Crop Profile for Carrot in Canada, 2018

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Agriculture and Agri-Food Canada

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Preface

National crop profiles are developed by the Pest Management Program of Agriculture and Agri-Food Canada (AAFC). The national crop profiles provide baseline information on crop production and pest management practices and document the pest management needs and issues faced by growers. This information is developed through extensive consultation with stakeholders.

Information on pest issues and management practices is provided for information purposes only. For detailed information on growing carrots, 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 carrot, 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.

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Contents

List of Tables

Crop Profile for Carrot in Canada

The carrot (*Daucus carota*) is a member of the Apiaceae family (formerly Umbelliferae). Carrots are biennial plants, but they are grown as an annual crop and harvested for their enlarged taproot. Wild carrots were consumed in prehistoric times, and are believed to have originated in the area around what is now Afghanistan. Today there are hundreds of varieties but orange carrots were not known until the 17th century, when they were developed in Holland. Orange carrots are now the predominant type on the world market, but 'coloured' varieties are making a comeback.

Carrots are grown for both the fresh market and processing industries and are an important crop of high per capita consumption. Fresh carrots can be sold as either "bunched" (with tops) or "topped" (without tops). 'Baby' carrots became popular in the late 1990's, taking over large parts of the traditional topped carrot market. Many of these pre-packaged, washed, ready to eat baby carrots may be cut from undersized carrots or pieces of larger carrots, but they generally are grown from selected cultivars planted at high density. Since they undergo minimal change from the actual carrot, baby carrots are not considered to be processed. Carrots may be consumed fresh, cooked, or juiced

Crop Production

Industry Overview

The value of vegetables was up for the eighth consecutive year to $1.2 billion in 2018, according to Statistics Canada, and it was 2.5 percent higher than the previous year. Carrots, including baby carrots, had the highest value ($129.9 million) of the vegetable crops. Carrots are grown in all regions of Canada with 8,344 hectares planted in 2018 (Table 1). Production in Ontario, Quebec and Nova Scotia accounted for 85% of the total area.

Table 1. General production information in 2018

Canadian Marketed Production[1]	**Carrots**
	347,749 metric tonnes
Total farm value[1]	$129.9 Million
Carrot consumption in Canada[2]	Fresh carrots: 7.16 kg/ person
	Canned and frozen carrots: 1.73 kg/ person

…continued

Table 1. General production information in 2018 (continued)

Exports[3]	Fresh and chilled: $72.8 Million
Imports[3]	Fresh and chilled: $153.2 Million

[1]Statistics Canada. Table 32-10-0365-01 - Area, production and farm gate value of vegetables (database accessed 2020-07-02)
[2]Statistics Canada. Table 32-10-0054-01 - Food available in Canada (database accessed: 2020-07-02).
[3]Statistics Canada. Canada International Merchandise Trade Database (accessed 2020-07-02): HS # 070610 - Carrots and Turnips, fresh or chilled.

Production Regions

The majority of carrot production for the fresh market occurs in Ontario (42%) and Quebec (36%), with some production in Nova Scotia, British Columbia, Prince Edward Island and Manitoba (Table 2).

Table 2. Distribution of carrot production by province, 2018

Production Regions	Area planted[1] (hectares) and national percentage	Marketed production[1] (metric tonnes) and national percentage	Total farm value[1] ($)
	Carrots		
British Columbia	381 ha (5%)	8,772 m. t. (2%)	$8.4 Million
Manitoba	244 ha (3%)	8,027 m. t. (2%)	$6.2 Million
Ontario	3,503 ha (42%)	187,024 m. t. (52%)	$43.8 Million
Quebec	3,000 ha (36%)	103,732 m. t. (29%)	$49.1 Million
Nova Scotia	588 ha (7%)	30,703 m. t. (9%)	x
Prince Edward Island	322 ha (4%)	13,148 m. t. (4%)	$4.8 Million
Canada	**8 344 ha**	**356 397 t. m.**	**$129.2 Million**

[1] Source: Statistics Canada. Table 32-10-0365-01 - Area, production and farm gate value of vegetables (database accessed: 2020-07-02).
x: suppressed to meet the confidentiality requirements of the Statistics Act.

Cultural Practices

The best soils for growing carrots are well-drained, stone-free, muck (rich, high organic matter) soils and sandy loam soils with good water holding capacity. In Canada, almost 50 percent of the carrot crop is grown in muck soils. In Ontario and Quebec, carrot acreage grown in mineral soil is increasing while acreage grown on muck soil is decreasing. Optimum growing temperatures for carrots are 15 to 20 °C, with a minimum of 5 °C and a maximum of 24 °C. In Canada, carrots are planted from mid-March to mid-July. Carrots take from 6 to 21 days to germinate, and from 70 to 120 days to fully mature. The optimum temperature for germination ranges from 10 to 25 °C. Carrot foliage is moderately tolerant to frost. Early frosts in in the fall do not usually damage the roots. Prolonged freezing over 24 hours may injure the crowns and may reduce the storability of the affected carrots.

Carrot harvest begins in mid-July with the first bunched crop harvested by hand. Roots for packaging are harvested later, starting in August. Carrots harvested from mid-September to November can yield a gross weight of 40 to 80 metric tonnes per hectare. However, marketable yields average 25 tonnes per hectare (fresh or processed). Carrots are mechanically harvested by undercutting roots and lifting them out of the soil or by grasping the foliage and pulling the roots out of the soil. It is important to maintain healthy leaves until the carrots are harvested to optimize harvest success and ensure a healthier root for better storability.

Table 3. General carrot production and pest management schedule in Canada

Time of year	Activity	Action
November - April	-	No activity
May	Plant care	Seeding (earlier in some areas)
	Soil care	Fertilization and cultivation
	Disease management	Seed treatment applied
	Insect and mite management	Seed treatment and in-furrow crop protectant application
	Weed management	Cultivation and pre-emergence sprays
June	Plant care	Irrigation and monitoring
	Disease management	Monitoring and spraying, if necessary
	Insect and mite management	Monitoring and spraying, if necessary
	Weed management	Post-emergence sprays
July - August	Plant care	Irrigation and monitoring
	Disease management	Monitoring and spraying, if necessary
	Insect and mite management	Monitoring and spraying, if necessary
	Weed management	Limited activity
September - November	Plant care	Harvesting (later in some areas) and storage
	Disease management	Limited activities late in the season
	Insect and mite management	Limited activities late in the season
November - March	-	Storage; periodic monitoring for emerging disease hot spots

Abiotic Factors Limiting Production

High Temperatures and Drought

Carrots are best adapted to long, cool, growing seasons. Carrots have a low tolerance for high temperatures. During hot, bright, sunny days, young plants can be badly injured or killed by high temperatures that develop at or just below the soil surface. Prolonged hot weather later in the development of the plants may reduce growth and decrease yield and also cause an undesirable strong flavour and coarseness in the roots.

Carrots have a low tolerance to drought. Carrots are most sensitive to moisture stress during seed germination and root enlargement. Irrigation can improve emergence, reduce wind erosion and lower temperatures at the soil line during germination.

Diseases

Key issues

- There is a need for the implementation of existing Alternaria leaf blight and Cercospora leaf spot forecasting models to help growers in the management of these diseases.
- There is a need for the registration of additional products for use in resistance management for the control of white mold both in the field and in storage. It is important that new registrations include alternatives to conventional products such as biopesticides.
- There is a need to continue work on the development of integrated approaches to the control of Pythium, Fusarium, and Rhizoctonia diseases of carrot.
- There is a need for the development of an effective control strategy that involves crop rotations and chemical and non-chemical solutions for the management of nematodes, including carrot cyst nematode and root lesion nematode.

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

Disease	Ontario	Quebec	Nova Scotia	Prince Edward Island
Alternaria leaf blight				
Cercospora leaf spot				
Bacterial leaf blight				
Powdery mildew				
Sclerotinia rot (white mold)				
Grey mold				
Common scab				
Crown and root rot				
Alternaria black rot				
Cavity spot				
Aster Yellows				
Nematodes				
Root lesion nematode				
Northern root knot nematode				

Widespread yearly occurrence with high pest pressure.

