Crop Profile for Field Lettuce and Spinach in Canada, 2021

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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 (>5% of the national production) and provide qualitative data on pest occurrence and integrated pest management practices used by growers in those provinces. This crop profile covers field leafy vegetables providing detailed information on lettuce (head and leaf) and spinach. For lettuce and spinach production, the reporting provinces are British Columbia, Ontario and Quebec.

Information on pest issues and management practices is provided for information purposes only. For detailed information on growing lettuce and spinach, 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 lettuce and spinach, 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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Cultivated lettuce, *Lactuca sativa*, is a quick growing, annual herb with a thin tap root and spirally arranged leaves that form a dense rosette or a head. It belongs to the Aster plant family or Asteraceae. Lettuce is grown almost exclusively for use in fresh salads. It has many health benefits, providing dietary fibre, phenolic compounds, vitamins A, B, C and E and minerals such as calcium and iron. Lettuce is produced commercially in many countries worldwide and is also grown widely in home gardens.

The ancestor of cultivated lettuce is *L. serriola*. Lettuce domestication began in the Caucasus region about 6,000 years ago. These first lettuces were only suitable for harvesting seeds to extract oil. Images on ancient Egyptian tombs and wall paintings from 4,500 years ago depict oil seed lettuce as a roughly 75 cm tall plant that resembled a large version of romaine lettuce. Approximately 2,500 years ago, the Egyptian lettuce was introduced to Greece and Rome. From southern Europe, lettuce spread to central and western Europe where it was often used as a medicinal herb. By the late 15th century, Europeans had introduced lettuce to the Americas. The three basic modern lettuces, head, loose-leaf, and romaine, were described in European literature by the 16th century.

Based on morphological characteristics, cultivated lettuce can be classified into five major types: butterhead (Boston), crisphead (iceberg), romaine (cos), loose-leaf and stalk (asparagus). Heading lettuce types include butterhead, characterized by soft tender leaves; crisphead, characterized by thick crisp leaves; and romaine, characterized by oblong ridged leaves with a prominent midrib. Loose-leaf lettuce is a non-heading lettuce harvested as whole open rosettes. Stalk lettuce has swollen stems which are eaten raw or cooked. All lettuce types except stalk lettuce are commercially cultivated in North America.

Cultivated spinach, *Spinacia oleracea*, is an annual, leafy vegetable that belongs to the Amaranth plant family or Amaranthaceae. Besides spinach, Amaranthaceae also includes important crops like beets, quinoa and amaranth. Spinach is either dioecious, having separate male and female plants, or monoecious, having separate male and female flowers on the same plant.

Cultivated spinach is a quick growing, shallow-rooted crop that does not tolerate water stress. It is rich in minerals and vitamins including carotenoids, vitamin A, C, E, lutein, zeaxanthin and phenolic compounds. However, spinach is also high in oxalic acid and nitrates that, if consumed at too high a rate, can have deleterious health effects such as kidney stones and digestive tract upsets.

It is estimated that spinach domestication occurred about 2,000 years ago. The most likely ancestor of cultivated spinach is *S. turkestanica*, a plant species indigenous to Afghanistan and Pakistan. Written records indicated cultivated spinach reached Mesopotamia by the 4th century and arrived in China by the 7th century. In the case of Europe, it is mostly likely that spinach was first introduced by the Moors to the Iberian Peninsula in the 11th century. Eventually, spinach was introduced to the Americas by the Europeans.

Based on geographic origin and morphological characteristics, there are two types of spinach cultivars: Asian (Eastern) and Western. The Asian cultivars have narrow, triangular-shaped, smooth leaves and long petioles. The Western group has round, enlarged leaves with a smooth to savoy (crinkly) leaf surface. Only the Western types are commercially cultivated in North America.

Western cultivars can be further described as flat, semisavoy and savoy. Flat and some semisavoy are grown for the processing market. All three types are used for the fresh market with semisavoy and savoy dominating.

Crop Production

Industry Overview

Field lettuce is an important component of Canada's overall field vegetable production. Out of the 32 field vegetables grown in Canada, lettuce has the 9th largest growing area at 3,420 ha, 6th highest yield at 75,612 metric tonnes, and 5th highest farm gate value of nearly $85 million (Table 1). From 2015 to 2021 there was little change in lettuce growing area, yields and farm gate value.

Field spinach is an important niche crop. Out of the 32 field vegetables grown in Canada, spinach has the 23rd largest growing area at 853 ha, 27th highest yield at 6406 metric tonnes, and 26th highest farm gate value of nearly $15.6 million (Table 1). From 2015 to 2021 there was a slow but steady decline in spinach growing area, yields and farm gate value. The exception is 2021, which saw an increase in the growing area from 427 to 853 ha, an increase in yield from 4,132 to 6,406 tonnes and an increase in farm gate value from 10.5 to 15.6 million dollars compared to 2020.

Canada is a net importer of lettuce and spinach (Table 1). The main importer of lettuce and spinach into Canada is the United States. By the same token, almost all exports of Canadian lettuce and spinach are to the United States.

Table 1. General production information for field lettuce and spinach, 2021

	Lettuce	Spinach
Canadian Marketed Production[1]	75,578 metric tonnes	6,530 metric tonnes
	3,420 hectares	853 hectares
Total Farm Gate Value[1]	$85.0 million	$15.6 million
Food Available[2]	7.84 kg/person/year	0.97 kg/person/year
Exports[3,4]	$70.2 million 39,557 metric tonnes	$8.7 million 1,614 metric tonnes
Imports[3,5]	$559.0 million 267,103 metric tonnes	$140.1 million 37,242 metric tonnes

[1]Statistics Canada. Table 32-10-0365-01 – Area, production and farm gate value of marketed vegetables (accessed June 14, 2023).
[2]Statistics Canada. Table 32-10-0054-01 – Food available in Canada (accessed June 14, 2023).
[3]Statistics Canada. Canadian International Merchandise Trade Web Application (accessed June 14, 2023).
[4]Exports: 0705.11.00 – Cabbage lettuce (head lettuce), fresh or chilled; 0705.19.00 – Lettuce, fresh or chilled nes; and 0709.70.00 – Spinach, N-Z spinach and orache spinach (garden spinach), fresh or chilled.
[5]Imports: 0705.11.90.20 – Cabbage lettuce, head lettuce, certified organic, fresh/chilled, nes; 0705.11.90.30 – Cabbage lettuce, head lettuce, not certified organic, fresh/chilled, nes; 0705.19.90.21 – Lettuce,fr/chd,nes,certified organic, pack fresh salad cut mixes,of a wt <= 1kg; 0705.19.90.29 – Lettuce, fresh or chilled, nes, certified organic; 0705.19.90.31 – Lettuce,fresh/chd, nes,not certified organic,pack fresh salad cut mixes,wt <=1kg; 0705.19.90.32 – Lettuce,fr/chd,nes,not certified organic,pack fresh salad cut mixes,of a wt >1kg; 0705.19.90.39 – Lettuce, fresh or chilled, nes, not certified organic; 0709.70.00.11 – Spinach,NZ & orache spinach garden, fresh/chd, certified organic, in pack <=500g; 0709.70.00.19 – Spinach, New Zealand & orache spinach garden, /chilled, certified organic, nes; 0709.70.00.21 – Spinach,NZ & orache spinach garden,fresh/chd, not certified organic,pack <= 500g; 0709.70.00.22 – Spinach,NZ & orache spinach garden,fresh/chilled,not certified organic,pack>500g; and 0709.70.00.29 – Spinach, NZ and orache spinach garden, fresh/chilled,not certified organic, nes.

Production Regions

Quebec is the largest producer of field lettuce in Canada. Lettuce production in British Columbia and Ontario are about equal (Table 2). Quebec is also the largest producer of field spinach, followed by Ontario and British Columbia (Table 2).

Table 2. Distribution of field lettuce and spinach production in Canada, 2021[1]

Production Regions	Area Planted (hectares)	Total Production (metric tonnes)	Farm Gate Value
Lettuce			
British Columbia	166 (5%)	3,601	$6.9 million
Ontario	168 (5%)	1,656	$2.3 million
Quebec	2970 (87%)	69,402	$72.8 million
Canada	**3,420**	**75,612**	**$85.0 million**
Spinach			
British Columbia	48 (6%)	812	$2.8 million
Ontario	251 (35%)	1,528	$3.7 million
Quebec	522 (54%)	4,001	$8.5 million
Canada	**853**	**6,406**	**$15.6 million**

[1]Statistics Canada. Table 32-10-0365-01 - Area, production and farm gate value of marketed vegetables (accessed June 14, 2023). (CDN production, Total Farm Gate Value)

Cultural Practices

Lettuce does not tolerate acid soils. It prefers a pH of 6.2 to 6.8 for optimal growth. Soil types suitable for lettuce cultivation are sandy peats and mucks; deep black, sandy loams; and loams. Good moisture holding capacity and drainage are important soil qualities for lettuce cultivation. Soil compaction must be avoided.

The lettuce roots are very thin and delicate and extend over a small area, and thus are very susceptible to drying out. Therefore, lettuce requires frequent irrigations, with lighter soils needing more frequent applications, but less water per application.

Raised beds help prevent soil compaction and flooding, and improve air flow around the lettuce, reducing disease incidence. Mulching helps to keep soil cooler in warm weather, helps retain soil moisture and aids in the prevention of some diseases. In addition, mulches prevent the bottoms of the lettuce heads from getting dirty.

Lettuce is a fast-growing crop with most varieties maturing within 30 to 60 days. For this reason, lettuce can be planted multiple times in a growing season.

Head lettuce types are direct seeded in the field from April through mid-August once the danger of frost has passed. Mosaic-indexed, fungicide-treated, pelletized seeds from a reliable source are used. The seeds germinate between 5 to 25 ºC and optimal lettuce growth occurs between 16 to 18 ºC.

Leaf lettuce types are transplanted into the field from greenhouse grown plugs. The seedlings are started in flats in greenhouses in early spring. Later they are transferred to modular trays and are planted once the field is prepared.

Lettuce is fragile and must be handled delicately during harvest. Most fresh market lettuce is hand cut, trimmed and placed in cardboard cartons in the field. It is then trucked to a central area for vacuum cooling before shipping to supermarkets. Lettuce can also be harvested when immature, in which case it is sold as baby lettuce.

Cut lettuce sold as "ready to eat" in plastic bags or containers is harvested differently. The lettuce is hand cut, cored and placed in bulk containers. The containers are taken to a processing facility where the lettuce is cut and washed in cold water. It is then centrifuged to remove excess water and is often mixed with other types of lettuce or greens. The lettuce may also be treated with a chlorine-containing compound, antioxidant, or preservative during washing or before packaging.

Lettuce is extremely perishable and needs to be marketed rapidly. It can be held at 0 °C and 90 to 100 percent relative humidity for two to three weeks.

Spinach prefers muck soils that provide organic matter and a high, uniform moisture content. A pH of 6.2 to 7.0 is ideal for good growth. Below pH 6.0, spinach grows very poorly. Spinach is a shallow rooted crop and so does not tolerate water stress. Therefore, frequent irrigation is necessary.

Spinach is also a fast-growing crop. Most spinach varieties mature within 40 to 50 days. It is direct seeded from April through August as weather permits. Spinach seeds germinate at temperatures of 5 to 20 °C. Temperatures of 10 to 17 °C are optimal for spinach growth. Slow-growing, slow-bolting varieties are grown in the late spring and summer while fast-growing, vigorous varieties are grown in the fall, winter and early spring.

Spinach for the processing market is machine harvested either once or twice in a season. If harvested twice, there is a three to four week interval between the first and second harvest. The processing market requires upright growth to minimize soil contamination. For this reason, growth regulators that cause more upright leaf growth may be used on the crop.

Spinach for the fresh market is either hand or machine harvested. It is prepackaged in perforated plastic bags to reduce moisture loss and physical injury. Spinach can also be harvested when immature, in which case it is sold as baby spinach.

Spinach is very perishable and can only be stored for 10 to 14 days when held at 0 °C and 95 to 100 percent relative humidity.

Table 3. Lettuce and spinach production (direct seeding/transplants) and pest management schedule in Canada

Time of Year	Activity	Action
March	Plant care	Transplants are started in greenhouses.
April	Plant care	**Transplants:** Transplants are hardened-off and planted from the beginning of April until mid August. If needed, row covers are installed to protect transplants from spring frosts and to speed plant growth. **Direct Seeding:** Direct sowing of seeds in open fields begins in April until mid August. If needed, seedlings are thinned at the 3-4 leaf stage.
	Soil care	Soil preparation (plowing, harrowing, disking, etc.) begins. Incorporation of pre-plant fertilizers into soil.
	Disease management	Based on historical information and disease monitoring, fungicides are applied, if needed.
	Insect management	Monitoring for insect pests begins.
	Weed management	Mechanical weed control begins and continues all year until the beginning of September. Before planting, weed burn down is used to augment the stale bed technique when perennial weeds are a problem or mechanical control is judged insufficient.
May	Plant care	Successive transplanting and sowing activities continue. Harvesting of baby lettuce and baby spinach begins.
	Soil care	Soil preparation and pre-plant fertilizer incorporation continues. Nitrogen application(s) are either one time, split or continuous (via drip irrigation).
	Disease management	Monitoring continues. Fungicides only applied if needed.
	Insect management	Monitoring continues. Insecticides only applied if needed.
	Weed management	Hand weeding and harrowing between rows is used for the management of newly emerged weeds. Herbicide burndown is used before planting for the stale seedbed technique. Herbicides are also used for inter-row, shielded post-emergence applications.
June	Plant care	Successive transplanting and sowing activities continue. Harvesting of mature lettuce and spinach begins. Irrigation begins.
	Soil care	Soil preparation and pre-plant fertilizer incorporation continues.
	Disease management	Monitoring continues. Fungicides only applied if needed.
	Insect management	Monitoring continues. Insecticides only applied if needed.
	Weed management	Hand weeding and harrowing between rows is used for the management of newly emerged weeds. Herbicide burndown is used before planting for the stale seedbed technique. Herbicides are also used for inter-row, shielded post-emergence applications.

