16 Potato

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BACTERIAL DISEASES

▶ 16.1 Bacterial ring rot (ring rot) *Figs. 16.1a-e*

Clavibacter michiganensis subsp. *sepedonicus* (Spieckermann & Kotthoff) Davis *et al.*
(syn. *Corynebacterium sepedonicum* (Spieckermann & Kotthoff) Skapston & Burkholder)

Bacterial ring rot is a very serious potato disease because of its destructiveness and highly infectious nature. It was originally described in Germany in 1906 and was first reported in North America in 1931. It often has caused major crop losses in Canada, but since the early 1970s rigid seed inspection procedures and disease control programs have kept outbreaks to a minimum. The objective in Canada is to systematically eradicate bacterial ring rot (see Introduced diseases and pests, 3.11).

In nature, the ring rot organism infects only potato, but under laboratory conditions it is also able to infect tomato, eggplant and a number of other *Solanum* species. The pathogen has been isolated from sugarbeet seed.

Symptoms Symptoms in the field vary with cultivar and overall crop condition and can range from nothing visible to distinctive symptoms. Foliar symptoms usually do not appear until after flowering, but certain cultivars, such as Russet Burbank, may develop an early season dwarf- rosette. More conspicuous foliar symptoms generally appear at mid-season or later, and usually begin on middle and lower leaves *(16.1a).* Wilted leaflets are slightly rolled at the margins, and light green to pale yellow areas develop in the interveinal spaces. As wilt progresses, the affected foliage becomes necrotic and symptoms move upward until the entire stem wilts and dies *(16.1b).* The most important diagnostic symptoms in the field are one or more wilted stems in a hill and a milky exudate that can be squeezed from the stem near the point of attachment to the mother tuber piece. Vascular tissues in these stems may appear brown.

The characteristic tuber symptom of ring rot is a decay of the vascular ring tissues *(16.1c).* Vascular discoloration is usually most apparent at the stem end of the tuber, which may exude a milky or cheezy ooze when squeezed. This decay usually occurs after the appearance of foliar symptoms, but it does not always develop in the tubers of infected plants.

Badly affected tubers *(16. 1d)* exhibit ragged skin cracks, reddish-brown discoloration near the eyes, and may collapse into a semi-liquid soup when handled *(16.1e).* Secondary invaders, notably soft rot bacteria, can cause a foul-smelling decay that masks the symptoms of ring rot.

Under cool growing conditions or in fields with high levels of soil nitrogen, plants may not develop symptoms but still produce infected tubers. Infected tubers may be symptomless at harvest and can take two or three months to develop ring rot symptoms in storage, if at all.

Causal agent Cells of *Clavibacter michiganensis* subsp. *sepedonicus* are Gram-positive, club-shaped, non-motile rods, measuring 0.4 to 0.6 by 0.8 to 1.2 pm. Colonies on nutrient agar are white, thin, translucent and glistening. Cells are non-acid-fast. Gelatin is not liquefied and nitrates are not reduced. Acid is produced from arabinose, xylose, dextrose, galactose, fructose, sucrose, maltose, cellobiose, mannitol and salicin, but not rhamnose. The optimum temperature for growth in culture is 18 to 21°C, with a maximum of 30°C.

Laboratory diagnostic techniques for confirming the presence of this pathogen from typical ring rot or symptomless tubers are varied. The Gram-staining technique, while reliable, has been superceded largely by the immunofluorescent antibody staining (IFAS) and latex agglutination tests. These highly specific antibody systems can detect extremely low levels of ring rot bacteria and are particularly useful for checking symptomless potatoes. The enzyme-linked immunosorbent assay (ELISA) test also offers sensitivity and specificity. It is used routinely in many provinces to detect both bacteria and viruses in potatoes. DNA probes are under development and should soon be available for general use.

Disease cycle The bacteria normally overwinter in infected tubers in storage, or in mild climates in the field. Infected tubers may not exhibit disease symptoms. The organism can survive many months on dry surfaces such as bags, crates and walls at temperatures below freezing. The viability of the organism is rapidly lost in warm, moist soil.

Tuber infection generally occurs through wounds from seed-cutting knives, picker planters and harvesters. Conditions for the spread of ring rot are most favorable at planting when tubers are cut into seed pieces. Bacteria from infected tubers may be smeared by cutting knives onto freshly cut seed surfaces. Extremely high levels of infection can occur from very few infected tubers in a multi-tonne seed lot. If infection levels or diseased tubers exceed 5% in the field, there is a high risk of the entire crop rotting in storage. Reports from the United States suggest that the Colorado potato beetle and green peach aphid can vector the pathogen.

No potato cultivars are immune, but some, such as Désirée, Rose Gold, BelRus, Urgenta and Teton, rarely exhibit symptoms yet may harbor the bacterium. There is also a range of susceptibility among cultivars; for example, Norchip, Red Pontiac and Shepody nearly always exhibit symptoms, whereas Russet Burbank and Red La Soda do not always show typical symptoms. More importantly, even among susceptible cultivars, individual plants may remain symptomless. This so-called “latency” is the major reason bacterial ring rot cannot be eradicated by visual inspection alone.

Management

Cultural practices — Planting Certified or higher class disease-free seed tubers and following strict sanitation procedures are the most practical control measures. If ring rot is confirmed on a farm, the grower should take the following measures to eradicate the disease:

- Dispose of all potato stocks by using them for food or feed;
- Thoroughly wash with a high pressure spray the storage area, pallets and all machinery involved in the handling of potatoes during planting, harvesting, storage and grading, and then disinfest them with products such as formaldehyde, commercial bleach, and quaternary ammonium solutions specifically formulated for this purpose are effective; washing and disinfesting should be done daily, and always between seed lots, when planting;
- Dispose of all used potato bags;
- Plant only Certified or a higher class of seed;
- Plant small, whole (uncut) seed tubers;
- Follow a three-year crop rotation, particularly where the climate is mild enough to allow volunteer potato plants to overwinter in the field;
- Avoid growing potato for at least two to three years after sugar beet has been grown in the same field;
- Control potential insect vectors such as the Colorado potato beetle and green peach aphid.

The Canadian certification system has a zero tolerance for this disease. All potatoes grown for seed are visually inspected for ring rot, and a major proportion of the seed hectarage is also checked by post-harvest laboratory tests. Seed potato growers who have had crops affected by bacterial ring rot must follow rigorous sanitation procedures before they will be permitted to produce seed potatoes again. Any fields in which ring rot was found cannot be replanted to potato for at least two years.

Resistant cultivars — No cultivars are known to be immune. The growing of resistant cultivars is discouraged in most areas of Canada, because they can be symptomless carriers of ring rot bacteria and a source of infection for susceptible, main crop cultivars. This risk can be reduced by requiring all growers to plant certified seed.

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(Original by I.R. Evans and B. Otrysko)

▶ 16.2 Bacterial soft rot (soft rot) *Figs. 16.2a,b; 16.2T1*

Bacillus spp.
Clostridium spp.
Erwinia carotovora subsp. *carotovora* (Jones) Bergey *et al.*
Erwinia carotovora subsp. *atroseptica* (van Hall) Dye
Flavobacterium spp.
Pseudomonas spp.

Soft rot can damage potato in the field and storage. Losses may be severe, especially in storage. Soft rot bacteria can attack a wide range of root, fruit and leafy vegetables, such as carrot, cabbage, onion and tomato.

Symptoms Bacterial soft rots generally occur with other diseases such as ring rot, late blight, leak and blackleg. Symptoms usually are confined to the tubers, which may be infected through lenticels, causing the surrounding tissue to collapse and form brown sunken lesions up to 1 cm in diameter *(16.2a).* If a tuber becomes badly bruised during handling, the whole tuber may become infected. Infected areas are cream-colored and later become brown, slimy and foul smelling *(16.2b).* A sharp line in the tuber separates diseased from healthy tissue. Wet growing conditions can result in infected tubers rotting in the ground. Stored potatoes can be seriously damaged if frozen or harvested under wet conditions.

Causal agents *Erwinia carotovora* subsp. *carotovora* is a rod-shaped, Gram-negative bacterium, 0.5 to 0.8 by 1.0 to 3.0 µm, with peritrichous flagella. It occurs singly, in pairs or as short chains, does not form spores, and is facultatively anaerobic. (For a description of *Erwinia carotovora* subsp. *atroseptica,* see blackleg, 16.3.)

Erwinia bacteria can be readily isolated from plant tissue taken from the edge of a rotted area. When plated onto selective media containing polypectate, such as Stewart-MacConkey or Cuppels-Kelman crystal violet pectate medium, these bacteria form deep pits or craters in the agar. Other aerobic, pectolytic bacteria that may be associated with soft rot, such as *Bacillus, Pseudomonas* and *Flavobacterium* spp., generally grow poorly or only form shallow pits on pectate media.

Most strains of *E. carotovora* subsp. *carotovora* do not form acid from α-methyl glucoside or reducing substances from sucrose. They do not grow on nutrient agar or in nutrient broth at temperatures greater than 36°C. Most strains do not produce acid from maltose. Serological techniques can be used to distinguish soft rot from blackleg bacteria.