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

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

Localized yearly occurrence with low to moderate pest pressure OR widespread sporadic occurrence with low pressure OR localized sporadic occurrence with low to moderate pest pressure OR pest not of concern.

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

Pest not present.

Data not reported.

[1]Source: Carrot stakeholders in reporting provinces; the data reflect the 2018, 2017 and 2016 production years.
[2]Refer to Appendix 1 for a detailed explanation of colour coding of occurrence data.

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

Practice / Pest		Sclerotinia (white mold)	Cercospora leaf spot and Alternaria leaf blight	Cavity spot	Aster yellows	Nematodes
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 (e.g., seed, cuttings or transplants)					
Prevention	Equipment sanitation					
	Canopy management (e.g., thinning, pruning, row or plant spacing)					
	Manipulating seeding / planting depth					
	Irrigation management (timing, duration, amount) to minimize disease infection periods and manage plant growth					
	Management of soil moisture (e.g., improvements in drainage, use of raised beds, hilling, mounds)					
	End of season or pre-planting crop residue removal / management					
	Pruning out / removal of infected material throughout the growing season					
	Removal of other hosts (weeds / volunteers / wild plants) in field and vicinity					

…continued

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

Practice / Pest		Sclerotinia (white mold)	Cercospora leaf spot and Alternaria leaf blight	Cavity spot	Aster yellows	Nematodes
Monitoring	Scouting / spore trapping					
	Maintaining records to track diseases					
	Soil analysis for the presence of pathogens					
	Weather monitoring for disease forecasting					
	Use of precision agriculture technology (GPS, GIS) for data collection and mapping of diseases					
Decision Making tools	Economic threshold					
	Use of predictive model for management decisions					
	Crop specialist recommendation or advisory bulletin					
	Decision to treat based on observed disease symptoms					
	Use of portable electronic devices in the field to access pathogen / disease identification / management information					
Suppression	Use of diverse product modes of action for resistance management					
	Soil amendments and green manuring involving soil incorporation as biofumigants, to reduce pathogen populations					
	Use of biopesticides (microbial and non-conventional pesticides)					
	Controlled atmosphere storage					
	Targeted pesticide applications (banding, spot treatments, use of variable rate sprayers, etc.)					
	Selection of pesticides that are soft on beneficial insects, pollinators and other non-target organisms					

…continued

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

Practice / Pest		Sclerotinia (white mold)	Cercospora leaf spot and Alternaria leaf blight	Cavity spot	Aster yellows	Nematodes
Crop Specific practices	Trimming of carrot foliage to reduce disease development					
This practice is used to manage this pest by at least some growers in the province.						
This practice is not used by growers in the province to manage this pest.						
This practice is not applicable for the management of this pest.						
Information regarding the practice for this pest is unknown.						

[1]Source: Carrot stakeholders in reporting provinces (Ontario, Quebec and Nova Scotia); the data reflect the 2018, 2017 and 2016 production years.

Alternaria Leaf Blight *(Alternaria dauci)*

Pest Information

Damage: Alternaria blight primarily affects leaflets and causes brown lesions along leaf margins that often coalesce causing leaflets to shrivel and die. The disease commonly develops late in the season on older foliage. Blighted carrot tops may break off from the root during mechanical harvesting, leaving carrots in the ground and thereby reducing yields. In addition to carrot, the fungus can infect parsley, rooted parsley, celery, celeriac, and a number of related weeds.

Life cycle: The pathogen affects only the leaves and not the edible carrot root. Alternaria overwinters in infected debris in the soil, on carrot tops discarded after storage, on weed hosts and is also spread on contaminated seed. During the growing season, Alternaria produces conidia (asexual spores) at temperatures ranging between 8 and 28 ^{o}C under high humidity. Spores and mycelium are spread by wind, water, splashing rain, farm equipment and field workers. The pathogen attacks older foliage. The disease occurs later in the season than Cercospora leaf spot. Damaged plants and nitrogen deficient plants are more susceptible to Alternaria infection.

Pest Management

Cultural control: Using disease-free seed and resistant cultivars may help prevent Alternaria leaf blight in carrot. A three-year crop rotation and planting in well drained soils will help reduce inoculum build-up. Cleaning equipment before moving between fields may help reduce the spread of inoculum. Fall ploughing will facilitate the decomposition of infected debris. Regular monitoring of fields and blight forecasting models can be used to assist with timing of fungicide sprays. Additional management practices for Alternaria leaf blight are listed in *Table 5.*

Resistant cultivars: Resistant varieties are available including *Orlando Gold* and *Hi-color*.

Issues for Alternaria Leaf Blight

1. There is a need for the registration of additional pest control products, including biopesticides, which are compatible with IPM programs for the management of leaf blight in carrot. Ideally, these products would be from a variety of chemical families to allow for product rotation for resistance management and fill gaps that may arise during the re-evaluation process.
2. The implementation of Alternaria leaf blight forecasting models would be helpful to growers for the management of this disease.

Cercospora Leaf Spot (*Cercospora carotae*)

Pest Information

Damage: The pathogen causes circular tan spots on the leaves and petioles of carrot. The spots eventually coalesce, causing death of leaflets. Lesions develop on leaflet margins which lead to lateral curling. With severe infections, photosynthesis may be reduced resulting in a reduction of the carrot root size. Petiole infections can weaken carrot tops, which break-off from the root during mechanical harvest, leaving carrot roots in the ground, thereby reducing yields.

Life cycle: The pathogen only affects young leaves and not the edible carrot root. The fungus overwinters in infected plant debris and wild hosts or is seed-borne. Spores are carried by wind or water to young carrots. The pathogen infects the leaves through the stomata (natural opening in plant epidermis), with lesions appearing three to five days after infection. New spores are produced in lesions in a short period of time, which spread and give rise to new infections. Periods of leaf wetness longer than 12 hours provide ideal conditions for infection, but spores are able to germinate over a wide range of conditions, with optimum temperatures between 16 and 30 ^{o}C. Disease may develop more quickly in late-sown carrot if earlier seeded adjacent fields are already infected. The Cercospora spores (conidia) are spread by air currents, splashing rain, flowing water, farm equipment and tools, and also on the clothing of workers.

Pest Management

Cultural control: Using disease-free seed, treated seed or resistant cultivars may help prevent this disease in carrot. A two to three-year rotation with non-host crops helps reduce inoculum build-up. In the fall, residue left after harvest can be ploughed under to speed decomposition. Promoting aeration through row spacing for late season varieties may help reduce the severity of this disease. Selecting varieties with an upright growth habit may also help foliage dry more quickly, reducing disease risk, as will careful planting site selection to avoid potential for cross contamination. Monitoring is also an important approach to help optimize management and reduce the impact of the disease. Some monitoring tools have been developed which can be used to predict the severity of Cercospora infection in carrot. Additional management practices for Cercospora are listed in *Table 5.*

Resistant cultivars: Resistant varieties are available including *Delite*, *Delux*, *Fancy*, *Bonus*, *Classic*, *Winner* and *Premium*.

Issues for Cercospora Leaf Spot

1. There is a need for the implementation of Cercospora leaf spot forecasting models to help growers manage this disease.
2. There is a need for the registration of additional control products including biopesticides that are compatible with IPM programs for the management of Cercorpora leaf spot in carrots. Ideally these new products would be from a variety of chemical families to allow for product rotation (resistance management) and fill gaps that may arise during the re-evaluation process.

Bacterial Leaf Blight (*Xanthomonas campestris* pv. *carotae*)

Pest Information

Damage: The cultivated carrot is the only host of *X. campestris* pv. *carotae*. The disease causes irregular, dark brown, necrotic spots in the center of leaves which become dry and brittle with an irregular yellow halo. In contrast, lesions on the petioles, peduncles and pedicels appear water-soaked. Infection also takes place along the leaf margin, causing curling on young leaves. A gummy bacterial exudate can flow down from the infected plant parts. Early symptoms can be mistaken for Cercospora and Alternaria diseases, but the flow of bacterial exudate from infected plant parts is characteristic of bacterial leaf blight.

Life cycle: The pathogen can survive on carrot seeds originating from diseased plants and may survive one winter season in infested crop residues. The bacteria are dispersed by splashing water and by insects. The presence of liquid water or plant exudates is required for infection. The optimum temperature for the pathogen is 25 to 30 °C. Symptoms appear 10 to 12 days after inoculation, and epidemics can develop rapidly under warm and wet conditions.