…continued

Table 3. Lettuce and spinach production (direct seeding/transplants) and pest management schedule in Canada (continued)

Time of Year	Activity	Action
July	Plant care	Successive transplanting and sowing activities continue. Irrigation used. Harvesting continues.
	Soil care	Soil preparation and pre-plant fertilizer incorporation continues.
	Disease management	Monitoring continues. Fungicides only applied if needed.
	Insect management	Monitoring continues. Insecticides only applied if needed.
	Weed management	Hand weeding and harrowing between rows is used for the management of newly emerged weeds. Herbicide burndown is used before planting for the stale seedbed technique. Herbicides are also used for inter-row, shielded post-emergence applications.
August	Plant care	Last sowing and transplanting occur in early August. Irrigation used. Harvesting continues. If needed, row covers are installed to protect transplants from late season frosts and to speed plant growth.
	Soil care	Soil preparation and pre-plant fertilizer incorporation continues.
	Disease management	Monitoring continues. Fungicides only applied if needed.
	Insect management	Monitoring continues. Insecticides only applied if needed.
	Weed management	Hand weeding and harrowing between rows is used for the management of newly emerged weeds. Herbicide burndown is used before planting for the stale seedbed technique. Herbicides are also used for inter-row, shielded post-emergence applications.
September	Plant care	Irrigation, if necessary. Harvesting continues. If needed, row covers are installed to protect transplants from late season frosts and to speed plant growth.
	Soil care	Cereal cover crops are planted. If needed, lime is applied to the fields. Soil is tested to determine soil fertility levels for next year’s crop.
	Disease management	Monitoring continues. Fungicides only applied if needed.
	Insect management	Monitoring continues. Insecticides only applied if needed.
	Weed management	Hand weeding if needed.
October	Plant care	Harvesting continues. If needed, row covers are installed to protect transplants from late season frosts and to speed plant growth.
	Disease management	Cereal cover crops are planted. If needed, lime is applied to the fields. Soil is tested to determine soil fertility levels for next year’s crop.

Abiotic Factors Limiting Production

Bruise Injury (lettuce)

Lettuce is fragile and must be handled delicately and as little as possible during harvest. For this reason, bruise injury of head lettuce can occur.

Herbicide Injury and Ammonium Toxicity (lettuce and spinach)

Various classes of herbicides used in excess or under adverse environmental conditions can result in herbicide injury. Excess ammonium levels during cool soil temperatures (< 10 to 15 °C) can result in ammonium toxicity.

Tip Burn (lettuce)

Lettuce tip burn occurs when there is a localized calcium deficiency and insufficient water uptake, high light intensity, warm temperatures and/or high fertilization rates. The first symptoms are necrotic spots near the leaf tips that expand until the entire edge of the leaf is brown. Injured tissues may become infected by bacterial soft rot.

Weather Injury (lettuce and spinach)

Hail storms during the early seedling stage or just before harvest can damage plants. Wind can whip seedlings about causing girdling. Wind can also blow soil particles into lettuce heads at harvest. Low temperatures (–2 to 1 °C) causes cold injury and high temperatures (>32 °C) during seedling stages causes heat injury. Prolonged high temperatures (35/25 °C, day/night) cause plant bolting. High temperatures after the onset of lettuce heading as well as rapid growth can cause rib discoloration and/or pink rib.

Post-Harvest Conditions (lettuce)

Higher than optimal postharvest storage temperatures (1.1 to 2.2 °C) causes pink rib. “Brown stain” occurs when there is an excess of carbon dioxide and “russet spotting” occurs when there is an excess of ethylene.

Oedema (spinach)

Oedema is a physiological problem that occurs when the epidermal cells of spinach leaves die. The dead cells discolour, leaving a warty appearance. Conditions that favour the oedema are high soil moisture, high relative humidity and an air temperature that is colder than the soil temperature. These conditions result in a low plant transpiration rate combined with an increase in water absorption by roots from the soil. This causes an increase in cell turgor pressure and the bursting of the spinach epidermal cells.

Diseases

Key issues

- Effective and economical management techniques for lettuce and spinach diseases are needed.
- Recommendations on fungicide use need to be strengthened by improving scouting methods, action thresholds, forecasting models and timing of fungicide applications.
- Alternative management tools for crop protection need to be identified and best management practices need to be developed to reduce the occurrence and spread of resistant diseases.
- Recently developed technologies that would aid with spraying, scouting and disease identification need to be evaluated to determine if they would work in a Canadian context and where they would fit within current integrated pest management recommendations.
- Action thresholds based on forecasting models and crop stage and improved disease management strategies, including preventative measures, are needed for a number of diseases including bacterial leaf spot, varnish spot, Rhizoctonia bottom rot, lettuce drop, white mould and sclerotinia, and Pythium stunt.
- Easy, rapid, farm level disease diagnostics that incorporate new technologies such as LAMP-based on farm disease assays, qPCR-based spore trapping networks and microclimate disease forecasting systems need to be identified for more efficient diagnosis of diseases (e.g., *Pythium*, *Sclerotinia*, *Pseudomonas* and *Xanthomonas*) and fungicide resistance.
- New resistant cultivars need to be developed for many diseases to minimize disease incidence and reduce reliance on conventional fungicides.

Table 4. 2022 Canadian Pest Management Top Priority Rankings of lettuce and spinach diseases in relative order of importance by province[1]

Pest	Provincial Rankings								
	Head Lettuce			Leaf Lettuce			Spinach		
	QC	ON	BC	QC	ON	BC	QC	ON	BC
Conventional Production									
Bacterial leaf spot	Yellow			Yellow	Yellow				
Varnish spot	Yellow			Yellow	Yellow				
Lettuce downy mildew	Blue		Red	Red	Orange	Red			
Botrytis					Blue				
Rhizoctonia bottom rot	Red			Orange	Blue				
Lettuce drop, White mould, Sclerotinia rot	Orange			Blue	Red				
Pythium					Blue		Red	Orange	Red
Anthracnose				Blue		Yellow		Red	
Stemphylium leaf spot							Yellow	Red	Orange
Cladosporium leaf spot						Orange	Blue	Red	
Downy mildew							Orange	Blue	Yellow
Fusarium wilt								Yellow	Blue
White rust								Blue	
Organic Production									
Damping-off	Orange			Orange			Orange		Red
Lettuce downy mildew	Red			Red	Red	Red			
Lettuce drop, White mould, Sclerotinia rot	Yellow			Yellow					
Spinach downy mildew							Red	Red	Orange
Spinach Stemphylium									Yellow
Anthracnose						Orange			

[1]Provinces provide rankings of their top pest priorities for the annual Canadian Pest Management Priority Setting Workshops. This table provides relative rankings for the key diseases for lettuce and spinach by province published in 2022 (BC and QC updated in October 2022). Rankings are colour coded in order of highest to lowest relative importance where red indicates a first highest priority, orange indicates a second highest priority, yellow indicates a third highest priority and blue indicates a priority of four and below. A blank does not mean that the disease does not occur in a province, it could be that the disease was not ranked in the top pests for 2022.

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

Practice	Damping -Off	Bacterial Leaf Spot	Varnish Spot	Downy Mildew	Rhizoctonia Bottom Rot	Lettuce Drop	Pythium
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, transplants)							
Prevention:							
Equipment sanitation							
Canopy management (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							

…continued

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

Practice	Damping off	Bacterial Leaf Spot	Varnish Spot	Downy Mildew	Rhizoctonia Bottom Rot	Lettuce Drop	Pythium
Removal of other hosts (weeds / volunteers / wild plants) in field and vicinity							
Do not use water contaminated with the pathogen							
Heat and vent propagation house to reduce relative humidity							
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							

…continued

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

<table>
<tr><th>Practice</th><th>Damping off</th><th>Bacterial Leaf Spot</th><th>Varnish Spot</th><th>Downy Mildew</th><th>Rhizoctonia Bottom Rot</th><th>Lettuce Drop</th><th>Pythium</th></tr>
<tr><td colspan="8">Suppression:</td></tr>
<tr><td>Use of diverse product modes of action for resistance management</td><td style="background-color:#46d456"></td><td style="background-color:#46d456"></td><td style="background-color:#46d456"></td><td style="background-color:#46d456"></td><td style="background-color:#46d456"></td><td style="background-color:#46d456"></td><td style="background-color:#46d456"></td></tr>
<tr><td>Soil amendments and green manure soil incorporation as biofumigants to reduce pathogen populations</td><td style="background-color:#46d456"></td><td></td><td></td><td></td><td></td><td style="background-color:#46d456"></td><td style="background-color:#46d456"></td></tr>
<tr><td>Use of non-conventional pesticides (e.g., biopesticides)</td><td style="background-color:#46d456"></td><td></td><td></td><td style="background-color:#46d456"></td><td></td><td style="background-color:#46d456"></td><td style="background-color:#46d456"></td></tr>
<tr><td>Controlled atmosphere storage</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Targeted pesticide applications (e.g., banding, spot treatments, use of variable rate sprayers)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Selection of pesticides that are soft on beneficial insects, pollinators and other non-target organisms</td><td style="background-color:#46d456"></td><td></td><td></td><td style="background-color:#46d456"></td><td></td><td style="background-color:#46d456"></td><td style="background-color:#46d456"></td></tr>
<tr><td colspan="8" style="background-color:#46d456">This practice is used to manage this pest by at least some growers in the province.</td></tr>
<tr><td colspan="8">This practice is not applicable for the management of this pest.</td></tr>
</table>

[1]Source: Stakeholders in reporting provinces (British Columbia and Quebec); the data reflect the 2019, 2020 and 2021 production.

Table 6. Adoption of integrated disease management practices in spinach production in Canada[1]

Practice	Damping off, Pythium spp.	Anthracnose	Stemphylium	Cladosporium	Downy Mildew	Fusarium Wilt	White Rust
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 / minimize stress							
Minimizing wounding and insect damage to limit infection sites							
Use of disease-free propagative materials (seed, cuttings, transplants)							
Prevention:							
Equipment sanitation							
Canopy management (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, raised beds, hilling, mounds)							

…continued

Table 6. Adoption of integrated disease management practices in spinach production in Canada[1] (continued)

Practice	Damping off, Pythium spp.	Anthracnose	Stemphylium	Cladosporium	Downy Mildew	Fusarium Wilt	White Rust
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							
Heat and vent propagation house to reduce relative humidity							
Monitoring:							
Scouting / spore trapping							
Maintaining records to track diseases							
Soil analysis for 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							

…continued

Table 6. Adoption of integrated disease management practices in spinach production in Canada[1] (continued)

Practice	Damping off, Pythium spp.	Anthracnose	Stemphylium	Cladosporium	Downy Mildew	Fusarium Wilt	White Rust
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 manure soil incorporation as biofumigants to reduce pathogen populations							
Use of non-conventional pesticides (e.g., biopesticides)							
Seed treatments conventional and organic							
Controlled atmosphere storage							
Targeted pesticide applications (e.g., banding, spot treatments, use of variable rate sprayers)							

…continued

Table 6. Adoption of integrated disease management practices in spinach production in Canada[1] (continued)

Practice	Damping off, Pythium spp.	Anthracnose	Stemphylium	Cladosporium	Downy Mildew	Fusarium Wilt	White Rust
Selection of pesticides that are soft on beneficial insects, pollinators and other non-target organisms							
This practice is used to manage this pest by at least some growers in the province.							
This practice is not applicable for the management of this pest.							
Information regarding this practice for this pest is unknown.							
This practice is not used by growers in the province to manage this pest.							

[1]Source: Stakeholders in reporting provinces (British Columbia and Quebec); the data reflect the 2019, 2020 and 2021 production.

Damping-Off (*Pythium, Fusarium* and *Rhizoctonia* spp.)

Pest Information

Damage: Damping-off attacks lettuce and spinach seedings before or after they emerge from the soil, resulting in gaps and uneven stands. Infected cotyledons and seedling stems are water soaked, soft, mushy, thin and may turn gray to brown. Young leaves wilt and turn green-gray to brown. Roots are absent, stunted or have grayish-brown sunken spots. Overall, seedings are shriveled, collapsed or stunted. Under high humidity, fungal growth may be seen on affected plants. *Pythium* attacks below the soil line, often at root tips. *Fusarium* and *Rhizoctonia* generally cause post-emergence damping-off by killing the seedlings at the soil line. As seedlings mature, they become resistant to attack. The disease can be a serious problem in cool, wet soils.

Life Cycle: Pythium spp. overwinters in the soil and plant root residues as oospores and chlamydospores. When conditions are right, oospores and chlamydospores germinate to produce hyphae. The hyphae can live in the soil on dead organic matter as well as infecting seeds and seedling roots. The disease is spread further when the fungus produces sporangia which release zoospores. The zoospores swim through water until they reach plant roots. The zoospores then encyst and produce hyphae that feed on root tissues. *Fusarium* spp. overwinters as tough, dormant spores. The spores are spread by rain and water run-off. The spores germinate in the spring and survive in the soil as saprophytes until they come into contact with seeds and plant roots. The spores invade the plant roots and develop in the xylem, impairing water transport. *Rhizoctonia* spp. overwinter in plant debris and soil as sclerotia. In the spring, sclerotia geminate, producing hyphae that grow towards chemical stimulants released by actively growing plant cells and decomposing plant residues. When the hyphae contact a plant surface, they secrete enzymes that help the fungus to infect the host plant. After the hyphae successfully invades the host, sclerotia form in and around the infected tissue and the process begins all over again. Plant pathogens that cause damping off prefer many different types of environmental conditions, but all need excess moisture in order to thrive. These diseases have a very large host range.

