided. Cut seed pieces should be pre-conditioned to reduce infection or whole seed should be used. Disinfection of all equipment is important to prevent spread. Before harvest and storage, tubers should be allowed to cure properly. Rotting and diseased tubers should be graded out before planting and storage. Only clean water should be used if tubers are to be washed and they should be allowed to thoroughly dry before packing.

Resistant Cultivars: None available

Chemical Controls: None available.

Issues for Bacterial Soft Rot

None identified.

Rhizoctonia Canker and Black Scurf (*Rhizoctonia solani*)

Pest information

Damage: Rhizoctonia solani infects tubers, stems and stolons, causing red-black lesions that often girdle the infected plant part and result in yield loss. Tuber quality is also reduced due to black sclerotia (scurf) that form on the tuber skin. Infection may result in rosetting of leaves, plant stunting, chlorosis, rolling of leaf tips, formation of aerial tubers and purple pigmentation of leaves. Tuber malformation, pitting and cracking may develop in association with black scurf. The use of infected seed can result in poor emergence.

Life Cycle: The pathogen is a natural inhabitant of many Canadian soils and can persist for many years, overwintering in the soil or crop residue. Disease is introduced mainly through the planting of seed potatoes infected with black scurf however soilborne inoculum can infect plants grown from clean seed. Disease incidence increases when soil is wet and cool (below 12°C). The disease is not transmitted to other tubers in storage.

Pest Management

Cultural Controls: Growing oats in rotation with potatoes has been shown to reduce rhizoctonia infections. Seed should be planted shallowly in well drained soils to reduce rhizoctonia infection. Only certified, disease-free or resistant seed should be planted. Harvesting should be done as soon as possible after skin sets.

Resistant Cultivars: The cultivars ‘Eramosa’ and ‘Shepody’ are moderately resistant.

Chemical Controls: Seed treatments must be used if potatoes are to be planted into soils with high levels of rhizoctonia. However seed treatments do not always provide the desired control. Some fungicides provide limited control of rhizoctonia on daughter tubers.

Issues for Rhizoctonia Canker and Black Scurf

None identified.

Pink Rot (*Phytophthora erythroseptica*)

Pest information

Damage: Pink rot can cause considerable losses in yield and tuber quality. The disease causes darkened areas around eyes and lenticels. Infections normally begin at the stem-end and spread to the bud end. Foliar symptoms include leaf chlorosis, stunting and wilting. With severe infections, aerial tubers may form.

Life Cycle: The pathogen can survive in the soil for many years and will invade potato roots, stolons, eyes and lenticels when conditions are favourable. Wheat and rye may be alternative hosts. Warm, poorly drained, wet soils favour the disease. The disease can be spread during harvest and handling through tuber contact. Pink rot spreads readily in storage when infected tubers break down. Infected tubers normally do not pass grading and are not planted as seed.

Pest Management

Cultural Controls: Planting potatoes in well-drained soils will suppress pink rot. A crop rotation of three to four years can reduce levels of inoculum in the soil. If foliar disease symptoms are visible, rogueing diseased plants and tubers may limit pink rot spread in the field or storage. Proper storage management to keep up air flow is important in preventing spread.

Resistant Cultivars: There are no resistant cultivars.
Chemical Controls: Fungicide applications have been successful in preventing or reducing pink rot infection if applied at the proper time.

Issues for Pink Rot

1. Ridomil (metalaxyl-m) resistant strains of the pathogen are present in some areas. There is a need for alternative, reduced risk products to be used in product rotation for the management of this disease. Phosphorus acid applied to the foliage is one such solution, but registration by the PMRA is needed.
2. Resistance is an on-going issue requiring monitoring.

Fusarium Dry Rot (*Fusarium* spp.)

Pest information

Damage: Fusarium dry rot affects tubers in storage and seed potatoes after planting. When no control measures are used, severe yield reductions are common. The disease causes poor stands, poor vigour and a large proportion of "misses". Only single sprouts emerge, leading to small, slow growing plants that yield very few tubers. Infected tubers may completely rot, shrivel and become mummified. The rot is dry, but can be wet if other pathogens, such as soft rot bacteria, infect the wound.
Life Cycle: The pathogens survive in the soil for many years and can overwinter in infected seed. The pathogens cannot infect intact tuber skin, so any operation where tubers may be damaged or wounded increases the risk of infection. The disease can develop in wounds caused by insects, rodents and in lesions of powdery scab and late blight. The pathogen produces many spores that can be spread during harvest. In storage, disease is favoured by high humidity and temperatures between 15 and 20°C. Lower temperatures and humidity slow the progress of the rot, but do not stop it. The disease is not spread readily to other tubers in storage.

Pest Management

Cultural Controls: Monitor for poor stands, a large proportion of misses and poor vigour. Plant certified, disease-free seed and disinfect and clean, seed cutters routinely. Leaving tubers in the ground for at least two weeks after vine killing promotes good skin set and results in less wounding. Harvest and post-harvest conditions are very important. Tubers must be handled very carefully to avoid injury.
Resistant Cultivars: The cultivars 'Belleisle' and 'Rideau' are highly resistant to fusarium dry rot.
Chemical Controls: Seed from lots with some fusarium present, or being planted into a field with a history of disease problems, could warrant application of a seed treatment fungicide. Some control of fusarium can be achieved by using a registered post-harvest fungicide before tubers go into storage.

Issues for Fusarium Dry Rot

1. There is concern over resistance to thiabendazole and fludioxonil
2. *Fusarium* spp. causing dry rot in Canada should be surveyed.
3. *Fusarium graminearum* has been identified as a predominant dry rot pathogen in some parts of Canada. Information is needed to better understand the potential for mycotoxin production in potato.

Pythium Leak (*Pythium* spp.)

Pest information

Damage: Pythium leak affects only tubers, causing a watery rot. The disease is very important in storage, with symptoms sometimes progressing from no visible signs to complete rot in a week. Secondary infections by bacteria can make diagnosis difficult.

Life Cycle: The pathogen is soilborne and is naturally present in most agricultural soils. The pathogen enters the tuber only through wounds. Although infection can occur at any time during the production cycle, tubers are at most risk during planting and harvesting. Wet soils and temperatures of 25-30°C favour the disease. The pathogen has a wide range of hosts.

Pest Management

Cultural Controls: Potatoes should be planted in well-drained soil. Potatoes should be harvested during cool weather. A long crop rotation of three to four years may reduce the levels of inoculum in the soil, but will not eliminate the pathogen. Tuber damage should be avoided by allowing the skin to set properly and by minimizing wounding during harvest, handling and storage. Tubers should not be harvested at temperatures above 21°C.

Resistant Cultivars: None available.

Chemical Controls: Applications of registered fungicides at planting or during the growing season have been successful at reducing pythium leak in storage.

Issues for Pythium Leak

1. Ridomil (metalaxyl-m) resistant strains of the pathogen are present in some areas. There is a need for alternative, reduced risk products to be used in product rotation for the management of this disease.

Silver Scurf (*Helminthosporium solani*)

Pest information

Damage: Silver scurf affects the skins of tubers causing a problem for the table stock market. Infected tubers can be difficult to steam peel, resulting in reduced recovery for the processing industry. Lesions have a silver glistening appearance when wet and can expand to cover much of the surface of the potato. The lesions penetrate only a few millimetres into the flesh of the tuber. In storage, the symptoms become more severe, with skin sloughing off and tubers shrinking.

Life Cycle: The fungus can overwinter in the soil, but infections in the field are usually caused by the planting of infected seed potatoes. Spores that develop in lesions can contaminate the surrounding soil and endanger future crops. This disease continues to spread in storage. The potato is the only known host.

Pest Management

Cultural Controls: Monitoring should be done late in the season or after harvest for the presence of tan to grey lesions normally at the stolon end of the tuber. Storage facilities should be cleaned prior to use to prevent pathogen carry-over.

Resistant Cultivars: None available.

Chemical Controls: Registered seed treatment fungicides for controlling silver scurf can prevent or reduce the spread of the fungus from infected seed to daughter tubers. Post-harvest fungicides may be applied prior to storage to prevent pathogen spread.

Issues for Silver Scurf

1. There are very limited control methods available and the currently registered control products only suppress the disease. IPM strategies are not available at this time.
2. There are no biological controls currently available for silver scurf on potato seed pieces both in storage and in the field.
3. National phyto-sanitary guidelines and reduced risk storage sanitation options for potato storages are not available.
4. The current understanding of the biology of the pathogen in soil and how the disease is transferred to daughter tubers is limited.

Common Scab *(Streptomyces scabies)*

Pest information

Damage: Although the disease causes little to no reduction in yield, lesions on the skin of the tuber reduce quality. The disease attacks only the skin of tubers, with symptoms varying, depending on the strain of the pathogen, cultivar, crop rotation, environmental conditions, organic matter level and soil pH. There are no above ground symptoms of the disease. The tuber becomes resistant to this disease once the tuber skin thickens and matures.