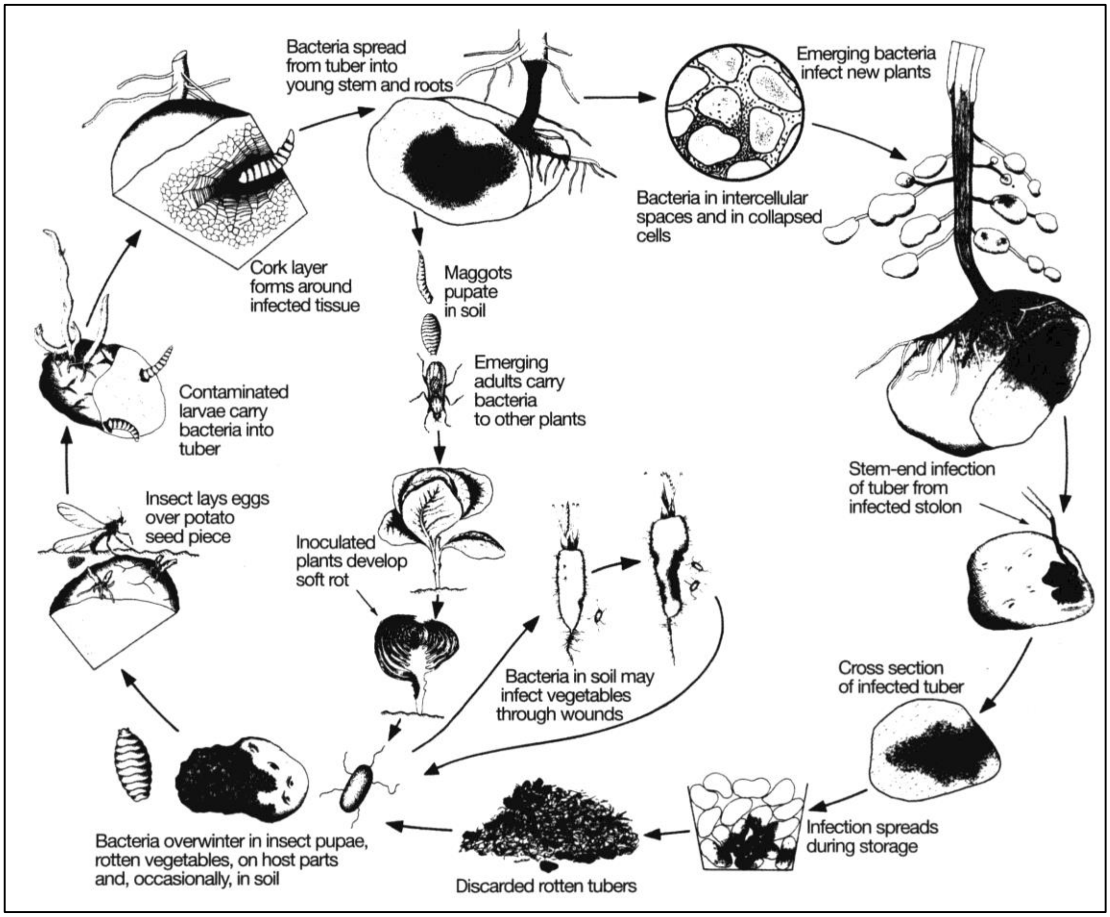
Disease cycle Soft rot bacteria can survive for several months in the soil and can be dispersed by irrigation water *(16.2T1).* They usually invade tubers following mechanical, freezing or insect injury and following damage by other disease organisms. Soft rot is favored by high temperatures and abundant soil moisture. Immature tubers are more susceptible to rot than mature ones.

The disease can spread from infected to healthy tubers during storage or transit under conditions of high humidity and poor ventilation. Washing potatoes in dirty water and packaging warm, wet tubers in poorly ventilated plastic bags promote soft rot development.

Management

Cultural practices — Potato should be grown in well-drained, fertile soils, and only mature tubers should be harvested. Vine killing before harvest hastens tuber maturation. Potatoes that are to be packaged soon after harvest should be dug when soil and air temperatures are low to cool the tubers. Controlling other tuber diseases and the careful handling of tubers to minimize wounds and bruises minimizes soft rot. Growers should follow the disease management strategies described for blackleg.

When washing table-stock tubers, the water should be changed frequently to avoid the build-up of high bacterial populations. Prolonged soaking should be avoided. Clean water should be used for the final rinse to cleanse the tubers and they should be dried before packaging. Seed potatoes should not be washed, thus avoiding damage and moisture build up on the tubers that could favor soft rot infection and increase seed piece decay.



16.2T1 Bacterial soft rot; disease cycle of *Erwinia* spp. on vegetable crops. Reprinted by permission from G.H. Agrios, *Plant Pathology.* © 1988 Academic Press.

Chemical control — Chlorination of rinse water reduces the residual populations of soft rot bacteria on tubers before packaging for market. Growers and packers should consult the Health Protection Branch, Health Canada, for guidelines on using chlorinated water on vegetables.

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(Original by I.R. Evans and R.J Howard)

▶ 16.3 Blackleg *Figs. 16.3a—c*

Erwinia carotovora subsp. *atroseptica* (van Hall) Dye
Erwinia carotovora subsp. *carotovora* (Jones) Bergey *et al.*

Blackleg occurs in all potato-growing areas and is often found in conjunction with soft rot. This disease can cause heavy losses in both seed and table stock crops. Blackleg severity depends on seed-handling techniques, amount of inoculum on seed tubers, soil moisture and temperature at planting, growing conditions, the cultivar used, and on external sources of bacteria. Potato is the only agricultural crop affected by *Erwinia carotovora* subsp. *atroseptica,* whereas *E. carotovora* subsp. *carotovora* has a wide host range that includes many vegetable crops.

Symptoms Seed piece decay can significantly reduce germination and plant stands. The disease is generally first noticed at flowering, when one or more stems on a plant suddenly wilt. Wilting is usually most apparent during hot weather and may be accompanied by leaf yellowing *(16.3a).* The lower part of the stem often appears grayish brown or black. The stem may later turn an inky black, generally from just above the soil line to around 15 cm up the stem *(16.3c).* Blackleg occurs with varying degrees of intensity in a crop and is most frequently seen in low areas of fields. Affected stems become soft above and below the soil line.

Blackleg can stunt the growth of young potato plants. On older plants, interveinal yellowing and browning and the upward cupping of leaves are characteristic symptoms. Under some conditions, affected plants appear stiff and erect. In certain cultivars, wilting and leaf symptoms caused by blackleg resemble those caused by ring rot, except that the tubers do not show the vascular decay typical of ring rot.

Blackleg bacteria also can infect and cause rotting of tubers, but such decay is not always associated with plants that have typical foliar symptoms. Tuber symptoms can range from a slight vascular discoloration to complete soft rot *(16.3b).* Infection usually begins at the stem end and appears as a creamy, odorless, soft decay that is sharply separated from the healthy tissue by a dark brown to black line. Infected lenticels are usually surrounded by sunken, water-soaked, circular lesions.

Infection by *Erwinia carotovora* subsp. *carotovora* can also produce blackleg symptoms under warm growing conditions.

Causal agent *Erwinia carotovora* subsp. *atroseptica* is a Gram-negative rod that occurs as single or paired cells or occasionally in chains of a few cells. It is 0.5 to 0.8 by 1 to 2.5 µm, motile by peritrichous flagella and facultatively anaerobic. It can be distinguished from *E. carotovora* subsp. *carotovora* (see bacterial soft rot, 16.2) by its failure to grow at 37°C and by the production of reducing substances from sucrose and acid from maltose and a-methyl glucoside.

Disease cycle Blackleg bacteria are borne in or on seed tubers, on the roots of some crops, such as cereals and sugar beet, and on the roots of weeds such as nightshade, lamb's-quarters, pigweed, Russian thistle, kochia, purslane and mallow (see Weeds, 2.3). Blackleg bacteria can also be dispersed in irrigation water. They probably do not survive in the soil for more than a year in the absence of a host. The bacteria can readily spread from diseased to healthy tubers during seed cutting, and infection is favored if wound healing is delayed. Bacteria can cause decay of infected seed pieces before sprouts emerge, especially if the soil is wet. In some cases, infected seed pieces decay slowly and the bacteria move into vascular tissues of stems after the sprouts emerge. *Erwinia* species can multiply in the stems, degrade the vascular and pith tissues and cause foliar symptoms. During the growing season, bacteria from decaying seed pieces may move as far as 60 cm in soil water and contaminate new tubers. In addition, bacteria from decaying stems and tubers may contaminate non-infested tubers during harvest. Infested tubers may rot in storage, further spreading this disease, or the bacteria may survive the winter in tuber lenticels. These infested tubers, if planted the following spring, can decay and allow the disease cycle to repeat.

Culled tubers are an important source of the blackleg bacteria. As they decay, large numbers of bacteria are produced. Insects such as flies may move these bacteria to non-infested potato crops.

Wet soil and low temperatures (<18°C) favor infection of tubers and spread of blackleg bacteria. Immature tubers are more susceptible to infection than those with a mature skin. Proper curing after harvest followed by consistent low storage temperatures (see dry rot, 16.7) prevent or restrict tuber soft rot. Moisture from soft-rotted tubers favors disease development and the spread of infection in storage.

Management

Cultural practices — Use of blackleg-free seed and good growing practices are the best means of controlling this disease. Seed from stem cutting or micropropagation programs is usually the most suitable. Seed tubers should be warmed before cutting by storing them at 10 to 13°C in 95% relative humidity for 10 to 14 days. Ideally, small whole seed should be planted, If seed is cut, good sanitation practices such as disinfesting cutting and handling equipment daily and between seed lots, should be followed. Cut seed should be treated with a recommended fungicide and planted immediately. Pre-cut potato seed pieces should be suberized at 10°C and 95% relative humidity for five to seven days before planting to reduce infection by *Fusarium* spp. and other pathogens that may predispose plants to bacterial soft rot. Potatoes should be planted in moist, well-drained soil when soil temperatures are 10°C or higher. Excessive irrigation must be avoided. At least two or three years should be allowed between successive potato crops in the same field. Cereals, grasses and forages are preferred rotation crops.

Culled potatoes and vegetables should be properly composted, buried or fed to livestock to prevent the spread of *Erwinia* spp. to potatoes by insects. Planters, harvesters and conveyers should be cleaned frequently and disinfested to lessen the risk of contaminating healthy tubers. Seed potatoes should not be washed and they should be handled carefully to minimize damage. If practicable, seed growers should remove infected plants as soon as they appear in the field.

Tubers should be allowed to mature before harvest. Freshly harvested crops should be cured and stored as outlined under the management strategies for dry rot.

Resistant cultivars — Russet Burbank has intermediate resistance to blackleg. All other cultivars commonly grown in Canada are susceptible.

Chemical control — Fungicidal seed treatments that are effective against fusarium seed-piece decay may reduce the severity of blackleg and bacterial soft rot.

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(Original by I.R. Evans, J.R. Letal and R.J. Howard)

▶ 16.4 Pink eye (brown eye) *Figs. 16.4a,b*

? *Pseudomonas fluorescens* (Trevisan) Migula

Pink eye occurs chiefly in eastern Canada. It is usually a minor disease of potato. *Pseudomonas fluorescens* occurs widely in nature in soil and water, and it is often associated with food spoilage. It is epiphytic and is often isolated from diseased plants. Some strains are ice-nucleation-active and may predispose plants to frost injury.

Symptoms Pink to brown, skin-deep patches are found around eyes or at the apex of tubers during harvest *(16.4a).* The skin of affected tubers dries and cracks easily. Internal reddish-brown to black discoloration, cavities and soft rot are often associated with severe pink eye *(16.4b).* Diseased tubers usually fluoresce under ultraviolet light.