Pest Management

Cultural Controls: All seed trays and flats are sanitized and stored in a clean location when not in use. Certified disease-free seeds are sown. Proper seeding and planting rates are used to avoid thick plant stands, poor air movement and low light intensity. Seeds are sown at the proper depth and only when the soil is warm, in order to promote quick crop establishment. Fields with large amounts of undecomposed plant residue and a history of damping-off are avoided. Field areas with heavy soils, poor drainage and high moisture are also avoided. The proper amounts of plant nutrients are provided to the crop. Seedling emergence and growth are monitored. Seedlings and transplants are examined for rotting and stem girdling.

Resistant Cultivars: There are no lettuce or spinach cultivars that are resistant to damping-off.

Issues for Damping-Off

1. Fungicide seed treatments are needed to manage damping-off.
2. New conventional and non-conventional pre- and post-emergent fungicides are needed for the management of damping-off on lettuce and spinach.

Bacterial Leaf Spot (*Xanthomonas campestris* pv. *vitians*)

Pest Information

Damage: Bacterial leaf spot affects older lettuce leaves, rarely infecting newly developing leaves. However, sometimes symptoms are seen in the greenhouse on the seed leaves of lettuce transplants. Initially, small water-soaked lesions appear on leaf margins and are only noticeable if the leaves are wet. The lesions eventually collapse and take on a transparent, dark-brown appearance. As the disease progresses, lesions appear on the mid-rib of the leaves. Plant tissue around the mid-rib lesions turns light green followed by yellowing of the entire leaf. If more than 50 percent of the leaf is affected, the leaf rapidly dies. When environmental conditions are favourable, the disease infects the lettuce heart, making the plant unmarketable. In addition, bacterial leaf spot infected lettuce is more susceptible to *Botrytis cinerea*, *Sclerotinia sclerotiorum* and *Rhizoctonia solani*. In cases of severe bacterial leaf spot outbreaks, entire lettuce fields are destroyed.

Life Cycle: Bacterial leaf spot is seed-borne and dispersal can occur via contaminated lettuce seeds. Bacterial leaf spot can also be found on undecomposed lettuce and growing epiphytically on weeds. Warm, humid, rainy weather favours disease infection and development. Splashing from overhead irrigation and rain move the bacteria from plant-to-plant. In addition to lettuce, *Xanthomonas campestris* pv. *vitians* is known to infect peppers and tomatoes.

Pest Management

Cultural Controls: Certified, disease-free lettuce seeds are sown. When possible, overhead irrigation is avoided. Fields with a history of bacterial leaf spot are avoided. Plants are inspected for disease signs and symptoms.

Resistant Cultivars: There are no lettuce cultivars that are resistant to bacterial leaf spot, but green leaf types were shown to be the least susceptible.

Issues for Bacterial Leaf Spot

1. Bacterial leaf spot resistant varieties are needed.
2. Disease biology including conditions that favour disease infection need to be researched.
3. Conventional and non-conventional pest control products are needed for the management of bacterial leaf spot on lettuce.
4. Research is needed on how biostimulants can improve plant defense responses so that lettuce bacterial leaf spot infections can be prevented.
5. Research is needed into beneficial soil bacteria that can supress pathogen growth as well as stimulate the plant’s defence system. Once introduced into the soil, the organisms can maintain themselves from year-to-year and suppress the pathogen populations.

Varnish Spot (*Pseudomonas cichorii*)

Pest Information

Damage: Varnish spot affects only the inner leaves of head lettuce cultivars. It appears as dark brown, shiny, firm, necrotic lesions. Lesion size can range from small to very large. Lesion borders are not delimited by veins, but areas along veins are most often affected. In severe cases, an infected leaf may have 90 percent or more of its surface area diseased. Initially, the lesions are intact. As the lesions become older, they can be soft or broken down because of infection by secondary soft rot bacteria. Varnish spot is an opportunistic pathogen that can cause significant crop losses from time-to-time.

Life Cycle: Varnish spot occurs when irrigation water becomes contaminated with *Pseudomonas cichorii*. When contaminated water is used to sprinkle irrigate head lettuce crops at the rosette stage, the bacteria are introduced into the developing head. It also survives for brief periods in the soil and is splashed up onto plants via sprinkler irrigation or rain. Varnish spot has a wide host range and can cause disease in a large number of plant species.

Pest Management

Cultural Controls: Use of contaminated water is avoided. When possible, overhead irrigation is avoided. Fields with a history of varnish spot are not planted with lettuce. Crop rotation is practiced. Plants are inspected for disease signs and symptoms.

Resistant Cultivars: Varnish spot does not develop on lettuce cultivars that form an open head such as romaine and leaf types.

Issues for Varnish Spot

1. Varnish spot biology including conditions that favour disease infection need to be researched.
2. Conventional and non-conventional pest control products are needed for the management of varnish spot on lettuce.
3. Research is needed on how biostimulants can improve plant defense responses so that lettuce varnish spot infections can be prevented.

Lettuce Downy Mildew (*Bremia lactucae*)

Pest Information

Damage: Bremia lactucae infects lettuce leaves, causing light green to yellow angular lesions. With red cultivars, initial lesions may appear more grayish and water soaked. Later, lesions turn tan or brown and papery as the tissue is killed. Under humid conditions, a white fluffy fungal growth develops on the underside of the lesions but may also be seen on the upper leaf surface. Severely infected leaves may die. On rare occasions the pathogen can become systemic, causing dark discoloration of stem tissue. Older leaves close to the ground usually are the first to show symptoms. However, downy mildew can also affect the cotyledons of young seedlings and greenhouse grown transplants, causing plant death. Downy mildew damaged leaf tissue is also an entry site for secondary rot producing organisms. These rot organisms may compound crop losses in the field and can also cause losses later when the lettuce is in transit. Although outbreaks of lettuce downy mildew are typically sporadic, yield losses in individual fields can reach 100 percent.

Life cycle: It is unknown how *B. lactucae* overwinters. Spring infections may be due to overwintering oospores, spores blown in from other more southerly growing regions or contaminated seed. The disease requires damp, cool conditions and moisture on leaves for the pathogen to infect lettuce and cause symptoms to develop. The short-lived spores are dispersed by winds during moist weather events. Cultivated lettuce is the main host, but it has also been reported on other plants such as artichoke, cornflower and strawflower.

Pest Management

Cultural controls: Certified, disease-free lettuce seeds are used. Crop rotation is practiced. Leaf wetness is reduced by appropriate plant and row spacing, orienting rows parallel with wind and controlling weeds within the field. When possible, drip irrigation is used. Greenhouses producing lettuce transplants are heated and vented to minimize moist air within the greenhouse. Crop residues are destroyed immediately after harvest. Spore traps are used to determine amount of inoculum present. Monitoring temperature and lettuce leaf wetness duration is used to determine the risk of downy mildew infection.

Resistant cultivars: There are many downy mildew resistant lettuce cultivars available. However, the pathogen is highly variable and dynamic. Resistant cultivars do not remain resistant indefinitely and can be overcome by new virulent isolates of downy mildew.

Issues for Lettuce Downy Mildew

1. Downy mildew resistant head and romaine lettuce varieties are needed.
2. Improved disease management strategies including preventative measures are needed.
3. How downy mildew overcomes plant cultivar resistance and a greater understanding of the complex interactions between downy mildew and its lettuce host needs to be determined.
4. More conventional and non-conventional pest control products are required for resistance management on lettuce.

Botrytis (*Botrytis cinerea*)

Pest Information

Damage: Botrytis affects seedlings and mature lettuce plants. Seedlings fall over when infection girdles the stem and can result in significant stand reduction. Infection of mature plants often starts as dark, water-soaked lesions on the damaged or senescent leaves that are in contact with the soil. From these leaves, the pathogen moves into the healthy parts of the lettuce and causes crown decay. Gray, powdery spore masses form, particularly on shaded basal leaves and crown tissues. Black sclerotia may also develop. Any time before harvest, leaves may wilt, beginning with the oldest leaves and continuing until the plant collapses and rots. Botrytis is usually a minor disease of lettuce but can cause significant damage if conditions are favorable for the pathogen.

Life Cycle: Botrytis cinerea overwinters as sclerotia and mycelia on plant debris of many different hosts. It is an opportunistic pathogen and its spores easily invade weak, damaged or senescing tissue when wet. Spores are produced throughout the growing season under a wide range of temperatures and humidity. However, cool temperatures, high humidity and free water on plant surfaces favour the disease, as do close plant spacing and irrigation practices that keep plants wet for a long time. Downy mildew and *Pythium* infections make lettuce susceptible to Botrytis infections.

Pest Management

Cultural Controls: Farming practices that injure lettuce plants are avoided. Other pathogens that infect leaves and the lower stems of lettuce are managed. Pests causing plant injuries are controlled. Whenever possible, overhead irrigation is avoided in order to reduce leaf moisture. Extensive and prolonged wetting of the bed tops is avoided. Crop debris and residues at crop planting are minimized. In greenhouse transplant production, the relative humidity is reduced. Care is taken to make sure lettuce transplants are not overgrown. Spore traps are used to determine amount of inoculum present.

Resistant Cultivars: Lettuce cultivars vary in their resistance to Botrytis. For example, Winterhaven, A35585-1, Fresh Heart and Rome 59 have less disease incidence compared to other lettuce cultivars.

Issues for Botrytis

1. Conventional and non-conventional pest control products are required for resistance management on lettuce.

Rhizoctonia Bottom Rot (*Rhizoctonia solani*)

Pest Information

Damage: Rhizoctonia bottom rot forms brown, sunken lesions on the midrib of lettuce leaves where the leaves are in contact with the ground. As the disease progresses, the fungus will infect leaves inside the head. Soft rots, due to secondary decay organisms, will often develop on bottom rot infection sites, resulting in collapse of the lettuce head. Warmer temperatures over the last few seasons were marked by an increase in disease incidence and severity, and the associated yield losses were significant for lettuce growers.

Life Cycle: Rhizoctonia solani overwinters in plant debris and soil as sclerotia. The sclerotia can survive for an indefinite period of time. In the spring, sclerotia geminate, producing hyphae that grow towards chemical stimulants released by actively growing plant cells and decomposing plant residues. When the hyphae contact a plant surface, they secrete enzymes that help the fungus to infect the host plant. After the hyphae successfully invades the host, sclerotia form in and around the infected tissue and the process begins all over again. Rhizoctonia bottom rot infections are worst when temperatures and humidity are high and so the disease occurs most frequently throughout the summer months. *Rhizoctonia solani* has a wide host range.

Pest Management

Cultural Controls: The principal management method for Rhizoctonia bottom rot in lettuce production is crop rotation, which in southwestern Québec mainly includes onions and carrots. Lettuce is planted in fields that have no history of Rhizoctonia bottom rot and fields with large amounts of undecomposed lettuce residues are avoided.

Resistant Cultivars: There are no lettuce cultivars that are resistant to Rhizoctonia bottom rot.

Issues for Rhizoctonia Bottom Rot

1. Disease biology including conditions that favour disease infection need to be researched.
2. Action thresholds based on forecasting models and crop stage are needed.
3. Improved disease management strategies including preventative measures are needed.
4. Conventional and non-conventional pest control products are needed for the management of Rhizoctonia bottom rot on lettuce.
5. Seed treatment fungicides are needed to manage bottom rot.

Lettuce Drop, White Mould, Sclerotinia Rot (*Sclerotinia sclerotiorum* and *Sclerotinia minor*)

Pest Information

Damage: Lettuce drop affects lettuce stems and leaves that are in contact with the soil. The initial infection produces a brown, soft decay and eventually the lettuce crown is destroyed. Older leaves then wilt, followed by the entire plant wilting and collapsing. Plant collapse usually occurs when lettuce is near maturity and makes the plant unmarketable. *Sclerotinia sclerotiorum* is also able to produce air dispersed spores that infect the upper leaves, causing a watery, soft rot. Typical signs of lettuce drop include white, fluffy, cottony mycelial and the formation of sclerotia on undersides leaves and on outside of the crown. Precise statistics for annual losses caused by lettuce drop are not available, but they have varied from < 1 percent to nearly 75 percent.

Life cycle: Lettuce drop pathogens overwinter as sclerotia that can survive in the soil for two to three years. In the spring, sustained and saturated soil moisture triggers sclerotia to germinate and infect lettuce plants. Cool, damp conditions favour pathogen growth and disease development. For *S. sclerotiorum*, the cool and moist conditions are also needed for the production of airborne spores. Both *S. sclerotiorum* and *S. minor* have a wide host range.

Pest Management

Cultural controls: Crop rotation into non-host crops is practiced for at least three years. Fields are levelled to provide even distribution of water and assure good drainage. High beds are also used to assure good drainage. Irrigation is managed to avoid overly wet soils. Appropriate planting densities are used to prevent overcrowding. Fertilizer levels are optimized to prevent succulent lettuce growth. The fields are scouted to identify and remove infected plants. Crop residues are destroyed immediately after harvest.

Resistant cultivars: There are no lettuce drop resistant lettuce cultivars currently available. However, cultivars with upright growth in which the leaves are more or less elevated from the soil may experience less severe lettuce drop.

Issues for Lettuce Drop, White Mould, Sclerotinia Rot

1. Disease biology including conditions that favour disease infection need to be researched.
2. Action thresholds based on forecasting models and crop stage are needed.
3. Improved disease management strategies including preventative measures are needed.
4. More conventional and non-conventional pest control products are required for resistance management on lettuce.

Pythium Stunt (*Pythium tracheiphilum*)

Pest Information

Damage: Pythium tracheiphilum is the predominant *Pythium* species associated with Quebec head lettuce crops. One-to-two-week-old plants are generally the most susceptible to infection. Pythium stunt affects the vascular root tissues, especially the xylem. The root system is reduced and secondary roots, root hairs, and fine feeder rootlets are lost. Above-ground symptoms include stunting and wilting of lettuce plants. Even if plants survive the infection, they usually do not reach a marketable size. In Quebec, Pythium stunt is responsible for large yield losses in lettuce crops each year, and in certain cases can be as great as 70 percent.