Life Cycle: The pathogen overwinters on infected plant debris and can survive livestock digestion. It can be spread by rain, wind and by soil adhering to farm equipment. The pathogen can remain in the soil indefinitely. Animal waste or organic material provides a food base for the bacterium in the soil. Dry, warm soil favours disease development and increases disease severity. Sandy or gravelly soils tend to dry out faster, increasing the likelihood of common scab as compared to wetter, heavier textured soils.

Pest Management

Cultural Controls: Over-liming of fields should be avoided. Monitoring should be done weekly after tuber initiation. Irrigation can help prevent infection by creating an unfavourable environment for pathogen infection, although this may increase the incidence of powdery scab. Soil moisture should ideally be held at 80% of field capacity during tuber initiation, until tubers are golf ball size. The use of livestock manure on scab-infected lands should be limited and manure from cull potato fed cattle should not be used.

Resistant Cultivars: 'Hilite Russett', 'Superior', 'Cherokee', 'Norking', 'Innovator', 'Satina' and 'Cecile' have good tolerance to common scab.

Chemical Controls: None available.

Issues for Potato Common Scab

1. Seed and soil treatments, including fumigants (although none are available in Canada) may not be efficacious or economically feasible for the control of common scab. Other alternative, reduced-risk products are also not currently available.
2. There are no accepted and proven management strategies for scab.
3. Potato breeders need to make scab resistance a priority trait in breeding programs.

Powdery Scab (*Spongospora subterranea*)

Pest information

Damage: Powdery scab results in significant cosmetic defects on the tuber skin. Infected tubers may shrivel and dry in storage. Scab infection sites serve as entry points for many other pathogens that can cause other damage in the field or in storage. The pathogen is a persistent vector of the potato mop-top virus (PMTV).

Life Cycle: The pathogen survives in the soil for many years. The disease can be transferred from one field to another with infected soil attached to equipment or seed potatoes. The organism survives digestion and can be spread in manure from livestock fed infected potatoes. Spores are transported in soil water to new hosts under cool and wet conditions.

Pest Management

Cultural Controls: Potatoes should not be planted in contaminated or poorly drained soils. Manure from livestock fed cull potatoes should not be used. Only certified disease free seed should be planted. Equipment should be cleaned between fields. A minimum crop rotation of four years is recommended for infected fields and only tolerant varieties should be planted. Note that other solanaceous weeds and species that bear tubers can also be host to the pathogen.

Resistant Cultivars: Russet cultivars are tolerant.

Chemical Controls: None available.

Issues for Powdery Scab

1. Chemical controls are insufficient for this disease.
2. Information on cultivar susceptibility is unavailable.
3. Powdery scab is becoming more important given its role as a vector for Potato Mop-Top virus.

Black dot *(Colletotrichum coccodes)*

Pest information

Damage: Black dot affects stressed plants and can result in some yield loss and a reduction in tuber quality. The pathogen causes decay of tubers, stolons, roots and stems. Symptoms of black dot often resemble those caused by verticillium wilt, early blight, silver scurf and rhizoctonia. Black dot can be present in plants infected with these diseases and interact to increase losses.

Life Cycle: The fungus overwinters in old potato vines and on the surface of infected tubers remaining in the field or in storage. Spread of the disease is primarily through the planting of infected seed potatoes, although some airborne spread may occur. Some weeds and other solanaceous crops are also hosts to the fungus.

Pest Management

Cultural Controls: Sanitation, ensuring good soil fertility, crop rotation and the use of disease free seed, are the main cultural management measures for this disease. Planting early maturing cultivars will reduce infection as the disease is favoured by fall conditions.

Resistant Cultivars: None available.

Chemical Controls: None available.

Issues for Black Dot

1. Economic thresholds for black dot have not been determined.

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Pink Eye (causal agent unknown)

Pest information

Damage: Pink eye can result in rot at harvest and in storage. Damage is initially concentrated near the bud end of the tuber. Affected skin may thicken over time, making peeling difficult. Infections may also cause deep cavities, allowing the development of soft rots. Tubers with pink eye may have reddish brown tissue beneath the skin that is easily confused with late blight tuber infection. The pathogen responsible for pink eye is not known, but symptoms have been associated with *Pseudomonas* sp., *Verticillium* sp. and *Rhizoctonia* sp.

Life Cycle: The severity of pink eye seems to be correlated with wet soil conditions, high temperatures and the early dying complex.

Pest Management

Cultural Controls: Efforts should be made to reduce rhizoctonia and verticillium diseases. If infected tubers must be stored, humidity should be kept low, with temperatures kept between 5-7°C with adequate ventilation.

Resistant Cultivars: Resistant cultivars include ‘Atlantic’ and ‘Costal Russe’.

Chemical Controls: None available.

Issues for Pink Eye

1. This is a serious issue in localized areas each year. Research is needed to better understand the interaction between field conditions, plant health and subsequent physiological changes resulting in pink eye.

Mosaic and Latent Viruses (PVY, PVA, PVX, PVS)

Pest information

Damage: The PVY virus is considered to be the main contributor to the mosaic disease, although other viruses do contribute in mixed infections. Significant yield reductions are possible and seed supplies can be contaminated. Each virus has different strains that vary in the degree of disease that they cause. Symptoms can include stunting, vein banding, leaf drop, streak and early plant death. Planting infected seed results in dwarfed plants with crinkled leaves. Tubers do not usually display any obvious symptoms, however new strains of PVY have recently been identified that may cause tuber necrosis.

Life Cycle: The viruses can overwinter in tubers left in the field. Viruses are easily transmitted during seed piece cutting operations or when poor handling and maintenance of the crop results in tissue damage. Aphids (especially the green peach aphid), are the primary mode of transmission for PVY and PVA. Feeding by aphids spreads these two viruses by non-persistent transmission. PVX is not believed to be transmitted by aphids, but may be spread to some extent by chewing insects, such as grasshoppers.

Pest Management

Cultural Controls: Field borders planted with non-hosts (soybean) may help reduce virus spread into the potato crop by cleansing the aphids' mouthparts of non-persistent viruses prior to their entry into the potato field. Border rows of potatoes have also reduced the spread of PVY into the inner part of the field. Alternate host plants of PVY include pepper, tobacco, legumes, tomato, pigweed and other members of the Solanaceae, Chenopodiaceae, and Leguminosae families. Fields should be monitored weekly, early in the season to identify and remove any plants showing symptoms of virus. Post-harvest testing can help predict possible infection levels. Aphid movement should be controlled as much as possible. Seed fields can benefit from early top kill in early to mid-August before the majority of aphids arrive. Growers in the United States have seen a reduction in PVY and other non-persistent viruses by applying mineral oils, which interfere with the aphid-virus transmission process. Good coverage and routine applications are needed for mineral oil to effectively reduce PVY spread.

Resistant Cultivars: The cultivars 'Jemseg', 'Kennebec' and 'Sante' are somewhat resistant to some viruses.

Chemical Controls: The use of insecticides to control aphid vectors, provides a limited reduction in virus spread within a field. Since insecticides do not kill migrating, non-colonizing aphids fast enough to prevent them from transmitting PVY, they are generally not recommended for stopping the spread of non-persistent viruses.

Issues for Mosaic and Latent Viruses

None identified.

Potato Leafroll Virus (PLRV)

Pest information

Damage: The PLRV is considered to be the most harmful aphid borne virus in Canadian potato production. Symptoms are rarely seen in the season of infection. The virus causes dark brown flecking, called net necrosis, of internal vascular tissues of the tuber. This reduces the quality of the tuber. The severity of symptoms varies, depending on whether the infection occurred in the current season (primary infection) or developed from infected seed pieces (secondary infection), the virus strain, growing conditions and cultivar. Primary infections cause little damage, while secondary infections can cause plants to be stunted and die prematurely.

Life Cycle: The green peach aphid is considered to be the most efficient aphid species transmitting PLRV, however, high populations of poor vectoring aphids can also cause significant problems. Once contaminated, aphids transmit the virus for the rest of their life. Winged aphids carry the disease over long distances. Aphids acquire the virus after feeding for a few minutes on an infected plant and are able to pass it on after 12-48 hours. The virus, unlike other viruses, cannot be spread mechanically through seed cutting, leaf contact or plant and tuber wounds.

Pest Management

Cultural Controls: Only certified virus free seed from non-susceptible potato cultivars should be planted. Seed fields can benefit from an early top kill done in early to mid-August before the majority of aphids arrive. Early planting and a reduction of nitrogen inputs facilitate early top kill. Using rotobeaters, root pruners and chemical desiccants together provides a fast kill when plants are still growing actively. Monitoring should be done weekly, early in the season to identify and remove any plants showing symptoms of the virus before the arrival of green peach aphids in the field. There are no forecasting methods available, but post-harvest testing assists in the prediction of possible infection levels in future crops. Monitoring for aphids should be done regularly and can involve in field, pan traps, suction traps and leaf sampling.

Resistant Cultivars: Resistant cultivars include ‘Cascade’, ‘Sierra’ and ‘Innovator’.