Causal agent (see Lettuce, pseudomonas diseases, 11.3)

Disease cycle A consistent association with a pathogen has not been established for this disease. Pink eye is sometimes associated with verticillium wilt, rhizoctonia canker and late blight, but it can occur on tubers free from these diseases. *Pseudomonas fluorescens* survives on organic matter in the soil and is generally a saprophyte rather than a pathogen. It requires high soil moisture for entry through lenticels, or damage such as wounds or other diseases for direct invasion. Under warm (greater than 7°C), moist storage conditions, the bacterium can spread to other tubers through wounds and lenticels.

Management

Cultural practices — Avoiding large fluctuations in soil moisture, especially late in the season, may reduce pink eye incidence. It may be possible to arrest pink eye development in storage by lowering the temperature, reducing the humidity and increasing air flow through the pile. Tubers with severe pink eye should be processed immediately.

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(Original by I.R. Evans and R.J Howard)

▶ 16.5 Scab *Figs. 16.5a-c; 16.5T1*

Common scab

Streptomyces scabies (Thaxt.) Waksman & Henrici
(syn. *Actinomyces scabies* (Thaxt.) Güssow)
Streptomyces spp.

Acid scab

Streptomyces acidiscabies Lambert & Loria

Russet scab

? *Streptomyces aureofaciens* Duggar

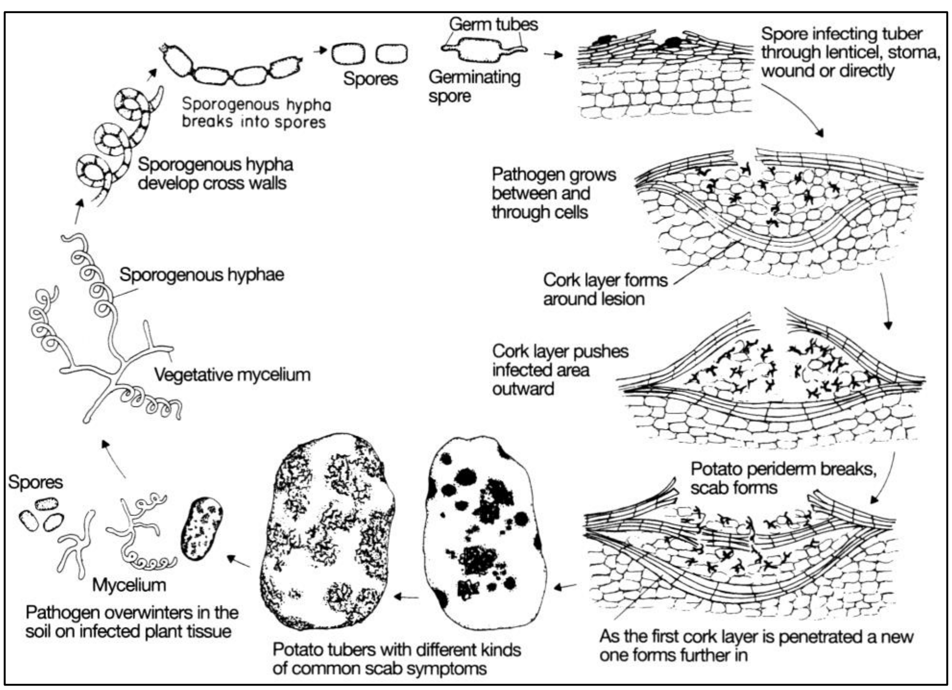
Common scab, acid scab and russet scab are unsightly diseases of potato tubers that can adversely affect grade and cooking quality but not yield or storability. *Streptomyces scabies* also can cause scab on the fleshy roots of beet, carrot, parsnip, rutabaga, turnip and radish, but damage is seldom severe on these crops (see Beet, Carrot and Crucifers, scab). *Streptomyces acidiscabies* has been reported to cause scab on potato in Quebec and some parts of the United States. Russet scab has been known in the United States and Europe since 1902, and more recently in Canada. Powdery scab, which may be confused with scab caused by *Streptomyces* species, is a fungal disease; see scab, powdery, 16.16.

Symptoms The symptoms of acid scab and common scab are indistinguishable on potato. Round, irregular, brown lesions, generally less than 1 cm across, occur on the tuber surface. On potato tubers, symptoms of scab can be of three types: shallow, with lesions that are superficial and corky (76.5c); raised, with erupting lesions (76.5a); and deep-pitted, with dark brown lesions up to 6 mm deep *(16.5b).* In contrast, russet scab is characterized by corky reticulations on the tuber surface *(16.5c).* Underground stems and stolons also may be attacked. Infection can range from a few spots to total coverage of the tuber surface. The severity and type of scab depends on such factors as the strain of *Streptomyces* present in the soil, the potato cultivar, the soil organic matter content, crop rotation practices, weather conditions, and moisture availability. Scabby, warty lesions associated with powdery scab (76.76) are smaller and rounder than those of common scab and acid scab, and the lesions are filled with dark brown, powdery masses of spore balls. See Scab (powdery), 16.16.

Causal agent *Streptomyces* species are actinomycètes that can survive in the soil either in a vegetative, mycelioid form or as spores. These organisms are classified with the bacteria because nuclear fusion does not occur and cell wall biochemical characteristics more closely resemble those of bacteria than fungi. *Streptomyces scabies* resembles a fungus in its mycelioid morphology, but differs in its very thin mycelial filaments, which are about 1 µm in diameter. The mycelium has few or no septa. The spores or conidia may be cylindrical or barrel shaped, averaging 0.5 by 0.9 to 1.0 µm. They are produced on branched hyphae or conidiophores that develop successive septa from their tip toward the base. As the septa constrict, the conidia are pinched off and eventually separate from the hyphae. The conidia may develop in spiral chains and germinate by means of one or two germ tubes that develop the mycelioid form. The morphology of isolates obtained from potato, red beet or carrot and root crucifers may differ markedly.

Streptomyces scabies is a weak pathogen and its cells may exist in low numbers or disappear during symptom development, which limits its successful recovery from affected tissues. This organism is more easily isolated from young lesions than from old ones, which may become overgrown by secondary organisms. In culture, *S. scabies* produces colorless vegetative filaments and pale, mouse-gray, aerial mycelium, often with melanin pigmentation of the medium surrounding the colony. Several selected media have been developed for isolation of this pathogen. Recovery from potato is usually easier than from radish and rutabaga. Not all isolates obtained from potato will infect other vegetable hosts. The nature of this specificity is not clearly understood. There is no reliable way to differentiate between pathogenic and saprophytic strains.

The primary characteristics of S. *acidiscabies* are the production of white spores borne in flexous chains of 20 or more, the inability to synthesize melanoid pigments, and the ability to utilize all ISP (International Streptomyces Project) sugars except raffinose. Its spores are smooth, cylindrical and 0.4 to 0.5 by 0.6 to 1.1 µm. It has a growth-medium-dependent spore mass color ranging from white to orange-red, with a pH-sensitive diffusable pigment that is red above pH 8.3 and golden yellow below pH 8.3. This species also is acid tolerant and will grow on agar media at pH 4.0 versus 5.0 for *S. scabies. Streptomyces acidiscabies* survives in the soil either in a vegetative, mycelioid form or as spores.



16.5T1 Common scab; disease cycle of *Streptomyces scabies* on potato. Reprinted by permission from G.H. Agrios, *Plant Pathology*. © 1988 Academic Press.

Actinomycetes causing russet scab are characterized by a bright yellow mycelium on yeast-malt extract agar, which turns brown after about two weeks of growth. The aerial mycelium forms flexuous spore chains, which appear as a gray mass on colonies in culture. Spores are cylindrical, smooth, and 0.5 to 0.6 pm in diameter by 0.7 to 0.9 pm in length. Canadian isolates of *S. aureofaciens* do not produce melanin but degrade xanthine and xylan. Most strains utilize D-fructose, D-glucose, D-mannitol, raffinose, sucrose and D-xylose. *Streptomyces aureofaciens* differs from *S. scabies* in that it produces pigmented mycelium and flexuous spore chains but no melanin. It differs from *S. acidiscabies* in mass spore color and in its inability to grow at pH 4.5.

Disease cycle *Streptomyces* species can persist indefinitely as saprophytes on decaying plant residue in the soil, and possibly on the roots of living plants and in animal manure (*16.5T1*). These pathogens can be spread by rain and windblown soil and by infected tubers. In potato, *Streptomyces* infects through lenticels, usually during the first five weeks of tuber development. If tubers are dry during the period, bacteria antagonistic to *Streptomyces* that are normally present in the lenticels disappear, allowing scab organisms to infect more easily. Scab lesions do not continue to develop in storage.

In other vegetable hosts, infection occurs through immature lenticels of young tissues and wounds caused by insects. After penetration, the scab pathogen colonizes a few layers of cells, which die, and it survives saprophytically on the necrotic tissue. Lesions may be invaded by secondary organisms, which can decay the host tissues.

Scab is generally more severe in light, sandy or gravelly soils that dry quickly. The disease develops most rapidly at soil temperatures of 20 to 22°C and may develop slowly at 11 to 13 and 30°C. Scab caused by *S. scabies* and *S. aureofaciens* is not a problem in acidic soils, but it increases in severity as soil pH increases from 5.2 to 8.0. *Streptomyces acidiscabies* occurs in soils with pH values as low as 4.5. It is not known whether this organism and *S. aureofaciens* can infect vegetable crops other than potato under field conditions in Canada.

Management

Cultural practices — Maintaining adequate soil moisture is an important method of controlling scab. This disease is most likely to occur in soil with moisture potentials of -0.4 to -0.6 bars or drier; it is less common under wetter conditions. Growers should maintain adequate soil moisture during and after tuber set, which is about 4 to 6 weeks after planting. Reduced oxygen concentrations in moist soils are thought to inhibit scab organisms. Moist soils also encourage the growth of antagonistic microorganisms.

Overliming may result in a high soil pH and should be avoided. Soil acidification with sulfur and acid-forming fertilizers may be effective in reducing pH and the incidence of common scab, but tends to be impractical in highly buffered organic soils and may increase the severity of acid scab. Manure from animals fed on scab-infected tubers and roots should not be used on land to be sown to susceptible crops. Well-rotted organic matter helps to retain moisture in the soil and reduces the onset of the dry conditions that favor scab. Organic matter should be allowed to decompose thoroughly before the land is cropped with potato or other susceptible vegetables. Potato growers are advised to plant scab-free tubers and to avoid short rotations between potato and other susceptible crops, including sugar beet, carrot and crucifers.

Resistant cultivars — Norking, Superior, Cherokee and Huron have good resistance to common scab. Chieftain, Russet Burbank, Monona, Norchip, Norgold Russet, Norland, Viking, Avon, Jemseg, Sable, Mirton Pearl and Sebago are intermediate in resistance.