Pest Management

Cultural control: Planting disease-free seed, following a two- to three-year crop rotation and disking infested crop residues into the soil can reduce inoculum levels.

Resistant cultivars: Some tolerance to bacterial leaf blight exists among cultivars.

Issues for Bacterial Leaf Blight

None identified.

Powdery Mildew (*Erisyphe hieraclei*)

Pest Information

Damage: Powdery mildew appears on older leaves and petioles as a white powdery growth. Slight foliar yellowing may develop as a result of infection. The risk of disease infection increases with plant maturity. The presence of powdery mildew on bunched carrots may make them unsaleable. For carrot seed production, severe infections may result in flower distortion and reduced seed production.

Life cycle: The pathogen survives in infected crop residues, on volunteer carrots and on alternate hosts, such as weeds of the Apiaceae family. Spores are dispersed by wind and splashing rain. Fungal development occurs during periods of high relative humidity (> 95%) and warm temperatures (13 to 31 °C). Symptoms appear 7 to 14 days after infection. Disease development is favoured by shade and high plant density.

Pest Management

Cultural control: Rotation, eradication of host weeds and destruction of volunteer carrots may help reduce the incidence of this disease. The elimination of infected plant material from a

field will remove a source of disease spread. Canopy aeration to reduce humidity can be improved by reducing plant density.

Resistant cultivars: Some tolerant varieties exist.

Issues for Powdery Mildew

None identified.

White Mold (*Sclerotinia sclerotiorum*)

Pest Information

Damage: Sclerotinia sclerotiorum has a broad host range including many vegetable crops. Carrots are particularly susceptible to this disease at the end of the season and during storage. In storage, the disease is characterized by a soft, watery rot and the presence of black sclerotia. In the field, the disease first develops at the base of petioles, and then spreads to other foliage which turns brown and becomes covered with white, cottony mycelium. Affected foliage may become weakened, and be more prone to breakage during mechanical harvest. Infection may not be apparent at harvest but can develop in storage where it can spread rapidly from infected carrots to healthy ones. Significant yield losses are possible when growing seasons are cool and wet.

Life cycle: The fungus is soil- borne and can survive in the soil for many years in the form of hard-bodied sclerotia (masses of fungal mycelium in a resting stage). Sclerotia germinate when exposed to adequate soil moisture and moderate temperatures (11 to 15° C). The carrot crop canopy creates an excellent environment for sclerotia germination and disease development, with dense foliage that blocks out sunlight and keeps the soil moist. Germinating sclerotia produce mycelium or apothecia which release ascospores into the air. The ascospores are carried by wind to host plants where they can infect leaves, stems and roots. White mold develops at temperatures ranging between 13 and 19 ^{o}C when foliage is wet or at dew point for at least 48 hours. In storage, the disease spreads from infected carrots, contaminated pallet boxes, or plastic bags to adjacent healthy roots by mycelial growth.

Pest Management

Cultural control: Growing non-susceptible crops in close proximity to carrot fields and ensuring a three to five-year crop rotation may help minimize the development of white mold. Growing carrots on raised beds will improve air circulation and help to reduce leaf-wetness, a condition favouring this disease. Planting in well drained soils, watering early in the day, weed control and the removal and destruction of infected plant material may also help reduce disease development. Increased row spacing in late season varieties will facilitate drying of the canopy and reduce the risk of disease development. Carrot foliage trimming, at about the time of row closure, has proven successful in reducing disease levels and the amount of fungicide required for disease control. This practice makes the micro-climate in the crop canopy less conducive to white mold development. Cooling of carrots immediately after

harvest, and storing at a constant 0° C and 95 percent relative humidity will reduce disease development in storage. Additional management practices for white mold are listed in *Table 5*.

Resistant cultivars: There are several tolerant varieties available.

Issues for White Mold

1. There is a need for registration of additional products for use in pathogen resistance management to control white mold both in the field and in storage. It is important that new registrations include alternative products such as biopesticides.

Grey Mold (*Botrytis cinerea*)

Pest Information

Damage: Grey mold is an important disease of carrots; it initially appears as brown spots developing into masses of silvery-gray spores on all plant tissues, which develop an extensive soft rot, resulting in reduced photosynthesis and unmarketable roots. Lesions will form at wound sites and on the crown, and will cause significant damage to the stored roots.

Life cycle: The fungus overwinters in plant debris and soil as sclerotia. Conidia (spores) are produced in infected crop residue and plants and from sclerotia, which are the primary means of disease spread. Conidia can be wind-borne, rain-splashed or carried on clothing and tools to plants, and can initiate new infections. The disease thrives in cool moist conditions at temperatures between 15 and 21 °C and relative humidity above 85 percent. It can also survive on storage structures. It does not sporulate in storage at low temperature (< 0 °C), but it produces a whitish mycelial network which colonizes nearby healthy plant material.

Pest Management

Cultural control: Ensuring good air circulation around carrot plants may help minimize the incidence of grey mold. Following a three to four-year crop rotation, which does not include other susceptible crops such as beans, cucurbits, celery and cabbage will reduce disease inoculum in the field. Planting in well-drained soil, watering early in the day, controlling weeds and the removal and destruction of infected plant material may also help reduce the build-up of botrytis inoculum in the soil. Ensuring good sanitation in storages and storing only healthy, uninjured roots will minimize the risk of disease development in storage.

Resistant cultivars: None available.

Issues for Grey Mould

1. There is a need for registration of additional products for use in resistance management to control grey mould both in the field and in storage. It is important that new product registrations include biopesticides.

Common Scab (*Streptomyces scabies*)

Pest Information

Damage: Streptomyces scabies can cause dry, sunken corky lesions on carrot roots and other root and tuber crops.

Life cycle: Streptomyces species are bacterial pathogens that can survive on decaying plant residue in the soil, and possibly on the roots of living plants and in animal manure. These pathogens can be spread by rain and windblown soil and by infected roots and tubers. In carrot infection occurs through immature lenticels of young tissues and wounds caused by insects. Common scab is generally more severe in light, sandy or gravelly soils that dry quickly.

Pest Management

Cultural control: Well-rotted organic matter helps to retain moisture in mineral soils and reduces the onset of the dry conditions that favor scab. It is important that organic matter be thoroughly decomposed before the land is cropped with susceptible vegetables, to minimize the chances of scab infection. However, manure from animals fed on scab-infected roots and tubers should not be used on land to be sown to susceptible crops. Avoiding short rotations between susceptible crops, including potatoes, sugar beet and crucifers will also minimize the likelihood of disease carry-over between crops. Mineral soil acidification with sulfur and acid-forming fertilizers may be effective in reducing pH and the incidence of common scab, but acidification is not feasible in highly buffered muck soils.

Resistant cultivars: None available.

Issues for Common Scab

1. Common scab has resulted in crop loss for carrot producers on Prince Edward Island. There is a need for additional research on the effects of crop rotation and field management on the development of this disease.

Rhizoctonia diseases: Violet Root Rot (*Rhizoctonia crocorum*) and Crater Rot (*Rhizoctonia carotae*)

Pest Information

Damage: Rhizoctonia diseases can cause severe losses especially in stored carrot. Violet root rot caused by *R. crocorum* appears during mid-summer to early fall, and is first apparent as chlorotic leaves that then wilt and die. Violet root rot causes lesions on roots and violet, leathery roots, with soft and rotted underlying tissues. Soil readily adheres to affected roots. The disease develops in patches in the field. Crater rot, caused by *R. carotae,* is primarily a disease of stored carrots and mostly affects carrots produced on mineral soil. Symptoms of *R. carotae* include dry, sunken root lesions with white mycelium which may take up to three

months to develop following the initial appearance of small white hyphal knots on the root surface.