Chemical Controls: Using systemic and contact insecticides has proven effective in reducing the spread of PLRV by aphids. The use of in-furrow insecticides can help control aphid populations.

Issues for PLRV

None identified.

Potato Spindle Tuber Viroid (PSTVd)

Pest information

Damage: Potato Spindle Tuber Viroid can reduce crop yield and tuber quality. It has been virtually eliminated in North America by implementing seed certification standards with zero tolerance for the pathogen in seed stock. Infected tubers may be long and spindly, have pointed ends and have slow emergence.

Life Cycle: Symptoms are not visible in the year of infection. The pathogen persists in infected seed tubers and is spread through seed cutting, plant-to-plant contact, mechanical injury and chewing insects or aphids.

Pest management

Cultural Controls: Tomatoes, eggplant, tobacco and other broadleaf plants can also be affected by the virus and therefore should not be planted near potatoes. Using whole seed or ensuring that seed cutters are disinfected between seed lots eliminates the spread of the pathogen to healthy tubers.

Resistant Cultivars: None available.

Chemical Controls: None available.

Issues for PSTVd

None identified.

Aster Yellows (Phytoplasma)

Pest information

Damage: Plants infected with aster yellows may be stunted and leaves can turn an intense purple or yellow colour. Tuber symptoms can be confused with net necrosis caused by potato leafroll virus. Plants may die prematurely. Severely infected plants will fail to produce tubers and severely infected tubers will fail to produce plants.

Life Cycle: The pathogen overwinters on several weed species and small grains and is transmitted to potatoes from other plant hosts by leafhoppers. Transmission is not known to occur due to contact between potato plants. Infected plants may produce infected and normal daughter tubers.

Pest management

Cultural Controls: Host crops in the vicinity of the potato field should be destroyed or limited. Leafhoppers should be controlled to prevent the spread of the disease. Rogueing infected plants and tubers is a beneficial practice.

Resistant Cultivars: None available.

Chemical Controls: None, other than the use of insecticides to control leafhopper.

Issues for Aster Yellows

None identified

Nematodes (Root lesion (*Pratylenchus penetrans*) and northern root knot nematode (*Meloidogyne hapla*

Pest information

Damage: Stunting of growth, development of small tubers and complete die-off are symptoms of nematode infestation. Root systems may become more susceptible to other diseases. Reductions in yield of up to 40% are possible.

Life Cycle: For many species, both juveniles and adults are able to infect roots and tubers. The pests are spread to other areas with wind- blown soil, infected seed and contaminated farm equipment. There may be several generations per year.

Pest Management

Cultural Controls: A rotation of 3 to 4 years is required. Other host crops such as soybean and red clover should not be used in rotation. Annual ryegrass, forage pearl millet or sorgum-sudangrass can be incorporated into the soil as a green manure and will help reduce populations, as toxic compounds are released during their decomposition. Grown in the season prior to potatoes, marigolds have helped to reduce nematode populations and increase yields compared to other rotational crops. Field samples should be taken to determine the degree of infestation if problems arise. Measures that promote a healthy crop, crop rotation, the use of certified seed free from nematodes and green manure are all important in the control of root lesion nematode.

Resistant Cultivars: There are only a few cultivars with resistance to nematodes, Russet Burbank being one with high tolerance to many species of nematodes.

Chemical Controls: With severe infestation, fumigation with nematicides may help reduce populations, but may not be cost effective.

Issues for Nematodes

1. There is insufficient information on nematode species causing problems in different areas and their economic thresholds.
2. The impact of green manures and crop rotation on nematode populations is not well understood.
3. Improved diagnostic services for nematodes are needed.
4. Testing for golden nematode is an export requirement for many Canadian seed potato producers. Cost effective field sampling and lab testing services for this pest are needed.

Insects and Mites

Key Issues

- The degree to which transient aphids transmit virus diseases is not known.
- The effect of mineral oils on virus transmission by aphids is not understood.
- There is a need for the development of economic thresholds for tarnished plant bug and potato flea beetle.
- Research is required into alternative control methods and season-long management strategies for tarnished plant bug.
- Label expansions to include tarnished plant bug, are required for some products currently registered on potato.
- With the increased use of in-furrow treatments for Colorado potato beetle, there is less incidental control of tarnished plant bug.
- With fewer products used for the control of wireworms, there is less incidental control of tuber flea beetle.
- The narrow application window makes foliar spray control difficult for European corn borer. There is a need to develop alternative controls for this insect. An ovicide or systemic product is required so that spray timing is not so crucial for control.
- The Colorado potato beetle has developed resistance to many of the insecticides registered in Canada for its control. There is a need for a national program to monitor insecticide resistance of this insect.
- Organic products and reduced risk insecticides with different modes of action than the neonicotinoids, are required for Colorado potato beetle control.
- The feasibility of using alternative Bt products, novel organic control measures and other methods such as optimization of burners or trenches, for the management of Colorado potato beetle, varies, depending on the production unit.
- There is a need for the development of additional potato varieties with resistance to the Colorado potato beetle.
- The variability of species of wireworms causing problems in different potato growing regions and their respective susceptibility to pesticides is a challenge for the development of effective management strategies.
- The movement of wireworm species under various soil moisture conditions and by season is not understood.
- There is a need for new and innovative products and approaches for the control of wireworm. The phase-out of phorate in 2015 will leave growers with no control options.
- There is a need for greater understanding of wireworm biology and green manuring.
- The use of crop rotations and trap crops for the management of wireworm is not fully understood.

Table 7. Occurrence of insect pests in Canadian potato production

Pest	British Columbia	Alberta	Saskatchewan	Manitoba	Ontario	Quebec	New Brunswick	Prince Edward Island
Aphids								
Buckthorn aphid								
Foxglove aphid								
Green peach aphid								
Potato aphid								
Colorado potato beetle								
Cutworms								
European corn borer								
Flea beetles								
Potato flea beetle								
Red headed flea beetle								
Tuber flea beetle								
Leafhoppers								
Aster leafhopper								
Potato leafhopper								
Loopers								
Tarnished plant bug								
Thrips								
Two spotted spider mite								
White grubs								
Wireworms								

Widespread yearly occurrence with high pest pressure

Widespread yearly occurrence with moderate pest pressure, OR localized yearly occurrence with moderate pest pressure OR widespread sporadic occurrence with high pest pressure

Widespread yearly occurrence with low to moderate pest pressure OR widespread sporadic occurrence with moderate pressure OR sporadic localized occurrence with moderate pressure.

Localized yearly occurrence with low to moderate pest pressure OR widespread sporadic occurrence with low pressure OR localized sporadic occurrence with low to moderate pest pressure.

Pest is present and of concern, however little is known of its distribution, frequency and importance.

Pest not present

Data not reported

[1]Source: Potato stakeholders in reporting provinces.

[2]Please refer to the colour key (above) and Appendix 1, for a detailed explanation of colour coding of occurrence data.

Table 8. Adoption of insect pest management practices in potato production in Canada

Practice / Pest		Aphids (general)	Colorado potato beetle	European corn borer	Potato leafhopper	Potato flea beetle	Tuber flea beetle	Wireworms	Thrips
Avoidance	resistant varieties								
	planting / harvest date adjustment								
	crop rotation								
	choice of planting site								
	optimizing fertilization								
	reducing mechanical damage								
	thinning / pruning								
	trap crops / perimeter spraying								
	physical barriers								
Prevention	equipment sanitation								
	mowing / mulching / flaming								
	modification of plant density (row or plant spacing; seeding rate)								
	seeding depth								
	water / irrigation management								
	crop residue removal / management								
	pruning out / removal of infested material								
	tillage / cultivation								
	removal of other hosts (weeds / volunteers / wild plants)								

Practice / Pest		Aphids (general)	Colorado potato beetle	European corn borer	Potato leafhopper	Potato flea beetle	Tuber flea beetle	Wireworms	Thrips
Monitoring	scouting - trapping								
	records to track pests								
	soil analysis								
	weather monitoring for degree day modelling								
	grading out infected produce								
Decision making tools	economic threshold								
	weather / weather-based forecast / predictive model (eg. degree day modelling)								
	recommendation from crop specialist								
	first appearance of pest or pest life stage								
	observed crop damage								
	crop stage								
	calendar spray								
Suppression	pesticide rotation for resistance management								
	soil amendments								
	biological pesticides								
	arthropod biological control agents								
	beneficial organisms and habitat management								
	ground cover / physical barriers								
	pheromones (eg. mating disruption)								
	sterile mating technique								
	trapping								

Practice / Pest		Aphids (general)	Colorado potato beetle	European corn borer	Potato leafhopper	Potato flea beetle	Tuber flea beetle	Wireworms	Thrips
New practices (by province)	Stem crusher (Ontario)								
	Insect vacuum (Manitoba)								

This practice is used to manage this pest by at least some growers in the province.

This practice is not used by growers in the province to manage this pest.

This practice is not applicable for the management of this pest

Information regarding the practice for this pest is unknown.