Chemical control — Seed treatment fungicides may provide some control of tuber-borne scab.

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(Original by RJ. Howard, I.R. Evans and P.D. Hildebrand)

FUNGAL DISEASES

▶ 16.6 Black dot *Figs. 16.6a,b*

Colletotrichum coccodes (Wahr.) S J. Hughes
(syn. *Colletotrichum atramentarium* (Berk. & Broome) Taubenhaus)

Black dot causes tubers *(16.6b),* stolons, roots and stems to rot. The pathogen produces dot-like, black microsclerotia *(16.6a)* (see Tomato, anthracnose, 18.6). Foliar symptoms may be confused with those of fusarium and verticillium wilts and rhizoctonia canker. Disease-free seed, crop rotation and optimal soil fertility are the only known control procedures.

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(Original by I.R. Evans and R.J. Howard)

▶ 16.7 Dry rot *Figs. 16.7a,b*

Fusarium avenaceum (Fr.:Fr.) Sacc.
Fusarium sambucinum Fuckel
(syn. *Fusarium sulphureum* Schlectend.)
Fusarium solani var. *coeruleum* (Lib.:Sacc.) C. Booth

Dry rot is a common disease of stored potatoes and may cause heavy losses. Under humid conditions, secondary soft rot organisms may follow dry rot and result in even greater damage. Dry rot is often a problem on lower classes of seed potatoes. This disease occurs in all potato-growing areas. The fungi that cause dry rot can also attack a variety of other crops including cereals, grasses, fruits, ornamentals and some vegetables.

Symptoms Dry rot symptoms usually first appear around wounds about one month after tubers are put into storage. Diseased tissue may appear light brown to black and be conspicuously dry. Large, sunken, concentric rings, which collapse under light pressure, may form on any part of the tuber *(16.7a).* Fully rotted tubers become shrivelled and mummified. Cavities underneath the rotted area *(16.7b)* are usually lined with the white, pink-tinted or bluish mycelial growth of the *Fusarium* fungus. Tubers also may be soft and wet if soft rot is present as well.

Causal agent Dry rot fusaria can be readily isolated and will grow rapidly on acidified potato-dextrose agar. *Fusarium solani* produces a dense, white mycelial mat that may develop a blue, blue-green or purple pigmentation with age. It forms stout, thick-walled, cylindrical macroconi- dia, oval to kidney-shaped microconidia, and chlamydospores in culture. *Fusarium sambucinum* grows with or without a dense aerial mycelium on potato-dextrose agar. When aerial mycelium is present, it may be white, tan, pink or reddish-brown. Macroconidia are short, stout, thick-walled and strongly curved. Microconidia are generally absent in culture, while chlamydospores are formed abundantly and quickly. *Fusarium avenaceum* forms a dense, aerial mycelium that may vary in color from tan to reddish- brown. Macroconidia are very long, slender and thin-walled with an elongate apical cell and a foot-shaped or notched basal cell. Microconidia are rare and chlamydospores are absent in this species.

Disease cycle *Fusarium* spp. can survive for many years in potato fields, but most infections originate from infested seed tubers. Diseased seed pieces decay and the fungus may infect young potato plants or end up in the soil particles and lumps that are harvested with the crop, thereby contaminating harvested tubers and the equipment used in their handling or storage. New infections can occur when tubers are wounded during harvesting, grading or seedcutting. Seed pieces infected during cutting turn brown under moist soil conditions. Soft rot bacteria can invade these rotted areas as secondary pathogens. *Fusarium* spp. alone or in combination with soft rot bacteria may damage or completely destroy potato seed pieces. This can result in stunted or missing plants and reduced yields. Dry rot fusaria cannot penetrate intact tuber skin, lenticels or suberized seed pieces. Tubers with well-developed skins and those that are harvested without wounding are resistant to dry rot. Immature tubers that are skinned or bruised are highly susceptible to the disease. Damp storage conditions favor dry rot.

Management

Cultural practices — Potatoes should be harvested during dry, cool weather and care should be taken to avoid bruising and wounding. Freshly dug tubers should be stored for 7 to 10 days at 12°C to favor wound healing, then the temperature should be lowered to 2 to 5°C (10°C for processing tubers). Relative humidity should be maintained at 90% with adequate air circulation. Seed tubers from cold storage should be warmed to 15°C for a few days before cutting. Planting cut seed immediately into warm, moist soil will promote growth and wound healing. Alternatively, cut seed can be stored under well-ventilated conditions (15°C at 95% relative humidity) for five to seven days to hasten suberization before planting.

Resistant cultivars — Irish Cobbler and Kennebec are moderately resistant to dry rot.

Chemical control — Registered fungicides to prevent dry rot are available for treating cut seed and tubers going into storage.

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(Original by I.R. Evans and R.J. Howard)

▶ 16.8 Early blight *Figs. 16.8a-c*

Alternaria solani Sorauer

Early blight occurs wherever potato is grown. Crop losses can be heavy if severe foliar infection occurs before or soon after flowering. This disease can also infect tomato, pepper, eggplant and many solanaceous weeds.

Symptoms Early blight first appears as small, brown, pinhead-like dots on older leaves. These lesions are circular, 3 to 10 mm across and consist of concentric rings of dead tissue that give them a target board appearance *(16.8a).* Lesions become angular in shape when expansion is limited by leaf veins. Diffuse, yellow margins often border the lesions. Heavy infection under prolonged wet or heavy dew conditions can cause loss of leaf area extensive enough to reduce yields. Infected leaves usually do not fall off *(16.8b).* As the disease spreads, lesions appear on the upper leaves and on the stems. Early blight is more prevalent on aging vines or those under stress from nitrogen deficiency and other diseases.

Tuber symptoms can appear during storage. Infections are visible as dark, sunken, generally circular areas surrounded by raised borders that may increase in size during storage *(16.8c).* Where they penetrate into the tuber flesh, the lesions are brown, leathery and remain superficial.

Causal agent *Alternaria solani* forms grayish-brown to black mycelium. Conidia are brown, beaked, 150 to 300 by 15 to 19 µm, with up to 11 transverse septa. The fungus grows well in culture but sporulates sparingly.

Disease cycle The fungus persists in infested crop residues, soil, infected tubers and on other solanaceous plants. Spores can contact leaves touching the soil and may be carried to leaf surfaces by wind or splashing water. These spores germinate in the presence of water and penetrate directly through leaf surfaces. Lesions are usually first seen around flowering. Young leaves and crops growing with high nitrogen regimes do not generally show symptoms because they are somewhat resistant to infection. Secondary infections occur when conidia produced on primary lesions are spread to healthy leaves. Conditions for conidial production are optimal at or near 20°C, and development stops at temperatures above 27°C. Cool nights (less than 15°C) and moist or dew-forming conditions favor spore production and germination. In many cases, early blight is principally a disease of senescing plants. Premature senescence may occur as the result of nitrogen deficiency, drought and other environmental stresses, or because of other diseases. Dead or dying potato foliage also may be colonized by other *Alternaria* spp. that are weakly parasitic or saprophytic.

Tubers can become infected as they are lifted through soil infested with *Alternaria* spores, which are concentrated at ground level. Conditions that increase the severity of foliar blight increase the quantity of spores on the soil surface. Tuber infections occur mostly through wounds. Harvesting immature tubers increases the risk of infection.

Management

Cultural practices — Growers should turn under diseased vines after harvest, maintain good soil fertility and avoid growing potato, tomato or eggplant in a crop rotation for at least two or three years. Tubers should be allowed to mature fully before harvest and should not be dug when the soil is wet. Mechanical injury during harvesting and handling should be avoided.

Chemical control — Several foliar fungicides are registered in Canada for controlling early blight. They should be applied as soon as most of the lower leaflets contain one or more spots. Several weekly applications may be necessary if weather conditions are warm and humid. For severe disease late in the season, sprays at or after vine killing may help to reduce the production of spores that cause tuber infection. Computer models are available to help growers predict disease outbreaks and schedule fungicide applications.

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(Original by I.R. Evans and R.J. Howard)

▶ 16.9 Fusarium wilt *Fig. 16.9*

Fusarium avenaceum (Fr.:Fr.) Sacc.
Fusarium oxysporum Schlechtend.:Fr.
Fusarium solani (Mart.) Sacc.
Fusarium solani f. sp. *eumartii* (Carpenter) W.C. Snyder & H.N. Hans.

Several species of *Fusarium* cause wilt disease in potatoes. Yield losses are most pronounced during hot, dry seasons. Potato is the only known host for *F. solani* f. sp. *eumartii***;** the other species can attack a wide variety of plants.

Symptoms Symptoms caused by the four wilt-causing *Fusarium* species are similar. Tubers exhibit surface blemishes and decay, including browning and decay at the stem end and vascular discoloration. Vascular browning may not be visible during grading, but it can substantially reduce market quality. Infection generally results in wilting and premature death of leaves and stems, often one stem at a time *(16.9).* Vascular discoloration and cortical rot usually are present in lower stems and roots. Additional symptoms may include chlorosis, yellowing or bronzing of the foliage, rosetting and purpling of aerial shoots, and formation of tubers in leaf axils.

Fusarium wilt can be confused with verticillium wilt, which causes similar foliar symptoms. However, symptoms of internal stem infections are generally extensive with fusarium wilt, while those of verticillium wilt are restricted to the vascular system.

Causal agent Differentiating the various fusarium wilt fungi may not be easy, even when the causal organisms are grown in pure culture. (For descriptions of *Fusarium solani* and *F. avenaceum,* see dry rot, 16.7; *F. oxysporum* is described under Celery, fusarium yellows, 7.5). *Fusarium solani* f. sp. *eumartii* produces sparse mycelium, light brown sporodochia, three- to four-septate macroconidia that are nearly straight in the lower half and slightly curved in the upper half, and occasional microconidia.

Wilt-causing *Fusarium* species are best isolated from infected roots and lower stems. *Fusarium solani* f. sp. *eumartii* and *F. oxysporum* are rarely isolated from discolored tuber tissue.

Disease cycle Fusarium wilt pathogens persist for many years in the soil and are spread by infected seed pieces. Standard three- or four-year crop rotations may not be effective in reducing the level of soil-borne inoculum in heavily infested fields. Wilts are most commonly observed when hot, dry growing conditions place potato plants under stress. Root infection can take place at temperatures below 20°C, but wilt fungi are most active at higher soil temperatures. Continual growing of potato on infested land leads to a build-up of wilt pathogens and may result in the land becoming unsuitable for potato production.