Life Cycle: All *Pythium* species are water-dependent; they need water to complete their life cycle. *Pythium tracheiphilum* overwinters in the soil and plant root residues as oospores and chlamydospores. When conditions are right, oospores and chlamydospores germinate to produce hyphae. The hyphae can live in the soil on dead organic matter, as well as infecting seeds and seedling roots. The disease is spread further when the fungus produces sporangia which release zoospores. The zoospores swim through water until they reach plant roots. The zoospores then encyst and produce hyphae that feed on root tissues. Incidence of Pythium stunt increases with high rainfall, overwatering and in areas of poor drainage. *Pythium tracheiphilum* has a limited host range compared to other *Pythium* species. In addition to lettuce, other known hosts include endive, chichory, Chinese cabbage and cauliflower.

Pest Management

Cultural Controls: Fields with a history of Pythium stunt are avoided and crop rotation is practiced. Field areas with heavy soils, poor drainage, and high moisture are avoided. Plants are inspected for disease signs and symptoms. The development of a qPCR assay is underway to facilitate the reliable detection and quantification of *P. tracheiphilum* from field soil.

Resistant Cultivars: There are no lettuce cultivars that are resistant to Pythium.

Issues for Pythium

1. Disease biology including conditions that favour disease infection need to be researched.
2. Action thresholds based on forecasting models and crop stage are needed.
3. Improved disease management strategies including preventative measures are needed.
4. More conventional pre-emergent pest control products are needed for the management of Pythium stunt in lettuce.

Anthracnose (*Colletotiorum* spp.)

Pest Information

Damage: Initial symptoms of anthracnose on spinach are small, circular, water-soaked lesions on young and old leaves. Lesions later enlarge, turn brown to tan in color, and become thin and papery. In severe cases, lesions coalesce, resulting in severe blighting of foliage. In all cases, numerous tiny black fruiting bodies form in diseased tissue and are a characteristic feature of the disease. Anthracnose on spinach reduces crop yield and quality and can be a concern in spinach production.

Life Cycle: The fungus overwinters in infected plant debris as dormant mycelium. However, the most important source of initial inoculum is seedborne. When the pathogen is present, spores are spread by splashing water from rains or overhead irrigation. Infection and disease development are enhanced by very wet conditions, so this disease is more often seen when spring rains are common. The heavy canopy of densely planted spinach retains moisture and favors disease development on the lower leaves. Epidemics are usually more severe in fields with low fertility. Both *C. dematium* and *C. spinaciae* are known to infect spinach. *C. dematium* has at least 33 known plant hosts and *C. spinaciae* at least five known plant hosts.

Pest Management

Cultural Controls: Certified disease-free seeds are planted. Whenever possible overhead irrigation is avoided in order to reduce leaf moisture. Spinach fields are adequately fertilized. Plants are visually inspected for disease signs and symptoms.

Resistant Cultivars: Resistant varieties are being developed by plant breeders.

Issues for Anthracnose

1. Conventional and non-conventional pest control products are needed for the management of anthracnose on spinach.

Stemphylium Leaf Spot (*Stemphylium botryosum* f. sp. *spinacia*)

Pest Information

Damage: Initial symptoms of Stemphylium leaf spot on spinach leaves consist of small, circular to oval, gray-green leaf spots. As the disease progresses, leaf spots enlarge, remain circular to oval in shape, and turn tan in color. Older spots coalesce, dry up, and become papery in texture. Visual signs of fungal growth are generally absent from the spots. Stemphylium on spinach reduces crop yield and quality and can be a concern in spinach production.

Life Cycle: The pathogen overwinters on spinach crop residues as black, pinhead-size fruiting bodies. The fruiting bodies mature over the winter and forcibly discharge spores in the spring when temperatures increase. Spores are disseminated by air, splashing water and equipment. The fungus is also seedborne. The fungus can grow under a wide range of temperatures but does the most damage at warmer temperatures and high relative humidity. Although there are many crops with leaf spot caused by Stemphylium, the isolates pathogenic on spinach do not appear to be pathogenic on other crops, and vice versa.

Pest Management

Cultural Controls: Certified disease-free seeds are planted. Crop debris are removed to minimize inoculum for crops grown in the following year. Crop debris can also be plowed under since the sexual stage of the fungus does not form fruiting bodies on buried spinach residues. Plants are visually inspected for disease signs and symptoms.

Resistant Cultivars: There are no Stemphylium resistant or tolerant spinach cultivars available.

Issues for Stemphylium Leaf Spot

1. Conventional and non-conventional pest control products are needed for the management of Stemphylium leaf spot on spinach.
2. Seed companies are encouraged to share Stemphylium leaf spot plant resistance research with growers.

Cladosporium Leaf Spot (*Cladosporium variabile*)

Pest Information

Damage: Initial symptoms of Cladosporium leaf spot on spinach are small, tan leaf spots. Adjacent spots may coalesce, forming irregular lesions. As the disease progresses, velvety dark green-brown sporulation develops within the lesions. In severe cases, older infected leaves are killed. However, the disease is rarely severe unless there are significant rains. Cladosporium on spinach reduces crop yield and quality and can be a concern in spinach production.

Life Cycle: The most important source of initial inoculum is seedborne. However, *Cladosporium variabile* sometimes overwinters on crop residue, spinach volunteers, and as yet unknown weed hosts. Cladosporium leaf spot is favored by cool, humid conditions that often occur in the fall and spring. In the field, spores are spread by splashing water, wind, workers, and equipment. The spores are long lived, remaining viable for at least eight years.

Pest Management

Cultural Controls: Certified disease-free seeds are planted. Crop debris are removed to minimize inoculum for crops grown in the following year. Plants are visually inspected for disease signs and symptoms.

Resistant Cultivars: There are no Cladosporium resistant or tolerant spinach cultivars available.

Issues for Cladosporium Leaf Spot

1. Conventional and non-conventional pest control products are needed for the management of Cladosporium leaf spot on spinach.

Spinach Downy Mildew (*Peronospora farinose* f. sp. *spinaciae*)

Pest Information

Damage: Downy mildew affects spinach leaves, causing dull to bright yellow lesions. With time, these lesions can enlarge and become tan and dry. Close inspection of the underside of the leaf often reveals the purple growth of the fungus. Occasionally, sporulation may also be seen on upper leaf surfaces. When downy mildew development is extensive, leaves appear curled and distorted and may take on a blighted effect as a result of numerous infection sites. In addition to loss of quality due to lesions, the downy mildew infections can also break down and rot spinach leaves packed in bags and cartons. The pathogen can grow and spread rapidly, resulting in widespread crop damage.

Life cycle: *Peronospora farinose* f. sp. *spinaciae* overwinters on contaminated seeds and in the soil as oospores. In the spring, spores are released into the air and are moved by wind and splashing water from plant-to-plant and field-to-field. Cool temperatures with long periods of leaf wetness or high humidity are favorable for disease development. The heavy canopy of densely planted spinach retains moisture and creates ideal conditions for infection and disease development. Spinach is the main host of *P. farinose* f. sp. *spinaciae*, but it is suspected that the fungus may also infect Chenopodium weed species. Oospores can survive in the soil for a few years.

Pest Management

Cultural controls: Certified, disease-free spinach seeds are used. Crop rotation out of spinach for at least three years is practiced. Leaf wetness is reduced by appropriate plant and row spacing, orienting rows parallel with wind and controlling weeds within the field. Row covers are put out when spinach leaves are dry. When possible, drip irrigation is used. Crop residues are destroyed immediately after harvest. Greenhouses producing spinach transplants are heated and vented to increase air circulation and minimize moist air within the greenhouse. Plants are inspected weekly for signs of downy mildew.

Resistant cultivars: There are several downy mildew resistant spinach cultivars available. However, no cultivar is resistant to all races of the pathogen, so an assortment of resistant cultivars are grown.

Issues for Spinach Downy Mildew

1. More cultivars with resistance to a broader range of downy mildew strains are needed, especially by organic growers.
2. Information on how downy mildew overcomes plant cultivar resistance, and a greater understanding of the complex interactions between downy mildew and its spinach host needs to be determined.
3. More conventional and non-conventional pest control products are required for disease management on spinach.

Fusarium Wilt (*Fusarium oxysporum* f. sp. *Spinaciae*)

Pest Information

Damage: Fusarium wilt affects seedlings and mature spinach plants. The fungus invades the root and blocks the vascular system reducing the plant's ability to take up water. In seedlings, black lesions are seen at the root base, the vascular tissue is dark or discolored, few feeder roots develop, seed leaves wilt and the plants eventually die. In older plants, the vascular tissue is dark, there is extensive secondary-root development, there is a general yellowing of lower leaves, and there is premature death. The stem base is discolored and fungal mycelia may be seen. Severe symptoms are most often found in full-sized spinach rather than in baby spinach production because the disease takes time to spread within the root. Fusarium wilt can cause up to 100 percent crop loss.

Life Cycle: The fungus responsible for Fusarium wilt is seed-borne or overwinters as tough, dormant spores in the soil and as mycelia in crop residues. In spring, hyphae from the overwintering spores or saprophytic mycelia grow toward host roots and infect them. Primary infection is also possible through contaminated seeds. *Fusarium oxysporum* f. sp. *spinaciae* wilt can survive many years in soil without a spinach crop; it requires moist soil conditions for root infection and warm, acidic soils favor the pathogen. The fungus can colonize roots of beet and Swiss chard plants but does not cause disease on these crops. The disease is spread throughout fields by farm equipment, people, and water. Long-distance spread is by contaminated seed.

Pest Management

Cultural Controls: Fields with a history of Fusarium wilt are avoided. Seeds are sown at the proper depth and only when the soil is warm, in order to promote quick crop establishment. Acidic fields are limed. The crop is regularly monitored, and the roots of wilting plants are inspected for signs of the disease.

Resistant Cultivars: There are no spinach cultivars that are resistant to Fusarium wilt, but the varieties C2606, Sardinia, POH-6116, Carmel, St. Helens, Jade, Chinook II and Skookum are less susceptible to the disease.

Issues for Fusarium Wilt

1. Seed treatments are needed to manage Fusarium wilt.
2. Conventional and non-conventional pest control products are needed for the management of Fusarium wilt on spinach.

White Rust (*Albugo occidentalis*)

Pest Information

Damage: White rust symptoms initially appear as a cluster of white, blister-like pustules on the lower surface of spinach leaves. The pustules often form rings and turn into patches of chalky white powder. On the upper surface of the leaf opposite the pustules, there may be a yellowish spot. There also may be pustules present on stems. Older leaves that grow close the ground are the most likely to be infected. The disease reduces spinach yield, quality, and marketability because infected leaves are inedible.

Life Cycle: Albugo occidentalis is seed-borne and overwinters as oospores in infested crop debris and the soil. In spring, oospores germinate and release mobile zoospores. Zoospores are spread by splashing rain and irrigation water. They penetrate plants through natural openings, germinate, and form mycelia in spinach tissues. The mycelia eventually produce a structure called the sporangia which releases spores. The spores are spread by wind to other spinach plants, whereupon they germinate, produce zoospores, and the infection cycle is repeated. Eventually oospores form in diseased tissue. Wet and cool conditions favour white rust infection. Weeds infected with white rust can act as an additional inoculum source of wind-blown spores. White rust has a host range limited to *Spinacia* and several species of *Chenopodium*.

Pest Management

Cultural Controls: Certified, disease-free spinach seeds are used. Crop rotation out of spinach for at least three years is practiced. Planting fall crops in or adjacent to fields where an infected spring crop was grown is avoided. Leaf wetness is reduced by appropriate plant and row spacing, orienting rows parallel with wind and controlling weeds within the field. Row covers are put out when spinach leaves are dry. When possible, drip irrigation is used. Crop residues are destroyed immediately after harvest. Plants are inspected weekly for signs of white rust.

Resistant Cultivars: There are some spinach cultivars such as Regal and Samish that are tolerant to white rust.

Issues for White Rust

None.

Insects and Mites

Key issues

- Effective and economical management techniques for lettuce and spinach pests are needed.

- Recommendations on insecticide use need to be strengthened by improving scouting methods, action thresholds and timing of insecticide applications.

- Alternative management tools for crop protection need to be identified and best management practices need to be developed to reduce the occurrence and spread of resistant pests.

- Recently developed technologies that would aid with spraying, scouting and pest identification need to be evaluated to determine if they would work in a Canadian context and where they would fit within current IPM recommendations.

- New resistant cultivars need to be developed for many pests to minimize pest incidence and reduce reliance on conventional pesticides.

Table 7. 2022 Canadian Pest Management Top Priority Rankings of lettuce and spinach insect pests in relative order of importance by province[1]

Pest	Provincial Rankings								
	Head Lettuce			Leaf Lettuce			Spinach		
	QC	ON	BC	QC	ON	BC	QC	ON	BC
Conventional Production									
Green peach aphids, Bean aphids	Orange		Red	Red	Red		Blue	Blue	Orange
Lettuce aphid	Orange		Red	Red	Red				Orange
Aster leafhoppers					Red			Blue	
Red-headed flea beetle	Yellow			Yellow			Yellow		
Spinach flea beetle							Yellow	Blue	
Plant bugs	Red			Red	Orange			Blue	
Leafminers					Blue			Blue	Yellow
Caterpillars including cutworms				Blue			Orange	Yellow	
Thrips				Blue			Red	Orange	Red
Seed corn maggot								Red	
Organic Production									
Aphids	Orange			Orange	Orange			Orange	
Plant bugs	Red			Red	Red			Red	
Leafminers							Red		
Thrips									Red

[1]Provinces provide rankings of their top pest priorities for the annual Canadian Pest Management Priority Setting Workshops. This table provides relative rankings for the key insects for lettuce and spinach by province published in 2022 (BC and QC updated in October 2022). Rankings are colour coded in order of highest to lowest relative importance where red indicates a first highest priority, orange indicates a second highest priority, yellow indicates a third highest priority and blue indicates a priority of four and below. A blank does not mean that the insect pest does not occur in a province, it could be that it was not ranked in the top pests for 2022.