[1]Source: Potato stakeholders in reporting provinces (Alberta, Manitoba, Ontario, Quebec, New Brunswick and Prince Edward Island).

Table 9. Active ingredients, classification and mode of action/ resistance groups for insect management in potato production in Canada

Active ingredient[1,2]	Classification[3]	Mode of action[3]	Resistance group[3]	Re-evaluation status[4]	Targeted pests[5]
Seed Treatments					
clothianidin	neonicotinoid	nicotinic acetylcholine receptor (nAChR) agonists	4A	R	aphids (including potato, green peach, foxglove and buckthorn aphids), Colorado potato beetle, potato flea beetle, wireworm (Agriotes obscurus, A. lineatus, Limonius agonus, Melanotus spp., M. communis (damage suppression only); may reduce damage caused by other wireworm species.
imidacloprid	neonicotinoid	nicotinic acetylcholine receptor (nAChR) agonists	4A	R	aphids, Colorado potato beetle, potato flea beetle (overwintering adults), potatl leafhopper
thiamethoxam	neonicotinoid	nicotinic acetylcholine receptor (nAChR) agonists	4A	R	aphids (including green peach, potato, buckthorn and foxglove aphid), Colorado potato beetle, potato leafhopper
In furrow					
clothianidin	neonicotinoid	nicotinic acetylcholine receptor (nAChR) agonists	4A	R	Colorado potato beetle
phorate	organophosphate	acetylcholinesterase (AChE) inhibitors	1B	PO Aug. 1, 2015	wireworm
thiamethoxam	neonicotinoid	nicotinic acetylcholine receptor (nAChR) agonists	4A	R	aphids (including green peach, potato, buckthorn and foxglove aphid), Colorado potato beetle, potato leafhopper

Active ingredient[1,2]	Classification[3]	Mode of action[3]	Resistance group[3]	Re-evaluation status[4]	Targeted pests[5]
imidacloprid	neonicotinoid	nicotinic acetylcholine receptor (nAChR) agonists	4A	R	aphids (including green peach, buckthorn, foxglove and potato aphid, Colorado potato beetle, potato flea beetle, potato leafhopper
Foliar treatments					
abamectin	avermectin, milbemycin	chloride channel activators	6	R	spider mites including two spotted spider mite
acephate	organophosphate	acetylcholinesterase (AChE) inhibitors	1B	RE	green peach aphid, potato aphid, potato flea beetle, tarnished plant bug
acetamiprid	neonicotinoid	nicotinic acetylcholine receptor (nAChR) agonists	4A	R	aphids, Colorado potato beetle
Bacillus thuringiensis subsp. kurstaki	*Bacillus thuringiensis* or *Bacillus sphaericus* and the insecticidal proteins they produce	microbial disruptors of insect midgut membranes	11	R	cabbage looper
Bacillus thuringiensis subsp. tenebrionis	*Bacillus thuringiensis* subsp. tenebrionis strain NB 176	microbial disruptors of insect midgut membranes	11	R	young Colorado potato beetle larvae
carbaryl	carbamate	acetylcholinesterase (AChE) inhibitors	1A	RE	Colorado potato beetle, cutworms (climbing) European corn borer, fall armyworm, flea beetles, leafhoppers, potato flea beetle, stink bugs, tomato fruitworm, tomato hornworm, tarnished plant bug
chlorantraniliprole	diamide	ryanodine receptor modulators	26	R	Colorado potato beetle, European corn borer

Active ingredient[1,2]	Classification[3]	Mode of action[3]	Resistance group[3]	Re-evaluation status[4]	Targeted pests[5]
chlorpyrifos	organophosphate	acetylcholinesterase (AChE) inhibitors	1B	RE	Colorado potato beetle (larvae), black cutworm, darksided cutworm, redbacked cutworm, potato flea beetle, tarnished plant bug, wireworm
clothianidin	neonicotinoid	nicotinic acetylcholine receptor (nAChR) agonists	4A	R	aphids, Colorado potato beetle, leafhoppers
cypermethrin	pyrethroid, pyrethrin	sodium channel modulators	3A	RE	Colorado potato beetle, cutworms (black, white, darksided, redbacked, army and pale western, variegated (climbing) cutworm, flea beetles, leafhoppers, potato flea beetle, potato leafhopper, tarnished plant bug, tuber flea beetle
cyromazine	cyromazine	Moulting disruptor, Dipteran	17	R	Colorado potato beetle
deltamethrin	pyrethroid, pyrethrin	Sodium channel modulators	3A	RE	buckthorn aphid, potato aphid, European corn borer, leafhopper, potato flea beetle, tarnished plant bug, tuber flea beetle
diazinon	organophosphate	acetylcholinesterase (AChE) inhibitors	1B	PO	aphids, Colorado potato beetle, dipterous leafminers, flea beetles, leafhoppers, root maggots (treat seed pieces by emersing in a dip)
dimethoate	organophosphate	acetylcholinesterase (AChE) inhibitors	1B	RE	aphids, leafhoppers, tarnished plant bug
endosulfan	cyclodiene organochlorine	GABA-gated chloride channel antagonists	2A	PO Dec 31, 2016	aphid, Colorado potato beetle, flea beetles, potato flea beetle, tuber flea beetle, leafhoppers, tarnished plant bug
kaolin				R	leafhoppers, including potato leafhopper

Active ingredient[1,2]	Classification[3]	Mode of action[3]	Resistance group[3]	Re-evaluation status[4]	Targeted pests[5]
lambda-cyhalothrin	pyrethroid, pyrethrin	sodium channel modulators	3A	RE	Colorado potato beetle, European corn borer, potato flea beetle, potato leafhopper, tarnished plant bug, tuber flea beetle
malathion	organophosphate	acetylcholinesterase (AChE) inhibitors	1B	RE	aphids, Colorado potato beetle, leafhoppers, spider mites
methamidophos	organophosphate	acetylcholinesterase (AChE) inhibitors	1B	DI Dec 31, 2012	aphids, Colorado potato beetle, potato flea beetle, potato leafhopper, tarnished plant bug
methomyl	carbamate	acetylcholinesterase (AChE) inhibitors	1A	RE	aphids, flea beetles, leafhoppers, variegated cutworm
mineral oil				R	reduce the spread of PVY by aphids
naled	organophosphate	acetylcholinesterase (AChE) inhibitors	1B	R	Colorado potato beetle, flea beetles, leafhoppers
novaluron	benzoylurea	inhibitors of chitin biosynthesis, type1	15	R	Colorado potato beetle, European corn borer
oxamyl	carbamate	acetylcholinesterase (AChE) inhibitors	1A	R	Colorado potato beetle, flea beetles, green peach aphid, potato aphid, potato leafhopper, tarnished plant bug
permethrin	pyrethroid, pyrethrin	sodium channel modulators	3A	RE	Colorado potato beetle, European corn borer, potato flea beetle, potato leafhopper, tarnished plant bug, variegated (climbing) cutworm
phosmet	organophosphate	acetylcholinesterase (AChE) inhibitors	1B	RE	Colorado potato beetle, potato aphid, potato flea beetle, potato leafhopper
pymetrozine	pyridine			R	aphids (including potato, green peach, foxglove and buckthorn aphids)

Active ingredient[1,2]	Classification[3]	Mode of action[3]	Resistance group[3]	Re-evaluation status[4]	Targeted pests[5]
spinosad	spinosyn	nicotinic acetylcholine receptor (nAChR) allosteric activators	5	R	Colorado potato beetle larvae, European corn borer larvae
spiromesifen	tetronic and tetramic acid derivative	inhibitors of acetyl CoA carboxylase.	23	R	two spotted spider mite, whiteflies(including silverleaf, sweet potato and greenhouse)
spirotetramat	tetronic and tetramic acid derivative	inhibitors of acetyl CoA carboxylase.	23	R	aphids, psyllids, whiteflies
thiamethoxam	neonicotinoid	nicotinic acetylcholine receptor (nAChR) agonists	4A	R	aphids (including green peach, potato, buckthorn and foxglove aphid), Colorado porato beetle, potato leafhopper

[1]Registrations confirmed on the PMRA Registered Products Database (www.hc-sc.gc.ca/cps-spc/pest/index-eng.php) August 15, 2012.

[2] Not all end use products containing this active ingredient may be registered for use on this crop. The information in these tables should not be relied upon for pesticide application decisions. Individual product labels must be consulted for up to date, accurate information concerning the use of these pesticides and specific registration details.

[3]Source: IRAC MoA Classification Scheme (Volume 7.2, issued April 2012) published by the Insecticide Resistance Action Committee (IRAC) International MoA Working Group (www.irac-online.org).

[4]PMRA re-evaluation status as of **October 31, 2012**: R – full registration, RE (yellow) – under re-evaluation, DI (red) – discontinued by registrant, PO (red) – being phased out as a result of re-evaluation.

[5]Please consult the pesticide label for a detailed listing of pests controlled by products containing each active ingredient. Information on registered pesticide uses is also available from the PMRA Registered Products Database (www.hc-sc.gc.ca/cps-spc/pest/index-eng.php).