Management

Cultural practices — Growers should use seed potatoes free of wilt disease and grow the crop on land that has been properly rotated with cereals, grasses or forages. It is advisable not to contaminate clean fields through the transfer of infested soil, diseased tubers or infested plant residues on machinery. Destruction of infected potato vines by tillage encourages rapid decomposition of residues and lessens the carry-over of *Fusarium* spp.

Chemical control — Fungicidal seed treatments may help to reduce disease levels on infested tubers and protect seed pieces from soil-borne infection, especially if freshly cut seed is to be planted.

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(Original by I.R. Evans and R.J Howard)

▶ 16.10 Gray mold *Fig. 16.10*

Botrytis cinerea Pers.:Fr.
(teleomorph *Botryotinia fuckeliana* (de Bary) Whetzel)

(syn *Sclerotinia fuckeliana* (de Bary) Fuckel)

Gray mold generally attacks plants weakened by other diseases or environmental stresses. The pathogen requires moist conditions in order to infect. It can attack many species of vegetables (see Lettuce, gray mold, 11.10). Airborne spores carried by wind and rain hasten the decay of aging potato floral parts and leaves, particularly late in the growing season. The pathogen may also cause tuber rot.

Gray mold is sometimes mistaken for late blight, but the gray-black to brown botrytis lesions on leaves *(16.10)* and occasionally on stems will produce a characteristic grayish growth of mycelium and spores during wet weather. The fungus overwinters in crop residue.

Fungicide sprays applied for early or late blight control often hold gray mold in check as well. Tuber rot can be reduced by allowing the tubers to mature before harvesting, eliminating excess soil and stems from the potatoes during digging, and storing the crop at low temperatures.

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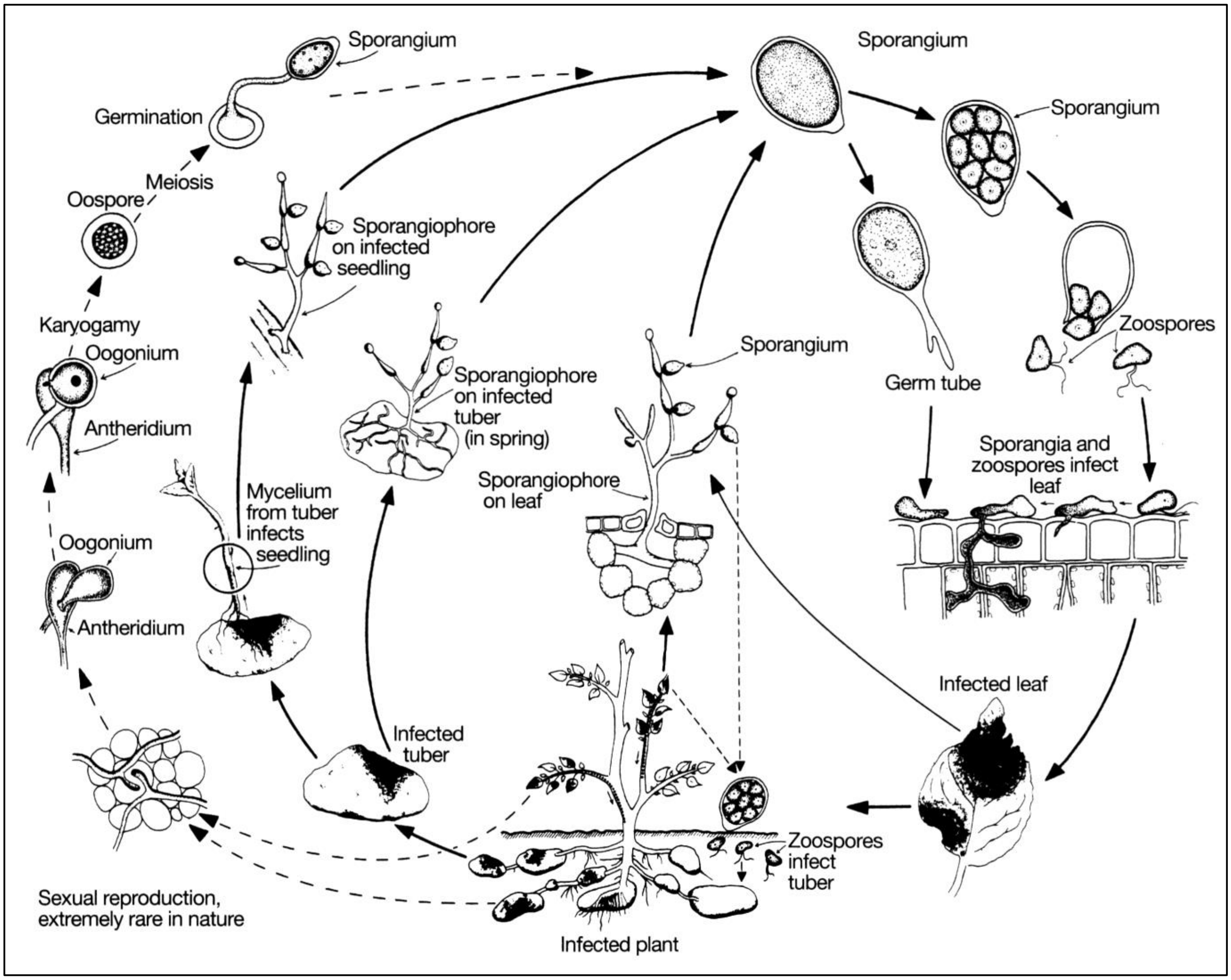
(Original by I.R. Evans and R.J. Howard)

▶ 16.11 Late blight *Figs. 16.11a-d; 16.11T1*

Phytophthora infestans (Mont.) de Bary

Before the general use of foliar fungicides, late blight was the most destructive fungal disease of potatoes. In the 19th and 20th centuries, dramatic crop losses caused by this disease resulted in major famines in Ireland and Germany. Late blight is most destructive in the Maritime provinces, less so in central Canada and British Columbia, and is usually negligible on the Prairies and in Newfoundland. Late blight can also affect tomato, pepper, eggplant and various solanaceous weeds.



16.11T1 Late blight; disease cycle of *Phytophthora infestans* on potato and tomato. Reprinted by permission from G.H. Agrios, *Plant Pathology.* © 1988 Academic Press

Symptoms The first symptoms of late blight usually appear on older leaves soon after flowering, following warm and wet or humid weather *(16.11a,b).* Dark green, water-soaked areas at the leaf tips spread inward and become dark brown and brittle in one or two days. On the underside of infected leaves, lesion edges may exhibit a fluffy white fungal growth that is visible on dewy mornings and during periods of high humidity. This fluffy mildew produces sporangia that are spread by rain and wind to other plants. Under suitably wet or humid conditions, the disease can spread rapidly within the crop, resulting in defoliation, plant death (*16.11c*) and yield loss.

Late blight lesions can resemble those of early blight in the early stages of development. However, late blight will obliterate the pattern of veination on leaves, whereas early blight does not.

Tubers at or near the soil surface can be infected. Lesions on the surface of tubers are irregular, sunken and usually appear in and around the eyes. Affected tissue is granular and reddish in appearance and it may penetrate up to 2 cm into the tuber *(16.11d).* Storage of diseased tubers can result in infection of other tubers and cause extensive crop loss.

Causal agent *Phytophthora infestans* typically reproduces asexually by sporangia borne on branched sporangiophores. Sporangia are lemonshaped, single-celled, hyaline, and measure 21 to 38 by 12 to 23 µm. Sexual reproduction occurs only when mating types A1 and A2 occur together. A1 has been known to occur world wide since the late 1800s, while A2 has long been found in Mexico. Since the early 1980s, A2 has appeared in European and Mediterranean countries and in some potatogrowing areas of the United States and western Canada. The thick-walled oospores that are produced probably play a role in the survival of the pathogen between growing seasons.

Disease cycle In Canada, *P. infestans (16.11T1)* can overwinter only in living potatoes. The fungus persists as mycelium in seed tubers, in cull piles or in volunteer potatoes that overwinter in the field. The fungus spreads primarily through sporangia, which can travel considerable distances. They germinate at 2 to 24°C on potato tissue either directly by formation of infection hyphae, or indirectly by zoospores that form in each sporangium. The optimal temperature for indirect germination via zoospores is 21°C, whereas direct germination of sporangia occurs best at 24°C. Zoospores, released by the rupture of the sporangial wall, swim in thin films of water. Zoospores encyst on solid surfaces, such as leaves, and produce germ tubes that can penetrate and infect potato tissue. Once penetration has occurred, infection and subsequent disease development are most rapid at 21°C. The fungus exists as 20 or more races that can attack individual potato cultivars with differing degrees of resistance.

Management

Cultural practices — Growers should destroy cull piles by composting, freezing or burying, and eliminate volunteer potato plants in nearby fields with herbicides and effective cultural practices. Sprinkler irrigation should be carefully scheduled, especially late in the season when the canopy is closed in and conditions for late blight development are favorable. Infected potato tops should be killed two weeks before harvest to reduce tuber infection and avoid serious disease problems in storage. Potatoes from infested fields should not be used for seed.

Resistant cultivars — Fundy, Kennebec, Brador, Nooksack and Sebago are resistant to some late blight races. No potato cultivars are immune to this disease.

Chemical control — Foliar fungicides provide control of late blight when applied at 7- to 10-day intervals from early July until the foliage begins to senesce. Where disease forecasting systems are available, the frequency of application can be reduced during periods when dry conditions reduce disease development. To reduce tuber infections late in the season, fungicides should be applied at or following topkilling. Most commercial fungicides prevent infection, but a few are curative in their activity. Continued use of curative fungicides can lead to resistance in the late blight pathogen.

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(Original by H.W. Platt)

▶ 16.12 Leak *Figs. 16.12a, b*

Pythium ultimum Trow
Pythium spp.

Leak occurs in all potato-growing areas. It is particularly troublesome in immature potatoes harvested under warm, moist soil conditions. *Pythium* spp. cause seed decay, damping-off and root rot in many kinds of vegetable crops.

Symptoms Leak is a disease of cut or bruised tubers. Infection is seen as extensive, light to dark brown lesions on the tuber surface, particularly at the stem end. Water may drip or run from diseased tubers and is most obvious in plastic retail packages stored at high temperatures. Diseased tuber tissue is granular, watery and cream-colored to black *(16.12a,b).* Infected seed pieces can decay in the soil before emergence.

Causal agent Leak is caused by *Pythium ultimum* or occasionally by other *Pythium* species. The fungus produces spherical sporangia that are 12 to 30 µm when produced terminally, or are barrel-shaped and 17 to 27 by 14 to 24 µm when they are intercalary. Oospores are smooth, thick- walled spheres, 14 to 20 µm, that are produced terminally on the hyphae. The pathogen is sometimes difficult to isolate from diseased potato tissue.