Table 8. Adoption of integrated insect pest management practices in lettuce production in Canada[1]

Practice	Aphids	Aster Leafhopper	Red-Headed Flea Beetle	Plant Bugs	Leafminers	Caterpillars
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, transplants)						
Use of reflective mulches to repel flying pests						
Use of trap and companion crops						
Prevention:						
Equipment sanitation						
Canopy management (e.g., thinning, pruning, row or plant spacing, etc.)						
Manipulating seeding / planting depth						
Irrigation management (timing, duration, amount) to manage plant growth						

…continued

Table 8. Adoption of integrated insect pest management practices in lettuce production in Canada[1] (continued)

Practice	Aphids	Aster Leafhopper	Red-Headed Flea Beetle	Plant Bugs	Leafminers	Caterpillars
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						
Tillage / cultivation to expose soil insects						
Removal of other hosts (weeds / wild plants / volunteers) in the 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						

…continued

Table 8. Adoption of integrated insect pest management practices in lettuce production in Canada[1] (continued)

Practice	Aphids	Aster Leafhopper	Red-Headed Flea Beetle	Plant Bugs	Leafminers	Caterpillars
Use of non-conventional pest control products (e.g., biopesticides)						
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						
Use of overhead watering to reduce pest populations						
This practice is used to manage this pest by at least some growers in the province.						
This practice is not applicable for the management of this pest.						

[1]Source: Stakeholders in reporting provinces (British Columbia and Quebec); the data reflect the 2019, 2020 and 2021 production.

Table 9. Adoption of integrated insect pest management practices in spinach production in Canada[1]

Practice	Aphids	Spinach Flea Beetle	Caterpillars	Thrips	Leafminers	Seedcorn Maggot
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, row covers)						
Use of pest-free propagative materials (seeds, cuttings, transplants)						
Use of reflective mulches to repel flying pests						
Use of trap and companion crops						
Soil analysis for pests before planting the crop						
Prevention:						
Equipment sanitation						
Canopy management (e.g., thinning, pruning, row or plant spacing, etc.)						
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						

…continued

Table 9. Adoption of integrated insect pest management practices in spinach production in Canada[1] (continued)

Practice	Aphids	Spinach Flea Beetle	Caterpillars	Thrips	Leafminers	Seedcorn Maggot
Pruning out / removal of infested material throughout the growing season						
Tillage / cultivation to expose soil insects						
Removal of other hosts (weeds / wild plants / volunteers) in the 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 manure involving soil incorporation as biofumigants to reduce pest populations						

…continued

Table 9. Adoption of integrated insect pest management practices in spinach production in Canada[1] (continued)

Practice	Aphids	Spinach Flea Beetle	Caterpillars	Thrips	Leafminers	Seedcorn Maggot
Use of non-conventional pest control products (e.g., biopesticides)						
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						
Use of overhead watering to reduce pest populations						
Use of green organic matter and manures at least 4 weeks before planting crops						
This practice is used to manage this pest by at least some growers in the province.						
This practice is not applicable for the management of this pest.						
Information regarding this practice for this pest is unknown.						
This practice is not used by growers in the province to manage this pest.						

[1]Source: Stakeholders in reporting provinces (British Columbia and Quebec); the data reflect the 2019, 2020 and 2021 production.

Green Peach Aphid (*Myzus persicae*) and Black Bean Aphid (*Aphis gossypi*)

Pest Information

Damage: Aphids favour the undersides of leaves and new growth. Nymphs and adults feed on plant sap by using stylet mouthparts to pierce plant tissues. Initial symptoms from aphid feeding are yellow spots near leaf veins. Later leaves become curled, puckered and distorted. Growth of heavily infested plants slows and the plant eventually wilts and dies. The green peach aphid does not usually produce high volumes of honeydew, but the black bean aphid secretes a great deal. Any honeydew excreted can lead to sooty mould and ants. The sooty mould grows on the honeydew, reducing plant photosynthesis and transpiration. Ants eat the honeydew and attack arthropods that feed on aphids. It is also important to note that winged aphids transmit serious viral diseases. For example, winged green peach aphids often deposit only a few young on a host plant and then take flight again. This highly dispersive behavior contributes to their effectiveness as vectors of plant viruses.

Life cycle: Aphids overwinter as eggs with green peach aphid laying eggs on *Prunus* species and black bean aphid laying eggs on woody shrubs such as *Euonymus*, *Viburnum* and *Philadelphus* species. Eggs hatch in the spring into wingless females who give live birth to immature females through asexual reproduction. During asexual reproduction aphid colonies grow quickly. When conditions become crowded or food becomes scarce, winged females are produced. The winged females fly to lettuce and spinach crops, establish a new colony and the cycle is repeated. Besides lettuce and spinach, both green peach and black bean aphids have hundreds of other secondary hosts. Asexual reproduction continues throughout the growing season. In the fall, male and female aphids are produced and they mate. The mated females lay the overwintering eggs.

Pest Management

Cultural controls: Vigorous, healthy plants are more resistant to aphid attack and are grown by using proper nutrient and water management. Excessive nitrogen is avoided as it favors aphid reproduction. Yellow sticky traps are placed at field edges to detect winged aphids migrating into the crop and plants are inspected for signs and symptoms of an aphid infestation. Reflective, light-coloured mulches can be used to repel flying aphids. Floating mulches, which act as a physical barrier, are used to keep aphids off crop plants. Perennial broadleaf weeds that act as reservoirs for viruses are eliminated. Fields infested with aphids are disked or plowed under as soon as harvest is complete. Ants that might protect aphids are managed. There are numerous natural enemies of aphids. Some common aphid predators include lady beetles and their larvae; minute pirate bugs*;* syrphid fly larvae; green and brown lacewing larvae; and larvae of the aphid midge, *Aphidoletes aphidimyza*. Some common aphid parasitoids (parasitic wasps) include *Aphidius, Lysiphlebus, Aphelinus* and *Diaeretiella* species.

Resistant cultivars: There are no aphid resistant or tolerant lettuce or spinach cultivars available. There are certain lettuce varieties that are resistance to certain viral diseases, but no viral resistant spinach varieties.

Issues for Green Peach and Black Bean Aphids

1. Green peach aphid and black bean aphid biology including factors that favour infestations need to be researched.
2. Action thresholds based on crop stage are needed.
3. Physical and biological control strategies that include predators and parasitoids need to be developed.
4. Conventional and non-conventional pest control products are needed.

Lettuce Aphid (*Nasonovia ribisnigri*)

Pest Information

Damage: Lettuce aphids feed deep inside the lettuce plant, toward the center on younger leaves. In head lettuce they are found almost exclusively at the heart of the plant. Lettuce aphid infestations can cause some stunting of the lettuce and honeydew deposits. This aphid does not appear to be an important virus vector. Unmarketability of the crop is often exclusively due to live aphids found inside the lettuce head. In 1982, British Columbia experienced iceberg lettuce crop losses of $2 million due to lettuce aphid infestations.

Life cycle: Lettuce aphids generally overwinter as eggs on their primary host, *Ribes* species. In areas with mild winters such as British Columbia's lower mainland, the aphid can also overwinter as nymphs and adults on secondary hosts. Other secondary hosts besides lettuce include endive, chicory, some weedy species (wild *Lactuca* species, hawksbeard, hawkweed, nipplewort, eyewort) and some flowering species (*Petunia*, *Veronica*, *Nicotiana*). Lettuce aphids have a very short life cycle and their numbers can increase rapidly.

Pest Management

Cultural controls: This aphid tends to disperse in the plant rather than forming colonies Therefore, regular and careful monitoring of the lettuce crop is crucial for early detection of lettuce aphid infestations. Monitoring occurs twice a week and includes all lettuce varieties. In lettuce seedlings and pre-heart lettuce, the innermost leaves and leaf folds where the aphid prefers to live are inspected. Once the lettuce has hearted some destructive sampling is necessary. Since the aphid may occur sporadically across fields, samples are taken from across a number of widely dispersed locations in the crop. Naturally occurring predators of the lettuce aphid include the syrphid fly and lacewing larvae. Control of this aphid is difficult because of its rapid population growth combined with its preferred locations deep within the head.

Resistant cultivars: Lettuce aphids have at least two distinct biotypes: Nr:0 and Nr:1. Lettuce cultivars resistant to Nr:0 are commonplace, but there are no cultivars resistant to Nr:1.

Issues for Lettuce Aphid

1. Aphid biology including factors that favour infestations and which species cause economic damage need to be researched.
2. Action thresholds need to be developed based on crop stage.
3. Physical strategies need to be developed for organic growers.
4. Systemic conventional and non-conventional pest control products are needed.
5. Aphid resistant cultivars need to be developed for Nr:1.

Aster Leafhoppers (*Macrosteles quadrilneatus*)

Pest Information

Damage: Aster leafhoppers use piercing, sucking mouthparts to feed on plant sap. Feeding causes lettuce leaves to have a white, mottled appearance. However, the main damage occurs when the aster leafhoppers transmit a mycoplasma-like organism known as aster yellows phytoplasma (AYP). Initial AYP symptoms include whitening of the youngest leaves. Later, plants become chlorotic, branched, stunted and form a rosette. Milky sap is found on the lower leaf surface along the midribs of affected leaves. In Ontario, AYP infections have reduced lettuce yields by 15 to 50 percent.

Life cycle: Aster leafhoppers overwinter as eggs on winter grains such as wheat and rye. In late spring, nymphs hatch from the eggs and go through five instars before reaching the adult stage. By late spring, the local, first-generation of leafhoppers disperse to more favourable hosts such as weeds, grasses, and vegetable crops including lettuce. There are two to three generations of local leafhoppers per year. Migrant leafhoppers from the south may also arrive following a persistent southerly flow of warm air associated with cold fronts. Because leafhopper movements are regulated by wind and weather patterns, migrations into Canada are not consistent from year to year. Both local dispersal and long-distance migration influences the incidence and severity of the aster leafhopper infestations and AYP. Both leafhoppers and AYP have a very wide host range.

Pest Management

Cultural controls: Weeds that act as alternate hosts for leafhoppers and as an AYP reservoir are controlled. Lettuce plants with AYP symptoms are rouged. Yellow or orange sticky cards are used to monitor for leafhoppers. When leafhoppers are detected on sticky cards, sweep nets are used to estimate leafhopper population size. For small acreages, floating row covers are used to protect lettuce crops from leafhopper feeding.

Resistant cultivars: There are no leafhopper resistant or tolerant lettuce cultivars available.

Issues for Aster Leafhoppers

1. The mechanisms of AYP transmission by aster leafhoppers needs to be better understood.

Red-Headed Flea Beetle (*Systena frontalis)* and Spinach Flea Beetle (*Disonycha xanthomeias*)

Pest Information

Damage: Adult flea beetles chew rounded areas on the top or bottom of leaves and also make small holes (shot holes). With spinach flea beetles, the larval stage also feeds on plant leaves. If there are numerous lesions or shot holes, the leaves become discoloured and dry out. Photosynthesis is impaired and plant growth is slowed. The leaf injuries allow diseases to infect the plant more easily. Early spinach and lettuce stages are the most vulnerable to leaf damage by flea beetles. For this reason, flea beetles are especially serious pests of baby lettuce and baby spinach. Heavy feeding can lead to yield loss due to the need to prune damaged leaves off lettuce heads. Severe damage also results in the rejection of lettuce and spinach plants at harvest.

Life cycle: Red-headed flea beetles overwinter as eggs laid in the soil at the base of the host plant. The larvae emerge in late May. They are likely root feeders but cause little damage and are rarely observed. After pupation, adults emerge from early July onwards. Flea beetle populations increase quickly during hot, dry weather. Adults are strong flyers and jumpers, able to move into crops from neighboring fields and weedy borders. They are less mobile during cool weather. Using olfactory cues, adults tend to congregate in areas where plant damage has started. Red-headed flea beetles are more polyphagous than other flea beetle species with more than 40 known hosts including lettuce and spinach. Red-headed flea beetles have one generation per year. Spinach flea beetles overwinter as adults in protected areas such as hedgerows and leaf litter. In May and June, the adults become active, feeding initially on chickweed, lamb's quarters, red root pigweed and other weeds, then moving into spinach, beets and Swiss chard crops. Females lay eggs in clusters on the underside of host leaves. The larvae hatch and feed on the underside of leaves. The second generation of adults emerge in late summer. Spinach flea beetles have one to two generations per year.

Pest Management

Cultural controls: Alternate hosts such as annual and perennial weeds found along field margins are controlled. Crop rotation is practiced so that susceptible crops are not grown in the same area every year. Planting dates are adjusted to avoid times when the adult populations are at their peak. Trap and companion crops are planted next to lettuce and spinach. When possible, floating row covers are used for several weeks to protect young crops. White or yellow sticky cards are used to monitor field edges. Sticky cards are also placed in hots spots to trap adult beetles. Wetting the crop leaves or soil causes flea beetle adults to leave the crop fields, but this practice needs to be weighted against the risk of increased plant diseases. Generalist predators such as lacewing larvae (*Chrysopa* spp.), adult big-eyed bugs (*Geocoris* spp.) and damsel bugs (*Nabis* spp.) feed on adult flea beetles.

Resistant cultivars: There are no known flea beetle resistant or tolerant lettuce or spinach cultivars.

Issues for Flea Beetles

1. Research and an understanding of flea beetle biology is needed. For example, what are the key host plants, how far are adult beetles able to travel, what is the role of annual and perennial weeds in the survival of eggs and larvae and what olfactory chemical(s) cause flea beetles to aggregate?

2. Action thresholds based on crop stage are needed for flea beetles.
3. Physical control strategies need to be developed for the management of flea beetles.
4. Research on trap crops and other techniques to attract flea beetles from lettuce and spinach crops is needed.
5. Conventional and non-conventional pest control products are needed for the management of flea beetles on lettuce and spinach.

Plant Bugs (*Lygus* spp.)

