Crop Profile for Potato in Canada, 2020

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Preface

National crop profiles are developed by the Pest Management Program of Agriculture and Agri-Food Canada (AAFC). The crop profiles provide baseline information on production and pest management practices and document growers' needs to address pest management gaps and issues for specific crops grown in Canada. This information is developed through extensive consultation with stakeholders and data collected from reporting provinces. Reporting provinces are selected based on their acreage of the target crop (>10 % of the national production) and provide qualitative data on pest occurrence and integrated pest management practices used by growers in those provinces. For potato production, the reporting provinces are Alberta, Manitoba, Ontario, Quebec, New Brunswick and Prince Edward Island.

Information on pest issues and management practices is provided for information purposes only. For detailed information on growing potatoes the reader is referred to provincial crop production guides and provincial ministry websites listed in the Resources Section at the end of the profile. For guidance about crop protection products registered for pests on potato, the reader is referred to provincial crop production guides and Health Canada's Pesticide label database.

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. The nightshade family includes a number of horticulturally important crops including tomato, pepper, eggplant and tobacco. Potatoes originated in the Andes Mountains of Peru and Bolivia and have been cultivated for over 5000 years. They were introduced into Europe in the sixteenth century. Potato cultivation and acceptance as a food product in Europe gradually increased into the 19th century. Potatoes were introduced into Canada in 1623 when a supply of potatoes was delivered to Annapolis Royal, Nova Scotia. The potato is now cultivated in all provinces of Canada.

Potatoes are grown for the fresh, processing (frozen, chipping, dehydrated and other products) and seed potato markets. In 2019-2020, 21 percent of the potatoes grown were intended for the fresh market, 66 percent intended for processing and 13 percent intended for the seed potato market.

Potato biosecurity is an issue for Canadian potato growers. Guidance is provided by the Canadian Food and Inspection Agency (CFIA) to growers on management practices to prevent, minimize and control the introduction and spread of pests and diseases into potato production areas. In addition, Canada's National Seed Potato Certification Program, administered by the CFIA, aims to prevent the introduction and spread of diseases and regulated quarantine pests of potatoes in Canada. Seed potato stock is developed from nuclear stock that is tested and confirmed pathogen-free. To be certified as pathogen-free, seed stocks are moved through a maximum of seven generations.

Crop Production

Industry Overview

Potato is the largest vegetable crop in Canada, accounting for $1.3 billion or 28 percent of all vegetable (field and greenhouse) farm gate receipts in 2020. Total potato production reached 4,738,041 metric tonnes over a total area of 144,262 ha (Table 1).

Canada is recognized internationally as a leader in seed potato production, producing about 150 registered seed potato varieties on 22,952 ha in 2020. Canada is the fourth largest seed potato exporter in the world.

Potato varieties are selected to target specific markets. Some of those commonly grown in Canada include: Russet Burbank, Shepody, Ranger Russet, CalWhite and Umatilla Russet, the leading frying varieties; Superior, Atlantic, Kennebec and Snowden, important chipping varieties; Superior, Russet Norkotah, Chieftain, Yukon Gold, Norland, Ranger Russet, Goldrush, Sangre and Umatilla Russet, the leading table varieties.

Table 1. General production information for potato, 2020

	Potato
Canadian production[1]	4,738,045 metric tonnes 144,262 hectares
Total crop receipts[2]	$1.3 B
Potato consumption[3]	26.09 kg/ person (white, fresh) 34.29 kg/ person (white, fresh and processed)
Exports[4]	$348.5 M
Imports[4]	$109.7 M

[1]Source: Statistics Canada. Table 32-10-0358-01 Area, production and farm value of potatoes (database accessed: 2021-07-22).
[2]Source: Statistics Canada. Table 32-10-0045-01 - Farmcash receipts, annual (Fresh potatoes) (database accessed: 2021-07-12).
[3]Source: Statistics Canada. Table 32-10-0054-01 Food available in Canada (database accessed: 2021-07-12).
[4]Source: Statistics Canada. Canada International Merchandise Trade Database (accessed 2021-07-12): HS # 070190 - Potatoes, fresh or chilled, nes.

Production Regions

Potatoes are commercially produced in every province in Canada, with the main production concentrated (east to west) in Prince Edward Island, New Brunswick, Quebec, Ontario, Manitoba, and Alberta, (Table 2).

In 2020, Prince Edward Island accounted for 23 percent of all potato planted areas, followed by Manitoba (20 percent) and Alberta (17 percent).

Table 2. Distribution of potato production in Canada by province, 2020

Production Regions	Cultivated area[1] (national percentage)	Marketed production[1] (national percentage)	Farm Cash Receipts[2]
Alberta	24,150 ha (16%)	1,063,955 metric tonnes (22%)	$271.9 M
Manitoba	28,935 ha (20%)	1,090,909 metric tonnes (23%)	$281.4 M
Ontario	14,771 ha (10%)	341,727 metric tonnes (7%)	$111.9 M
Quebec	18,469 ha (13%)	586,500 metric tonnes (12%)	$183.5 M
New Brunswick	19,643 ha (14%)	522,727 metric tonnes (11%)	$153.7 M
Prince Edward Island	33,832 ha (23%)	954,545 metric tonnes (20%)	$252.1 M
Canada	**144,262 ha**	**4,738,041 metric tonnes**	**$1.3 B**

[1]Source: Statistics Canada. Table 32-10-0358-01 Area harvested, production and farm value of potatoes (database accessed: 2021-07-22).
[2]Source: Statistics Canada. Table 32-10-0045-01 Farm cash receipts, annual (x 1,000) (database accessed: 2021-07-12).

Cultural Practices

Sites with deep, well-drained sandy or silt loam soils are best suited to growing potatoes. A soil pH of 6.5 to 7.5 is best for nutrient availability and potato growth. However, potatoes can be grown on more acidic soils (pH as low as 5.5), and growing potatoes on soils with lower pH can reduce the incidence of common scab. Crusting soils are undesirable because heavy spring rains may seal the surface, trapping the sprouts below. The growing of potatoes involves frequent travel over the field, places a high demand on soil nutrients and returns little crop residue after harvest. Therefore, it is important that good soil management practices that replenish soil fertility, maintain or increase soil organic matter, and reduce surface and subsurface soil compaction, be followed in order to maintain soil health and ensure continued, sustainable production.

Crop rotation is important for soil conservation and overall crop health. Good crop rotations involve planting cereals, corn, forages, brassicas and pulse crops in sequence with potatoes. Longer rotations improve rooting depth, yields and soil organic matter, and also help

in weed control and reduce the incidence of disease and insect pests in potato production by breaking pest life cycles. The use of cover crops following potato crops is also useful in preventing soil erosion and improving soil health.

Potatoes are grown from tuber seed pieces or whole small tubers that are planted 10 to 12 cm deep in rows, and hilled up either at planting or shortly thereafter. Soil temperature at planting should be at least 7 °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.

Irrigation is used in many growing regions to supply the crop with an adequate supply of water throughout the growing season. Some producers also deliver nutrients through irrigation water (known as fertigation).

At harvest, tuber pulp temperatures should be 10 to 18 °C. At cooler temperatures, tubers are more prone to bruising. When pulp temperatures at harvest are above 18 °C, tubers are susceptible to breakdown in storage due to bacterial soft rot, Pythium leak and other disorders.

Before being placed in storage, the skin of potatoes must be hardened (set) to ensure good storability. Temperature, humidity and air movement all are carefully managed in potato storage facilities to maintain potato tuber quality. Tubers are kept in complete darkness to prevent greening. Sprout inhibitors can be used on table and processing potatoes. Good storage and equipment sanitation are 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	Seed beds are prepared; hilling may be performed after planting and before emergence or with planting in one operation
	Soil care	Fertilization
	Disease management	Sanitation of seed cutting and planting equipment; seed piece and in-furrow treatments are applied
	Insect and mite management	Seed piece or in-furrow insecticide treatment
	Weed management	Pre-emergence spray
June	Plant care	Hilling, irrigation (where used); use of wheeled pocket press machine (dammer-diker) to create pockets for water retention
	Soil care	Conservation tillage and topdressing (AB, MB); herbicide application instead of conservation tillage (AB)
	Disease management	Monitoring for diseases, including spore traps and weather station deployment for early and late blight spore monitoring; begin fungicide spray program
	Insect and mite management	Monitoring and spraying where necessary; begin oil spray on seed crop at emergence to control viruses (NB)
	Weed management	Hilling and post- emergence spray; pre-emergence herbicide application and weeding with cultivator (QC)
July	Plant care	Monitoring, irrigation and fertigation (where used)
	Soil care	Topdressing of fertilizer, if required Soil sampling of problem areas within field (ON)
	Disease management	Monitoring, application of fungicide as required
	Insect and mite management	Monitoring and spraying where necessary; oil spray on seed crop to control viruses (NB)
	Weed management	Limited activities
August	Plant care	Monitoring, irrigation (where used); top killing and harvest of early varieties in MB, ON, QC
	Disease management	Monitoring for disease, application of fungicide regularly
	Insect and mite management	Monitoring and spraying where necessary; oil spray on seed crop to control viruses (NB).
	Weed management	Limited activities

…continued

Table 3. Potato production and pest management schedule in Canada (continued)

Time of Year	Activity	Action
September	Plant care	Top killing and harvest of potatoes (main harvest in Western Canada, early harvest in Eastern Canada)
	Soil care	Field tillage and cover crop planting following harvest
	Disease management	Monitoring, application of fungicide when necessary; sanitation of harvest equipment and storage facilities before use; application of storage fungicide (NB, MB)
	Insect and mite management	Limited activity; wireworm baiting (PEI)
	Weed management	Limited activity
October	Plant care	Completion of harvest in Western Canada; primary harvest season in Eastern Canada
	Soil care	Soil sampling and analysis for nutrients and diseases; planting of cover crops following potatoes (PEI)
	Disease management	Limited activity; application of storage fungicide (NB)
	Insect and mite management	Limited activity
	Weed management	Limited activity

Abiotic Factors Limiting Production

Wind

Strong winds can result in foliar abrasion and tipburn. Wind-damaged leaves are dry, easily torn and have a leathery texture. Symptoms of tipburn include yellow to brown to black discolouration on leaf tips and margins. Leaves may roll upward, become brittle and eventually die. The incidence of tipburn increases when roots have been damaged or pruned by cultivation. Symptoms are more extensive when strong winds occur in hot, dry weather. Wind damage can be confused with many foliar diseases.