Disease cycle *Pythium* species can live indefinitely as saprophytes in the soil, where they may attack the underground parts of many plant species. Potatoes are infected through cut surfaces or bruises that occur during harvesting. Significant losses can occur when harvesting takes place during hot weather if tubers are handled roughly, and when crops are stored at high temperatures with poor ventilation. Leak can also be a problem on cut seed in the field.

Management

Cultural practices — It is advisable to allow the crop to mature in the field before harvest and to minimize mechanical injury to the tubers during digging, grading and storage operations. As well, growers should harvest during cool weather or during the coolest part of the day. If tubers are dug during warm weather, they should be immediately cooled before storage and air movement increased to hasten drying. Freshly harvested potatoes should not be kept in the sun for extended periods as this increases susceptibility leak. Potatoes should not be planted in low, poorly drained fields.

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(Original by I.R. Evans)

▶ 16.13 Phoma rot (button-hole rot, pocket rot) *Fig. 16.13*

Phoma exigua var. *exigua* Desmaz.

Phoma rot is a less serious problem than that caused by the closely related pathogen *Phoma exigua* var. *foveata* (Foister) Boerema, which is not present in Canada but causes gangrene in potato crops in Europe and Australia (see Foreign diseases and pests, 3.10). *Phoma exiqua* infects tubers through wounds incurred during harvest and grading operations, particularly when soils are wet and cool. Small, dark depressions appear on the tuber, and the covering skin may crack. Lesions are easily removed, leaving a cavity bordered by healthy tissue *(16.13).*

Control measures include the use of clean seed, crop rotation of three to four years, minimizing tuber wounds, applying of post-harvest fungicides, and providing proper wound-healing conditions in storage immediately after harvest.

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(Original by I.R. Evans and R.J. Howard)

▶ 16.14 Pink rot *Fig. 16.14*

Phytophthora erythroseptica Pethybr.

Pink rot causes a soft, spongy rot in harvested tubers *(16.14).* On exposure to air, the infected flesh develops a salmon pink color. *Phytophthora erythroseptica* infects underground parts of potato plants, particularly when soil moisture levels are high. Wilt symptoms can occur on the foliage. Tubers become infected through stolons, eyes and lenticels. Infected tubers are dull brown with dark skin tones around eyes and lenticels. A dark line on the skin delineates the extent of infection. Internal rot usually begins at the stem end and is creamy or light brown. Cut tubers ooze a clear odorless liquid when squeezed. Infected tissues change to pink, brown and black shortly after exposure to air.

Disease management involves use of healthy seed tubers, planting in well-drained soils, roguing diseased plants, and removing diseased tubers before crop storage.

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(Original by I.R. Evans and R.J. Howard)

▶ 16.15 Rhizoctonia canker (black scurf) *Figs. 16.15a-g*

Rhizoctonia solani Kühn
(teleomorph *Thanatephorus cucumeris* (A.B. Frank) Donk)

This disease is common wherever potato is grown. It is most readily recognized by the “black scurf” on the potato skin that resists washing off. The disease has assumed more importance in recent years because of the increased trend toward consumption of potatoes with intact skins. Most of the strains of *Rhizoctonia solani* that attack potato are specific to this crop.

Symptoms *Rhizoctonia* causes the most severe losses when soil conditions are cold and wet, and when potato crops are grown too frequently in the rotation. The main damage is a loss of tuber quality. The fungus is responsible for a considerable range of symptoms on potato *(16.15a-f),* including emergence failure, reddish-brown discoloration of roots, stem and stolon cankers, swollen stems, aerial tubers, leaf rolling, wilting and purpling, premature death of vines, and tuber malformations. A growth-regulating toxin produced by the fungus causes root necrosis, stolon pruning, leaf curling, stunting and leaf margin chlorosis *(16.15e).* Signs of the fungus include sclerotia (black scurf) on tuber surfaces *(16.15c)* and a grayish white, felt-like mycelium on stems at the soil surface. This covering is the hymenial stage of the teleomorph *(16.15g)* and it forms only under humid conditions. Basidiospores are produced on basidia within this growth but they do not appear to play an important role in disease development on potato.

Causal agent (see Bean, rhizoctonia root rot, 15B.7) *Rhizoctonia solani* strains pathogenic to potato generally belong to the anastomosis group AG-3, while those affecting crucifers belong to anastomosis groups AG-2 or AG-4. The mycelium is usually dark brown and coarse, 8 to 10 pm in diameter, with characteristic right-angled branching. Dark sclerotia of various sizes and shapes are produced in agar culture.

Disease cycle The fungus persists between seasons as sclerotia (black scurf) on tubers and in the soil or as mycelium on crop residues. Sclerotia germinate and the mycelium infects emerging potato sprouts, roots, stolons and tubers throughout the growing season. Sclerotial formation on young tubers is affected by tuber maturation and senescence in mother plants. *Rhizoctonia* may survive for long periods in potato fields by saprophytically colonizing plant residues other than those of potato.

Management

Cultural practices — Growers should plant seed potato tubers free from sclerotia in fields that have not grown potato or any other solanaceous crop for at least three years. Practices that favor rapid emergence, such as warming the seed, planting in warm soil, seeding shallow, hilling after emergence, and delaying irrigation until sprouts have emerged, may reduce the incidence of stem cankers and sprout damage. Potato should be rotated with cereals or grasses. In small plantings, early harvesting and hand-pulling the tops to remove stems, stolons and roots will help to reduce scurf.

Chemical control — Fungicidal seed treatments may help to control seed-borne inoculum, but they are not effective in protecting young plants in heavily infested soils. To ensure adequate coverage, fungicides should be applied to tubers that are free of soil.

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(Original by I.R. Evans and R.J. Howard)

▶ 16.16 Scab, powdery *Fig. 16.16*

Spongospora subterranea (Wallr.) Lagerh.

This disease causes scabby, warty lesions on tuber surfaces. The lesions fill with dark brown, powdery masses of spore balls. Each spore ball contains numerous, individual, uninucleate resting spores, which germinate by releasing a zoospore. The zoospore is motile and can infect root hairs of potato plants. Tuber lesions usually remain superficial unless the soil is wet. Tuber symptoms may be confused with those of common scab *(16.5)*, but powdery scab is characterized by lesions that are smaller and rounder *(16.16)* than those of common scab. Disease outbreaks are usually sporadic. *Spongospora subterranea* is a vector of potato mop-top virus, which occurs in Europe and South America. See also Bacterial diseases: scab, 16.5.

Powdery scab can be managed by planting Certified or a higher class of seed, following crop rotations of three to four years, not planting potato in infested fields, and not over-irrigating. Russet cultivars are tolerant to powdery scab.

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(Original by I.R. Evans and R.J. Howard)

▶ 16.17 Seed-piece decay *Figs. 16.17a-c*

Erwinia carotovora subsp. *carotovora* (Jones) Bergey *et al.*
Erwinia carotovora subsp. *atroseptica* (van Hall) Dye
Fusarium spp.
Pythium spp.

Failure of seed pieces to produce vigorous seedlings (plant misses) in potato crops may be caused by disease or environmental factors. Disease organisms associated with seed-piece decay may be fungal, bacterial or a combination of the two. Other tuber- and soil-borne diseases and pests also may play a role in the failure of plants to become established.

Symptoms Gaps, missing hills or delayed emergence *(16.17a)* are the first indications of a seed-piece decay problem. Occasional blanks may have little effect on the crop, but misses that exceed 10% of the planted seed may have economic consequences on yield and quality of the harvested crop. The extent of decay *(16.17b,c)* can be determined by digging to recover the seed piece. If the tubers are sound, then physiological causes such as chilling injury or broken sprouts may be the problem.

Causal agents *Fusarium, Pythium, Erwinia* and other genera of pathogens may be isolated from decaying tuber pieces. (For descriptions of these pathogens, refer to dry rot, leak, blackleg and bacterial soft rot in this chapter.)

Disease cycle (Refer to dry rot, 16.7; leak, 16.12; blackleg, 16.3; bacterial soft rot, 16.2.)

Management

Cultural practices — Using high quality seed that has been properly stored and handled should be the primary consideration in managing seed-piece decay. Growers should plant Certified or a better grade of seed potatoes and avoid using old tubers. The cutting of seed pieces can spread pathogens from diseased to healthy tubers, and it also exposes the seed pieces to soil-borne disease organisms. In Europe, virtually all potato planting is done with small, whole tubers to minimize the risk of mechanical spread of pathogens. Seed should be planted into warm soil immediately after it has been cut. If this is not feasible, the seed should be stored in open containers and held at 10 to 15°C for three to four days under high humidity, with good ventilation to promote suberization. If further storage is necessary, temperatures should be dropped to 5°C, then raised again before planting. Cut seed should never be stored under closed, moist conditions. Seed-cutting equipment should be disinfested frequently, using steam or disinfectants, especially between different lots of seed potato to prevent the spread of tuber-borne pathogens.

Chemical control — Chemical treatment of tuber pieces is not a substitute for the use of Certified seed and proper handling practices. Seed treatments will protect against pathogens in the soil and on the cut surface of the tuber, but not from infections already established within the tuber. Post-harvest treatment of seed tubers with fungicides, followed by dusting of seed pieces immediately after cutting, offers the best chemical protection against seed-piece decay.

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(Original by I.R. Evans)

▶ 16.18 Silver scurf *Figs. 16.18a-c*

Helminthosporium solani Durieu & Mont.
(syn. *Spondylocladium atrovirens* (C. Harz.) C. Harz.:Sacc.)

Silver scurf is a skin disease which is usually of minor importance on unwashed potatoes intended for peeling. However, with the marketing of washed potatoes in clear plastic bags, the increased consumption of potato skins, and the use of unpeeled tubers for french fries and chips, concern for this problem is increasing. Potato is the only vegetable crop affected by silver scurf.

Symptoms Symptoms can develop prior to harvest or during storage. Round, light brown or grayish, leathery spots form on the tuber *(16.18a).* These lesions enlarge to cover most of the surface *(16.18b).* Moist or wet infected tubers have a distinctive silvery sheen. Spore formation, especially at the margins of young lesions, gives the tubers a sooty appearance. Silver scurf is most noticeable on red potatoes, where it may obscure the color. Infection reduces quality and causes tubers to lose excessive amounts of moisture and shrivel in storage. Lesions penetrate a few millimetres into the flesh and are difficult to remove during commercial peeling operations *(16.18c).*

Causal agent *Helminthosporium solani* produces brownish mycelium and septate conidiophores with conidia borne in whorls that are visible to the naked eye. Spores are 7 to 11 by 24 to 85 µm, dark brown, two- to eight-septate, tapered at the apex, and possess a distinct dark scar at the base.