Pest Information

Damage: Nymphs and adults consume plant sap by using piercing, sucking mouthparts. Feeding results in sunken, callused lesions that become necrotic with time. Egg laying injury is also associated with lesions. Adults lay eggs in the midrib areas of the leaf. The injury initially appears as holes or pits on the midrib and later expands into lesions. Plant bugs also feed on the youngest growth in the heart of the plants, resulting in symptoms similar to blackheart. Plant bugs can transmit serious plant diseases such as aster yellows, via their mouthparts.

Life cycle: Plant bugs overwinter as adults in sheltered spots in the soil, on weeds and in plant debris. In the spring, females emerge and lay eggs into plant stems. Eggs hatch and nymphs emerge to feed on the tender, new growth of the host plant. Plant bugs undergo five molts before emerging as adults. Plant bug species produce one to five generations per year, with fewer generations produced in the northern range of the insects. Plant bugs infest at least 385 plant species, with the majority of host plants belonging to the Rose and Aster plant families. Adults continue to feed until early fall before moving to sheltered sites to overwinter.

Pest Management

Cultural controls: Crop residues that might shelter overwintering adults are destroyed after harvest. Deep plowing kills any overwintering adults hiding in the soil. Alternative food sources such as weeds are controlled. Growing lettuce and spinach close to other susceptible crops is avoided. Yellow or white sticky traps, sweep nets and visual inspection of lettuce and spinach plants are used to monitor for the presence of plant bugs. Various generalist predators such as damsel bug, lacewings and crab spiders, are known to feed on plant bugs. In addition, plant bug eggs are parasitized by wasps including those of the genus *Anaphes*, *Telenonus* and *Polynema*. Other wasps such as the genus *Leiophron* and *Peristenus* attack nymphs. Trachinid flies target adult plant bugs.

Resistant cultivars: There are no plant bug resistant or tolerant lettuce or spinach available.

Issues for Plant Bugs

1. Plant bug biology including factors that favour infestations need to be researched.
2. Conventional and non-conventional pest control products are needed for the management of plant bugs.

Leafminers (*Liriomyza* sp*.* And *Pegomya hyoscyami*)

Pest Information

Damage: Leafminers are the larval stage of various fly species that feed on leaf lettuce and spinach. Both larvae and adults damage plants. Adults make feeding and egg laying punctures on the crop leaves. Larvae feed on the leaf mesophyll layer, resulting in slender, winding mines, blisters, and large white blotches on the leaves. Frass may be visible within the mines and can contaminate leaves. Excessive feeding reduces photosynthetic capacity, provides easy access for disease organisms and makes the leaves unmarketable.

Life cycle: Leafminers overwinter as pupae in the soil. Adults emerge in spring and summer, mate, and the females lay eggs. *Liriomyza* species lay their eggs inside leaf lettuce and spinach leaves while *Pegomya hyoscyami* lay their eggs on the undersides of spinach leaves. The eggs hatch and the larvae go though 4 instar stages. When mature, larvae pupate within the mines, on the underside of leaves or more typically, fall to the ground and pupate just under the soil surface. Adults emerge and begin laying eggs for another generation. There are at least three generations each year. *Liriomyza* species have a host range of at least 55 plant species, while the host range of *Pegomya hyoscyami* is limited to spinach, beets and weeds that belong to the Chenopodiaceae plant family.

Pest Management

Cultural controls: Weeds and ornamental plants that act as alternate leafminer hosts are removed from field edges. Transplants are inspected for signs of leafminer damage before planting and infested plants are destroyed. Planting next to leafminer infested fields is avoided. Floating row covers are placed over the crop to prevent adult flies from laying eggs on the crop plants. Excessive nitrogen levels are avoided to reduce leafminer infestations. Adequate irrigation is used to keep crop plants healthy and stress free. Infested leaves are clipped and destroyed to prevent larval development. Immediately after harvest, fields are plowed or disked to bury crop debris and destroy leafminer pupae. Visual inspections for new stippling on crop leaves, yellow sticky traps or yellow bowls containing soapy water are used to monitor for the presence of adult leafminers. Natural enemies, especially parasitic wasps, commonly reduce populations of leafminers. However, because leafminers feed within the leaf, they are generally protected from most predators.

Resistant cultivars: Lettuce and spinach cultivars differ in their susceptibility to leafminer damage. For example, the lettuce cultivar Valmaine and the spinach cultivar Wisemona were observed to have fewer leafminer stings when compared to other cutlivars.

Issues for Leafminers

1. Leafminer pest biology, including factors that favour infestations need to be researched.
2. Action thresholds based on crop stage are needed.
3. Physical control strategies need to be developed.
4. Conventional and non-conventional insecticides are needed for the management of leafminers on lettuce and spinach.

Caterpillars including Cutworms (Lepidoptera)

Pest Information

Damage: Caterpillars are the larvae of moths and butterflies. Caterpillars feed in the crown of the lettuce and spinach seedlings, severely stunting or killing the plants. Caterpillars also damage lettuce seedlings by chewing away the midrib and growing point. Once lettuce heads form, caterpillars bore into the heads, making them unmarketable. The potential for damage and contamination of lettuce and spinach plants continues right up until harvest. One sub-group of caterpillars, the cutworms, usually cut seedlings off at or just below the soil line. Another sub-group, the loopers, feed primarily on the undersides of lower leaves, skeletonizing them.

Life cycle: Caterpillars overwinter as eggs, larvae, pupae or adults on plants, in plant debris or in the soil depending upon the species. Not all caterpillar species overwinter in Canada. For example, a large proportion of the variegated cutworm population is thought to migrate into Canada each season. Caterpillars have one to four generations per year depending upon the species and location.

Pest Management

Cultural controls: Fields are disked or plowed after harvest in order to kill larvae and pupae. Alternative food sources such as weeds along field borders are controlled. Monitoring starts before crop seedlings emerge by checking for eggs and young larvae in surrounding vegetation. If populations are high on surrounding vegetation, crop seedlings are carefully monitored for egg masses and larvae. Many natural enemies attack caterpillars. Among the most common parasites are the wasps such as *Hyposoter* and *Chelonus* species and tachinid flies such as *Lespesia*. Viral diseases also kill significant numbers of caterpillars.

Resistant cultivars: There are no caterpillar resistant or tolerant lettuce or spinach cultivars.

Issues for Caterpillars

1. Action thresholds based on crop stage are needed for caterpillar management.
2. Physical control strategies for caterpillars need to be developed.
3. Non-conventional pest control products are needed for the management of caterpillars on lettuce.

Thrips (*Thrips tabaci* and *Frankliniella occidentalis*)

Pest Information

Damage: Adults and nymphs use rasping-sucking mouthparts to puncture leaves and consume plant sap. Thrips feed on upper and lower leaf surfaces, in leaf folds, and in protected inner leaves. Thrip feeding causes leaf scarring, blemishes, discoloration, bronzing and distortion. Baby spinach crops are vulnerable to thrips damage on young terminal growth because as the leaves expand and grow, they become scarred and distorted. Such damage can turn into larger necrotic lesions in postharvest storage and transit. Lettuce is also vulnerable because thrips damage harvestable leaves, resulting in excessive trimming and reduced plant weight. The presence of live thrips can contaminate the harvested crops. Thrips can also vector some plant viruses, including tomato spotted wilt virus. Yield loss may be 50 percent or more in severe infestations. If yield is not severely affected, there may still be significant pest management costs.

Life cycle: All thrips life stages overwinter in the soil. Adults and nymphs also overwinter in plant litter and prefer grain, clover, alfalfa and hay fields. Thrips become active in early spring and lay eggs over several weeks, most often in plant tissue. The eggs hatch and the nymphs feed before descending into the soil or leaf litter. There they molt and become prepupae, then pupae. During this period, they cause no crop damage. The adults then climb back up to the vegetation above to feed and reproduce. By mid to late summer, when overwintering crops are cut or dry down, thrips populations move into lettuce and spinach fields. Hot and dry weather are ideal conditions when populations of thrips can build up very quickly. With a relatively short life cycle, thrips have several overlapping generations throughout the summer months. Both onion thrips and western flower thrips have an extremely wide host range.

Pest Management

Cultural controls: Weeds and other possible hosts of viruses are removed from around lettuce and spinach fields. Plant residues from harvested fields are quickly removed or plowed under to reduce spread of thrips to younger crops. Planting close to crops that harbour thrips is avoided. Sprinklers are used to help suppress thrips, because the water washes the thrips off the crop plants. Sticky traps or gently shaking foliage and flowers over white paper are used to monitor for adult thrips. Plants are carefully examined for the presence of thrips and feeding scars. Biological controls and natural enemies are encouraged and maintained. These natural enemies include predator thrips, predator mites, minute pirate bugs, lacewings and parasitic wasps.

Resistant cultivars: There are no thrips resistant or tolerant lettuce or spinach cultivars.

Issues for Thrips

1. Pheromone and trap crop research is needed to push and/or pull thrips out of spinach and lettuce crops.
2. Conventional and non-conventional pest control products are needed for the management of thrips on spinach.

Seedcorn Maggot (*Delia platura*)

Pest Information

Damage: Seedcorn maggot is the larval stage of the bean seed fly. The maggots damage spinach foliage by feeding on the terminal buds of overwintering crop plants in late fall and early spring. Larvae occasionally feed on head lettuce, making the heads unmarketable. Larvae also feed on the cotyledons of germinating seeds, resulting in stand loss. Damaged seedlings are spindly, with few leaves and die before they mature. Seedcorn maggots also tunnel into seeds and seedling stems. Areas of plant damage act as entry sites for disease. Serious seedcorn maggot infestations can reduce crop stands by 25 percent.

Life cycle: Seedcorn maggot overwinters as pupae in the soil. Adults emerge in early spring and lay eggs singly or in clusters in the soil near plant stems. Eggs hatch, larvae feed and then burrow into the soil to pupate and emerge as adults. Adults lay eggs as before and larvae again feed to maturity and pupate. There are three to five generations of seed corn maggots each year before the overwintering pupal stage is reached. The host range of seedcorn maggot includes approximately 50 plant species including lettuce and spinach. However, seedcorn maggots can also develop in organic matter in humid soils where the organic matter acts as the main larval food when no seeds are available. Cool, wet winters and springs favour seedcorn maggots and crop damage becomes especially severe.

Pest Management

Cultural controls: The incorporation of live, green organic matter or animal manure into the soil in the spring is done more than four weeks before the crop is planted. Otherwise, the organic matter and manure attract egg-laying flies to the crop. Early planting dates and cool-wet weather that favour seedcorn maggot numbers are avoided. Instead, crops are planted in warm soils to speed growth and shorten the time spent in the vulnerable seed and seedling growth stages. A chain is dragged behind the planter to prevent any moisture gradients because adult flies are attracted to moist soil. Food sources like flowering weeds are removed from field margins. Potential infestation levels prior to planting are assessed using bait traps. Areas with high risk of seedcorn maggot damage are avoided. Crops are monitored during seedling emergence for wilted plants and gaps in the plant stand. Seeds and seedlings are examined for the presence of seed corn maggot.

Resistant cultivars: There are no seedcorn maggot resistant or tolerant lettuce or spinach cultivars.

Issues for Seedcorn Maggots

1. Seedcorn maggot biology including factors that favour infestations need to be researched.
2. Action thresholds based on crop stage are needed for seedcorn maggot management.
3. A sterile male release program that is similar to that used to manage the onion maggot, *Delia antiqua*, is needed.

Weeds

Key Issues

- Effective and economical management techniques for lettuce and spinach weeds are needed.
- Improved integrated weed management strategies are needed for lettuce and spinach cropping systems.
- Recommendations on herbicide use need to be strengthened by improving scouting methods, action thresholds and timing of herbicide applications.
- More conventional and non-conventional herbicides, which are not phytotoxic to lettuce and spinach, are needed for weed management.
- Alternative management tools for weed control need to be identified and best management practices need to be developed to reduce the occurrence and spread of resistant weeds.

Table 10. 2022 Canadian Pest Management Top Priority Rankings of lettuce and spinach weed issues in relative order of importance by province[1]

Pest	Provincial Rankings								
	Head Lettuce			Leaf Lettuce			Spinach		
	QC	ON	BC	QC	ON	BC	QC	ON	BC
Conventional Production									
Annual broadleaved weeds									
Perennial broadleaved weeds									
Annual grassy weeds									
Perennial grassy weeds									

[1]Provinces provide rankings of their top pest priorities for the annual Canadian Pest Management Priority Setting Workshops. This table provides relative rankings for the key weeds for lettuce and spinach by province published in 2022 (BC and QC updated in October 2022). Red indicates the weed is of first highest priority. A blank does not mean that the weed does not occur in a province, it could be that it was not ranked in the top pests for 2022.

Table 11. Adoption of integrated weed management practices in lettuce production in Canada[1]

Practice	Annual Broadleaf	Annual Grassy	Perennial Broadleaf	Perennial Grassy
Avoidance:				
Varietal selection / use of competitive varieties				
Planting / harvest date adjustment				
Crop rotation				
Choice of planting site				
Optimizing fertilization for balanced growth and to minimize stress				
Use of weed-free propagative materials (seed, cuttings, 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 minimize disease infection periods and manage plant growth				
Management of soil moisture (e.g., improvements in drainage, use of raised beds, hilling, mounds)				
Weed management in non-crop lands				
Prevent any weeds present from going to seed				
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 11. Adoption of integrated weed management practices in lettuce production in Canada[1] (continued)

Practice	Annual Broadleaf	Annual Grassy	Perennial Broadleaf	Perennial Grassy
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 manure soil incorporation as biofumigants to reduce weed populations				
Use of non-conventional pesticides (e.g., biopesticides)				
Release of arthropod biological control agents				
Mechanical weed control (cultivation / tillage)				
Manual weed control (e.g., 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				
This practice is used to manage this pest by at least some growers in the province.				
This practice is not applicable for the management of this pest.				

[1]Source: Stakeholders in reporting provinces (British Columbia and Quebec); the data reflect the 2019, 2020 and 2021 production.