Lightning Injury

Lightning strikes in a potato field can injure plants, with symptoms appearing two to 24 hours after the strike. Affected plants are often found in a well defined circular or oval pattern. Leaves may remain green 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 collapse, creating a hole in the tuber. Affected tubers are highly susceptible to secondary diseases and usually decay completely before harvest.

Aerial Tubers

Aerial tubers develop along stems as a result of an accumulation of carbohydrates on the stem. The build-up of carbohydrates is a result of blockages or restrictions of the stem vascular tissue caused by disease, mechanical injury or waterlogged soils.

Bruising

Tubers are prone to bruising from mechanical injury during handling. Most bruising occurs during windrowing, harvesting, conveyor drops and bin piling. Internal, blue-gray discolouration (blackspot) and splitting or cracking of skin (shatter bruise) are symptoms of bruising. Bruising may also occur when the tuber surface is under pressure from other tubers while in storage. Pressure bruising is more severe when tubers are dehydrated due to low moisture in the field prior to harvest or inadequate humidity during storage. Bruising reduces the quality of affected tubers and skin breaks provide entry points for disease.

Low Temperature and Freezing Injury

Low temperature and freezing injuries can occur in tubers in the field before harvest or in storage, if temperatures fall below 3 ^{o}C. Symptoms include darkening of the interior of the tuber followed by a soft wet rot of affected tissue. Tissues damaged by freezing in storage are often infected by bacteria, which caused further breakdown of the tuber.

Blackheart

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

Hollow Heart and Brown Centre

Hollow heart and brown centre are two phases of the same disorder that can develop in tubers when periods of slow growth due to moisture, fertility and temperature stresses are followed by periods of rapid growth. Symptoms appear as longitudinal cracks that vary in size and shape within 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. Brown center may be induced when soil temperatures are below 13 °C for approximately five to seven days around tuber initiation. Symptoms appear as a brown discoloration in the centre of the tuber near the stem end. If growth is rapid, affected cells will split apart creating a cavity resulting in hollow heart.

Tuber Surface Cracks

Surface cracks result from irregular moisture patterns in the field, often developing following a heavy rainfall or an irrigation event 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. At harvest, the excessive pressure on tuber skin will cause small cracks when exposed to dry air. Surface cracks make table-stock tubers unmarketable.

Malformed Tubers

Tuber malformations (e.g., knobs, dumbbell shapes, pointed ends and bottle necks) can develop when there is disruption in growth (e.g., inadequate moisture and/or fertility) followed by regular growth. Additional causes of malformed tubers include periods of high temperature, plants with few stems or tubers, *Rhizoctonia* infections, pruning and excessive vine. Cultivars, including round or oblong varieties that are less susceptible to malformed tubers, are commercially available.

Tuber Greening

Tuber greening occurs when tubers are exposed to light from the sun or artificial sources, resulting in chlorophyll production. Tubers that mature close to the soil surface as a result of shallow planting, insufficient hilling or exposure by erosion or ground cracks, are prone to greening. Tuber greening is both a quality and health issue. The production of chlorophyll in the tuber skin increases levels of glycoalkaloids (e.g., solanine), which are mildly toxic to humans and result in a bitter tasting potato. Most glycoalkaloids are removed when the tuber skin is peeled.

Internal Sprouting

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

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 observed shortly after harvest or may develop over the first couple of months in storage. The disorder occurs when immature vines are killed rapidly. The symptoms of stem-end browning are very similar to those seen on tubers with necrosis caused by potato leaf roll virus or Verticillium wilt.

Enlarged Lenticels

Enlarged lenticels (pores in the tuber skin) develop when tubers are exposed to excessive moisture in the field or in storage or under dry conditions in compacted soil. With prolonged exposure to these conditions, lenticels will swell until the protective suberin layer of the skin bursts, forming raised masses over the tuber skin. The rupture of the suberin layer opens up tubers to infection by many diseases.

Disorder of Unknown Cause

Skin russeting of smooth-skinned potatoes is a complex disorder, thought to be physiological in origin, with few options for its management. This disorder reduces the quality and marketability of affected potatoes.

Diseases

Key issues

- There is a need for continued monitoring of the development and distribution of late blight strains and research on the impact of common and new strains of late blight on potato, and how these strains behave under Canadian conditions. Rapid typing and identification techniques are required, as is access to localized weather data and spore trapping for more accurate late blight disease risk forecasting.

- There is a need for new fungicides with broad-spectrum modes of action.

- The continued harmonization of pesticide registrations between Canada and the United States, including aspects such as pre-harvest intervals, are very important to ensure the competitiveness of Canadian potato growers.

- There is a need for continued surveillance for the aggressive European blackleg caused by *Dickeya dianthicola* and *Pectobacterium* spp.

- Alternative strategies to fumigation are required for the management of soilborne diseases related to early dying complex, including root lesion nematodes (*Pratylenchus penetrans*), *Verticillium* spp. and black dot (*Colletotrichum coccodes*). Further studies are required on the impact of green manures, biofumigants, trap crops and crop rotation on inoculum levels and crop yield.

- A better understanding of the impact of early blight and brown spot on yield is needed. *Alternaria* spp. (early blight and brown spot) resistance to registered fungicides is of concern. Monitoring of resistant populations and improved resistance management strategies need to be implemented.

Table 4. Occurrence of diseases in potato production in Canada[1,2]

Disease	Alberta	Manitoba	Ontario	Quebec	New Brunswick	Prince Edward Island
Bacterial ring rot						
Bacterial soft rot						
Blackleg						
Periderm disorder syndrome (pink eye)						
Common scab						
Black dot						
Brown spot						
Early blight						
Fusarium dry rot						
Fusarium wilt						
Gray mold						
Late blight						
Pink rot						
Powdery scab						
Pythium leak						
Rhizoctonia canker and black scurf						
Seed piece decay						
Silver scurf						
Verticillium wilt						
White mold						
Viruses						
Potato Virus Y						
Potato leafroll virus						
Root lesion nematode						

Widespread yearly occurrence with high pest pressure.

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

Widespread yearly occurrence with low pest pressure OR widespread sporadic occurrence with moderate pressure OR sporadic localized occurrence with high pest 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 OR pest not of concern.

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

Pest not present.

Data not reported.

[1]Source: Potato stakeholders in reporting provinces (Alberta, Manitoba, Ontario, Quebec, New Brunswick and Prince Edward Island); the data reflect the 2018, 2019 and 2020 production years.
[2]Refer to Appendix 1 for a detailed explanation of colour coding of occurrence data.

Table 5. Adoption of disease management practices in potato production in Canada[1]

	Practice / Pest	Common Scab	Late Blight	Fusarium Dry Rot	Rhizoctonia canker and Black Scurf	Verticillium Wilt	Viruses (General)
Avoidance	Varietal selection / use of resistant or tolerant varieties						
	Planting / harvest date adjustment						
	Rotation with non-host crops						
	Choice of planting site						
	Optimizing fertilization for balanced growth and to minimize stress						
	Minimizing wounding and insect damage to limit infection sites						
	Use of disease-free propagative materials (seed, cuttings or transplants)						
Prevention	Equipment sanitation						
	Canopy management (e.g., thinning, pruning, row or plant spacing)						
	Manipulating seeding / planting depth						
	Irrigation management (timing, duration, amount) to minimize disease infection periods and manage plant growth						
	Management of soil moisture (e.g., improvements in drainage, use of raised beds, hilling, mounds)						
	End of season or pre-planting crop residue removal / management						
	Pruning out / removal of infected material throughout the growing season						
	Removal of other hosts (weeds / volunteers / wild plants) in field and vicinity						

…continued

Table 5. Adoption of disease management practices in potato production in Canada[1] (continued)

Practice / Pest		Common Scab	Late Blight	Fusarium Dry Rot	Rhizoctonia canker and Black Scurf	Verticillium Wilt	Viruses (General)
Monitoring	Scouting / spore trapping						
	Maintaining records to track diseases						
	Soil analysis for the presence of pathogens						
	Weather monitoring for disease forecasting						
	Use of precision agriculture technology (GPS, GIS) for data collection and mapping of diseases						
Decision making tools	Economic threshold						
	Use of predictive model for management decisions						
	Crop specialist recommendation or advisory bulletin						
	Decision to treat based on observed disease symptoms						
	Use of portable electronic devices in the field to access pathogen / disease identification / management information						
Suppression	Use of diverse product modes of action for resistance management						
	Soil amendments and green manuring involving soil incorporation as biofumigants, to reduce pathogen populations						
	Use of biopesticides (microbial and non-conventional pesticides)						
	Controlled atmosphere storage						
	Targeted pesticide applications (banding, spot treatments, use of variable rate sprayers, etc.)						
	Selection of pesticides that are soft on beneficial insects, pollinators and other non-target organisms						

…continued

Table 5. Adoption of disease management practices in potato production in Canada[1] (continued)

Practice / Pest		Common Scab	Late Blight	Fusarium Dry Rot	Rhizoctonia canker and Black Scurf	Verticillium Wilt	Viruses (General)
Crop specific practices	Mustard rotational crop						
New practices	Species identification for variety (ON)						
	Genotyping for fungicide selection (ON)						
	Precision irrigation (ON)						
	Soil fumigation (NB)						
	Foliage top-kill (NB)						

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); the data reflect the 2018, 2019 and 2020 production years.

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

Pest Information

Damage: Pathogens infecting potato seed pieces can cause decay, resulting in poor emergence of potato seedlings and stunted plant growth. Infected seed pieces turn black and watery as they are colonized by bacteria, eventually they completely rot.

Life Cycle: Wounds in seed potatoes and cut surfaces of seed pieces provide entry sites for pathogens. Pathogens can be spread from diseased to healthy seed tubers during the cutting process or may be soil-borne. Planting into cold wet soils can favour seed piece decay.

Pest Management

Cultural Controls: The planting of high quality, certified disease-free seed will reduce the development of seed piece decay. Seed cutting equipment must be cleaned and disinfected regularly, especially between seed lots to minimize spread of tuber-borne inoculum. If cut seed are not planted immediately they must be stored at proper temperatures with sufficient air circulation to promote 'healing' of the cut tissues. It is important that potatoes not be planted into cool, wet, and poorly drained soil. Seed piece fungicide treatments will reduce decay caused by soil-borne pathogens and pathogens introduced on the cut surface; however, these treatments will not eliminate disease carried internally on the seed.

Resistant Cultivars: Kennebec has moderate resistance to seed-piece decay.