Disease cycle The fungus can be carried on seed pieces and on tuber residues in the soil. Clean seed can be infected when planted in infested soil. Mature tubers left in the field late in the season in warm, moist soil are also susceptible to infection. The pathogen can infect tubers through lenticels or directly through the skin. Disease levels increase in storage, and further tuber infections can occur at humidities over 93% and temperatures above 3°C.

Management

Cultural practices — Growers should plant disease-free tubers and practice crop rotation. Tubers should be harvested when mature. Storages should be ventilated with dry, warm air to remove moisture from tuber surfaces, and then tubers should be stored at temperatures as low as possible.

Chemical control — When symptoms of silver scurf are present, or where the potential for disease development in storage is high, potatoes going into storage, particularly seed potatoes, should be treated with a fungicide. Seed pieces should be treated with a recommended fungicide before planting. Resistance to benzimidazole fungicides in the silver scurf fungus has been recorded.

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(Original by I.R. Evans and J.D. Holley)

▶ 16.19 Skin spot *Fig. 16.19*

Polyscytalum pustulans (M.N. Owen & Wakef.) M.B. Ellis (syn. *Oospora pustulans* M.N. Owen & Wakef.)

Skin spot primarily damages tubers, but roots, stolons and underground stems can also exhibit symptoms. Symptoms on tubers *(16.19)* appear as small sunken depressions with raised centers that are darker than healthy tuber skin when dry. These lesions can grow together to form larger diseased areas. The fungus overwinters on potatoes and in soil. New infections are caused by the pathogen entering lenticels, wounds and tuber eyes. Planting healthy tubers and avoiding tuber damage before storage will control this disease.

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(Original by I.R. Evans and R.J. Howard)

▶ 16.20 Verticillium wilt *Figs. 16.20a-c*

Verticillium albo-atrum Reinke & Berthier
Verticillium dahliae Kleb.

Verticillium wilt is a common disease of potato that is often confused with other wilt and early maturity diseases. This disease is often implicated with early dying, a syndrome caused by a combination of several pathogens and environmental conditions such as ozone injury and drought. The most important pathogens associated with early dying are *Verticillium* spp., *Erwinia carotovora* (see bacterial soft rot, 16.2) and the root-lesion nematode (see Nematode pests, 16.38). The distribution of early dying in Canada has not been determined. *Verticillium* pathogens have a wide host range and are capable of attacking tomato, pepper, eggplant, cucurbits, and other broadleaf crops and weeds (see Greenhouse cucumber, verticillium wilt, 22.17).

Symptoms Characteristic symptoms of verticillium wilt are the early dying of leaves and stems on plants *(16.20a)* in irregular patches in the field, particularly on well-drained sandy soils. Lower leaves are generally affected first. Typically only one stem or leaves on one side of a stem shows wilting, especially during hot, windy days or when soil conditions are dry. Areas between leaf veins turn yellow and later brown. Wilted plants may recover at night or during cool, moist weather. Wilted stems cut at ground level show a brown discoloration of the vascular tissues *(16.20b).* Tubers from infected plants may have discolored vascular rings, particularly at the stem end *(16.20c).*

Causal agent *Verticillium dahliae* produces ovate, single-celled conidia, 2.5 to 8.0 by 1.4 to 3.2 µm, at the tips of phialides. The phialides are arranged in whorls (verticils) on septate conidiophores and are often produced within the xylem vessels of the host, which accounts for the rapid systemic spread of the pathogen. It forms small, thick-walled, variably shaped, brown to black microsclerotia, 15 to 50 µm in diameter. They occur within infested plant residues and eventually are released into the soil.

Verticillium albo-atrum is similar in appearance to *V. dahliae,* except that instead of microsclerotia it develops a septate, dark, resting mycelium on potato stems and in culture. Its conidia are slightly larger, 3.5 to 10.5 by 2.0 to 4.0 µm.

Both *Verticillium* species are relatively slow-growing in culture. They can be readily cultured on potato-dextrose or V-8 agar. The mycelium is floccose, white to grayish-white, compact and occasionally sectored. The production of microsclerotia and resting mycelium in culture is variable, but often occurs as cultures age.

Disease cycle *Verticillium albo-atrum* and *V. dahliae* are soil-inhabiting fungi. Both may be present in the same field or on the same plant. *Verticillium albo-atrum* is generally more pathogenic than *V. dahliae,* but disease responses vary depending on climatic conditions, potato cultivar and pathogen. These fungi are spread by infected or contaminated seed pieces and by infested soil, farm machinery and irrigation water. They can persist and build up in the soil if potato is grown several years in succession. Other crops and weeds can harbor these pathogens without symptoms. Infection of the potato plant occurs through the root, particularly root hairs. Hyphae of the fungi grow within the xylem vessels and block the movement of water. Spores may be air-borne and the fungi can also spread to other plants by root contact. High soil temperatures (22 to 27°C) favor the growth of *V. dahliae,* while *V. albo-atrum* has a broader temperature range (16 to 27°C). Some soil-borne plant parasitic nematodes have been shown to increase the incidence and severity of verticillium wilt.

Management

Cultural practices — A high level of plant vigor should be maintained by adequate fertilization and irrigation practices. It is advisable to follow a three- or four-year crop rotation. Both fungi can survive for many years in the soil, in the absence of potato, on related solana- ceous crops or weeds. *Verticillium dahliae* has a longer survival potential than *V. albo-atrum* in soil. Cereals, oilseeds, grasses and legumes grown in rotation with potato should be kept weed-free. Highly susceptible potato cultivars should not be grown. Certified or better grades of seed potato should be used.

Resistant cultivars — No resistant cultivars are available but considerable variation exists among cultivars. Russet Burbank is somewhat less susceptible to *V. albo-atrum* than to *V. dahliae.*

Chemical control — Seed pieces can be treated with a recommended fungicide immediately before planting. Soil fumigants (nematicides, fungicides) are effective in reducing disease losses, but may not be economical.

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(Original by I.R. Evans and R.J. Howard)

▶ 16.21 Wart (canker) *Figs. 16.21a-d*

Synchytrium endobioticum (Schilberszky) Percival

Potato wart disease is prevalent in most potato-growing regions of the world and is one of the most damaging potato diseases. The causal agent is a soil-borne fungus that attacks growing points on the potato plant, such as eyes, buds and stolon tips.

The considerable economic importance of wart is due to the resting spores that can live for 40 years in soil and are spread easily by contaminated tubers and soil. Once in the soil, the fungus cannot be eradicated without fumigation. In severe infestations, no tubers develop. The presence of this pathogen in Newfoundland warrants strict quarantine legislation (see Introduced diseases and pests, 3.11).

The fungus is believed to be indigenous to Peru, where the potato originated. It spread rapidly throughout western Europe at the turn of this century and was discovered in Newfoundland in 1909 and in Maryland, Pennsylvania and West Virginia 10 years later. These infestations probably originated with the import of European table potatoes, some of which likely were used as seed. In Newfoundland, most infested soils are found in backyard gardens. Infestations in the United States were believed to have been eradicated, but recent examination of old quarantine areas in Maryland has shown that the fungus is still present.

Potato is the only host plant of economic importance. However, other *Solanum* hosts are susceptible, including tomato and henbane *(Hyoscyamus niger* L.). The pathogen is spread by infected potato tubers and infested soil. The fungus can serve as a vector for potato virus X.

Symptoms *Synchytrium endobioticum* causes galls and warty outgrowths that may be pea- to fist-sized. Aerial galls (*16.21a*) are greenish and turn brown and then black at maturity. They can decay and slough-off into the soil. On occasion, galls may form on the upper parts of the plant and even on the flower parts, but generally galls are found on stem bases, stolon tips and in tuber eyes *(16.21b-d).* Eye infections are whitish and resemble small cauliflower heads. Potato roots are not attacked by the wart fungus.

The tuber surface may be over-grown with warty tissue, as the fungus continually germinates and repenetrates the original infected area. The entire tuber may rot and disintegrate. Infected tubers that appear clean at harvest may develop warty outgrowths in storage.

Causal agent *Synchytrium endobioticum* is an obligate parasite and belongs to the Chytridiomycetes, a group of fungi generally found in fresh water habitats. Up to 20 races or pathotypes have been identified, four of which (1,2, 6/7, and 8) occur in Newfoundland.

The fungus has a complex life cycle. It does not produce hyphae but enters a host epidermal cell through an infection peg formed from an encysted zoospore. Zoospores measure 2 to 4 µm and possess a tail-like flagellum about seven times the length of the spore. After penetration, potato cells surrounding the infected cell enlarge, the fungus multiplies and the zoospores, which are produced asexually, are released. Some zoospores will penetrate to continue the cycle, others will conjugate and then penetrate. Conjugation produces a sexual entity that re-infects several cells deep, giving rise to a resting spore.

Resting spores are golden brown and spherical, have prominent ridges or flanges, and measure 35 to 80 µm. Resting spores are known to live for 40 years or more in undisturbed soil. When they germinate, the contents flow into a sac which forms a wall around itself. The resulting sporangium is expelled from the sac. The wall of the sporangium splits and releases 200 to 300 motile zoospores. Zoospores live for one to two hours in soil water before encysting. If the zoospore encysts on susceptible potato tissue, the cyst forms a penetration peg and the contents flow into the host cell to renew the cycle.

Disease cycle The disease occurs in soils of pH 3.5 to 9.0, and is favored by low summer temperatures and abundant water. Water is required for germination of the resting spores, dispersal of zoospores, and rotting and dissolution of infected plant tissue. In areas where the disease occurs, the annual precipitation is equal to or greater than 700 mm, summers are cool, with an average temperature of 18°C or less, and the winters have approximately 160 days that are 5°C or colder. The fungus is most active when susceptible tissues, such as sprouts, tuber eyes and stolon buds, are being formed.

Management

Monitoring — Soil tests are available to determine the number and viability of resting spores per unit of soil. Tests for viability of resting spores include plasmolysis, vital stains, fluorescent stains, and dark-field microscopy but none gives absolute values. The simplest method is to plant a susceptible tuber in soil suspected of harboring the fungus. However, this test also may be unreliable because of low numbers of spores or other inhibiting factors. In addition, this test only gives estimates of population viability and not of single spores. Recent bioassay work indicates that nodal cuttings may provide a more sensitive measure of population viability than tubers.