Table 12. Adoption of integrated weed management practices in spinach production in Canada[1]

Practice	Annual Broadleaf	Annual Grassy	Perennial Broadleaf	Perennial Grassy
Avoidance:				
Varietal selection / use of competitive varieties				
Planting / harvest date adjustment				
Crop rotation				
Choice of planting site				
Optimizing fertilization for balanced growth and to minimize stress				
Use of weed-free propagative materials (seed, cuttings, 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 minimize disease infection periods and manage plant growth				
Management of soil moisture (e.g., improvements in drainage, use of raised beds, hilling, mounds)				
Weed management in non-crop lands				
Prevent any weeds present from going to seed				
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 12. Adoption of integrated weed management practices in spinach production in Canada[1] (continued)

Practice	Annual Broadleaf	Annual Grassy	Perennial Broadleaf	Perennial Grassy
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 manure soil incorporation as biofumigants to reduce weed populations				
Use of non-conventional pesticides (e.g., biopesticides)				
Release of arthropod biological control agents				
Mechanical weed control (cultivation / tillage)				
Manual weed control (e.g., 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				
This practice is used to manage this pest by at least some growers in the province.				
This practice is not applicable for the management of this pest.				
Information regarding this practice for this pest is unknown.				
This practice is not used by growers in the province to manage this pest.				

[1]Source: Stakeholders in reporting provinces (British Columbia and Quebec); the data reflect the 2019, 2020 and 2021 production.

Annual Broadleaf and Grassy Weeds

Pest Information

Damage: Annual weeds compete with lettuce and spinach for light, water and nutrients, substantially reducing stand uniformity, plant vigour and crop yields. Direct-seeded lettuce is a poor competitor against weeds. Transplanted lettuce seedlings grow rapidly and are more competitive with newly emerged weed seedlings than direct-seeded lettuce. Later in the growing season, weeds compete with lettuce for space in the row and heavy infestations can cause misshapen, small lettuce heads. Weed cover of 25 percent reduces lettuce yields by 20 to 40 percent, and more than 25 percent weed cover may cause complete yield loss. Spinach is also a poor competitor against weeds. Weed management in spinach is necessary throughout the season to achieve a sufficient marketable yield. When harvested, baby lettuce and spinach contaminated with weeds are unmarketable. Weeds can also harbor insects, pathogens or nematodes that can spread to lettuce and spinach crops.

Life Cycle: Annual weeds complete their life cycles in one year starting with seed germination in the spring, followed by vegetative growth, flowering and seed production. By contrast, winter annuals germinate in the fall and overwinter as plants. In spring, they start to grow again, eventually flowering and setting seed. The main source of annual weeds in any cropping system are the numerous, dormant seeds found in the soil. The seeds remain viable for many years, germinating when environmental conditions favour weed growth. Annual weeds are spread when farm equipment and farmers' boots move soil containing weed seeds from one field to another.

Pest Management

Cultural Controls: Fields with a history of problematic weeds are avoided. Lettuce and spinach are rotated with crops whose planting dates, emergence, height and nutrient requirements are different, disrupting weed life cycles. Certified seed, free of weed seeds is used. Stale seedbeds are prepared to stimulate weed seeds to germinate. The weeds are destroyed before the crop is planted. A well-prepared seedbed, free of large clods, permits precision planting and the rapid, uniform emergence and growth of lettuce and spinach seedlings and transplants. Mulches are laid out before the crop is planted. Equipment and footwear are cleaned when moving between fields to reduce the spread of weed seeds. Fields are monitored and weed species are mapped so that field specific weed management strategies can be developed. Weeds are prevented from going to seed in previous crops to help reduce weed pressure in subsequent lettuce and spinach crops. Overall, fields are kept as weed-free as possible.

Issues for Annual Weeds

None.

Perennial Broadleaf and Grassy Weeds

Pest Information

Damage: Perennial weeds cause the same damage to lettuce and spinach crops as described previously for annual weeds.

Life Cycle: Perennial weeds are long lived, completing their life cycles over many years. Perennial weeds propagate through seeds and vegetative parts such as roots, rhizomes and corms. Cultivation, tillage and plowing cut roots, rhizomes and corms into pieces and spreads them around the field. Each piece has the potential to grow into a new perennial weed. Farm equipment and farmers' boots that are not cleaned can move soil containing vegetative parts and seeds from one field to another.

Pest Management

Cultural Controls: Fields with difficult to control perennial weeds are avoided. Most of the cultural control practices used to control annual weeds can also be used to control perennial weeds. One exception is cultivation, tillage and plowing, which can spread vegetative weed parts around the field. Instead, minimum tillage is used to prevent the multiplication of perennial weeds.

Issues for Perennial Weeds

1. Conventional herbicides with short preharvest intervals and flexible use directions are needed for the management of perennial weeds in spinach.

Resources

Integrated pest management / integrated crop management resources for Field Lettuce and Spinach crops in Canada

British Colombia Ministry of Agriculture. Lettuce. Production Guides. https://www2.gov.bc.ca/gov/content/industry/agriservice-bc/production-guides/vegetables/lettuce

British Columbia Ministry of Agriculture. Spinach. Production Guides. https://www2.gov.bc.ca/gov/content/industry/agriservice-bc/production-guides/vegetables/spinach

Cornell University. 2016 Production Guide for Organic Spinach. https://ecommons.cornell.edu/bitstream/handle/1813/42898/2016-org-spinach-NYSIPM.pdf?sequence=1

Ontario Ministry of Agriculture, Food and Rural Affairs. Ontario Crop Protection Hub. https://cropprotectionhub.omafra.gov.on.ca/

Provincial Contacts

Province	Ministry	Crop Specialist	Minor Use Coordinator
British Columbia	British Columbia Ministry of Agriculture www2.gov.bc.ca/gov/content/industry/agriservice-bc	Susan Smith susan.l.smith@gov.bc.ca	Caroline Bedard caroline.bedard@gov.bc.ca
Ontario	Ontario Ministry of Agriculture, Food and Rural Affairs www.omafra.gov.on.ca	Travis Crammer travis.crammer@ontario.ca	Joshua Mosiondz joshua.mosiondz@ontario.ca
Quebec	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (in French only) www.mapaq.gouv.qc.ca	Eve Abel eve.abel@mapaq.gouv.qc.ca	Mathieu Coté mathieu.cote@mapaq.gouv.qc.ca

Provincial and National Vegetable Grower Organizations

Ontario Fruit and Vegetable Growers Association: https://www.ofvga.org/

BC Fresh: https://bcfresh.ca/

Association des Producteurs maraichers du Québec: https://apmquebec.com/ (in French only)

Fruit and Vegetable Growers of Canada: https://fvgc.ca/

References

Alston, D. (2018). Leafminers of Vegetable Crops. Online: https://extension.usu.edu/pests/research/leafminers-vegetables

Berbegal, M., L.A. Álvarez, A. Pérez-Sierra and J. Armengol (2012). Identification of *Pythium tracheiphilum* as the causal agent of vascular necrosis of endive (*Cichorium endivia*) in Spain. Phytoparasitica, 40(1): 1-4. Online: https://link.springer.com/article/10.1007/s12600-011-0194-0

Bi, J.L. (2011). Seedcorn Maggot, a Serious Pest of Winter and Spring Vegetables. Online: https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=4301

Bunn, B., D. Alston and M. Murry (2015). Flea beetles on vegetables. Online: https://extension.usu.edu/pests/uppdl/files/factsheet/flea-beetles.pdf

Chaput, J. (1998). Tarnished Plant Bug Damage on Vegetable Crops in Ontario. Online: http://www.omafra.gov.on.ca/english/crops/facts/98-025.htm

Chaput, J. (2009). Managing Cutworms in Vegetable Crops. Online: https://www.ontario.ca/page/managing-cutworms-vegetable-crops

Chaput, J. and M. Sears (1998). Aster Leafhopper and Aster Yellows. Online: https://www.ontario.ca/page/aster-leafhopper-and-aster-yellows

Collins, B.D. (2016). Management of Fusarium wilt in bunching spinach production in Ontario, Canada. M.Sc. Thesis, The University of Guelph. Online: https://atrium.lib.uoguelph.ca/xmlui/bitstream/handle/10214/9586/Collins_Brian_201604_MSc.pdf?sequence=1

Correll, J.C., T.E. Morelock, M.C. Black, S.T. Koike, L.P. Brandenberger and F.J. Dainello (1994). Economically important diseases of spinach. Plant Disease, 78(7): 653-660. Online: https://web.archive.org/web/20040328132308id_/http://comp.uark.edu:80/~morelock/images/EIDS_grey.pdf

Cranmer, T. (2017). Scouting for Onion Thrips. Online: https://www.ontario.ca/page/scouting-onion-thrips

Cranshaw, W.S. (2019). Flea Beetles Fact Sheet No. 5.592. Online: https://extension.colostate.edu/topic-areas/insects/flea-beetles-5-592/

Delahaut, K.A. (1997). Aster Leafhopper. Online: https://vegento.russell.wisc.edu/wp-content/uploads/sites/249/2017/03/Aster-leafhopper-A3679-1997.pdf

Dixon, W.N. (2015). Featured Creatures: Tarnished Plant Bug. Online: https://entnemdept.ufl.edu/creatures/trees/tarnished_plant_bug.htm du Toit, L.J. and C.M. Ocamb (n.d.). Spinach (*Spinacia oleracea*)- Stemphylium Leaf Spot. Online: https://pnwhandbooks.org/plantdisease/host-disease/spinach-spinacia-oleracea-stemphylium-leaf-spot

Fall, M.L., H. Van der Heyden, C. Beaulieu and O. Carisse (2015). *Bremia lactucae* infection efficiency in lettuce is modulated by temperature and leaf wetness duration under Quebec field conditions. Plant Disease, 99(7): 1010-1019. Online: https://apsjournals.apsnet.org/doi/pdf/10.1094/PDIS-05-14-0548-RE

Forbes, A.R. and J.R. MacKenzie (1982). The lettuce aphid, *Nasonovia ribisnigri* (Homoptera: Aphididae) damaging lettuce crops in British Columbia. Journal of the Entomological Society of British Columbia, 79: 28-31. Online: https://journal.entsocbc.ca/index.php/journal/article/download/2067/2133

Forbes, A.R. and R.S. Veron (1988). Sampling for distribution of the lettuce aphid, *Nasonovia ribisnigri* (Homoptera: Aphididae), in fields and within heads. Journal of the Entomological Society of British Columbia, 85: 10-14. Online: https://journal.entsocbc.ca/index.php/journal/article/view/674/683

Harsimran, K.G., G. Goyal, and J.L. Gillet-Kaufman (2019). Featured Creatures – Seedcorn Maggot *Delia platura* (Meigen) (Insecta: Diptera: Anthomyiidae). Online: https://entnemdept.ufl.edu/creatures/FIELD/CORN/seedcorn_maggot.htm#damage

Higgins, G. (2020). Spinach, Cladosporium Leaf Spot. Online: https://ag.umass.edu/vegetable/fact-sheets/spinach-cladosporium-leaf-spot

Hoffmann, M., R. Hoebeke and H.R. Dillard (1999). Flea beetle pests of vegetables. Online: https://ecommons.cornell.edu/bitstream/handle/1813/43272/flea-beetles-veg-FS-NYSIPM.pdf?sequence=1

Jenni, S., D. Brault and K.A. Stewart (2002). Degradable mulch as an alternative for weed control in lettuce produced on organic soils. In: XXVI International Horticultural Congress: Sustainability of Horticultural Systems in the 21st Century 638: 111-118. Online: https://wwwlib.teiep.gr/images/stories/acta/Acta%20638/638_13.pdf

Kandel, S.L., B. Mou, N. Shishkoff, A. Shi, K.V. Subbarao and S.J. Klosterman (2019). Spinach downy mildew: Advances in our understanding of the disease cycle and prospects for disease management. Plant Disease, 103(5): 791-803. Online: https://apsjournals.apsnet.org/doi/pdfplus/10.1094/PDIS-10-18-1720-FE

Kaur, N. (Editor) (2021). Seedcorn maggot. In: Pacific Northwest Insect Management Handbook. Online: https://pnwhandbooks.org/insect/vegetable/vegetable-pests/common-vegetable/vegetable-crop-seedcorn-maggot

Kaur, N. (Editor) (2021). Spinach-Leafminer. In: Pacific Northwest Insect Management Handbook. Online: https://pnwhandbooks.org/node/7866/print

Koike, S.T. and J.L. Bi (2010). Spring Head Lettuce Crop Affected by Insect [Seedcorn Maggot]. Online: https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=2648

Koike, S.T. and T.A. Turini (2017). Lettuce Pest Management Guidelines: Bacterial Leaf Spot. Online: https://www2.ipm.ucanr.edu/agriculture/lettuce/Bacterial-leaf-spot/

Koike, S.T. and T.A. Turini (2017). Lettuce Pest Management Guidelines: Downy Mildew. Online: https://www2.ipm.ucanr.edu/agriculture/lettuce/downy-mildew/

Koike, S.T. and T.A. Turini (2017). Lettuce Pest Management Guidelines: Lettuce Drop. Online: https://www2.ipm.ucanr.edu/agriculture/lettuce/Lettuce-drop/

Koike, S.T. and T.A. Turini (2017). Lettuce Pest Management Guidelines: Rhizoctonia Diseases. Online: https://www2.ipm.ucanr.edu/agriculture/lettuce/Rhizoctonia-diseases/

Koike, S.T. and T.A. Turini (2017). Lettuce Pest Management Guidelines: Varnish Spot. Online: https://www2.ipm.ucanr.edu/agriculture/lettuce/Varnish-spot/

Koike, S.T. and M. LeStrange (2012). Spinach Pest Management Guidelines: Anthracnose. Online: https://www2.ipm.ucanr.edu/agriculture/spinach/Anthracnose/