Issues for Seed Piece Decay

1. Additional broad-spectrum fungicides are needed to complement available products for the control of seed piece decay in order to minimize the risk of resistance development.

Late Blight (*Phytophthora infestans*)

Pest Information

Damage: Late blight affects the leaves, stems and tubers of potato plants. Potato, tomato and other solanaceous crops such as eggplant and pepper are also susceptible to the disease. Water-soaked, gray-green lesions that become brown and dry develop on foliage. Under favourable conditions the disease can rapidly spread and kill plants. Infected tubers develop irregularly shaped lesions that penetrate up to 2 cm. Late blight infected tubers are extremely susceptible to secondary rot pathogens.

Life Cycle: The fungus survives between seasons as mycelium in infected tubers in storage, in cull piles, and in tubers left in harvested potato fields. The disease spreads when infected tubers are planted or infected volunteer potato plants develop. The pathogen produces sporangia in infected tissues. The sporangia are spread by wind and rain to healthy potato

tissues. The sporangia germinate and release zoospores or produce germ tubes causing new infections. Cool wet conditions favour disease development. Tubers become infected late in the season and during harvest when spores in the soil come in contact with the tubers. Blight will spread in storage if free moisture is present. 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 spores 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 pathogenic strains.

Pest Management

Cultural Controls: The removal and destruction of cull piles and volunteer potatoes, the elimination of solanaceous weeds and the use of disease-free certified seed will eliminate sources of the disease. It is important to monitor crops immediately prior to emergence and at weekly intervals there-after for early detection of late blight. Delaying harvest for at least two weeks following complete vine kill will allow time for sporangia on the foliage to die and reduce the incidence of tuber infection. Ventilation is required for tubers that go into storage wet or damp, so that the tubers dry as quickly as possible. Storing only healthy tubers and monitoring tubers in storage for signs of disease and removing as necessary, will reduce disease incidence in storage. Additional management practices for late blight are listed in Table 5.

Resistant Cultivars: The planting of moderately resistant cultivars such as Atlantic, Chieftain, Innovator, and Kennebec will reduce the spread of this disease.

Issues for Late Blight

1. It is important that growers follow an IPM strategy using all available options for the management of late blight to prevent fungicide resistance development. Grower education is required on the use and role of new fungicides.
2. Continued support and maintenance of a conventional potato breeding program for the development of late blight resistant varieties continues to be an industry priority.
3. *Phytophhora infestans* strains in Canada have changed in recent years. Continued research is required on the pathogenicity and behaviour of these strains under Canadian growing conditions.
4. Rapid strain typing and identification techniques are required to monitor the development and distribution of new strains of late blight to help growers select the best treatment options.
5. There is a need for an effective control strategy for seed-borne late blight, especially with the loss of mancozeb-based seed treatments following re-evaluation.
6. An effective system of disease forecasting is required that uses localized weather data, weather forecasts and spore trapping data. Disease models need to be revised to reflect the environmental behavior of current *P. infestans* strains.

Early Blight (*Alternaria solani*)

Pest Information

Damage: Early blight causes dark brown spots with concentric rings on foliage. Older lower foliage is infected initially with the disease progressing to younger foliage under suitable conditions. Heavy infections can kill entire leaves and yield losses can be serious when lesions cover large areas of the leaves. Dark brown sunken lesions can develop on tubers. In storage, infected tubers become dry and shrivelled as the disease progresses.

Life Cycle: The pathogen overwinters in infected crop residue, on tubers and on other hosts including tomato, pepper and solanaceous weeds. Spores are produced in infected material in the spring and are wind-blown to potato plants where they cause new infections. Rapid early blight spread occurs during alternating wet and dry weather, as dry conditions aid in spore dispersal by wind. Plants that have nitrogen or phosphorous deficiencies, or are infected with *Verticillium* or mosaic virus are more prone to early blight than healthy plants.

Pest Management

Cultural Controls: Burying crop residues will promote decay of plant tissues and reduce overwintering inoculum. Following crop rotations with non-host crops will also reduce the incidence of disease. Disease development can be minimized by planting only certified seed, providing adequate fertilization and following cultural practices that promote plant health. Regular monitoring, beginning just before crop emergence, followed by weekly assessments for foliar lesions, is important to determine whether fungicide treatments are required.

Resistant Cultivars: Some cultivars, such as Eva, Ranger Russet, Sangre, and Shepody exhibit tolerance to early blight.

Issues for Early Blight

1. A better understanding of the impact of early blight on yields and the development of an economic threshold is needed.
2. The modernization and validation of a disease forecasting model, including weather conditions, crop phenology and spore trapping, would be of benefit to the industry.
3. Fungicide resistance in the early blight pathogen population is of concern. Monitoring of resistant populations and improved resistance management strategies need to be implemented.

Brown Spot (*Alternaria alternata*)

Pest Information

Damage: Symptoms of brown spot include small round, dark brown spots on leaves and stems 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. Small black pits may develop on tubers.

Life Cycle: The pathogen overwinters in infected crop residue, tubers and on other susceptible hosts. Spores are produced in infected material and are spread by wind to healthy potato tissues where they cause new infections. New infections are favoured by periods of leaf wetness and warm temperatures.

Pest Management

Cultural Controls: Burying crop residues will promote decay of plant tissues and reduce overwintering inoculum. Following crop rotations with non-host crops will also reduce sources of disease. Cultural practices which promote plant health such as providing balanced nutrients and moisture will help to reduce disease development. Weekly monitoring is used to determine whether fungicide treatments are necessary.

Resistant Cultivars: None available.

Issues for Brown Spot

1. There is a need for greater understanding of the impact of brown spot on yield and the development of an economic threshold.
2. Fungicide resistance in the *Alternaria* spp. pathogen population is of concern. Monitoring of fungicide sensitivity in pathogen populations is needed.

White Mold *(Sclerotinia sclerotiorum)*

Pest Information

Damage: Initial symptoms of white mold are water-soaked lesions on stems. As the lesions expand, stems become girdled resulting in wilting of foliage. Under humid conditions, white cottony growth is produced in the lesions. Lesions dry out and become beige or tan under dry conditions.

Life cycle: Sclerotinia sclerotiorum has a wide host range that includes most vegetable crops. The fungus is soilborne and can survive in the soil for many years in the form of sclerotia. When exposed to adequate soil moisture and moderate temperatures, sclerotia germinate and produce apothecia, spore producing structures that release ascospores into the air. The ascospores are carried by wind to host plants where they cause new infections. Sclerotia are produced in infected tissues and eventually drop to the soil.

Pest Management

Cultural control: Planting in well drained soils that have not previously supported crops infected with white mold reduces the potential for disease development. Long crop rotations using cereal and other non-host crops can reduce inoculum in the soil. The disease is favoured by dense canopies, high moisture and leaf wetness. Avoiding excessive nitrogen applications that promote foliar growth and following irrigation practices that minimize the duration and frequency of foliar wetting, will help minimize disease development. Weed control to eliminate other host plants, as well as the removal and destruction of infected plant material, can help reduce disease spread.

Resistant cultivars: None available.

Issues for White Mold

1. White mold is becoming a problem on some potato varieties. Research is required on the management of this disease.

Gray Mold (*Botrytis cinerea*)

Pest Information

Damage: Botrytis cinerea causes tan spots on leaves and stems with injured and senescing tissues often being colonized first. Lesions can girdle stems. Infected tissues may become covered by grayish mycelium and spores, especially under humid conditions. When disease pressure is high, tubers may be infected at harvest.

Life Cycle: The pathogen attacks a wide range of plants including ornamentals and vegetables. The fungus overwinters as sclerotia (resting bodies) and mycelium in infected plant debris. In the spring, spores produced in crop debris are dispersed by wind and rain to susceptible tissues where they cause new infections. Under suitable conditions of humidity and leaf wetness, the fungus produces spores in infected tissues which contribute to further disease spread.

Pest Management

Cultural Controls: Cultural practices that minimize the duration of leaf wetness and reduce humidity in the crop canopy will make conditions less favourable for the development of gray mold. Avoiding tuber damage at harvest and allowing tubers to heal before being stored will minimize disease development in storage. Once the disease becomes established, hot and dry periods are required to stop disease spread.

Resistant Cultivars: None available.

Issues for Gray Mold

None identified.

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

Pest Information

Damage: Early symptoms of Verticillium wilt include yellowing and dieback of lower leaves and in some cases, development of brown discolouration of the vascular tissue of the stem. Symptoms may develop on only one side of the plant. Plants die prematurely resulting in reduced yields. The disease is often associated with other pathogens, including root lesion nematodes, giving rise to what is called "potato early dying".

Life Cycle: Verticillium spp. have a broad host range. *V. dahliae* persists in the soil as resting bodies called microsclerotia; *V. albo-atrum* persists as thick-walled hyphae. *Verticillium* spp. can be spread by infected soil displaced by wind or mechanical means. The disease can be introduced into new fields with infected seed potatoes. Verticillium wilt infects young plants through developing roots. The fungus establishes itself in the vascular tissues of the plants and moves upwards, infecting stems, petioles and leaves. As plant tissues die, microsclerotia and thick-walled hyphae are returned to the soil. There is an increase in disease incidence and severity when Verticillium wilt and root lesion nematodes occur in the soil together. Verticillium wilt infects tubers, but does not spread easily nor cause significant damage in storage.

Pest Management

Cultural Controls: Including non-host crops in rotations will help to prevent the build-up of *Verticillium* spp. in the soil. Minimizing plant stress through good fertilization and irrigation practices will help plants tolerate Verticillium wilt. Controlling weeds that are hosts to *Verticillium* spp. in and around the field contributes to managing this disease. Laboratory soil analysis can determine the levels of the pathogen in the soil and aid planting decisions. Additional management practices for Verticillium wilt are listed in Table 5.

Resistant Cultivars: Ranger Russet is considered as a resistant cultivar. Moderately resistant cultivars include Atlantic, Chieftain, Goldrush, and Umatilla Russet.

Issues for Verticillium Wilt

1. Continued research is required into new integrated strategies that could include fungicides and biofungicides, rotational crops, soil amendments, more tolerant varieties and other alternative approaches to reduce the incidence and impact of Verticillium wilt.
2. Improved diagnostic methods to quantify the amount of *Verticillium* in the soil have been developed. The next step is to develop economic thresholds using data collected as a result of these improved diagnostic methods.