Life cycle: Rhizoctonia pathogens are soil-borne. Once the pathogens are in the soil, they remain there indefinitely, overwintering as mycelium or sclerotia or in infected plant material. Farm implements and infected plants enable the spread of disease through transfer of contaminated soil from one field to another. The *R. carotae* inoculum sources may also include contaminated pallet boxes. The hyphae (vegetative filament) of this pathogen take only a few days to grow, penetrate and kill carrot root cells. This pathogen grows at temperatures as low as -1 ^{o}C and spreads rapidly under high relative humidity. Development of *R. crocorum* occurs under a wide range of temperatures from 5 to 30 ^{o}C.

Pest Management

Cultural control: Avoiding planting in fields with a history of *Rhizoctonia* spp. may help reduce the spread of these diseases. Sanitation practices to prevent the transfer of the pathogens to other fields including use of clean machinery and storage facilities and discarding of infected plant material, will help reduce losses caused by these pathogens. Using disease-free seed, early spring seeding into well drained and weed-free sites, and early harvest if rot is detected will also contribute to minimizing the impact of these pathogens. In storage, box and skids must be cleaned and carrots washed and cooled rapidly to 0 °C and maintained at a relative humidity below 95 percent.

Resistant cultivars: None available.

Issues for Violet Root Rot and Crater Rot

None identified.

Crown Rot (*Rhizoctonia solani)*

Pest Information

Damage: Rhizoctonia solani can cause seedling damping-off early in the season. On developing carrot roots, the disease is characterized by horizontal, dark brown lesions that develop near the top of the root; lesions may penetrate several millimetres. The lesions are very distinct from the surrounding healthy tissue. As the season progresses, rot may develop at the crown of the plant. Outer leaves wilt and die, leaving few inner, enlarged, upright ones. This can be a problem for mechanical harvest. Control of this disease is nearly impossible if late summer and fall conditions are wet.

Life cycle: The fungus overwinters as mycelium or sclerotia in the soil, in crop residues and organic matter. Similar to other Rhizoctonia species, *R. solani*can survive a long time in the soil by colonizing infected host plant residues. In spring, sclerotia germinate and produce a sterile mycelium without spores. Mycelium penetrates the cuticle of young tissues, natural openings such as stomata and mechanical wounds. The fungus is spread by wind, rain splash and on contaminated soil and equipment. The optimum developmental temperature for *R.*

solani in the field ranges between 15 and 20 ºC when plant development is slower. Carrot susceptibility decreases as plants mature.

Pest Management

Cultural control: Disease-free seeds and well-drained soils will alleviate infection. Earlier harvests, planting on ridges, a three-year crop rotation with non-host crops (such as cereals), careful handling during harvest, maintaining clean storage will reduce losses to the disease. Reducing the spread of infected soil by cultivation and harvesting equipment is also important.

Resistant cultivars: None available.

Issues for Crown Rot

1. Crown rot has resulted in crop loss for carrot producers on Prince Edward Island. There is a need for additional research on the effects of crop rotation on the management of this disease.

Alternaria Black Rot (*Alternaria radicina*)

Pest Information

Damage: Alternaria radicina produces a black mycelium that may envelop seeds. Among the various symptoms that may develop are seed decay, seedling damping-off, and deformed seedling roots. Damping-off may result from seed-borne infection or planting in infested soil. Lesions can also extend from soil level upward and sometimes reach cotyledons. When the fungus attacks the crown, the invasion is usually deep and extends along the core. Lesions on the side of the root are generally circular, shallow and slightly depressed. However, the greatest damage occurs on the roots. In storage, the fungus requires a relative humidity above 90 percent for rapid root rot development. Extensive leaf and root infections usually reduce the storage life of carrots.

Life cycle: Alternaria radicina is seed- and soil-borne. It survives on carrot residues left on the soil surface and can persist for at least eight years in mineral soil. When diseased residue is buried rather than being left on the soil surface, inoculum is reduced. Germination of conidia and infection requires one to two weeks and is most rapid if relative humidity is above 90 percent and temperature above 27 °C. The next generation of conidia can be produced in newly infected tissues within two to three weeks and, under favorable conditions, secondary spread and infection can occur.

Pest Management

Cultural control: A minimum eight-year crop rotation with crops other than carrot, dill, parsley, parsnip or celery reduces the chances of disease-carry-over between crops. Using only seed that has been treated with a fungicide will prevent the introduction of the disease into a field. Burying infested crop residues will eliminate a source of spread of the disease. All diseased or damaged roots should be discarded before storage. Maintaining the storage temperature near

0 °C and the relative humidity at about 92 percent will help keep storage decay to a minimum. It is important that storage space and containers be cleaned and disinfested before use.
Resistant cultivars: Some resistance exists among cultivars.

Issues for Alternaria Black Rot

None identified.

Pythium Diseases: Cavity Spot and Pythium Root Dieback (Rusty Root) (*Pythium* spp.)

Pest Information

Damage: Symptoms of Pythium root dieback include a rusty discolouration of lateral roots and forking and stunting of tap roots, which results in poor tap root quality. Foliage is stunted and wilted and whole seedlings may wilt or die. Cavity spot rarely reduces yield, but can have significant effects on quality. Roots have elliptical lesions on the surface that are horizontally elongated and sunken and that enlarge as carrot grows. These lesions may also serve as entry points for secondary infections leading to rapid rotting. Symptoms can be easily confused with damage from nematodes, soil compaction or soil drainage problems.

Life cycle: Pythium is favoured by moist soil conditions with spores transported by water to the host. The pathogen survives on dead plant material and on living plants in wet soils, and may persist indefinitely in fields. The primary carrot root may become infected within the first week of growth followed by root tip necrosis at the two-leaf stage. Mature plants are able to resist infection; however, seeds and young seedlings are much more susceptible.

Pest Management

Cultural control: Seeding after soil has warmed up and avoiding dense seeding into severely infested fields and poorly drained soil, may help reduce infection. A three-year crop rotation including potato, onion, corn, mint and cabbage can reduce pathogen pressure. Avoiding problem fields is helpful if that option is available. Additional management practices for cavity spot are listed in *Table 5*.

Resistant cultivars: Several cultivars that have high tolerance to *Pythium* spp. are available including *Spartan Fancy*, *Canada Super X*, *Orlando Gold*, *Six Pack* and *Paramount*.

Issues for Pythium Diseases

1. Continued work is required to develop cultural and chemical controls for cavity spot.
2. The value and cost/benefit of fungicide applications for cavity spot and rusty root control need to be determined.
3. Continued work is required to develop cultural and chemical controls for rusty root.

Aster Yellows (Phytoplasma)

Pest Information

Damage: Aster yellows is characterized by a yellowing of the leaves and vein clearing at the center of the crown followed by new growth with a "witch's broom" appearance where older leaves become bronze or reddish colour. When grown for seed, the flowering umbels display stunting, chlorosis, malformation and sterility. Carrots become deformed and dwarfed, produce masses of fibrous side roots and have poor texture, colour and flavour. The pathogen also pre-disposes plants to other diseases, such as soft rot. Severe yield losses are possible, as the disease affects both above and below ground parts of the plant.

Life cycle: Various species of leafhoppers spread the pathogen. The phytoplasma can overwinter in leafhoppers and also in perennial host plants, such as weeds, susceptible grains and ornamental plants. After acquiring the pathogen, 10 days are required before leafhoppers are able to transmit the disease to new plants. A leafhopper may remain active and continue to spread the disease for more than 100 days after acquiring the pathogen. Disease symptoms become visible between 10 and 21 days after infection. The occurrence of the disease in carrots is directly related to the flight of leafhoppers from areas with diseased plants to new plantings of carrots. Once the carrot is infected, this disease may also continue its development during storage.

Pest Management

Cultural control: Management of weed hosts of the pathogen, both in field and in adjacent fields and ditches as well as avoiding planting near lettuce or other susceptible crops, can help to reduce the risk of disease development. Early planting is important to establish plants before infection is a concern. Monitoring leafhoppers and their migrations from field to field is important for early season vectors. Scouting is done using sweep nets and sticky traps. Additional management practices for aster yellows are listed in *Table 5*.

Issues for Aster Yellows

1. There is a need to formally assess carrot varieties to determine their tolerance to aster yellows.

Root Lesion Nematode (*Pratylenchus* spp.)