Koike, S.T. and M. LeStrange (2012). Spinach Pest Management Guidelines: Downy Mildew. Online: https://www2.ipm.ucanr.edu/agriculture/spinach/downy-mildew/

Koike, S.T. and M. LeStrange (2012). Spinach Pest Management Guidelines: Stemphylium Leaf Spot. Online: https://ipm.ucanr.edu/agriculture/spinach/stemphylium-leaf-spot/

Koike, S.T. and M. LeStrange (2012). Spinach Pest Management Guidelines: Virus Diseases. Online: https://www2.ipm.ucanr.edu/agriculture/spinach/Virus-Diseases/

Křístková, E., I. Doležalová, A. Lebeda, V. Vinter and A. Novotná (2008). Description of morphological characters of lettuce (*Lactuca sativa* L.) genetic resources. Horticultural Science (Prague), 35(3): 113–129. Online: https://www.agriculturejournals.cz/publicFiles/4_2008-HORTSCI.pdf

Leblanc, M. (n.d.). L’altise à tête rouge [power point slides]. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. Online: https://docplayer.fr/25012383-L-altise-a-tete-rouge-mario-leblanc-m-sc-agr-mapaq-ste-martine.html

LeStrange, M. and S.T. Koike (2009). Spinach Pest Management Guidelines: Caterpillars (Lepidopterous Pests). Online: https://www2.ipm.ucanr.edu/agriculture/spinach/Caterpillars-Lepidopterous-Pests/

Liu, B., L. Stein, K. Cochran, L.J. du Toit, C. Feng and J.C. Correll (2021). Three new fungal leaf spot diseases of spinach in the United States and the evaluation of fungicide efficacy for disease management. Plant Disease, 105(2): 316-323. Online: https://apsjournals.apsnet.org/doi/pdfplus/10.1094/PDIS-04-20-0918-RE

Madeiras, A. (2017). Spinach, Downy Mildew. Online: https://ag.umass.edu/vegetable/fact-sheets/spinach-downy-mildew

Matheron, M.E. and M. Porchas (2007). Effect of Fungicides and Lettuce Cultivar on Severity of Botrytis Gray Mold: 2007 Study. Vegetable Report. Online: https://repository.arizona.edu/handle/10150/215034

McGrath, M.T. (2021). Spinach Downy Mildew. Online: https://www.vegetables.cornell.edu/pest-management/disease-factsheets/spinach-downy-mildew/

Meadows, I., S. Sharpe and M. Henson (2020). Damping-off in Flower and Vegetable Seedlings. Online: https://content.ces.ncsu.edu/damping-off-in-flower-and-vegetable-seedlings

Mollema, C. and R.A. Cole (1996). Low aromatic amino acid concentrations in leaf proteins determine resistance to *Frankliniella occidentalis* in four vegetable crops. Entomologia Experimentalis et Applicata, 78(3): 325-333. Online: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1570-7458.1996.tb00797.x

Mou, B. (2008). Leafminer Resistance in Spinach. HortScience, 43(6): 1716-1719. Online: https://journals.ashs.org/hortsci/view/journals/hortsci/43/6/article-p1716.xml

Mou, B. and E.J. Ryder (2003). Screening and breeding for resistance to leafminer (*Liriomyza langei*) in lettuce and spinach. Van Hintum T.J.L., A. Lebeda, D.A. Pink, J.W. Schut (eds.) In: Proceedings of the EUCARPIA Meeting on Leafy Vegetables Genetics and Breeding, Noordwijkerhout, Netherlands. Online: http://baniameri.entomology.ir/SciRef/SciRefEng19.pdf

Natwick, E.T, S.V. Joseph and S.K. Dara (2017). Lettuce Pest Management Guideline: Cutworms. Online: https://www2.ipm.ucanr.edu/agriculture/lettuce/Cutworms/

Natwick, E.T., S.V. Joseph and S.K. Dara (2017). Lettuce Pest Management Guidelines: Lettuce Aphid. Online: https://www2.ipm.ucanr.edu/agriculture/lettuce/Lettuce-aphid/

Natwick, E.T, S.V. Joseph and S.K. Dara (2017). Lettuce Pest Management Guideline: Loopers. Online: https://www2.ipm.ucanr.edu/agriculture/lettuce/Loopers/

Natwick, E.T., S.V. Joseph, S.K. Dava and N.C. Toscano (2017). Lettuce Pest Management Guidelines: Lygus Bug (Western Tarnished Plant Bug). Online: https://www2.ipm.ucanr.edu/agriculture/lettuce/lygus-bug-western-tarnished-plant-bug/

Natwick, E. T., S.V. Joseph and S.K. Dara (2017). Lettuce Pest Management Guidelines: Western flower thrips. Online: https://www2.ipm.ucanr.edu/agriculture/lettuce/Western-flower-thrips/

Noumedem, J.A.K., D.E. Djeussi, L. Hritcu, M. Mihasan and V. Kuete (2017). Chapter 20 *Lactuca sativa*. In: Medicinal Spices and Vegetables from Africa. Elsevier Inc., 437-438. Online: https://www.researchgate.net/profile/Opeyemi-Avoseh/publication/312686177_Cymbopogon_citratus/links/5ec284d5299bf1c09ac4e3a8/Cymbopogon-citratus.pdf#page=458

Nuessly, G.S. and R.T. Nagata (1994). Differential probing response of serpentine leafminer, *Liriomyza trifolii* (Burgess), on cos lettuce. Journal of Entomological Science, 29(3): 330-338. Online: https://edis.ifas.ufl.edu/publication/HS1196

Oklahoma State University (n.d.). Seed Cron Maggot, *Delia platura*. Online: http://entoweb.okstate.edu/ddd/insects/seedcornmaggot.htm

Oregon State University (2010). Spinach. Online: https://horticulture.oregonstate.edu/oregon-vegetables/spinach-0

Pacific Northwest Extension Group of Washington State University, Oregon State University and University of Idaho (2022). Spinach. Online: https://mtvernon.wsu.edu/path_team/spinach.htm#edema

Palumbo, J.C. (2000). Management of Aphids and Thrips on Leafy Vegetables. Online: https://cals.arizona.edu/crop/vegetables/insects/aphid/aphidsandthrips.html

Park, S., P. Kumar, A. Shi and B. Mou (2021). Population genetics and genome-wide association provide insights into the influence of selective breeding on genetic variation in lettuce. The Plant Genome, 14:e20086. Online: https://acsess.onlinelibrary.wiley.com/doi/pdfdirect/10.1002/tpg2.20086

Petrovic, K. (2018). Field Scouting Guide: Thrips. Online: https://www.growingproduce.com/vegetables/field-scouting-guide-thrips/

Pscheidt, J.W. and C.M. Ocamb (2021). Lettuce (*Lactuca sativa*) – Damping Off. In: Pacific Northwest Plant Disease Management Handbook. Corvallis, OR: Oregon State University. Online: https://pnwhandbooks.org/plantdisease/host-disease/lettuce-lactuca-sativa-damping

Pscheidt, J.W. and C.M. Ocamb (2021). Lettuce (*Lactuca sativa*) – Grey Mold. In: Pacific Northwest Plant Disease Management Handbook. Corvallis, OR: Oregon State University. Online: https://pnwhandbooks.org/plantdisease/host-disease/lettuce-lactuca-sativa-gray-mold

Pscheidt, J.W. and C.M. Ocamb (2021). Spinach (*Spinacia oleracea*) – Fusarium Wilt. In: Pacific Northwest Plant Disease Management Handbook. Corvallis, OR: Oregon State University. Online: https://pnwhandbooks.org/plantdisease/host-disease/spinach-spinacia-oleracea-fusarium-wilt

Ribera, A., Y. Bai, A.A. Wolters, R. van Treuren and C. Kik (2020). A review on the genetic resources, domestication and breeding history of spinach (*Spinacia oleracea* L.). Euphytica, 216(48). Online: https://link.springer.com/article/10.1007/s10681-020-02585-y

Ribera, A., R. van Treuren, C. Kik, Y. Bai and A.A. Wolters (2021). On the origin and dispersal of cultivated spinach (*Spinacia oleracea* L.). Genetic Resources and Crop Evolution, 68: 1023-1032. Online: https://link.springer.com/article/10.1007/s10722-020-01042-y

Saharan, G.S. and P.R. Verma (1992). White rusts: a review of economically important species. IDRC, Ottawa, ON, CA. Online: https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/11840/IDL-11840.pdf?sequence=1

Sahin, F., P.A. Abbasi, M.L. Ivey, J. Zhang and S.A. Miller (2003). Diversity among strains of *Xanthomonas campestris* pv. *vitians* from lettuce. Phytopathology, 93(1): 64-70. Online: https://apsjournals.apsnet.org/doi/pdf/10.1094/PHYTO.2003.93.1.64

Sauvageau, A., V. Gravel and H. Van der Heyden (2019). Soilborne inoculum density and environmental parameters influence the development of Pythium stunt caused by *Pythium tracheiphilum* in head lettuce crops. Plant disease, 103(7): 1685-1692. Online: https://apsjournals.apsnet.org/doi/pdf/10.1094/PDIS-09-18-1486-RE

Sauvageau, A. (2018). Factors Influencing the Incidence of Pythium Stunt Caused by *Pythium tracheiphilum* in Head Lettuce Crops. McGill University (Canada). Online: https://escholarship.mcgill.ca/concern/theses/qb98mh80k

Scheufele, S. (2017). Lettuce, Downy Mildew. Online: https://ag.umass.edu/vegetable/fact-sheets/lettuce-downy-mildew

Schwartz, H.F. and D.H. Gent (2016). Spinach Downy Mildew. Online: https://wiki.bugwood.org/HPIPM:Downy_Mildew_Spinach#Identification_and_Life_Cycle

Schwartz, H.F. and D.H. Gent (2016). White Rust Spinach. Online: https://wiki.bugwood.org/HPIPM:White_Rust_Spinach

Simko, I., R.J. Hayes, B. Mou and J.D. McCreight (2014). Lettuce and spinach. In: Yield gains in major US field crops, 33: 53-85. Online: https://www.researchgate.net/profile/Ivan-Simko-4/publication/262415049_Lettuce_and_Spinach/links/53d300dd0cf220632f3cc497/Lettuce-and-Spinach.pdf

Smith, R.F., S.A. Fennimore and M. LeStrange (2009). Spinach Pest Management Guidelines: Integrated Weed Management. Online: https://www2.ipm.ucanr.edu/agriculture/spinach/Integrated-Weed-Management/

Smith, R.F., S.A. Fennimore and M. LeStrange (2017). Lettuce Pest Management Guidelines: Integrated Weed Management. Online: https://www2.ipm.ucanr.edu/agriculture/lettuce/Integrated-Weed-Management/

Smith, R.F., S.A. Fennimore and M. LeStrange (2017). Weed Management for Organic Lettuce Production. Online: https://www2.ipm.ucanr.edu/agriculture/lettuce/weed-management-for-organic-lettuce-production/

Subbarao, K.V., R.M. Davis, R.L. Gilbertson and R.N. Raid, primary collators (2017). Diseases of Lettuce (*Lactuca sativa* L.). Online: https://www.apsnet.org/edcenter/resources/commonnames/Pages/Lettuce.aspx

Subbarao, K.V. (1998). Progress toward integrated management of lettuce drop. Plant Disease, 82(10): 1068-1078. Online: https://apsjournals.apsnet.org/doi/pdfplus/10.1094/PDIS.1998.82.10.1068

Talhinhas, P. and R. Baroncelli (2021). Colletotrichum species and complexes: geographic distribution, host range and conservation status. Fungal Diversity, 110(1): 109-198. Online: https://link.springer.com/article/10.1007/s13225-021-00491-9

Toussaint, V. (1999). Bacterial leaf spot, a new disease of lettuce in Quebec caused by *Xanthomonas campestris* pv. *vitians*. Phytoprotection, 80(2): 121-125. Online: https://www.erudit.org/fr/revues/phyto/1999-v80-n2-phyto3370/706187ar.pdf

University of Idaho (n.d.). Black Bean Aphid. Online: https://www.uidaho.edu/extension/ipm/pests/aphid-adelgid/black-bean-aphid

University of Missouri (2016). Monitoring, Detection and Management of Lettuce Drop Caused by Sclerotinia species. Online: https://ipm.missouri.edu/MEG/2016/2/Monitoring-Detection-and-Management-of-Lettuce-Drop-caused-by-Sclerotinia-spp/

Utah State University (2021). Leaf Spots. In: Utah Vegetable Production and Pest Management Guide, 117. Online: https://extension.usu.edu/vegetableguide/leafy-greens/leaf-spots

Van Dyk, D. (2011). White Rust on Spinach. Online: https://onvegetables.com/2011/05/09/white-rust-in-spinach/

Wallon, T., A. Sauvageau and H. Van der Heyden (2021). Detection and Quantification of *Rhizoctonia solani* and *Rhizoctonia solani* AG1-IB Causing the Bottom Rot of Lettuce in Tissues and Soils by Multiplex qPCR. Plants, 10(1): 57. Online: https://www.mdpi.com/2223-7747/10/1/57

Wei, T., R. van Treuren, X. Liu, Z. Zhang, J. Chen, Y. Liu, S. Dong, P. Sun, T. Yang, T. Lan, X. Wang, Z. Xiong, Y. Liu, J. Wei, H. Lu, S. Han, J.C. Chen, X. Ni, J. Wang, H. Yang, H. Yang, X. Xu, H. Kuang, T. van Hintum, X. Liu and H. Liu (2021). Whole-genome resequencing of 445 Lactuca accessions reveals the domestication history of cultivated lettuce. Nature Genetics, 53: 752-760. Online: https://www.nature.com/articles/s41588-021-00831-0

Van der Heyden, H., T. Wallon, C.A. Lévesque and O. Carisse (2019). Detection and quantification of *Pythium tracheiphilum* in soil by multiplex real-time qPCR. Plant Disease, 103(3): 475-483. Online: https://apsjournals.apsnet.org/doi/epdf/10.1094/PDIS-03-18-0419-RE