Fusarium Wilt (*Fusarium spp.*)

Pest Information

Damage: Fusarium wilt causes yellowing and wilting of potato foliage and brown discolouration of the vascular system. Symptoms are similar to Verticillium wilt, with the pathogen interfering with water transport causing plants to become stunted, wilt and die.

Life Cycle: The causal agent can persist for many years in the soil. Infection occurs through wounds in potato roots and stolons. The disease can be spread from one field to another by the movement of soil, tubers or other plant material. These pathogens are more active when soil temperatures are above 20 ^{o}C.

Pest Management

Cultural Controls: Planting certified disease-free seed will minimize the potential of introducing Fusarium wilt into a new field. It is important to plant in fields that have a disease-free history, and to follow sanitation practices such as the removal of potato vines to reduce the spread of the disease from infected fields. Crop rotation with non-host crops for five to six years will help reduce *Fusarium* spp. levels in the soil.

Resistant Cultivars: None available.

Issues for Fusarium Wilt

1. Continued research into new integrated strategies including rotational crops, soil amendments and other approaches, to reduce the impact of Fusarium wilt is needed.

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

Pest Information

Damage: Bacterial ring rot (BRR) is a serious disease of and is a regulated pest in Canada. Symptoms include yellowing and wilting of foliage, dieback of individual stems, vascular discolouration in stems and tubers and plant death. Affected tubers may develop a decay of the vascular ring and become prone to secondary rots. Symptoms vary depending on the variety of potato. Infected plants and tubers may not show symptoms under certain environmental conditions. There is a zero tolerance for this disease in seed potatoes.

Life Cycle: The pathogen multiplies within stems and tubers of potato plants and overwinters in infected tubers left in the field or in storage. When squeezed, infected tubers and stems may exude bacterial "ooze" that contains millions of pathogenic bacteria. Bacterial rink rot can survive for years in dried slime on farm equipment, bins, bags and storage facility walls. The pathogen is highly infectious and is readily spread on cutting knives at planting and on field equipment. In addition, some insects (e.g., Colorado potato beetle, potato flea beetle, green peach aphid) are also capable of spreading the disease.

Pest Management

Cultural Controls: The use of seed certified to be free of bacterial ring rot and adoption of strict sanitation protocols are essential in the management of this disease. The regular disinfection of equipment, containers and storage areas between seed lots or crops helps to prevent disease carryover between crops. It is important that all machinery that comes in contact with potatoes that may be infected, be cleaned and disinfected with a product registered for ring rot. Following a crop rotation of at least three years, during which time volunteer potatoes are killed and all plant material removed, will reduce disease carryover between crops. If disease develops, leaving the crop in the field as long as possible will allow the majority of infected tubers to rot before harvest. If the pathogen is found in the field, a mandatory quarantine period of two years is established during which time potatoes cannot be grown in that field.

Resistant Cultivars: None available.

Issues for Bacterial Ring Rot

1. Promotion of educational resources that outline best management practices for cleaning and disinfecting storage facilities and equipment are required by growers to improve storage sanitation practices.

Blackleg (*Pectobacterium atrosepticum*)

Pest Information

Damage: Blackleg can result in seed piece decay at planting, stunting of young plants, foliar yellowing and wilt of older plants, and ultimately yield loss. Black discolouration may develop on the lower stems originating at the seed piece. Leaves become yellow and roll upwards and severely infected plants eventually die. Tuber infection and decay may occur in the field or in storage.

Life Cycle: The disease is primarily seed borne, although the pathogen can survive in potato crop debris, other host crops and weeds. The pathogen does not survive for long in the soil without a suitable host. Blackleg spreads primarily during planting when seed pieces are cut. Cool and wet soil conditions 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 by the blackleg pathogen.

Pest Management

Cultural Controls: Planting only certified disease-free seed will help to prevent the introduction of blackleg into the field. Strict sanitation practices including frequent cleaning and disinfecting of seed cutters and other equipment will reduce the chances of disease spread. A three-year crop rotation is recommended to ensure the decay of crop debris that could harbour the blackleg bacterium. It is important that storage facilities be well-ventilated and

temperature and humidity be adjusted to facilitate wound healing in stored potatoes. After curing, holding tubers at a cooler temperature may slow disease progression. Registered fungicide seed treatments can control diseases that when left unmanaged allow infections by the blackleg pathogen.

Resistant Cultivars: Resistant cultivars available include Kennebec and Russet Burbank.

Issues for Blackleg

1. Blackleg is a concern for the Canadian potato industry and more research is needed to understand the epidemiology of new aggressive strains of *Pectobacterium atrosepticum*.
2. There is a need for continued surveillance of imported seed tubers and other hosts for the aggressive European blackleg (*Dickeya dianthicola*).

Bacterial Soft Rot (*Pectobacterium carotovorum*)

Pest Information

Damage: Water-soaked lesions develop on tubers and enlarge to form wet, cream to tan-coloured areas of soft and slimy decay. Decayed tissues become foul smelling as they are invaded by secondary organisms. Losses in storage can be severe.

Life Cycle: Potatoes may be infected in the field, in transit or in storage. The bacterium infects tubers through lenticels, wounds or as a result of chilling injury or bruising. Soft rot development is favoured by immaturity of tubers, moisture on tuber surfaces and improper storage temperatures. Soft rot bacteria can survive for several months in the soil. These bacteria prefer higher temperatures and soil moisture.

Pest Management

Cultural Controls: It is important to minimize tuber wounding and bruising to reduce points of entry for soft rot bacteria. Pre-conditioning (warming) of cut seed pieces prior to planting will reduce infection, as will the use of whole seed for planting. Disinfection of all equipment is important to prevent spread. Allowing tubers to cure properly before storage, along with grading-out rotting and diseased tubers before planting and storage will help to minimize soft rot development. The use of clean water for washing tubers after harvest and allowing washed tubers to dry thoroughly before packing will also minimize soft rot development.

Resistant Cultivars: 'Sangre' is identified as moderately resistant to bacterial soft rot.

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 may be reduced due to black sclerotia (scurf) that form on the tuber skin. Infection may result in leaves forming rosettes, plant stunting, chlorosis, rolling of leaf tips, development 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 on crop residue. Disease is introduced into a field primarily through the planting of infected seed potatoes; however, soil-borne 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. Shallow planting in well drained soils reduces infection as well. The use of only certified disease-free or resistant seed will help to reduce the chance of disease development. It is important to harvest potatoes as soon as possible after skin set, to minimize disease development. Additional management strategies for Rhizoctonia canker and black scurf are included in Table 5.

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

Issues for Rhizoctonia Canker and Black Scurf

None identified.

Pink Rot (*Phytophthora erythroseptica*)

Pest Information

Damage: Foliar symptoms of pink rot include leaf chlorosis, stunting and wilting. Roots and underground stems may become discoloured. With severe infections, aerial tubers may form. Infected tubers develop a ‘spongy’ decay starting at the stem end and do not normally pass grading nor are they planted as seed.

Life Cycle: Pink rot develops late in the season close to harvest. High soil moisture and poorly drained soils are conducive to this disease. The pathogen can survive in the soil for many years as oospores (sexual spores) and will invade potato roots, stolons, eyes and lenticels when conditions are favourable. Wheat and rye may be alternate hosts. The disease can be

spread during harvest and handling through tuber contact. Pink rot spreads readily in storage when infected tubers break down.

Pest Management

Cultural Controls: Planting potatoes in well-drained soils will reduce the risk of pink rot development. 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 management of storage conditions to keep up air flow is important in preventing disease spread.

Resistant Cultivars: None available.

Issues for Pink Rot

1. There is a need for conventional and non-conventional products for the management of pink rot and for use as resistance management tools.
2. The development of resistance to metalaxyl-m by *Phytopthora erythroseptica* populations is an on-going issue requiring continued monitoring and grower education.

Fusarium Dry Rot (*Fusarium* spp.)

Pest Information

Damage: Fusarium dry rot affects tubers in storage and seed potatoes after planting (see also seed piece decay). If planted, infected seed causes poor stands with poor vigour, reducing yield. Infected tubers develop a brown to black dry rot and mold growth may develop in cavities of infected tissues.

Life Cycle: The pathogens survive in the soil for many years and can also be introduced into fields in infected seed. Tubers are infected through wounds and bruises that occur during harvest, transit or storage. In storage, Fusarium dry rot is favoured by high humidity and temperatures between 15 to 20 °C. New infections in storage result from inoculum carried in soil adhering to tubers. Resistance to fungicides has been reported for some *Fusarium oxysporum* strains in Eastern Canada.

Pest Management

Cultural Controls: Planting certified disease-free seed and disinfecting and cleaning seed cutters routinely will reduce the chances of introducing *Fusarium* spp. into the field. Leaving tubers in the ground for at least two weeks after vine killing promotes good skin set, and careful handling of tubers results in less wounding. Additional management options for Fusarium dry rot are included in Table 5.

Resistant Cultivars: The cultivars Belleisle, Kennebec, Ranger Russet, Russet Burbank, and Shepody are moderately resistant to this disease.

Issues for Fusarium Dry Rot

1. Field surveys are required to establish the prevalence of fungicide resistance in *Fusarium* pathogen populations.

Pythium Leak (*Pythium* spp.)

Pest Information

Damage: Pythium leak causes a watery rot of tubers. The disease can be very severe in storage, with symptoms progressing from no visible symptoms to complete rot in one week. Secondary infections by bacteria can make diagnosis difficult.

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

Pest Management

Cultural Controls: Planting into fields with well-drained soil will help reduce the development of Pythium leak. A crop rotation of three to four years may reduce the levels of inoculum in the soil. Allowing the tuber skin to set properly and minimizing wounding during harvest, handling and storage will reduce infection sites. Avoiding temperatures above 21 °C at harvest will help reduce problems due to this disease.

Resistant Cultivars: None available.

Issues for Pythium Leak

1. The incidence of Pythium leak has been increasing in both the field and in storage. Additional management practices to control *Pythium* spp. are needed.

Silver Scurf (*Helminthosporium solani*)

Pest Information

Damage: Silver scurf affects the skin of tubers causing silvery, circular to irregular shaped superficial spots that can eventually coalesce and cover the entire tuber surface. Severe infections reduce the marketability of the crop. In storage, the symptoms can become more important, with skin sloughing off and tubers shrinking.

Life Cycle: The fungus overwinters in organic matter in the soil and is also carried on seed. Potato is the only known host. Spores develop in infected tissues and lesions on seed potatoes

and are spread to new tubers by water. Infections occur through the skin of the tuber or through lenticels. Silver scurf develops late in the season and continues to spread in storage.