Aphids *(buckthorn aphid (Aphis nasturtii), foxglove aphid (Aulacorthum solani), green peach aphid (Myzus persicae) and the potato aphid (Macrosiphum euphorbiae) and others)*

Pest information

Damage: Feeding by high populations of aphids during hot, dry summers can affect plant health. Some species can produce toxins that can affect the leaves. More importantly, many aphid species are capable of transmitting viruses, such as PVY, PVA and PLRV.

Life Cycle: In general, aphids overwinter as eggs on various woody or herbaceous plants or for some species, as females in protected sites or greenhouses. In the spring the eggs hatch, giving rise to winged females which move to emerging potato plants or other plants, depending on host range of the aphid species. Throughout the summer, the female aphids bear live, female young. A winged generation of males and females may be produced later in the season and following mating, the females move back to the woody host to lay the overwintering eggs.

Pest Management

Cultural Controls: Field borders planted with non-host crops for viruses (soybean, wheat) may attract aphids and cleanse their mouthparts of non-persistent viruses prior to entry into the potato crop. To limit the spread of viruses, rogue early and top-kill as soon as possible after aphid flight begins. Weekly monitoring should be done, making several counts throughout the field. Yellow or green aphid traps should be placed in the field. Identification of the species of aphid is very important, as some species are much more destructive than others. The economic threshold for green peach, foxglove and potato aphid is 3 to 10 aphids per 100 lower compound leaves in seed fields. At this threshold, an insecticide should be used to reduce the spread of PLRV. There are no established thresholds for processing or table-stock potato fields.

Resistant Cultivars: None available.

Chemical Controls: Chemical control is achieved using systemic insecticides at planting or foliar insecticides when thresholds have been reached.

Issues for Aphids

1. The degree to which transient aphids transmit virus diseases is not known.
2. The effect of mineral oils on virus transmission by aphids is not well understood.

Tarnished Plant Bug *(Lygus lineolaris)*

Pest information

Damage: Adults and nymph tarnished plant bugs damage potatoes by piercing tissue and removing sap. While feeding, the bug introduces a toxin into the plant, causing leaves to deform and curl, new growth to wilt and flowers to drop prematurely. The bug is a vector for PSTVd. The heaviest infestations occur in mid-August. Only severe crop injury generally affects crop yield. Yield is not affected in early maturing cultivars.

Life Cycle: The insect attacks a wide variety of crops, including alfalfa, clover, cabbage, plum and many types of weeds. Adult tarnished plant bugs overwinter in sheltered sites and lay eggs in the spring on weeds. Following hatching, the nymphs feed on various plants including potato. The life cycle is completed in about 4 weeks and 2-3 generations are possible during the growing season.

Pest Management

Cultural Controls: Population size can be controlled by ensuring fields and hedgerows are weed free. Planting next to alfalfa or clover fields should be avoided. Close monitoring is required in mid to late summer. Using insect sweep nets is the most accurate sampling method. Control is only recommended for late maturing varieties.

Resistant Cultivars: Early maturing cultivars do not suffer from yield losses due to this pest.

Chemical Controls: Insecticides used to manage other insects normally control this pest.

Issues for Tarnished Plant Bug

1. Economic thresholds are not available.
2. Research is required into alternative control methods and season-long management strategies.
3. Label expansions to include tarnished plant bug, are required for some products currently registered on potato.
4. With the increased use of in-furrow treatments for Colorado potato beetle there is less incidental control of tarnished plant bug.

Colorado Potato Beetle (*Leptinotarsa decemlineata*)

Pest information

Damage: Both adults and larvae of the Colorado potato beetle feed on potato foliage and stems. Feeding by high populations can result in complete defoliation of plants. Defoliation decreases the ability of plants to produce nutrients and eventually reduces yields. Significant reductions in yield are possible. The Colorado potato beetle feeds only on plants in the family Solanaceae (potatoes, tomato, eggplant, nightshade, horse-nettle, etc.)

Life Cycle: Adults overwinter in the soil of potato fields. In the spring, adults emerge and feed for a short period before mating and ovipositing. Females lay between 300 and 500 eggs on potato plants. Following egg hatch, larvae feed for two to three weeks before pupation. The new adults that emerge, overwinter. In most areas of Canada, there is one generation per year, although in Ontario, there are two generations and sometimes a partial third generation in a given year.

Pest Management

Cultural Controls: Adults can be trapped by planting several rows of potatoes around the field boundary a week or two prior to planting the rest of the field. Other host crops must not be located near or used in rotation with the potato crop. The potentially overwintering, summer adults can be reduced by leaving a few green rows when top-killing and targeting these with a foliar insecticide application, a flamer or insect vacuum. The bacterium *B. thuringiensis* has both been shown to be an effective biological control.

Resistant Cultivars: Although there are GMO cultivars that have been developed with resistance to the pest, they have been removed from production due to the lack of consumer acceptance. Research on the development of cultivars with resistance to the pest is underway.

Chemical Controls: In-furrow systemic insecticides are applied at planting and can provide season-long control. There are several foliar insecticides registered for use on Colorado potato beetle and many of these control several other pests at the same time. In some instances, pesticide application can be minimized by treating field borders.

Issues for Colorado Potato Beetle

1. Survey work completed by AAFC London detected some populations with resistance and decreased sensitivity to neonicotinoids. Insecticides with different modes of action are required.
2. There is a need for a national program to monitor insecticide resistance of Colorado potato beetle.
3. Additional organic products are needed for Colorado potato beetle control.
4. The feasibility of alternative Bt (*Bacillus thuringiensis*) products, novel organic control measures and other methods such as optimization of burners or trenches, is variable depending on the production unit.
5. There is a need for additional varieties with resistance to this pest.
6. Colorado potato beetle has developed resistance to many of the insecticides registered in Canada for its control.

European Corn Borer (ECB) (*Ostrinia nubilalis*)

Pest information

Damage: The European corn borer feeds on more than 200 different species of plants, including corn, potatoes, beans, beets, celery and peppers. Yields can be reduced following heavy infestations with wind damage, water stress and secondary pathogen invasion. The larvae feed in potato stems, causing wilting symptoms. Damage may not be apparent until a month or two after infestation.

Life Cycle: Mature larvae overwinter in plant debris and pupate in late spring. Adult moths emerge in late spring and early summer and lay eggs on stems.

Pest Management

Cultural Controls: Potatoes should be planted as far away from corn fields as possible. Weeds and volunteers must be controlled. Raking and burning vines and fall plowing destroys overwintering sites. The bacterium *Bacillus thuringiensis* is an effective biological control. Monitoring should begin when adult moths appear (mid-July) or when 200-300 degree-days have accumulated using a base temperature of 10°C. Larvae are predicted after 400-500 degree-days have accumulated. Scouting can also be based on pheromone traps bated with the Iowa Strain, which attracts male moths. Egg masses are hard to find. Economic thresholds have been set at 25-30% of plants showing egg masses, with a stressed crop having a lower threshold of 10-15%.

Resistant Cultivars: Early season cultivars have no loss in yield due to this pest.

Chemical Controls: If economic thresholds are surpassed and the cultivar being grown has a late maturity, registered insecticides may be used. Insecticides should be applied when most egg masses reach peak egg hatch and before the larvae bore into the stem, a very narrow window for spraying.

Issues for European Corn Borer

1. The narrow application window makes foliar spray control difficult.
2. There is a need to develop alternative controls. An ovicide or systemic product is required so that spray timing is not so crucial for control.
3. It is unknown whether the increased use of in-furrow treatments for Colorado potato beetle, have resulted in a decrease in the incidental control of ECB.

Potato Leafhopper (*Empoasca fabae*)

Pest information

Damage: Adults and nymphs of the potato leafhopper feed on potatoes with piercing-sucking mouthparts. Nymphs of the fourth and fifth instars inflict the most damage. Toxins are injected as the pest feeds, interfering with vascular flow. Symptoms of feeding injury, referred to as “hopper-burn”, include yellowing, browning and curling of leaf tips and margins. Certain leafhoppers are vectors of aster yellows. High populations can result in early plant death and reduced yields.

Life Cycle: The pest feeds on over 100 host plants including beans, corn, alfalfa, clover, apples and potatoes. The pest does not overwinter in Canada, dispersing each year on wind currents from the United States. Migrant leafhoppers lay eggs on alfalfa. Leafhoppers developing from the eggs infest potatoes.

Pest Management

Cultural Controls: Planting alfalfa or clover fields near potatoes should be avoided. When nearby forage crops are harvested, leafhoppers may move to potato fields. Scouting for damage should be frequent at this time.

Resistant Cultivars: None available.

Chemical Controls: Foliar insecticide applications for the control of the Colorado potato beetle keep populations of this pest sufficiently low.

Issues for Potato Leafhopper

None identified.

Potato Flea Beetle (*Epitrix cucumeris*)

Pest information

Damage: Adult potato flea beetles feed on the leaves creating a shot-hole appearance. Considerable defoliation can occur when plants are young or not growing actively. Yields can be reduced in severe infestations, but direct damage to tubers by larvae is rare.