Pest Information

Damage: Root lesion nematode is a plant parasitic nematode which feeds on the roots of carrot causing yellowing, stunting and wilting of foliage. Feeding sites also provide entrance sites for pathogenic soil bacteria and fungi which can grow rapidly in the lesion and accelerate decomposition of root tissues. Affected tap roots are undersized, branched and slow to mature.

Life cycle: The pest is a microscopic, plant parasitic roundworm found in the soil. It pierces plant cell walls with a hollow stylet from which it injects secretions. Nematodes migrate through the soil and infect roots. Eggs are laid in soil or root tissues and upon hatching, juvenile nematodes feed on plant cells killing plant tissues. Depending on moisture, host type and soil temperature, the life cycle from egg to adult can take between 40 to 90 days with an optimum temperature ranging from 15 to 25 ^{o}C. The entire development cycle takes place inside the root. By moving within the root, the nematode causes injuries or lesions, allowing certain pathogenic fungi to enter the plants. A complete development cycle lasts four to six weeks.

Pest Management

Cultural control: Elimination of infested crop residue, rotation with non-host crops and fallowing between crops may be effective in reducing nematodes in carrot fields. Weed control in the field and along field edges will help reduce population, since weeds are excellent host plants. Soil from fields suspected to be infested can be tested for nematodes to enable growers to avoid planting carrots in fields where these are a problem. Additional management practices for nematodes are listed in *Table 5.*

Resistant cultivars: None available.

Issues for Root Lesion Nematode

1. The development of an effective control strategy that involves crop rotations, chemicals, biofumigants and antagonistic plants is required for the management of root lesion nematode in carrots.

Northern Root-Knot Nematode (*Meloidogyne hapla)*

Pest Information

Damage: The first indications of root knot nematode are missing or stunted plants in the field. Infected plants will appear chlorotic with a tendency to wilt. Older leaves may turn yellow, dry or senesce prematurely. Nematodes feed on root tips and rootlets, affecting foliar and root growth. The pest delays maturity and causes malformation of the edible root, including branching, galling (knobbing) and hairiness resulting in reduced marketable yields due to poor appearance of tap roots. Damage levels can be high even when nematode populations are low.

Life cycle: Meloidogyne hapla is an endoparasitic nematode with six stages of development (egg, four juvenile stages, and adult). Juvenile nematodes are mobile and are attracted by root secretions, pick through root tips and feed on plant cells. As they mature, they move through the roots and establish other feeding sites in the vascular tissue. Feeding results in gall formation, branching roots and other root distortions. Then mature females lay eggs on the surfaces of galls. Infective second-stage juveniles develop in about two weeks to re-infect new roots and form new galls. The northern root knot nematode can have more than one generation per year. Females can lay from 500 to 1000 eggs in a gelatinous matrix which protect and maintain the eggs viability. Contrary to other *Meloidogyne* species, the northern species can survive in frozen soils in its egg or juvenile forms.

Pest Management

Cultural control: Crop rotation using non-host crops such as onions, corn and cereals may help reduce populations of this nematode. Treatment thresholds are available for the pest. Early harvesting may help to reduce *M. hapla* damage. Fall soil sampling for nematodes is important, especially for carrots grown in sandy, mineral soils. Threshold levels for *M. hapla* depend on soil type. Additional management practices for nematodes are listed in *Table 5*.

Resistant cultivars: None available.

Issues for Root-Knot Nematode

1. The development of an effective control strategy that involves crop rotations, chemicals, biofumigants and antagonistic plants is required for the management of the northern root-knot nematode in carrots.

Carrot Cyst Nematode (*Heterodera carotae*)

Pest Information

Damage: Carrot cyst nematode has a similar physiology to the root-knot nematode and can cause serious damage to carrot crops. Infected plants have stunted growth, resulting in smaller, forked carrots with a proliferation of secondary roots and in some cases, visible cysts.

Life cycle: The life cycle from egg to adult is similar to the root-knot nematode and the root lesion nematode.

Pest Management

Cultural control: Elimination of infested crop residue, rotation with non-host crops and fallowing between crops may be effective in reducing nematodes in carrot fields. Weed control on the edges and in the fields will help reduce population, since weeds are excellent host plants. Additional management practices for nematodes are listed in *Table 5.*

Resistant cultivars: None available.

Issues for Carrot Cyst Nematode

1. The development of an effective control strategy that involves crop rotations, chemicals biofumigants and antagonistic plants is required for the management of cyst nematode in carrots.

Fusarium Dry Rot (*Fusarium* spp.)

Pest Information

Damage: Fusarium dry rot pathogens produce a crown rot and cankers on the carrots and affect carrots in storage. The disease causes discolored carrot root tissues which dry and crumble easily, and may completely rot.

Life cycle: The pathogens survive in the soil for many years, can overwinter on infected seed and may persist in plant residues as dormant hyphae or chlamydospores. In storage, disease is favoured by high humidity and temperatures between 15 and 20 °C. Lower temperatures and humidity slow the progress of the rot, but do not stop it. The disease can be spread to healthy carrots by air-borne spores or mycelial contact in storage.

Pest Management

Cultural control: Planting certified disease-free seed and use of clean equipment help reduce the spread of this disease. Gentle handling at harvest and post-harvest conditions are very important in reducing the impact of this disease. Rapid cooling of carrots after harvest and storage with proper ventilation, a temperature of 1 ^{o}C or less and a relative humidity between 90 and 95 percent, help reduce losses caused by storage rot.

Resistant cultivars: None available.

Issues for Fusarium Dry Rot

1. Fusarium dry rot can significantly affect fields and substantially reduce carrot yields. More research is needed on the management and control of this disease.

Bacterial Soft Rot (*Pectobacterium carotovorum* subsp. *carotovorum*)

Pest Information

Damage: Symptoms of bacterial soft rot appear on carrot as water-soaked lesions which become mushy, opaque and slimy. Affected tissues collapse or form cracks, enabling secondary organisms to invade the roots under waterlogged soil conditions. Rotted roots break easily when removed from the soil.

Life cycle: Carrots may be affected by bacterial soft rot in the field, in transit or in storage. The bacterium infects roots through lenticels, wounds or as a result of chilling injury or bruising. Soft rot development is more prevalent on young roots in the field when soil conditions are wet and temperatures are warm. In storage, the disease occurs when carrots are stored at improper temperatures.

Pest Management

Cultural control: Well drained soil is less conducive to the development of bacterial soft rot. Planting on raised beds, especially in poorly drained areas may reduce infection. Minimizing wounding or bruising of carrots during harvest and allowing carrots to cure properly before

storage will reduce development of the disease in storage. Sanitation practices including disinfection of all equipment before planting, grading-out of rotting and diseased roots before storage, and the use of clean water for washing carrots will also minimize soft rot development. Rapid cooling of carrots after harvest, maintaining proper ventilation and a temperature of 1 ^{o}C or less as well as a relative humidity between 90 and 95 percent in storage, help reduce losses caused by storage rot.

Resistant cultivars: None available.

Issues for Bacterial Soft Rot

None identified.

Sour Rot (*Geotrichum candidum*)

Pest Information

Damage: Sour rot is a post-harvest storage disease in carrots that causes a rapid, sour-smelling, watery decay.

Life cycle: Geotrichum candidum is a yeast-like, soil-borne fungus producing conidia, which are able to grow at a temperatures ranging from 5 to 30 ^{o}C with optimum growth at 25 ^{o}C. Carrots are most susceptible to this fungus when they are over-matured and in high moisture environments. The pathogen may be spread by contaminated farm machinery or equipment.

Pest Management

Cultural control: Well drained soil is less conducive to the development of sour rot. Minimizing wounding or bruising of carrots during harvest and allowing carrots to cure properly before storage will reduce development of the disease in storage. Sanitation practices including disinfection of all equipment, grading-out of rotting and diseased roots before storage, and the use of clean water for washing carrots will also minimize sour rot development.

Resistant cultivars: None available.

Issues for Sour Rot

None identified.

Insects and Mites

Key issues

- There is a need for the registration of additional pest control products, both conventional and non-conventional, for the control and for resistance management of carrot weevil, carrot rust fly, and aster leafhoppers.

- Additional research is needed to develop and facilitate the adoption of alternative cultural control methods for carrot weevil, as well as research into the biology of second generation of weevils.