Pest Management

Cultural Controls: The use of disease-free seed will reduce the likelihood of disease development in the field. Monitoring can be done late in the season or after harvest for the presence of tan to gray lesions on tubers. Disease incidence increases the longer tubers are left in the ground after maturity; therefore, a timely harvest shortly after crop maturity will reduce disease development. Thorough cleaning and sanitizing of storage facilities prior to use will prevent pathogen carryover.

Resistant Cultivars: The cultivar Ranger Russet is considered to have good resistance to silver scurf, while cultivars Chieftain and Goldrush have moderate resistance.

Issues for Silver Scurf

1. The development of an effective integrated approach including the use of fungicides and biofungicides is required for the management of silver scurf in the field and in storage. Silver scurf is particularly problematic in organic production.

Common Scab (*Streptomyces scabies*)

Pest Information

Damage: Although common scab 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, soil organic matter and pH. There are no above-ground symptoms of the disease. Tubers become resistant to this disease once the skin thickens and matures.

Life Cycle: The pathogen can be soil-borne or introduced into fields on infected seed or manure from animals that have been fed scab infected potatoes. Infection occurs at tuber initiation when the scab bacterium invades the tuber through lenticels. 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: Planting disease-free seed will prevent the introduction of *Streptomyces scabies* into new fields. The planting of scab resistant varieties in scab infested soils will prevent problems due to this disease. Maintaining soil moisture at 80 percent of field capacity during tuber initiation, until tubers are golf ball size, will create an unfavourable environment for scab infection. As scab can survive the digestive process, manure from cull potato fed cattle should not be applied to land intended for potato production. Additional management options for common scab are included in Table 5.

Resistant Cultivars: Many cultivars have resistance to common scab. Goldrush and Russet Norkotah have a good resistance. Cultivars with moderate resistance are: Atlantic, Chieftain, Coastal Russet, Innovator, Norland, Prospect, Ranger Russet, Russet Burbank, Snowden, Superior, and Umatilla Russet.

Issues for Potato Common Scab

1. Further studies are required to develop an effective approach to the management of common scab. Effective and economical seed and soil treatments are required.
2. There is a continued need for the development of additional scab resistant potato varieties.

Powdery Scab (*Spongospora subterranea*)

Pest Information

Damage: Powdery scab results in significant cosmetic defects of the tuber skin. Tubers develop raised pustules up to 5 mm in diameter. Infected tubers may shrivel and dry in storage. Scab infection sites serve as entry points for many other disease causing pathogens in the field and in storage. The pathogen is a persistent vector of the potato mop-top virus (PMTV).

Life Cycle: The pathogen is a protozoan, which survives in the soil for many years as resting spores and can be introduced into the field on infected seed potatoes. Motile zoospores are released from resting spores in the presence of potato roots and infect roots, stolons and tubers. Zoospores swim through water films and require free water for infection. The disease can be transferred from one field to another via infected soil attached to equipment or seed potatoes. The organism survives animal 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: To minimize disease development, it is important that only certified disease-free seed be planted in non-contaminated or poorly drained soils. Avoiding the use of manure from livestock fed infected cull potatoes will reduce the introduction of powdery scab to new fields. Cleaning equipment between fields will also reduce the spread of the pathogen. A minimum crop rotation of four years and planting only tolerant varieties is recommended for infected fields. Other solanaceous weeds and species that produce tubers can also act as hosts of *Spongospora subterranean.*

Resistant Cultivars: 'Eva' is considered to have a moderate resistance and 'Russet' cultivars are tolerant.

Issues for Powdery Scab

1. Powdery scab is of increasing concern, especially to seed growers. The development of effective management strategies including chemical controls are needed.
2. Research on cultivar susceptibility to powdery scab is needed.
3. Powdery scab is becoming more important given its role as a vector for potato mop-top virus and its increased occurrence in some growing regions.

Black Dot (*Colletotrichum coccodes*)

Pest Information

Damage: Black dot affects stressed potato 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. Discolouration and tiny, dot-like sclerotia (resting bodies) develop on infected plant tissues.

Life Cycle: The fungus overwinters as sclerotia in old potato vines and on the surface of infected tubers in the field or in storage. Sclerotia germinate to produce acervuli (fruiting bodies) that release conidia (spores) that cause new infections. The disease spreads through the planting of infected seed potatoes. Some weeds and other solanaceous crops are also hosts to this fungus.

Pest Management

Cultural Controls: Planting disease-free seed, ensuring good soil fertility and the use of crop rotations with non-susceptible plants are important management practices for this disease. Planting early maturing cultivars will reduce infection as the disease tends to develop later in the season.

Resistant Cultivars: None available.

Issues for Black Dot

1. Further studies are required to develop chemical and cultural approaches to the management of black dot, which is becoming of increasing concern in some growing areas of Canada.
2. There is a need for effective detection methods and the development of economic thresholds for black dot.
3. There is a need for fungicide options for the control of black dot.

Mosaic and Latent Viruses (PVY, genus *Potyvirus*, PVA, genus *Potyvirus*, PVX, genus *Potexvirus* and PVS, genus *Carlavirus*)

Pest Information

Damage: Potato virus Y (PVY) is considered to be the main contributor to development of the mosaic disease, although other latent 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 virulence (the degree of disease that they cause). Symptoms can include stunting, vein banding, leaf drop, streak and early plant death. Infected plants are often dwarfed with crinkled leaves. While tubers do not usually display any obvious symptoms, new strains of PVY have 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. Alternate host plants of PVY include pepper, tobacco, legumes, tomato, pigweed and other members of the Solanaceae, Chenopodiaceae, and Leguminosae families.

Pest Management

Cultural Controls: Field borders planted with non-hosts (e.g., soybeans) 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. Weekly monitoring of fields early in the season to identify and remove any plants showing viral symptoms and management of aphid movement, can be used to reduce the impact of this disease. Post-harvest testing can help predict infection levels. 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. Additional management options for viruses are listed in Table 5.

Resistant Cultivars: The cultivars Eva, Kennebec, and Ranger Russet are considered to have good resistance to virus PVX and PVY. Kennebec, Norland, and Yukon Gold are resistant to PVA. Cultivars with moderate resistance to PVY are: Innovator, Prospect, Sangre and Umatilla Russet.

Issues for Mosaic and Latent Viruses

1. As some strains of PVY can cause necrosis in tubers, it is important that emphasis continues to be placed on controlling viral diseases in non-seed and seed crops.
2. Investigation into mechanical transmission of PVY during field operations is warranted.

Potato Leafroll Virus (PLRV, genus *Polerovirus*)

Pest Information

Damage: Potato leafroll virus (PLRV) causes dark brown flecking (net necrosis) of vascular tissues of the tuber, reducing tuber quality. The severity of symptoms varies depending on factors such as whether the infection occurred during the current season or arose from infected seed pieces, the virus strain, growing conditions and potato cultivar. Most damage results from infections arising from the seed, which result in stunting and premature death.

Life Cycle: The green peach aphid is the most efficient aphid vector of PLRV. The aphid acquires the virus after feeding for a few minutes on an infected plant and is able to pass it on 12 to 48 hours after exposure. Once contaminated, the aphid transmits the virus for the rest of its life. Winged aphids can carry the disease over long distances. PLRV is not spread mechanically through seed cutting, leaf contact or plant and tuber wounds.

Pest Management

Cultural Controls: The use of certified virus-free seed will eliminate a source of the virus. Planting early varieties and harvesting early will eliminate problems due to aphids that arrive late in the season. Weekly monitoring early in the season will facilitate the identification and removal of 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.

Resistant Cultivars: Moderately resistant cultivars include Innovator, Ranger Russet and Yukon Gold.

Issues for Potato Leafroll Virus

None identified.

Aster Yellows Phytoplasma (AYp)

Pest Information

Damage: Plants infected with aster yellows may be stunted with leaves that become purple or yellow in colour. Tuber symptoms can be confused with net necrosis caused by potato leafroll virus. Plants may die prematurely. Infected seed tubers produce stunted plants of poor vigour. Aster yellows is an uncommon but destructive disease.

Life Cycle: The pathogen overwinters on several weed species and small grains and is transmitted to potatoes by leafhoppers. Transmission is not known to occur due to contact between potato plants. Weather conditions that favor an increase in leafhopper populations can promote the spread of the disease.

Pest Management

Cultural Controls: Potato crops are monitored for the presence of leafhoppers and control measures are implemented to prevent the spread of the disease. Rogueing out infected plants and tubers will eliminate a source of the phytoplasma. Aster yellows cannot be controlled with pesticides. However, sprays to control the leafhopper vector, especially along field borders, can help reduce spread.

Resistant Cultivars: None available.

Issues for Aster Yellows Phytoplasma

None identified.

Root-Lesion Nematode (*Pratylenchus penetrans*)

Pest Information

Damage: Root-lesion nematodes feed on the roots of many vegetable crops, including potatoes, creating tiny lesions that interfere with nutrient absorption. Affected roots become brown to black. With heavy infestations, affected plants show poor growth, turn yellow and become stunted. Nematode feeding increases the susceptibility of potatoes to Verticillium wilt.

Life Cycle: Nematodes are soil-borne and attracted to root hairs. They feed within the cortical tissue of roots. Females lay eggs within the root tissues and in the soil. The eggs hatch as second stage juveniles and begin feeding on root tissues. The nematodes develop from egg through four juvenile stages to become adults. Under unfavourable soil conditions, the nematodes become quiescent and can survive for several months. The pests are spread to other areas via wind-blown soil, infected seed and contaminated farm equipment. There may be several generations per year.

Pest Management

Cultural Controls: Soil sampling and laboratory evaluation are used to determine the species and numbers of nematodes in field soils. A rotation of three to four years with non-host crops will help reduce nematode numbers. Annual ryegrass, forage pearl millet or sorghum-Sudan grass can be incorporated into the soil as a green manure and will help reduce populations, as compounds toxic to nematodes are released during the decomposition of these crops. When grown in the season prior to potatoes, marigolds have helped to reduce nematode populations and increase yields compared to other rotational crops.

Resistant Cultivars: None available

Issues for Root Lesion Nematodes and Other Nematode Species

1. Identification of nematode species causing problems in various growing regions and the development of economic thresholds for different potato varieties is required.
2. Alternative strategies to fumigation are required for the management of plant pathogenic nematodes. Studies are required on the impact of green manures, crop rotation and non-fumigant nematicides on nematode populations.
3. Diagnostic services that identify nematodes to species level are required.
4. A cost-effective surveillance program for potato cyst nematodes (PCN) is needed to replace the current program of testing every field, even in areas where no PCN has been detected.