Life Cycle: This pest also attacks pepper, tomato and solanaceous weeds. Adult beetles overwinter in litter and protected sites. They move into potato fields in the spring where they feed on young plants or weeds. Eggs are laid in the soil around the roots of the potato and following hatch, the larvae feed on root hairs. Larvae feed for 4 to 5 weeks, pupate and emerge as adults that feed on the foliage. There are no more than 2 generations per year.

Pest Management

Cultural Controls: Destroying plant residues where flea beetles hibernate, prevents the build-up of high populations. A three year crop rotation is essential. Scouting should be done after mid-July and continued for the rest of the season. Monitoring is done by assessing damage, as the pest is difficult to count or capture.

Resistant Cultivars: None available.

Chemical Controls: Insecticide applications directed at this pest may only be needed if there is a severe outbreak.

Issues for Potato Flea Beetle

1. There is a need for better economic threshold data for this pest.

Tuber Flea Beetle (*Epitrix tuberis*)

Pest information

Damage: Adult tuber flea beetles chew small round holes in leaves, causing a shot-hole appearance. Larvae cause the most economic damage by creating feeding tunnels just below the tuber skin. Vacant tunnels have a corky brown lining. Shallow networks of fine tunnels cause cracks and pimples on the skin and may resemble symptoms of common scab. Damaged tubers look rough and must be heavily peeled to remove the tunnels. As few as two larvae per tuber can result in quality downgrades. Late potato cultivars can be severely damaged. Yield is only affected when foliar damage is severe.

Life Cycle: The adult beetle overwinters in soil. There can be up to 3 overlapping generations per year.

Pest Management

Cultural Controls: Volunteer potato plants and cull piles should not be left in the field. Crop rotation will reduce flea beetle numbers in proportion to the length (in years) of the rotation. Pesticide treatment may be necessary when the threshold of more than 1 feeding hole per sample of 10 plants or more than 1 beetle per 10 net sweeps is reached.

Resistant Cultivars: None available.

Chemical Controls: Refer Table 6.

Issues for Tuber Flea Beetle

1. With fewer products used for the control of wireworms, there is less incidental control of tuber flea beetle.

Wireworm (*Agriotes* spp., *Limonius* spp., and *Ctenicera* spp.)

Pest information

Damage: Wireworms attack seed pieces and developing tubers. They are especially a problem on land recently broken from sod. In the spring, wireworms tunnel into potato seed pieces and the developing roots and shoots. Heavy infestations result in poor emergence and vigour. Later in the season, the pest feeds on developing tubers, producing tunnels up to 3 mm in diameter and 4 cm deep. Attacks on young tubers result in deformation and attacks on mature tubers result in holes throughout, reducing quality at harvest and increasing the incidence of secondary infection by bacteria and fungi.

Life Cycle: There are several native wireworm species that are recognized as major or minor pests of potatoes. They attack a wide range of host plants, including most vegetable crops. Wireworms thrive in sod, red and sweet clover and in small grains, such as barley and wheat. The life-cycle ranges from 3-6 years, depending on the species, with 2-5 years being spent as actively feeding larvae.

Pest Management

Cultural Controls: If damage is severe, a long rotation out of potato and grassy crops is necessary. A good rotational crop is corn if the corn is treated with a wireworm insecticide. Alternatively, an untreated trap crop may be retained to sequester the wireworms. Maintaining fields and fallow fields free of weeds will help to control wireworms. Fields should be monitored for wireworms prior to planting to establish whether threshold levels of wireworm are present.

Resistant Cultivars: None available.

Chemical Controls: There are a limited number of chemicals that can be used against wireworms.

Issues for Wireworms

1. The variability of species of wireworms causing problems in the potato growing regions and their respective susceptibility to pesticides is a challenge for the development of effective management strategies.
2. The movement of wireworm species under various soil moisture conditions and by season is not understood.
3. There is a need for new and innovative products and approaches for the control of wireworm. The phase-out of phorate in 2015 will leave growers with no control options.
4. Growers do not have a good understanding of wireworm biology and green manuring.
5. The use of crop rotations and trap crops for the management of this pest is not fully understood.

Weeds

Key Issues

- In some areas of Canada, annual weeds have developed resistance to herbicides. Triazine-resistant lambsquarter's now infests many fields across the country. There is concern over the development of resistance to metribuzin.
- Current products do not control a number of problematic weeds including wild buckwheat, kochia, hairy nightshade and eastern black nightshade. In the east, there are new weeds including mugwort, cleavers, perennial broadleaf weeds, marsh hedge nettle and Canada and perennial sow thistles, for which there is no specific control.
- There is a need for improved tillage implements to control weeds on organic farms.
- There is a need for control products for volunteer potatoes in rotational crops.
- The use of row shapers has prevented the use of some mechanical methods of weed control.
- There is concern with the quality control of seed that is used in rotational crop years, as problem weeds are being introduced.
- The registration of post-emergent, broadleaf herbicides would assist IPM efforts. Currently, growers must rely predominantly on pre-emergent residual herbicides.
- There are no organic crop desiccants available.
- Alternatives to the sprout inhibitor MH60 are required.
- Currently registered herbicides have unacceptable pre-harvest interval restrictions. Harmonizing with the US products (reduced PHI), would provide more tools for control.

Table 10. Occurrence of weeds in Canadian potato production

Weed	British Columbia	Alberta	Saskatchewan	Manitoba	Ontario	Quebec	New Brunswick	Prince Edward Island
Annual broadleaf weeds								
Annual grass weeds								
Perennial broadleaf weeds								
Perennial grass weeds								
Solanaceous weeds								
Volunteer potatoes								
Herbicide resistant weeds								

Widespread yearly occurrence with high pest pressure

Widespread yearly occurrence with moderate pest pressure, OR localized yearly occurrence with moderate pest pressure OR widespread sporadic occurrence with high pest pressure.

Widespread yearly occurrence with low to moderate pest pressure OR widespread sporadic occurrence with moderate pressure OR sporadic localized occurrence with moderate pressure.

Localized yearly occurrence with low to moderate pest pressure OR widespread sporadic occurrence with low pressure OR localized sporadic occurrence with low to moderate pest pressure.

Pest is present and of concern, however little is known of its distribution, frequency and importance.

Pest not present

Data not reported

[1]Source: Potato stakeholders in reporting provinces.

[2]Please refer to the colour key (above) and Appendix 1, for a detailed explanation of colour coding of occurrence data.

Table 11. Adoption of weed management practices in potato production in Canada

Practice / Pest		Annual broadleaf weeds	Annual grass weeds	Perennial broadleaf weeds	Perennial grassweeds	Solanaceous weeds	Volunteer potatoes	Herbicide resistant weeds
Avoidance	use of weed-free seed							
	planting / harvest date adjustment							
	crop rotation							
	choice of planting site							
	optimizing fertilization							
Prevention	equipment sanitation							
	mowing / mulching / flaming							
	modification of plant density (row or plant spacing; seeding)							
	seeding / planting depth							
	water / irrigation management							
	weed management in non-crop lands							
	weed management in non-crop years							
	tillage / cultivation							
Monitoring	scouting - field inspection							
	field mapping of weeds / record of resistant weeds							
	soil analysis							
	grading of grain / produce for weed contamination							
Decision making tools	economic threshold							
	weather / weather-based forecast / predictive model							
	recommendation from crop specialist							
	first appearance of weed or weed growth stage							
	observed crop damage							
	crop stage							
	calendar spray							

Practice / Pest		Annual broadleaf weeds	Annual grass weeds	Perennial broadleaf weeds	Perennial grassweeds	Solanaceous weeds	Volunteer potatoes	Herbicide resistant weeds
Suppression	pesticide rotation for resistance management							
	soil amendments							
	biological pesticides							
	arthropod biological control agents							
	habitat / environment management							
	ground cover / physical barriers							
	mechanical weed control							

This practice is used to manage this pest by at least some growers in the province.

This practice is not used by growers in the province to manage this pest.

This practice is not applicable for the management of this pest

Information regarding the practice for this pest is unknown.

[1]Source: Potato stakeholders in reporting provinces (Alberta, Manitoba, Ontario, Quebec, New Brunswick and Prince Edward Island).

Table 12. Active ingredients, classification and mode of action/ resistance groups for weed management in potato production in Canada.