- There is a need for the development of alternative approaches for management of the carrot rust fly including methods such as the use of row covers, exclusion fences, sterile flies, baits and deterrent products.

- Wireworms can be a serious problem on minerals soils (much less of an issue on muck soil) with no effective insecticides available for their control. There is a need for the registration of effective products and alternative strategies for wireworm control in carrots.

Table 6. Occurrence of insect pests in carrot production in Canada[1,2]

Insect and mite	Ontario	Quebec	Nova Scotia	Prince Edward Island
Aster leafhopper				
Carrot weevil				
Carrot rust fly				
Cutworms				
Wireworms				
Millipedes				

Widespread yearly occurrence with high pest pressure.

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

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

Localized yearly occurrence with low to moderate pest pressure OR widespread sporadic occurrence with low pressure OR localized sporadic occurrence with low to moderate pest pressure OR pest not of concern.

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

Pest not present.

Data not reported.

[1]Source: Carrot stakeholders in reporting provinces ; the data reflect the 2018, 2017 and 2016 production years.
[2]Refer to Appendix 1 for a detailed explanation of colour coding of occurrence data.

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

	Practice / Pest	Aster leafhopper	Carrot weevil	Carrot rust fly	Cutworms	Wireworms
Avoidance	Varietal selection / use of resistant or tolerant varieties					
	Planting / harvest date adjustment					
	Rotation with non-host crops					
	Choice of planting site					
	Optimizing fertilization for balanced growth					
	Minimizing wounding to reduce attractiveness to pests					
	Reducing pest populations at field perimeters					
	Use of physical barriers (e.g., mulches, netting, floating row covers)					
	Use of pest-free propagative materials (e.g., seeds, cuttings or transplants)					
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					
	Pruning out / removal of infested material throughout the growing season					

…continued

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

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

…continued

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

Practice / Pest		Aster leafhopper	Carrot weevil	Carrot rust fly	Cutworms	Wireworms
Suppression	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, etc.)					
	Mating disruption through the use of pheromones					
	Mating disruption throught the release of sterile insects					
	Trapping					
	Targeted pesticide applications (banding, spot treatments, use of variable rate sprayers, etc.)					
	Selection of pesticides that are soft on beneficial insects, pollinators and other non-target organisms					
This practice is used to manage this pest by at least some growers in the province.						
This practice is not used by growers in the province to manage this pest.						
This practice is not applicable for the management of this pest.						
Information regarding the practice for this pest is unknown.						

[1]Source: Carrot stakeholders in reporting provinces (Ontario, Quebec and Nova Scotia); the data reflect the 2018, 2017 and 2016 production years.

Aster Leafhopper (*Macrosteles quadrilineatus*)

Pest Information

Damage: This insect is present across Canada. Adults and nymphs feed on carrot foliage and many other plant species. This feeding does not cause economic damage but can result in the transmission of the aster yellows disease. The severity of the disease is dependent on the numbers of leafhoppers and the proportion of phytoplasma-infected leafhoppers in the population (see description in disease section).

Life cycle: While some leafhoppers are able to overwinter as eggs on winter cereals or in weedy areas along field margins, most are blown northward on prevailing winds from the United States and arrive in early spring. Adults appear from early to late May on cereals, grasses and forages where they mate before moving to carrots. They lay eggs in the stems of carrot plants in early July. Depending on location and suitability of the weather, the aster leafhopper may have up to five overlapping generations per year.

Pest Management

Cultural control: Early seeding may minimize damage from leafhopper populations; however, there are no effective preventative measures for aster leafhopper since it has many host crops including thistles, fleabane, wild lettuce, sow-thistle, chicory, wild carrot, dandelion, plantain, and others. Monitoring for aster leafhopper can be done using sticky traps and sweep nets. Crops such as lettuce, endive, parsnip and celery may also be affected by aster yellows. Additional management practices for aster leafhopper are listed in *Table 7*.

Resistant cultivars: Resistant cultivars are available.

Issues for Aster Leafhopper

1. There is a need for a timely, economical, and accurate method to determine the percentage of leafhoppers carrying the phytoplasma. As well, thresholds for leafhoppers populations need to be established.
2. There is a need to improve monitoring methods for control of the aster leafhopper.
3. There is a need for the registration of additional products for the control of aster leafhopper and for resistance management.

Carrot Weevil (*Listronotus oregonensis*)

Pest Information

Damage: Carrot weevil can also attack other members of the Apiaceae, Umbellifereae, Polygonaceae and Plantaginaceae families. Economic damage to carrots results from larvae tunnelling in the petioles and roots of the plant. Larval tunnels appear in the upper third of the carrot root. Adults also cause injury when they excavate areas for egg laying in young carrots. Carrot plants wilt or die due to these injuries. In addition, plants become susceptible to bacterial and fungal infections through tunnels made by larvae.

Life cycle: Adults overwinter in fields, field margins and ditch banks in the upper 6 to 8 cm of the soil. They emerge early spring and feed on young carrot foliage. Females lay two to three eggs per carrot petiole, sealing the cavity with a black exudate, when plants reach the four-leaf stage. Larvae tunnel into the roots where they feed, then leave the root to pupate in the soil, emerging as adults in late summer. Adults then feed on carrot foliage, then search for a wintering site. There is usually only one generation per year, but there may be a partial second generation in some regions depending on temperature and earliness of the carrot crop.

Pest Management

Cultural control: Monitoring using wooden-plate traps may be effective in determining the level of infestation in order to determine the appropriate treatment. Good weed control to remove alternate hosts throughout the year can help reduce populations of the pest. Late plantings will avoid the first generation of weevils in the spring. Adults rarely fly and do not spread rapidly. A serious infestation can be delayed by not planting carrots on or adjacent to sites that were infested the preceding year. There are also many naturally occurring beetles and wasps that prey on the weevil in the egg, larval and adult stages. Additional management practices for carrot weevil are listed in Table 7.

Resistant cultivars: None available.

Issues for Carrot Weevil

1. The registration of additional products for carrot weevil control is required. Carrot weevils have become resistant to the primary insecticide that was used for control. Currently only one product (Group 15 insecticide) is registered and effective on muck soils. Proposed regulatory re-evaluations might result in the loss of products available for use on mineral soils as well.
2. Additional research is needed to develop and facilitate the adoption of alternative, cultural control methods for carrot weevil.
3. Additional research is required on the biology of the second generation of weevil in Ontario and Quebec.
4. There is a need for biological control alternatives to improve the management of carrot weevil.

Carrot Rust Fly (*Psila rosae*)

Pest Information

Damage: Larvae of the carrot rust fly create tunnels in the roots of carrots, making them unmarketable. Roots may become forked or fibrous and riddled with rust-red tunnels. Attacks also result in the stunting of carrot plants, and seedlings may be killed if the growing tips are severely injured. Increased incidence of secondary infection of carrot roots by bacteria and fungi through tunnels made by larvae may result, contributing to post-harvest decay in storage.

Life cycle: The insect overwinters as pupae in the soil, with adults emerging from early spring to early summer, depending on location, when soil temperature is above 5 ^{o}C. Adults begin to emerge in late May, after about 250 degree-days above 5 °C, and may be present until near the end of June. Females lay eggs in the soil around carrots. After hatching, larvae feed on the lower third of the carrot root. When full-grown, after their third moult, larvae leave the roots to pupate in the soil. There may be one, two or a partial third generation per year depending on the growing region. Larvae of the second-generation spend the winter in the soil.

Pest Management

Cultural control: The use of a three-year crop rotation and avoiding fields in which carrots were planted the previous year or in the vicinity of wild hosts may help to reduce the population of the carrot rust fly. Injury caused by the first generation of the pest can be avoided by delaying planting until mid-June. Adults can be monitored with yellow sticky traps. Harvesting can be done in late September before damage is incurred in the fall. Additional management practices for carrot rust fly are listed in *Table 7.*

Resistant cultivars: None identified.

Issues for Carrot Rust Fly

1. There is a need for the registration of additional products to allow rotation of different modes of action for the control of carrot rust fly and management of pesticide resistance in the pest population.
2. The development of alternative approaches to control the carrot rust fly including the use of row covers, exclusion fences, sterile flies, baits and deterrent products, is required.
3. Continued research on degree day models, the distribution and movement of infestations in the field and the life cycle of the carrot rust fly is needed.