Periderm Disorder Syndrome (causal agent unknown)

Pest Information

Damage: Periderm disorder syndrome is colloquially referred to as "pink eye" and is a sporadic disease which occurs mainly in Eastern Canada. It can result in loss of quality at harvest and during storage. Damage is initially concentrated near the bud- end of the tuber and other periderm areas. Affected skin may thicken over time, making peeling difficult. Infections may also cause deep cavities, allowing the development of soft rots. Tubers with periderm disorder may have reddish brown tissue beneath the skin.

Life Cycle: The pathogen responsible for this syndrome is not known, but symptoms have been associated with *Pseudomonas* spp., *Verticillium* spp. and *Rhizoctonia* spp. The severity of the disorder seems to be correlated with wet soil conditions, soil compaction, high temperatures and the early dying complex. Diagnostically, affected tissue will fluoresce when exposed to ultraviolet light due to a suberin accumulation.

Pest Management

Cultural Controls: Efforts to reduce *Rhizoctonia* spp. and *Verticillium* spp. diseases may be helpful in reducing the incidence of this disorder. If infected tubers must be stored, "pink eye" will dry out at low humidity and cool temperatures (5 to7 °C) with adequate ventilation.

Resistant Cultivars: Resistant cultivars include Atlantic and Costal Russet.

Issues for Periderm Disorder Syndrome

1. Research is needed to better understand the interaction between field conditions, plant health and subsequent physiological changes resulting in periderm disorder syndrome.

Insects and Mites

Key issues

- The development and knowledge transfer of new approaches including the use of: crop rotations, biofumigants / green manures, trap crops, mass trapping and genetic disruption in the management of wireworm would be of great benefit to producers. There is an urgent need for new pest control products and associated maximum residue limits for wireworm control.

- There is a need for the registration conventional and non-conventional pesticides, including biopesticides and others products, suitable for use in organic systems for the management of Colorado potato beetle.

Table 6. Occurrence of insect pests in Canadian potato production[1,2]

Insect and mite	Alberta	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						
Leafhoppers						
Aster leafhopper						
Potato leafhopper						
Potato psyllid						
Tarnished plant bug						
Wireworms						

Widespread yearly occurrence with high pest pressure.

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

Widespread yearly occurrence with low pest pressure OR widespread sporadic occurrence with moderate pressure OR sporadic localized occurrence with high pest 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 OR pest not of concern.

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

Pest not present.

Data not reported.

[1]Source: Potato stakeholders in reporting provinces (Alberta, Manitoba, Ontario, Quebec, New Brunswick and Prince Edward Island); the data reflect the 2018, 2019 and 2020 production years.

[2]Refer to Appendix 1 for a detailed explanation of colour coding of occurrence data.

Table 7. Adoption of insect pest management practices in potato production in Canada[1]

	Practice / Pest	Aphids	Colorado Potato Beetle	Potato Leafhopper	Potato Flea Beetle	Tarnished Plant Bug	Wireworms
Avoidance	Varietal selection / use of resistant or tolerant varieties						
	Planting / harvest date adjustment						
	Rotation with non-host crops						
	Choice of planting site						
	Optimizing fertilization for balanced growth						
	Minimizing wounding to reduce attractiveness to pests						
	Reducing pest populations at field perimeters						
	Use of physical barriers (e.g., mulches, netting, floating row covers)						
	Use of pest-free propagative materials (seeds, cuttings or transplants)						
Prevention	Equipment sanitation						
	Canopy management (e.g., thinning, pruning, row or plant spacing)						
	Manipulating seeding / planting depth						
	Irrigation management (timing, duration, amount) to manage plant growth						
	Management of soil moisture (e.g., improvements to drainage, use of raised beds, hilling, mounds)						
	End of season or pre-planting crop residue removal / management						
	Pruning out / removal of infested material throughout the growing season						

…continued

Table 7. Adoption of insect pest management practices in potato production in Canada[1] (continued)

Practice / Pest		Aphids	Colorado Potato Beetle	Potato Leafhopper	Potato Flea Beetle	Tarnished Plant Bug	Wireworms
	Tillage / cultivation to expose soil insect pests						
	Removal of other hosts (weeds / wild plants / volunteer crops) in field and vicinity						
Monitoring	Scouting / trapping						
	Maintaining records to track pests						
	Soil analysis for pests						
	Weather monitoring for degree day modelling						
	Use of precision agriculture technology (GPS, GIS) for data collection and mapping of pests						
Decision making tools	Economic threshold						
	Use of predictive model for management decisions						
	Crop specialist recommendation or advisory bulletin						
	Decision to treat based on observed presence of pest at susceptible stage of life cycle						
	Use of portable electronic devices in the field to access pest identification / management information						
Suppression	Use of diverse pesticide modes of action for resistance management						
	Soil amendments and green manuring involving soil incorporation as biofumigants, to reduce pest populations						

…continued

Table 7. Adoption of insect pest management practices in potato production in Canada[1] (continued)

Practice / Pest		Aphids	Colorado Potato Beetle	Potato Leafhopper	Potato Flea Beetle	Tarnished Plant Bug	Wireworms
Suppression	Use of biopesticides (microbial and non-conventional pesticides)						
	Release of arthropod biological control agents						
	Preservation or development of habitat to conserve or augment natural controls (e.g., preserve natural areas and hedgerows, adjust crop swathing height)						
	Mating disruption through the use of pheromones						
	Mating disruption through the release of sterile insects						
	Trapping						
	Targeted pesticide applications (e.g., banding, spot treatments, use of variable rate sprayers)						
	Selection of pesticides that are soft on beneficial insects, pollinators and other non-target organisms						
Crop specific Practices	Use of stem crusher						
	Use of insect vacuum						
	Biofumigant crops (e.g., brown mustard)						

…continued

Table 7. Adoption of insect pest management practices in potato production in Canada[1] (continued)

Practice / Pest		Aphids	Colorado Potato Beetle	Potato Leafhopper	Potato Flea Beetle	Tarnished Plant Bug	Wireworms
New Practices (ON)	Click beetle adult trapping						
	Propane flaming for organic growers						
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); the data reflect the 2018, 2019 and 2020 production years.

Aphids: Buckthorn Aphid (*Aphis nasturtii*), Foxglove Aphid (*Aulacorthum solani*), Green Peach Aphid (*Myzus persicae*) and Potato Aphid (*Macrosiphum euphorbiae*) and Others

Pest Information

Damage: Aphids feed on plant sap using piercing-sucking mouthparts. Feeding by high populations can result in yellowing and wilting of foliage. More importantly, many aphid species transmit viruses such as PVY, PVA and PLRV between plants within a field or to new fields. Transmission of viruses by aphids can be persistent, semi-persistent or non-persistent. Persistent transmission occurs when an aphid must feed for an extended period of time to acquire the virus. The virus remains latent in the aphid for hours or days, after which the aphid is able to transmit the virus for a long period of time. With semi and non-persistent transmission, the virus becomes associated with the mouthpart or foregut. The virus can be transmitted only to the next plant the aphid feeds upon. In these cases, the aphid does not remain infective for long.

Life Cycle: Aphids overwinter as eggs on various woody or herbaceous plants. Some species overwinter as adult females in protected sites or greenhouses. In the spring, the eggs hatch and give rise to winged females that move to emerging potato plants or other host plants, depending on each species host range. Throughout the summer 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 alternate hosts to lay the overwintering eggs.

Pest Management

Cultural Controls: Weekly monitoring of fields by visual counts or trapping is important for early detection of aphids. Identification of the species is helpful, as different species transmit different viral diseases. Field borders planted with virus non-host crops (e.g., soybean, wheat) may attract feeding aphids, which cleanses their mouthparts of non-persistent viruses prior to entry into the potato crop. The elimination of weeds that can serve as alternate hosts for aphids in and around the potato field will also help prevent the build-up of aphid populations. Many natural parasites and predators help to keep aphid numbers in check. Additional management practices for aphids are listed in Table 7.

Resistant Cultivars: None available.

Issues for Aphids

1. Transient, non-colonizing aphids can pose a serious threat in the transmission of viral diseases. Additional efforts are required to track populations of aphids and provide information to growers on effective management options to prevent the spread of viruses to potato fields.
2. The effect of mineral oils on virus transmission by aphids is not well understood. Further studies are required to improve our understanding of the physiological effects of oils and other oil-based alternatives on aphids, and what efficacy they have in reducing virus transmission by aphids.

Tarnished Plant Bug (*Lygus lineolaris*)

Pest Information

Damage: Adult and nymph tarnished plant bugs feed on young foliage of potatoes by sucking plant sap. While feeding, tarnished plant bugs introduce a toxin into the plant resulting in wilting of new growth and premature drop of flowers.

Life Cycle: The tarnished plant bug attacks a wide variety of crops, including alfalfa, clover, cabbage, plum and many types of weeds. Adults overwinter in sheltered sites and lay eggs in the spring on weeds. Following hatching, nymphs feed on various plants including potato. The life cycle is completed in about four weeks and two to three generations are possible during the growing season.

Pest Management

Cultural Controls: Ensuring fields and hedgerows are weed-free and planting potato crops away from other susceptible crops helps to keep populations low. Close monitoring of tarnished plant bug populations is required in mid-to-late summer. Treatments are typically warranted only for late maturing varieties of potato and insecticides used to manage other insects normally control tarnished plant bug. Additional management practices for tarnished plant bugs are listed in Table 7.

Resistant Cultivars: Although not resistant to the pest, early maturing cultivars do not suffer from yield losses due to this pest.

Issues for Tarnished Plant Bug

None identified.

Colorado Potato Beetle (*Leptinotarsa decemlineata*)

Pest Information

Damage: Both Colorado potato beetle adults and larvae feed on potato foliage and stems. Feeding by large populations can result in complete defoliation of plants. Significant reductions in yield are possible.

Life Cycle: Colorado potato beetle (CPB) feeds solely on plants in the Solanaceae family (e.g., potatoes, tomato, eggplant, nightshade, horse-nettle). Adults overwinter in the soil of potato fields, and in the spring adults emerge and feed for a short period before mating and oviposition. Each female can lay between 300 and 500 eggs on potato plants. Following egg hatch, larvae feed for two to three weeks before pupation. Emerging adults then overwinter. There is only one generation per year in most potato growing regions of Canada.