Active ingredient[1,2]	Classification[3]	Mode of action[3]	Resistance group[3]	Re-evaluation status[4]	Targeted pests[5]
carfentrazone-ethyl (harvest aid)	triazolinone	Inhibition of protoporphyrinogen oxidase (PPO)	14	R	burclover, carpetweed, cocklebur, common purslane, corn spurry, eastern black nightshade, field pennycress, glyphosate tolerant volunteer canola, hairy nightshade, jimsonweed, kochia, lamb's-quarters, morning glory, Pennsylvania smartweed (seedling), pigweed (prostrate, smooth, tumble), prickly lettuce, round-leaved mallow, redroot pigweed, tall waterhemp, tansy mustard, velvetleaf, Venice mallow, volunteer canola
diclofop-methyl	Aryloxyphenoxy-propionate 'FOP'	Inhibition of acetyl CoA carboxylase (ACCase)	1	DI Dec 31, 2014	barnyard grass, fall panicum, foxtail (green, yellow), wild oats, witchgrass
EPTC	thiocarbamate	Inhibition of lipid synthesis - not ACCase inhibition	8	R	Annual Grasses: annual bluegrass, annual ryegrass (Italian ryegrass), barnyard grass (water grass), crabgrass, fall panicum, foxtail (green, yellow), goose grass, volunteer cereals (barley, oats, wheat), wild oats, witchgrass; annual broadleaf weeds: common chickweed, corn spurry, hairy nightshade, henbit (deadnettle) lamb's-quarters, pigweed (prostrate, redroot, tumble), purslane, nettleleaf goosefoot; perennial weeds: quackgrass (couchgrass, twitch), yellow nutsedge
fenoxaprop-P-ethyl	aryloxyphenoxy-propionate 'FOP'	Inhibition of acetyl CoA carboxylase (ACCase)	1	R	barnyard grass, crabgrass, fall panicum, foxtail (green, yellow), old witch grass, volunteer corn, wild proso millet

Active ingredient[1,2]	Classification[3]	Mode of action[3]	Resistance group[3]	Re-evaluation status[4]	Targeted pests[5]
fluazifop-P-butyl	aryloxyphenoxy-propionate 'FOP'	Inhibition of acetyl CoA carboxylase (ACCase)	1	R	barnyard grass, crabgrass, fall panicum, green foxtail (wild millet in the west), giant foxtail, Johnson grass, old witchgrass, Persian darnel, quack grass, volunteer corn, volunteer barley and wheat, wild oats, wild proso millet, wirestem muhly, yellow foxtail
flumioxazin	N-phenylphthalimide	Inhibition of protoporphyrinogen oxidase (PPO)	14	R	weeds suppressed: common ragweed, eastern black nightshade, green pigweed, hairy nightshade, lamb's-quarters, redroot pigweed
linuron (pre-emergence)	urea	Inhibition of photosynthesis at photosystem II	7	RE	Most annual grasses, chickweed, common ragweed, corn spurry, goosefoot, groundsel, knotweed, kochia, lamb's-quarters, prostrate pigweed, purslane, redroot pigweed, shepherd's purse, smartweed, wild buckwheat, wild radish, wormseed mustard, seedlings of dandelion, plantain and sow thistle
metribuzin	triazinone	Inhibition of photosynthesis at photosystem II	5	R	grass weeds: barnyard grass, cheat grass, crabgrass, fall panicum, foxtail (giant, green, yellow), Johnson grass (seedling), witchgrass; broadleaf weeds: carpetweed, cocklebur, common chickweed, common ragweed, corn spurry, dandelion (seedling), green smartweed, hempnettle, jimsonweed, lady's-thumb, lamb's-quarters, prickly mallow, prostrate pigweed, redroot pigweed, Russian thistle, shepherd's purse, stinkweed, velvetleaf, wild buckwheat, wild mustard, wild potato vine, yellow wood-sorrel

Active ingredient[1,2]	Classification[3]	Mode of action[3]	Resistance group[3]	Re-evaluation status[4]	Targeted pests[5]
rimsulfuron	sulfonylurea	Inhibition of acetolactate synthase ALS (acetohydroxyacid synthase AHAS)	2	R	barnyard grass, fall panicum, foxtail (green, yellow), lamb's-quarters (suppression), quackgrass, redroot pigweed, witchgrass
sethoxydim	cyclohexanedione 'DIM'	Inhibition of acetyl CoA carboxylase (ACCase)	1	R	annual grasses, barnyard grass, fall panicum, foxtail barley (suppression), large crabgrass, Persian darnel, proso millet, quackgrass (suppression), volunteer barley, volunteer corn, volunteer wheat, wild oats, witchgrass
s-metolachlor	chloroacetamide	Inhibition of cell division (Inhibition of VLCFAs)	15	R	American nightshade, barnyard grass, crabgrass (smooth, hairy), eastern black nightshade, fall panicum, foxtail (green, yellow, giant), old witchgrass, redroot pigweed (suppression), yellow nutsedge

[1]Registrations confirmed on the PMRA Registered Products Database (www.hc-sc.gc.ca/cps-spc/pest/index-eng.php) August 17, 2012.

[2] Not all end use products containing this active ingredient may be registered for use on this crop. The information in these tables should not be relied upon for pesticide application decisions. Individual product labels must be consulted for up to date, accurate information concerning the use of these pesticides and specific registration details.

[3]Source: Herbicide Resistance Action Committee, Classification of Herbicides According to Site of Action (January 2005) at: www.hracglobal.com/

[4]PMRA re-evaluation status as of **October 31**, **2012**: R – full registration, RE (yellow) – under re-evaluation, DI (red) – discontinued by registrant, PO (red) – being phased out as a result of re-evaluation.

[5]Please consult the pesticide label for a detailed listing of pests controlled by products containing each active ingredient. Information on registered pesticide uses is also available from the PMRA Registered Products Database (www.hc-sc.gc.ca/cps-spc/pest/index-eng.php).

Annual and Biennial Broadleaf and Grass Weeds

Pest information

Damage: Broadleaf weeds reach heights similar to the potato crop and compete for light, water and nutrients. If not effectively controlled, they reduce potato growth and yield. Annual grasses also cause significant problems in potato production because of their fast growth and ability to compete for necessary resources. Grass weeds are very tolerant of extremes in moisture and temperature once established. They can be very difficult to eliminate from infested fields and they require control prior to seed-set due to their prolific seeding.

Life Cycle: Annual weeds complete their life cycle in one year, going from seed germination, through vegetative growth, flowering and seed production. Winter annuals begin their growth in the fall, producing a rosette and flower and produce seeds early in the following year. Annual weeds produce a large numbers of seeds. Most arable land is infested with annual weed seeds at all times and some weed seeds can remain viable in the soil for many years, germinating when conditions are right. The critical stage for control of annual weeds is early in the growing season. Biennial weeds germinate in the spring and produce a rosette of leaves during the first summer. They overwinter as rosettes and in the second summer flower and produce seeds. The plants die at the end of the second growing season.

Pest Management

Cultural Controls: Site selection is the first step in a weed management program and knowing the weed history of a field is vital. Measures to reduce difficult to control weeds, should be implemented before planting the potato crop. Weed seeds can be transported from field to field by equipment, wind, water and animals, so equipment should be cleaned of adhering soil and debris before moving between fields. Weed seeds in forages fed to livestock may not be destroyed through digestion or from composting, so a potential weed source lies in manure and poor quality compost. Repeated tilling prior to planting and cultivation after planting, can help reduce the number of germinating weeds that survive. Potato hilling provides some weed control. Having vigorous potato stands and choosing row spacing that will speed up row closure will help the potatoes out-compete weeds. As cereal crops often precede potato crops in a rotation, volunteer cereals are likely to occur in potato. Hence crop rotation is not effective for some volunteer crops. Crop rotation can disrupt perennial and biennial weed life cycles by allowing a variety of control options and cultural practices that discourage normal weed growth. Weed problems can be reduced if the soil is not left bare for extended periods of time.

Resistant Cultivars: Cultivars having quick emergence and vigorous crop stands will help shade-out germinating weed seeds.

Chemical Controls: Most annual broadleaf and grass weeds can be controlled in potatoes with a soil applied, pre-emergent, residual herbicide. This can provide season long protection against germinating weeds and seedlings. Once the potatoes emerge, there are limited herbicide options for controlling broadleaf weeds in the crop. Using selective, systemic herbicides can control grass that emerges after the crop.

Issues for Annual and Biennial Weeds

1. In some areas of Canada, annual weeds have developed resistance to herbicides. Triazine-resistant lambsquarter's now infests many fields across the country.
2. There is concern over the development of resistance to metribuzin.
3. Current products are not effective for the control of wild buckwheat, kochia, hairy nightshade and eastern black nightshade.
4. There is a need for control products for volunteer potatoes in rotational crops.

5. There is a need for better tillage implements to control weeds on organic farms.
6. There is concern with quality control of seed that is used in rotational crop years, as there are problems with weed seed being introduced during these years.
7. The registration of a post-emergent broadleaf herbicide would assist IPM efforts. Currently, growers must rely predominantly on pre-emergent residual herbicides.
8. Row shapers have reduced mechanical methods of weed control.
9. In the east there are new weeds including mugwort, cleavers, perennial broadleaf weeds, marsh hedge nettle and Canada and perennial sow thistles for which there is no specific control.
10. There are no organic crop desiccants currently available.
11. Alternatives to the sprout inhibitor MH60 are required.
12. Current herbicides have unacceptable PHI restrictions. Harmonizing with the US products (reduced PHI), would provide more tools for control.