Cutworms (Noctuidae): Variegated Cutworm (*Peridroma saucia*), Black Cutworm (*Agrotis ipsilon*), and other species

Pest Information

Damage: Cutworms feed at or below the soil surface at night. They also actively feed on young foliage and stem tissue and can cut-off young seedlings. Heavy spring weed growth, broken sod and crop debris will favour cutworm infestations. Cutworms are most problematic in low, wet, grassy areas.

Life cycle: Cutworms pass through egg, larval, pupal, and adult stages with the number of generations per year depending on the species. In general, the first generation causes the most damage. The variegated cutworm overwinters as pupae in warmer parts of Canada and may also be blown into Canada from overwintering sites to the south. The black cutworm is wind-blown northward from the United States. The adult moths lay eggs on vegetation and plant debris in the vicinity of carrot fields. Following egg hatch, larvae feed on carrot foliage, developing through a number of instars prior to pupating and emerging as adults. Preferred egg laying sites are low growing vegetation, including chickweed, mustards or plant residues.

Pest Management

Cultural control: Crop rotation to avoid susceptible crops and refraining from planting in wet, grassy areas may help reduce the cutworm population. Ploughing in the fall will reduce overwintering populations. Fields can be monitored for cutworms early in the season by visually checking for damage. Pheromone traps may be used to monitor the flights of male moths and establish the period of egg-laying. Controlling weeds in the field and surrounding areas will make the area less attractive to egg-laying by cutworm moths. There are a number of naturally occurring braconid parasitoids and predaceous ground beetles that can help control cutworms. Additional management practices for cutworms are listed in *Table 7*.

Resistant cultivars: None available.

Issues for Cutworms

None identified.

Wireworms (*Elateridae*)

Pest Information

Damage: Wireworms feed on roots of carrot. They are especially a problem on land recently broken from sod. Heavy infestations result in poor emergence and vigour of carrots. Later in the season, the pest feeds on developing carrot roots, producing tunnels. Attacks on young carrot roots result in deformation and attacks on mature tap roots result in holes throughout, reducing quality at harvest and increasing the incidence of secondary infection by bacteria and fungi. Crops can be rendered unmarketable due to wireworm infestations. There are several native wireworm species that are recognized as major or minor pests of carrots. They attack a wide range of host plants, including most vegetable crops. A distribution map has been developed for wireworm species in some parts of Canada (see reference section).

Life cycle: Wireworms thrive in sod, red and sweet clover and in small grains such as barley and wheat. The adults are click beetles that lay eggs in the soil around the roots of host plants. Following hatching, larvae (wireworms) feed on plant roots then pupate and emerge as adults. The life-cycle ranges from three to six years, depending on the species, with two to five years spent as actively feeding larvae. There may be a number of different larval stages present in a field at a given time.

Pest Management

Cultural control: It is important to monitor fields prior to planting to establish whether threshold levels of wireworm are present. Wireworms can be monitored by sampling the soil in the fall or spring or through the use of bait stations. Avoiding fields that are severely infested will minimize injury to carrots due to wireworms. Wireworm numbers may also be reduced through rotations with non-host crops. Maintaining fields including fallow fields free of weeds will help to reduce wireworm populations. Additional management practices for wireworms are listed in *Table 7*.

Resistant cultivars: None identified.

Issues for Wireworms

1. Wireworms can be a serious problem on minerals soils (much less of an issue on muck soil) with no effective insecticides available for their control. There is a need for new products and integrated strategies for wireworm control in carrots.

Millipedes: *Cylindroiulus caeruleocinctus, Blaniulus guttulatus and Pseudopolydesmus* spp.

Pest Information

Damage: Millipedes feed on decaying organic matter and provide a useful role by breaking down organic matter and returning it to the soil. High populations can feed on carrot roots and seedlings. Millipedes are nocturnal feeders and release a defensive chemical if crushed.

Life cycle: Millipedes lay clusters of eggs in the soil. Larvae hatch from the eggs and mature through several successive moults. Fourteen moults are required in the case of *C. caeruleocinctus*, while *B. guttulatus* goes through 11 moults. It takes a year and half to achieve sexual maturity. Millipedes live up to five years.

Pest Management

Cultural control: Various traps are available to monitor millipedes in order to determine if control interventions are required. Early harvest, removal of crop residue after harvest, and avoiding practices that increase soil moisture above that required for the crop may help mitigate damage and reduce the millipede population.

Resistant cultivars: None available.

Issues for Millipedes

None identified.

Weeds

Key Issues

- Linuron is an important weed management tool in carrot production. It is anticipated that some critical uses of this herbicide may be phased out as a result of regulatory re-evaluation. Thus, it is critical that replacement product(s) be registered.

- There is a need for the development of alternative approaches to weed control in carrots.

Table 8. Occurrence of weeds in carrot production in Canada[1,2]

Weeds	Ontario	Quebec	Nova Scotia	Prince Edward Island
Annual broadleaf weeds				
Annual grasses				
Perennial broadleaf weeds				
Perennial grasses				
Herbicide resistant weeds				

Widespread yearly occurrence with high pest pressure.

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

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

Localized yearly occurrence with low to moderate pest pressure OR widespread sporadic occurrence with low pressure OR localized sporadic occurrence with low to moderate pest pressure OR pest not of concern.

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

Pest not present.

Data not reported.

[1]Source: Carrot stakeholders in reporting provinces; the data reflect the 2018, 2017 and 2016 production years
[2]Refer to Appendix 1 for a detailed explanation of colour coding of occurrence data.

Table 9. Adoption of weed management practices in carrot production in Canada

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

…continued

Table 9. Adoption of weed management practices in carrot production in Canada (continued)

Practice / Pest		Annual broadleaf weeds	Annual grasses	Perennial broadleaf weeds	Perennial grasses	Yellow nutsedge
Decision making tools	Economic threshold					
	Crop specialist recommendation or advisory bulletin					
	Decision to treat based on observed presence of weed at susceptible stage of development					
	Decision to treat based on observed crop damage					
	Use of portable electronic devices in the field to access weed identification / management information					
Suppression	Use of diverse herbicide modes of action for resistance management					
	Soil amendments and green manuring involving soil incorporation as biofumigants to reduce weed populations					
	Use of biopesticides (microbial and non-conventional pesticides)					
	Release of arthropod biological control agents					
	Mechanical weed control (cultivation / tillage)					
	Manual weed control (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 used by growers in the province to manage this pest.

This practice is not applicable for the management of this pest.

Information regarding the practice for this pest is unknown.

[1]Source: Carrot stakeholders in reporting provinces (Ontario, Quebec and Nova Scotia); the data reflect the 2018, 2017 and 2016 production years.

Annual and Biennial Weeds

Pest Information

Damage: Broadleaf weeds can reach heights similar to the carrot crop and compete for light, water and nutrients. Carrots are poor competitors and annual weeds can significantly reduce carrot growth and yield, if not controlled effectively. Weeds can also harbour pests such as nematodes. Annual grasses cause significant problems in carrot production due to their fast growth and ability to compete for necessary resources. Additionally, grass weeds are very tolerant to extremes in moisture and temperature once established. They can be very difficult to eliminate from infested fields. The critical stage for crop damage is early in the growing season when weeds must be controlled to prevent yield losses. It is important to control weeds during the harvest period to facilitate crop harvesting.

Life cycle: Annual grass and broadleaf weeds complete their life cycle from seed germination to new seed production in a single season. Spring annuals germinate in the early spring and produce seed in the summer or fall of the same year. Winter annuals grow to the rosette stage in the fall, maturing and producing seed early the following year. Annual weeds produce large numbers of seeds by which they easily spread. Most arable land is infested with annual weed seeds at all times. Some weed seeds can remain viable in the soil for many years, germinating when conditions are suitable. Biennial weeds are plants that germinate in the spring and produce a rosette of leaves that remains vegetative during the first summer. They overwinter as rosettes and in the next season, they flower and produce seed. The biennial plant dies at the end of the second growing season.