Pest Management

Cultural Controls: Scouting for CPB starts early in the growing season when the crop is emerging from the soil. 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. Treatments to control the beetles can be applied to the trap rows. Overwintering populations of beetles can be avoided by planting new potato fields away from other solanaceous crops and away from fields planted to potatoes the preceding year. Avoiding planting other host crops in rotation with potato will help prevent the build-up of CPB in a field. The potentially overwintering generation of adults can be reduced by leaving a few green rows of potatoes when top-killing and targeting these with a foliar insecticide application, a flamer or insect vacuum. Additional management practices for CPB are listed in Table 7.

Resistant Cultivars: None available.

Issues for Colorado Potato Beetle

1. The registration of conventional and non-conventional pest control products, including biopesticides and products suitable for use in organic systems, with different modes of action, is required for CPB management.
2. Colorado potato beetle populations have developed resistance to many insecticides. There is a need for a national program to monitor CPB insecticide resistance.
3. Insecticide resistance and the risk of losing active ingredients as a result of re-evaluation processes impact the availability of effective insecticides; therefore, effective IPM strategies are required that involve cultural and biological methods of control and reduce the emphasis on insecticides.

European Corn Borer (*Ostrinia nubilalis*)

Pest Information

Damage: European corn borer (ECB) larvae feed internally in potato stems, causing plant wilt. Heavy infestations weaken stems and can predispose plants to wind damage, water stress and invasion by pathogens. Potatoes are more likely to be attacked by ECB in seasons when cool growing conditions delay the development of corn, its main alternate host.

Life Cycle: This pest feeds on more than 200 different species of plants, including corn, potatoes, beans, beets, celery and peppers. Moths emerge in late spring and early summer and lay eggs on stems. Following hatch, young larvae feed for a short period on foliage before tunnelling into the stems. Stems left in the field act as overwintering sites for full grown larvae, which pupate and emerge as adults in the spring. Depending on location, there may be more than one generation per year.

Pest Management

Cultural Controls: Planting potatoes away from corn fields reduces the likelihood of infestation by ECB, as does management of weeds and volunteer potatoes that act as hosts. Crushing potato vines and fall plowing can reduce overwintering insects. Monitoring of moths using pheromone traps will help to determine the potential for an ECB infestation. Degree-day models that predict timing of moth flights have been developed and economic thresholds have been established. If sprays are deemed necessary, proper timing is critical to target ECB larvae before they burrow into potato stems where they are protected from insecticides.

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

Issues for European Corn Borer

1. Given the narrow application window for foliar sprays, the registration of ovicides or systemic pest control products is required to control the ECB.
2. There is a need to determine the efficacy of non-conventional products (e.g., Bt and RNAi) to control ECB in potato.
3. There is a need to investigate the impact of crop rotation (e.g., grain, corn) and irrigation on the incidence of ECB in potato.

Cutworms: Variegated Cutworm (*Peridroma saucia*) and Black Cutworm (*Agrotis ipsilon*)

Pest Information

Damage: Cutworms attack a wide variety of plants. The variegated cutworm feeds on the foliage, buds and flowers of potato. Black cutworms feed on foliage and stems, often cutting off stems at ground level early in the season. Black cutworms will also feed on tubers, leaving holes. Damage may occur in the spring and also later in the growing season.

Life Cycle: Cutworms pass through egg, larval, pupal and adult stages, and depending on the species, can have one or more generations per year. The variegated cutworm overwinters as pupae in warmer parts of Canada and may be blown into Canada from the U.S. The black cutworm is wind-blown northward from the U.S. Adult moths lay eggs on vegetation and plant debris in the vicinity of the potato field. Following egg hatch, larvae feed on potato foliage, developing through a number of instars prior to pupating and emerging as adults.

Pest Management

Cultural Controls: Monitor for cutworms early in the season by visually checking for damage. Pheromone traps may be used to monitor the flights of male moths and establish the period of egg-laying. Controlling weeds in the field and surrounding areas will make the area less attractive for egg-laying by cutworm moths.

Resistant Cultivars: None available.

Issues for Cutworms

1. There is a need to establish an economic threshold and management approach for the variegated cutworm.
2. The economic threshold for black cutworm needs to be validated in Canada.

Leafhoppers: Potato Leafhopper (*Empoasca fabae*) and Aster Leafhopper (*Macrolestes quadrilineatus*)

Pest Information

Damage: Leafhoppers feed with piercing-sucking mouthparts. 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. High populations can result in early plant death and reduced yields. Aster leafhoppers can carry the aster yellows phytoplasma. The severity of aster yellows that develops in the crop is affected by the number of leafhoppers and the proportion of leafhoppers carrying the phytoplasma.

Life Cycle: Leafhoppers have a broad host range. The potato leafhopper does not overwinter in Canada, instead dispersing each year on wind currents from the United States. The aster leafhopper overwinters in Canada as an egg in plant tissues but may also be carried northward on wind currents from the U.S. Leafhoppers develop from egg through several nymphal stages to become adults. There may be two to five generations per year depending on species and temperature.

Pest Management

Cultural Controls: Planting potatoes away from alfalfa or clover fields will reduce the likelihood of a leafhopper infestation. When nearby forage crops are harvested, leafhoppers may move to potato fields. It is important to scout frequently for damage at this time. Leafhoppers in potato crops can be monitored by using sticky traps or sweep nets. Laboratory testing is required to determine whether the aster leafhoppers are carrying the aster yellows phytoplasma. Additional management practices for potato leafhopper are listed in Table 7.

Resistant Cultivars: None available.

Issues for Leafhoppers

1. Extension efforts are needed to improve growers' understanding of the differences between these two pest species, the potential for economic impact to potato, and management strategies.

Potato Flea Beetle (*Epitrix cucumeris*)

Pest Information

Damage: Adult potato flea beetles feed on potato leaves creating a shot-hole appearance. Considerable defoliation can occur when plants are young or when they are not actively growing. 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 potato roots, and following hatch the larvae feed on root hairs. Larvae feed for four to five weeks, pupate and emerge as adults that feed on the foliage. There are two generations per year.

Pest Management

Cultural Controls: Eliminating plant residues where flea beetles overwinter prevents the build-up of populations. A minimum three-year crop rotation is essential for reducing numbers of potato flea beetle. Scouting for flea beetles begins at crop emergence and continues throughout the growing season. As the pest is difficult to count or capture, monitoring is done by assessing damage. Additional management practices for potato flea beetles are listed in Table 7.

Resistant Cultivars: None available.

Issues for Potato Flea Beetle

1. Further studies are required to establish a more accurate economic threshold for potato flea beetle.

Red-headed Flea Beetle (*Systena frontalis*)

Pest Information

Damage: Adult red-headed flea beetles feed on the foliage of potatoes and a wide range of other plant species. Their abundance in potato fields may depend on the proximity to corn fields.

Life Cycle: Adults emerge in May and June, feed on foliage and lay eggs that hatch in late June. Larvae feed on the roots of a wide range of weeds and cultivated plants, including corn, until mid-July. They then pupate and overwinter as adults in the soil or in protected places on the soil surface. One generation per year is common in Canada.

Pest Management

Cultural Controls: Eliminating plant residues where flea beetles overwinter prevents the build-up of high populations. A minimum three-year crop rotation is essential to reduce pest numbers. Scouting for flea beetles begins at crop emergence and continues throughout the growing season. Monitoring is done by assessing damage, as the pest is difficult to count or capture.

Resistant Cultivars: None available.

Issues for Red-headed Flea Beetle

None reported.

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

Pest Information

Damage: Wireworms, the larval stage of click beetles, attack a wide range of host crops including potato. Potato seed pieces and developing tubers may be attacked. Heavy infestations result in poor emergence and vigour. Feeding on developing tubers results in 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 identified as major or minor pests of potatoes, with species distribution varying by region of the country. Wireworms thrive in sod, red and sweet clover and in small grains, such as barley and wheat. Adult beetles lay eggs in the soil around the roots of host plants. Following hatch, larvae (wireworms) feed on plant roots and tubers then pupate and emerge as adults. The life cycle ranges from three to seven years, depending on the species, with two to five years being spent as actively feeding larvae. There may be a number of different larval stages present in a field at any given time.

Pest Management

Cultural Controls: Monitoring fields prior to planting will establish whether threshold levels of wireworm are present that will damage a subsequent crop. Wireworms can be monitored by sampling the soil in the fall or spring or through the use of bait stations using carrots, wheat, oats or corn as bait. Avoiding fields that are severely infested with wireworms will minimize injury. Wireworm numbers may also be reduced through rotations with non-host crops. Maintaining fields and fallow fields free of weeds will help to reduce wireworm populations. Additional management practices for wireworms are listed in Table 7.

Resistant Cultivars: None available.

Issues for Wireworms

1. The variety of wireworm species in various growing regions and their respective susceptibility to pesticides is a challenge for the development of effective management strategies.
2. Knowledge transfer of wireworm research must be supported so growers can effectively develop and implement IPM strategies like biofumigation, green manures and trapping.
3. There is a need for an improved understanding of the life cycle and biology of specific species of wireworms. For example, studies on the seasonal movement of wireworms and on the effect of soil moisture on wireworm movement within the soil strata are needed.
4. Additional pest control options, with different modes of action are needed. The continued availability of bifenthrin and phorate should be supported.

Potato Psyllid (*Bactericera cockerelli*)

Pest Information

Damage: Potato psyllid can cause psyllid yellows in potatoes, resulting in stunted growth, chlorosis and small misshapen tubers. This pest can transmit a bacterial pathogen, '*Candidatus* Liberbacter solonacearum' (Lso), the causal agent for zebra chip disease in potato. This disease can significantly impact plant growth, potato yield and cause serious quality issues during cooking with the appearance of dark stripes and off-taste when tubers are cut and fried. Potatoes infected with this disease are often rejected by processors.

Life Cycle: The potato psyllid has three life stages: egg, nymph and adult. It can complete a generation in less than a month and may have two to three generations per year. Adult psyllids can be dispersed by wind, from the United States and are most active in warm temperatures (above 33 ^{o}C). This insect does not overwinter in Canada.

Pest Management

Cultural Controls: Scouting and monitoring using yellow sticky cards and sweep netting can provide evidence of the presence of adult psyllids. There are no established economic threshold levels for this pest.

Resistant Cultivars: None available.

Issues for Potato Psyllid

None identified.

Weeds

Key Issues

- The development of resistance in annual weeds to commonly used herbicides (e.g., metribuzin, rimsulfuron) continues to be a concern. New commercially available herbicides including post-emergent products, are needed as resistance management tools.