Perennial Weeds

Pest information

Damage: Perennial weeds can grow to be very large and be very competitive, especially if they have been established for several years. This can reduce growth and yield of the potato crop.

Life Cycle: Perennial grass and broadleaf weeds can live for several to many years. They can spread effectively through the expansion of root systems, vegetatively through the dissemination of root pieces and by the distribution of seeds. The critical stage for damage is early in the growing season.

Pest Management

Cultural Controls: Weed control strategies discussed in the previous section can also be applied to perennial weeds. Perennial weeds are more difficult to control because of their large underground root systems. Tillage and cultivation may break up the underground portions of the plant and increase the weed problem. Weed seeds and other reproductive parts such as roots and rhizomes can be transported from field to field by equipment, wind, water and animals. To reduce the transport of perennial weeds by equipment, clean adhering soil and debris from equipment when leaving each field.

Resistant Cultivars: Choose potato cultivars having quick emergence and vigorous crop stands that will help shade out germinating weed seeds.

Chemical Controls: Many perennial broadleaf and grass weeds cannot be effectively controlled with herbicides once established in the potato crop and successful controls may be accomplished more easily by using herbicides in rotational crops.

Issues for Perennial Weeds

1. There is a need for better tillage implements to control weeds on organic farms.
2. There is concern with quality control of seed that is used in rotational crop years, as there are problems with weed seed being introduced during these years.
3. The registration of a post-emergent broadleaf herbicide would assist IPM efforts. Currently, growers must rely predominantly on pre-emergent residual herbicides.
4. Row shapers have made mechanical methods of weed control unavailable.
5. There are new perennial weeds for which there is no specific control.

Resources

IPM / ICM resources for production of potato in Canada

Agri-Réseau (www.agrireseau.qc.ca)

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Ontario Ministry of Agriculture, Food and Rural Affairs. Publication 838, Vegetable Crop Protection Guide 2012-13 http://www.omafra.gov.on.ca/english/crops/pub838/p838order.htm

Ontario Ministry of Agriculture, Food and Rural Affairs. Publication 839, Ontario Field Vegetable Guide (publication pending) http://www.omafra.gov.on.ca/english/crops/pub363/p363toc.htm

Ontario Ministry of Agriculture, Food and Rural Affairs. Publication 75. Guide to Weed Control 2012-13. http://www.omafra.gov.on.ca/english/crops/pub75/pub75toc.htm

Prince Edward Island Department of Agriculture and Forestry. Atlantic Canada Potato Guide http://www.gov.pe.ca/agriculture/index.php3?number=1001552&lang=E

Saskatchewan Ministry of Agriculture http://www.agriculture.gov.sk.ca/default.aspx?dn=e0b9f4ad-49e3-4016-b2eb-10c88e62b194

Western Potato Council. Guide to Commercial Potato Production on the Canadian Prairies http://www1.agric.gov.ab.ca/$department/deptdocs/nsf/all/opp9546

Provincial Crop Specialists and Provincial Minor Use Coordinators

Province	Ministry	Crop Specialist	Minor Use Coordinator
British-Columbia	British Columbia Ministry of Agriculture and Lands www.gov.bc.ca/al	Susan Smith susan.l.smith@gov.bc.ca	Caroline Bédard caroline.bédard@gov.bc.ca
Alberta	Alberta Agriculture and Rural Development www.agric.gov.ab.ca/	Patricia McAllistair tricia.mcallister@gov.ab.ca	Jim Broatch jim.broatch@gov.ab.ca
Saskatchewan	Saskatchewan Agriculture www.agriculture.gov.sk.ca	Connie Achtymichuk connie.achtymichuk@gov.sk.ca	Sean Miller sean.miller@gov.sk.ca
Manitoba	Manitoba Agriculture, Food and Rural Initiatives www.gov.mb.ca/agriculture/	Vikram Bisht vikram.bisht@gov.mb.ca	Jeanette Gaultier jeanette.gaultier@gov.mb.ca
Ontario	Ontario Ministry of Agriculture, Food and Rural Affairs www.omafra.gov.on.ca	Eugenia Banks eugenia.banks@ontario.ca	Jim Chaput jim.chaput@ontario.ca
Quebec	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec www.mapaq.gouv.qc.ca	Laure Boulet laure.boulet@mapaq.gouv.qc.ca	Luc Urbain luc.urbain@mapaq.gouv.qc.ca
New Brunswick	New Brunswick Department of Agriculture, Aquaculture and Fisheries www.gnb.ca/0027/index-e.asp	David Wattie (IPM) david.wattie@gnb.ca Jacques Lavoie (SeedProduction) jacques.lavoie@gnb.ca	Gavin Graham gavin.graham@gnb.ca
Prince Edward Island	Prince Edward Island Department of Agriculture and Forestry www.gov.pe.ca/af	Susan MacKinnon sdmakinnon@gov.pe.ca	Shauna Mellish smmellish@gov.pe.ca

National and Provincial Potato Grower Organizations

Province	Organization	Contact Information
British Columbia	British Columbia Potato and Vegetable Growers Association	www.bcac.bc.ca/member-associations
Alberta	Potato Growers Of Alberta	www.albertapotatoes.ca/industry/industry-links
Saskachewan	Saskatchewan Seed Potato Growers Association	www.sspga.ca
Manitoba	Chipping Potato Growers Association of Manitoba	N/A
Ontario	Ontario Potato Board	http://www.ontariopotatoes.ca
	Ontario Seed Potato Growers	http://apps.omafra.gov.on.ca/scripts/english/rural/thelist/detail.asp?organizationid=209
Quebec	Fédération des producteurs de pommes de terre du Québec	http://www.fpptq.qc.ca
New Brunswick	Potatoes New Brunswick	http://www.potatoesnb.com
Prince Edward Island	PEI Potato Board	http://www.peipotato.org
	PEI Potato Producers Association	(902) 892-6551
National	Canadian Horticultural Council	www.hortcouncil.ca

Appendix 1

Definition of terms and colour coding for pest occurrence tables of the crop profiles

Information on the occurrence of disease, insect and mite and weed pests in each province is provided in Tables 4, 7 and 11 of the crop profile, respectively. The colour coding of the cells in these tables is based on three pieces of information, namely pest distribution, frequency and importance in each province as presented in the following chart.

<table>
<tr><th>Presence</th><th colspan="4">Occurrence information</th><th rowspan="2">Colour Code</th></tr>
<tr><td rowspan="15">Present</td><td rowspan="13">Data available</td><th>Frequency</th><th>Distribution</th><th>Pressure</th></tr>
<tr><td rowspan="6">Yearly - Pest is present 2 or more years out of 3 in a given region of the province.</td><td rowspan="3">widespread - The pest population is generally distributed throughout crop growing regions of the province. In a given year, outbreaks may occur in any region.</td><td>High - If present, potential for spread and crop loss is high and controls must be implemented even for small populations</td><td>Red</td></tr>
<tr><td>Moderate - If present, potential for spread and crop loss is moderate: pest situation must be monitored and controls may be implemented.</td><td>Orange</td></tr>
<tr><td>Low - If present, the pest causes low or negligible crop damage and controls need not be implemented</td><td>Yellow</td></tr>
<tr><td rowspan="3">localized - The pest is established as localized populations and is found only in scattered or limited areas of the province.</td><td>High - see above</td><td>Orange</td></tr>
<tr><td>Moderate - see above</td><td>White</td></tr>
<tr><td>Low - see above</td><td>White</td></tr>
<tr><td rowspan="6">Sporadic - Pest is present 1 year out of 3 in a given region of the province.</td><td rowspan="3">widespread - as above</td><td>High - see above</td><td>Orange</td></tr>
<tr><td>Moderate - see above</td><td>Yellow</td></tr>
<tr><td>Low - see above</td><td>White</td></tr>
<tr><td rowspan="3">localized - as above</td><td>High - see above</td><td>Yellow</td></tr>
<tr><td>Moderate -see above</td><td>White</td></tr>
<tr><td>Low - see above</td><td>White</td></tr>
<tr><td rowspan="2">Data not available</td><td colspan="3">Not of concern: The pest is present in commercial crop growing areas of the province but is causing no significant damage. Little is known about its population distribution and frequency in this province; however, it is not of concern.</td><td>White</td></tr>
<tr><td colspan="3">Is of concern: The pest is present in commercial crop growing areas of the province. Little is known about its population distribution and frequency of outbreaks in this province and due to its potential to cause economic damage, is of concern.</td><td></td></tr>
<tr><td>Not present</td><td colspan="4">The pest is not present in commercial crop growing areas of the province, to the best of your knowledge.</td><td>black</td></tr>
<tr><td>Data not reported</td><td colspan="4">Information on the pest in this province is unknown. No data is being reported for this pest.</td><td>grey</td></tr>
</table>

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Agriculture and Agri-Food Canada. A Snapshot of the Canadian Vegetable Industry, 2010 (http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1330373416993&lang=eng#sec01-3)

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University of Kentucky Entomology-Potato Pests (www.uky.edu/Agriculture/Entomology/entfacts/veg/ef304.htm)