Pest Management

Cultural control: Avoiding planting carrots in fields known to be heavily infested with weeds or for which the weed history is unknown may reduce the chances of serious weed problems in the crop. Scouting fields the season before planting will help determine what weeds might be present and whether they can be controlled in the carrot crop. It is important to reduce difficult to control weed infestations to a manageable level before planting carrots. Purchasing certified seed will help ensure that weed seed is not planted along with the carrots. The removal of weeds from fence lines, ditches, and roadways will also help to prevent weed establishment in cropping areas. Weed seeds can be transported from field to field by equipment, wind, water, and animals. Cleaning soil and debris from equipment when leaving each field will help reduce the spread of weeds between fields. Manure applications can also introduce weeds to a field. Repeated tilling, prior to planting and cultivation after planting, can help reduce the number of weed seedlings. Monitoring for annual weeds can be done during the first two to three weeks after weed emergence if post-emergence controls are to be applied. Vigorous carrot stands are important to shade out germinating weed seed. Row spacing can be selected that will facilitate quick closure of the crop canopy. Crop rotation, that enables the use of a variety of weed control approaches in non-carrot years, is very useful for reducing weed pressure Additional management practices for weeds are listed in *Table 9.*

Resistant cultivars: Carrot varieties that give quick emergence and vigorous crop stands will help shade-out germinating weed seeds.

Issues for Annual and Biennial Weeds

1. There is a need to register herbicides in different chemical groups for weed management and to combat resistance development in some weed populations (e.g., crabgrass and redroot pigweed in Ontario; hairy nightshade, cleavers and common ragweed in Prince Edward Island; redroot pigweed and small ragweed in Quebec; and common ragweed in Nova Scotia).
2. Linuron is a vital tool in carrot production. As some uses of linuron may be phased out as a result of the regulatory re-evaluation, it is critical that replacement product(s) be registered.
3. There is a need for the development of alternative approaches to weed control in carrots.

Perennial Weeds

Pest Information

Damage: Perennial weeds can grow very large and be very competitive with carrots, especially if they have been established for several years. This can reduce growth and yield of the crop. The critical stage for crop damage is early in the growing season and during harvest as for annual weeds.

Life cycle: Perennial weeds live for several to many years. Perennials usually flower and produce seeds every year as well as expand their root system, and can spread effectively by both methods. Tillage practices can break up the underground root systems and aid in the spread of perennial weeds.

Pest Management

Cultural control: Management of perennial weeds is difficult in carrots, especially after the crop has been planted. It is important to avoid planting carrots into a field that has a history of serious perennial weed problems. Purchasing certified seed ensures that it contains the lowest possible quantities of weed seed. The removal of weeds from fence lines, ditches, and roadways will also help to reduce weed establishment in cropping areas. Cultivation is less effective in controlling perennial weeds than annual weeds, as the practice breaks up the underground portions of the plant, contributing to the weed problem. Equipment can be cleaned of all soil and debris when leaving each field, to reduce spread of weeds. Crop rotation effectively controls weeds by disrupting perennial weed life cycles and allowing a variety of control options and cultural practices that discourage normal weed growth. Additional management practices for weeds are listed in *Table 9*.

Resistant cultivars: Carrot varieties that give quick emergence and vigorous crop stands will help shade out germinating weed seeds.

Issues for Perennial Weeds

None identified.

Vertebrate Pests

There are a few vertebrate pests that can affect carrots. Groundhogs can destroy seedlings in the spring and deer can eat roots, and can be very destructive in fall.

Resources

Integrated Pest Management and Integrated Crop Management Resources for the Production of Carrot in Canada

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Centre de référence en agriculture et agroalimentaire du Québec. http://www.craaq.qc.ca

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Sage Pesticides. http://www.sagepesticides.qc.ca/default.aspx

Statistics Canada. *Fruit and vegetable production, 2018.*
https://www150.statcan.gc.ca/n1/daily-quotidien/190222/dq190222c-eng.htm

Provincial Contacts

Province	Ministry	Crop Specialist	Minor Use Coordinator
British Columbia	British Columbia Ministry of Agriculture www.gov.bc.ca/al	Susan Smith susan.l.smith@gov.bc.ca	Caroline Bédard caroline.bédard@gov.bc.ca
Manitoba	Manitoba Agriculture http://www.gov.mb.ca/agriculture/	Tom Gonsalves tom.gonsalves@gov.mb.ca	Colleen Flynn Colleen.Flynn@gov.mb.ca
Ontario	Ontario Ministry of Agriculture, Food and Rural Affairs www.omafra.gov.on.ca	Dennis Van Dyk dennis.vandyk@ontario.ca	Jim Chaput jim.chaput@ontario.ca
Quebec	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec www.mapaq.gouv.qc.ca	Melissa Gagnon melissa.gagnon@mapaq.gouv.qc.ca	Mathieu Coté mathieu.cote@mapaq.gouv.qc.ca
Nova Scotia	Nova Scotia Department of Agriculture https://novascotia.ca/agri/ Perennia www.perennia.ca	Rosalie Gillis-Madden madden@perennia.ca	Jason Sproule jason.spoule@novascotia.ca
Prince Edward Island	Prince Edward Island Department of Agriculture and Forestry www.gov.pe.ca/af	Adam MacLean adammaclean@gov.pe.ca	Sebastian Ibarra sibarra@gov.pe.ca

Provincial and National Carrot Grower Organizations

Association des producteurs maraîchers du Québec: https://apmquebec.com/en/index.sn/

Canadian Federation of Agriculture: https://www.cfa-fca.ca/

Canadian Horticultural Council: http://www.hortcouncil.ca

Canadian Organic Growers: https://www.cog.ca/

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

Prince Edward Island Horticultural Association peihort@pei.aibn.com

Appendix 1

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

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

<table>
<tr><th>Presence</th><th colspan="4">Occurrence information</th><th>Colour Code</th></tr>
<tr><td rowspan="12">Present</td><td rowspan="9">Data available</td><th>Frequency</th><th>Distribution</th><th>Pressure</th><td></td></tr>
<tr><td rowspan="6">Yearly - Pest is present 2 or more years out of 3 in a given region of the province.</td><td rowspan="3">Widespread - The pest population is generally distributed throughout crop growing regions of the province. In a given year, outbreaks may occur in any region.</td><td>High - If present, potential for spread and crop loss is high and controls must be implemented even for small populations.</td><td>Red</td></tr>
<tr><td>Moderate - If present, potential for spread and crop loss is moderate: pest situation must be monitored and controls may be implemented.</td><td>Orange</td></tr>
<tr><td>Low - If present, the pest causes low or negligible crop damage and controls need not be implemented.</td><td>Yellow</td></tr>
<tr><td rowspan="3">Localized - The pest is established as localized populations and is found only in scattered or limited areas of the province.</td><td>High - see above</td><td>Orange</td></tr>
<tr><td>Moderate - see above</td><td>White</td></tr>
<tr><td>Low - see above</td><td>White</td></tr>
<tr><td rowspan="6">Sporadic - Pest is present 1 year out of 3 in a given region of the province.</td><td rowspan="3">Widespread - as above</td><td>High - see above</td><td>Orange</td></tr>
<tr><td>Moderate - see above</td><td>Yellow</td></tr>
<tr><td>Low - see above</td><td>White</td></tr>
<tr><td rowspan="3">Localized - as above</td><td>High - see above</td><td>Yellow</td></tr>
<tr><td>Moderate -see above</td><td>White</td></tr>
<tr><td>Low - see above</td><td>White</td></tr>
<tr><td rowspan="2">Data not available</td><td colspan="3">Not of concern: The pest is present in commercial crop growing areas of the province but is causing no significant damage. Little is known about its population distribution and frequency in this province; however, it is not of concern.</td><td>White</td></tr>
<tr><td colspan="3">Is of concern: The pest is present in commercial crop growing areas of the province. Little is known about its population distribution and frequency of outbreaks in this province and due to its potential to cause economic damage, is of concern.</td><td>Blue</td></tr>
<tr><td>Not present</td><td colspan="4">The pest is not present in commercial crop growing areas of the province, to the best of your knowledge.</td><td>Black</td></tr>
<tr><td>Data not reported</td><td colspan="4">Information on the pest in this province is unknown. No data is being reported for this pest.</td><td>Grey</td></tr>
</table>

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