- Cultural or novel management approaches and the registration of new herbicides to allow growers to reduce their reliance on pre-emergent residual herbicides for annual and perennial weeds are needed.

- Sprout inhibition on organic potatoes and conventional alternatives to CIPC continues to be a concern. There is a need to register an organic sprout suppressant in Canada.

- Work towards the continued harmonization of pesticide registrations, particularly with the United States, is important for Canadian producers in their efforts to remain competitive.

- Better understanding of new emerging weeds and changing weed profiles in Canadian potato production systems is needed.

Table 8. Occurrence of weeds in Canadian potato production[1,2]

Weeds	Alberta	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 high pest pressure OR widespread sporadic occurrence with high pest pressure.

Widespread yearly occurrence with low pest pressure OR widespread sporadic occurrence with moderate pressure OR sporadic localized occurrence with high pest 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 OR pest not of concern.

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

Pest not present.

Data not reported.

[1]Source: Potato stakeholders in reporting provinces (Alberta, Manitoba, Ontario, Quebec, New Brunswick and Prince Edward Island); the data reflect the 2018, 2019 and 2020 production years.
[2]Refer to Appendix 1 for a detailed explanation of colour coding of occurrence data

Table 9. Adoption of weed management practices in potato production in Canada[1]

Practice / Pest		Annual broadleaf weeds	Annual grasses	Perennial broadleaf weeds	Perennial grasses	Solanaceous weeds	Herbicide resistant weeds
Avoidance	Varietal selection / use of competitive varieties						
	Planting / harvest date adjustment						
	Crop rotation						
	Choice of planting site						
	Optimizing fertilization for balanced crop growth						
	Use of weed-free propagative materials (seed, cuttings or transplants)						
	No till or low disturbance seeding to minimize weed seed germination						
	Use of physical barriers (e.g., mulches)						
Prevention	Equipment sanitation						
	Canopy management (e.g., thinning, pruning, row or plant spacing)						
	Manipulating seeding / planting depth						
	Irrigation management (timing, duration, amount) to maximize crop growth						
	Management of soil moisture (improvements in drainage, use of raised beds, hilling, mounds)						
	Weed management in non-crop lands						
Monitoring	Scouting / field inspection						
	Maintaining records of weed incidence including herbicide resistant weeds						
	Use of precision agriculture technology (GPS, GIS) for data collection and mapping of weeds						

…continued

Table 9. Adoption of weed management practices in potato production in Canada[1] (continued)

Practice / Pest		Annual broadleaf weeds	Annual grasses	Perennial broadleaf weeds	Perennial grasses	Solanaceous weeds	Herbicide resistant weeds
Decision making tools	Economic threshold						
	Crop specialist recommendation or advisory bulletin						
	Decision to treat based on observed presence of weed at susceptible stage of development						
	Decision to treat based on observed crop damage						
	Use of portable electronic devices in the field to access weed identification / management information						
Suppression	Use of diverse herbicide modes of action for resistance management						
	Soil amendments and green manuring involving soil incorporation as biofumigants to reduce weed populations						
	Use of biopesticides (microbial and non-conventional pesticides)						
	Release of arthropod biological control agents						
	Mechanical weed control (cultivation / tillage)						
	Manual weed control (hand pulling, hoeing, flaming)						
	Use of stale seedbed approach						
	Targeted pesticide applications (e.g., banding, spot treatments, use of variable rate sprayers)						
	Selection of herbicides that are soft on beneficial insects, pollinators and other non-target organisms						

…continued

Table 9. Adoption of weed management practices in potato production in Canada[1] (continued)

Practice / Pest		Annual broadleaf weeds	Annual grasses	Perennial broadleaf weeds	Perennial grasses	Solanaceous weeds	Herbicide resistant weeds
Crop specific practices	Use of non-crop year cover crops (e.g., millet, daikon radish)						
	Weeding by flaming						
New practices (ON)	Resistance testing with PCR quick tests						
	Weed Wicker						

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); the data reflect the 2018, 2019 and 2020 production years.

Annual Broadleaf and Grass Weeds

Pest Information

Damage: Weeds compete for light, water and nutrients and may serve as hosts for insects and diseases. If not effectively controlled they reduce potato growth and yield. Once established, grass weeds are very tolerant of extremes in moisture and temperature and can be very difficult to eliminate from fields. They require control prior to seed-set due to their prolific seeding capacity.

Life Cycle: Annual weeds complete their life cycle in one year, going from seed germination, through vegetative growth and flowering to seed production. Winter annuals begin their growth in the fall, producing a rosette which overwinters to flower and produce seeds early the following year. Annual weeds produce a large number of seeds. Most arable land holds an abundance of annual weed seeds at all times. Some weed seeds can remain viable in the soil for many years, germinating when conditions are favourable. The critical stage for control of annual weeds in potato is early in the growing season.

Pest Management

Cultural Controls: Choosing planting sites that are free from high weed populations and difficult to control weeds is the first step in weed management in potatoes. Knowing the weed history of a field is important so that measures to reduce difficult to control weeds can be implemented in the non-potato years of the crop rotation. Crop rotation can disrupt weed life cycles. Weed seeds can be transported from field to field by equipment, wind, water and animals; therefore, cleaning equipment to remove soil and debris before moving between fields will help to reduce the spread of weed seeds. Some weed seeds in forages fed to livestock are not 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 weeds that survive. Potato hilling provides some weed control. Maintaining vigorous potato stands and choosing row spacing that allows early row closure will help potatoes out-compete weeds.

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

Issues for Annual Weeds

1. The development of resistance to commonly used herbicides (e.g., metribuzin, rimsulfuron) in annual weeds is a continuing concern. There is an urgent need for new chemistries for use as resistance management tools.
2. The registration of new herbicides is required for nightshade species and nutsedge because they are not controlled by currently registered products.
3. Herbicides are also needed to control volunteer potatoes in subsequent crops.
4. Post-emergent broadleaf herbicides would help to reduce the reliance on pre-emergent, residual herbicides.

Perennial Broadleaf and Grass Weeds

Pest Information

Damage: Perennial weeds are very competitive with potato crops for moisture, nutrients and light, especially if they have been established for several years. Perennial weeds can greatly reduce growth and yield of the potato crop.

Life Cycle: Perennial grass and broadleaf weeds can live for many years. They can spread effectively through the expansion of root systems, through the dissemination of vegetative root pieces and by the distribution of seeds. Weed seeds and other reproductive parts such as roots and rhizomes can be transported from field to field by equipment, wind, water and animals.

Pest Management

Cultural Controls: Weed control strategies discussed under annual weeds can also be applied to perennial weeds. Perennial weeds can be 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. Cleaning soil and debris from equipment when leaving each field will reduce the transport of perennial weeds from one field to another. Many perennial weeds cannot be effectively controlled with herbicides once established in potato fields and successful control may only be possible by using herbicides in rotational crops.

Resistant Cultivars: None available. However, cultivars having quick emergence and vigorous crop stands may out-compete weeds for light.

Issues for Perennial Weeds

1. Continued research is required on mechanical weed control options for use in organic production systems.
2. Currently, growers rely predominantly on pre-emergent residual herbicides for broadleaf control. The registration of a post-emergent broadleaf herbicide would benefit existing integrated weed management efforts.
3. New management approaches and herbicide registrations are required for a number of emerging perennial weed problems, including sow thistle and sage.

Resources

Integrated pest management / integrated crop management resources for production of potato in Canada

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Provincial Crop Specialists and Provincial Minor Use Coordinators

Province	Ministry	Crop Specialist	Minor Use Coordinator
Alberta	Alberta Agriculture and Forestry https://www.alberta.ca/agriculture-and-forestry.aspx	Mike Harding michael.harding@gov.ab.ca	Gayah Sieusahai gayah.sieusahai@gov.ab.ca
Manitoba	Manitoba Agriculture www.gov.mb.ca/agriculture/	Vikram Bisht vikram.bisht@gov.mb.ca	Pratisara Bajracharya pratisara.bajracharya@gov.mb.ca
Ontario	Ontario Ministry of Agriculture, Food and Rural Affairs www.omafra.gov.on.ca/	Dennis Van Dyk dennis.vandyk@ontario.ca	Joshua Mosiondz joshua.mosiondz@ontario.ca
Quebec	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec www.mapaq.gouv.qc.ca	Marie-Pascale Beaudoin pascale.beaudoin@mapaq.gouv.qc.ca	Mathieu Coté mathieu.cote@mapaq.gouv.qc.ca
New Brunswick	New Brunswick Department of Agriculture, Aquaculture and Fisheries www2.gnb.ca/content/gnb/en/departments/10.html	David Wattie david.wattie@gnb.ca	Gavin Graham gavin.graham@gnb.ca
Prince Edward Island	Prince Edward Island Department of Agriculture and Land https://www.princeedwardisland.ca/en/topic/agriculture-and-land	Lorraine MacKinnon lormakinnon@gov.pe.ca	Sebastian Ibarra sibarra@gov.pe.ca

National and Provincial Potato Grower Organizations

Canadian Horticultural Council
www.hortcouncil.ca

Horticulture HNS Nova Scotia
http://horticulturens.ca

Les Producteurs de pomme de terre du Québec
http://www.pptq.ca/bienvenue.htm

Ontario Potato Board
http://www.ontariopotatoes.ca

Ontario Fruit and Vegetable Growers' Association
www.ofvga.org

Potatoes Canada
www.potatoescanada.com

Potato Growers of Alberta
www.albertapotatoes.ca/about-pga

Potatoes New Brunswick
https://www.potatoesnb.com

Prince Edward Island Potatoes
https://www.peipotato.org

The Seed Potato Growers Association of Manitoba
http://manitobaseedpotatoes.com

United Potato Growers of Canada
https://unitedpotatocanada.com

Appendix 1

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

Information on the occurrence of disease, insect and mite and weed pests in each reporting province is provided in Tables 4, 6 and 8 of the potato profile, respectively. The colour coding of the cells in these tables is based on three pieces of information, namely pest distribution, frequency and pressure in each province as presented in the following chart.

<table>
<tr><th>Presence</th><th colspan="4">Occurrence information</th><th>Colour Code</th></tr>
<tr><td rowspan="12">Present</td><td rowspan="10">Data available</td><td>Frequency</td><td>Distribution</td><td>Pressure</td><td></td></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>Blue</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>Gray</td></tr>
</table>

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