Cultural practices — Studies in Newfoundland have shown that crushed crabshell, which contains chitin, reduces the level of the fungus in the soil when used as a soil amendment. Absolute control has been recorded in greenhouses trials, and clean potato crops have also been raised using this material in the field. Plant quarantine regulations prohibit the planting of potato on land infested with the wart pathogen. In addition, the importation of potato tubers and soil from Newfoundland into other Canadian provinces, or from infected areas of other countries into Canada, is prohibited (see Introduced diseases and pests, 3.11).

Resistant cultivars — Several resistant cultivars have been developed in Newfoundland. These include Anson, Blue Mac, Brigus, Cupids, Mirton Pearl and Pink Pearl.

Chemical control — Copper sulfate and methyl bromide are known to destroy *S. endobioticum,* but their use is not practical or economical in commercial fields.

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(Original by M.C. Hampson, S. Wood and I.A. MacLatchy)

▶ 16.22 White mold *Fig. 16.22*

Sclerotinia sclerotiorum (Lib.) de Bary
(syn. *Whetzelinia sclerotiorum* (Lib.) Korf & Dumont)

Sclerotinia sclerotiorum white mold has a very wide host range that includes many solanaceous, cruciferous and leguminous plants (see Bean, white mold, 15B.9). In potato, damage may occur to the growing vines *(16.22),* particularly to intensively managed crops, and occasionally on tubers in storage. The presence of white mycelium and large, black, irregularly shaped sclerotia in or on infected tissue is a characteristic sign of this disease.

White mold can be controlled by rotating potato with non-host crops, such as cereals and grasses, and by planting on well-drained soils. Growers should apply balanced levels of nitrogen fertilizer and irrigate as required. If the disease appears, irrigation should be stopped to allow the plant canopy to dry to halt disease development.

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(Original by I.R. Evans and R.J. Howard)

VIRAL AND VIRAL-LIKE DISEASES

▶ 16.23 Aster yellows (haywire, purple dwarf, purple-top wilt) *Fig. 16.23*

Aster yellows mycoplasma-like organism

Aster yellows is an uncommon but potentially destructive disease of potato. Many vegetables (see Lettuce, aster yellows, 11.15), ornamentals, field crops and weeds are affected by aster yellows.

Symptoms Upper leaflets roll and develop purple or yellow pigmentation *(16.23).* Affected stems usually die prematurely, preventing some tubers from reaching maturity. Aerial tubers occasionally form on affected plants, while below-ground tubers may feel spongy. The causal agent rarely survives in stored tubers, and the usual evidence of aster yellows infection in the second year is a failure of seed to produce plants of normal size and vigor.

Causal agent The aster yellows mycoplasma-like organism is characterized by pleomorphic particles bound by a unit membrane and measuring 50 to 1000 nm in diameter. Absolute proof of the host-parasite relationship has not been established.

Disease cycle The aster yellows pathogen does not normally overwinter in potato tubers and it can be transmitted only by leafhoppers. The extent of its spread to potato depends on the access of the aster leafhopper vector to other infected hosts. Weather conditions that favor the increase and mobility of the vector promote the spread of the disease. The pathogen propagates within the leafhopper vector which remains infectious for life.

Management

Cultural practices — The use of carefully selected, Certified or a higher class of seed grown in areas where aster yellows is rarely found is important. Growers located in areas where aster yellows is widespread should use insecticides to control leafhoppers that migrate into potato fields, particularly along field margins.

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(Original by N.S. Wright)

▶ 16.24 Calico *Fig. 16.24*

Alfalfa mosaic virus

Calico is a minor disease of potato. It occurs in most potato-growing areas of Canada. The virus has a wide host range, including Leguminosae, Solanaceae and 10 other plant families.

Symptoms Alfalfa mosaic virus causes pale to bright yellow mottling or blotching of potato leaflets *(16.24)* and usually some necrosis in leaflets, stems and tubers.

Causal agent Alfalfa mosaic virus has bacilliform particles of different lengths, the largest being about 60 nm. The three largest RNA species comprise the genome; the fourth is a sub-genomic messenger for the coat protein.

Disease cycle Alfalfa mosaic virus overwinters in potato tubers and perennial hosts. It is transmitted by seed in some alfalfa cultivars and in chili pepper. While rub transmission is possible, most natural spread probably occurs through the feeding of several aphid species, including the green peach aphid. Alfalfa mosaic virus is transmitted in a stylet- borne or non-persistent manner.

Management

Cultural practices — Producers should avoid planting seed potatoes adjacent to alfalfa and clover crops or in fields where volunteer plants of these two crops are present. Only Certified or a higher class of seed should be planted and plants visibly affected with calico symptoms in seed fields should be rogued.

Selected references

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Slack, S. 1981. Alfalfa mosaic virus. Pages 82-84 *in* W.J. Hooker, ed., *Compendium of Potato Diseases.* APS Press, St. Paul, Minnesota. 125 pp.

(Original by R. Stace-Smith, N.S. Wright and P.J. Ellis)

▶ 16.25 Corky ring spot (spraing, stem mottle) *Figs. 16.25a,b*

Tobacco rattle virus

Corky ring spot is rare in Canada. It has been found only in a few isolated home gardens in Alberta and Saskatchewan where it is of no economic significance. The pathogen has a host range that includes plant species in over 50 families.

Symptoms Stem mottle, a symptom rarely seen in North America, is caused by the feeding of numerous viruliferous nematodes on emerging stems. Secondary symptoms vary from a slight mottle to severe distortion. Ring spot symptoms on tubers also vary considerably from small necrotic flecks to prominent concentric rings *(16.25a,b).*

Causal agent Tobacco rattle virus is a variable, rod-shaped virus, with particles 17 to 25 nm in diameter by 180 to 210 nm long. It is usually accompanied by short, non-infectious rods (about 45 to 115 nm), which are involved in synthesis of coat protein.

Disease cycle Tobacco rattle virus is spread by nematodes of the genera *Paratrichodorus* and *Trichodorus* (see stubby-root nematodes, 16.39). The virus can persist in these vectors indefinitely. Primary tuber infection follows nematodes feeding directly on tubers. Transmission through seed tubers is infrequent.

Management

Cultural practices — Only Certified or a higher class of seed should be used if this virus occurs in the area.

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(Original by R. Stace-Smith, N.S. Wright and P.J. Ellis)

▶ 16.26 Leafroll *Figs. 16.26a,b*

Potato leafroll virus

Potato leafroll occurs worldwide and causes significant losses in yield and quality. It is widespread in Canada and is generally considered to be the most serious virus disease of potato. Processing potatoes from fields severely affected by leafroll usually are rejected. Several crop and weed species, mostly in the potato family (Solanaceae), are known hosts for this virus.

Symptoms Aphids may transmit potato leafroll virus to potato plants at any time during the growing season. Plants infected late in the growing season may not show any symptoms, while symptoms that develop following aphid feeding early in the season differ from those in plants grown from infected tubers.

Primary (current season) leafroll — If infection occurs early, the upper leaves roll, turn pale green (sometimes pink-tinged), and are stiffer than normal. Primary infection in some cultivars, for instance Russet Burbank, Norgold Russet, Green Mountain and Irish Cobbler, causes internal net necrosis in the tubers either before or during storage (*16.26b).* Similar symptoms can be caused by aster yellows, verticillium and fusarium wilts, top killing and heat stress.

Secondary (chronic) leafroll — Plants that develop from tubers infected with potato leafroll virus develop characteristic symptoms *(16.26a).* The lower leaflets are rolled, stiff, dry and leathery, and may rattle when shaken. The older leaves of some cultivars turn pink or yellow and become severely necrotic; the plants often appear stunted and rigid. Symptoms are less pronounced on the upper leaves, which may be pale or chlorotic. Symptom severity is determined by the virus isolate, the potato cultivar and the growing conditions.

Causal agent Potato leafroll virus is classified as a member of the luteovirus group. The virus particles are isometric and about 24 nm in diameter.

Disease cycle Potato leafroll virus overwinters in infected tubers. In Canada, no other hosts have been implicated as important reservoirs. Weeds, such as shepherd's-purse *(Capsella bursa-pastoris* (L.) Medic.) and black nightshade *(Solanum nigrum* L.), can be infected by potato leafroll virus, but they are not significant reservoirs. Infected seedstocks, sprouted cull potatoes and volunteer potato plants are the most important sources of the pathogen. In some areas, leafroll-infected potato plants in backyard gardens are significant reservoirs of the virus. Several aphid species transmit the virus, the green peach aphid being the most efficient and important vector. Aphids acquire the virus while feeding on infected plants and remain viruliferous for life. Potato leafroll virus is spread over long distances by winged aphids, and to adjacent plants by wingless aphids. Plants become more resistant to infection as they mature. Some tubers from plants that are infected late in the season may escape infection. Potato leafroll virus is not transmitted by rubbing healthy plants with sap from an infected plant.

Management (See individual aphid species for their control.)

Cultural practices — Seed certification is the foundation of any management program for potato virus diseases. Growers should select seedstocks from those inspected and found to be free of leafroll and other virus diseases. Recommendations to control aphid vectors should be followed. Volunteer potato plants that appear in or near potato fields should be destroyed.

Potatoes that are free of potato leafroll virus traditionally are grown by specialized seed potato growers in areas relatively free of aphids. Seed plots are usually harvested early to avoid infection late in the season, when aphid numbers are highest. Often, the potato vines are cut or chemically killed to reduce chances of potato leafroll virus infection. In seed-growing operations, clonal selection and roguing of infected plants are practiced to minimize or eliminate spread of the virus.

Resistant cultivars — The traditional approach to plant breeding has not successfully controlled potato leafroll. The difficulty of combining desirable agronomic characteristics with resistance to potato leafroll virus makes it unlikely that present cultivars will be replaced by leafroll-resistant cultivars in the near future. However, genotypes with low concentrations of potato leafroll virions may be useful for delaying virus acquisition by vectors and in slowing plant- to-plant spread.

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(Original by P.J. Ellis and I.R. Evans)

▶ 16.27 Mosaic diseases *Figs. 16.27a,b; 3.11a-c*

Potato virus A
Potato virus M
Potato virus S
Potato virus X
Potato virus Y

Mosaics are the most common viral diseases of potato in Canada. Their effects on tuber yield and quality can range from no discernible damage to severe damage. The impact of these viruses is greater in seed than in table-stock potato production.

Potato virus A

Potato virus A is relatively rare, especially in pedigreed seed. Its host range is limited to solanaceous plants.

Symptoms Potato virus A causes varying degrees of leaf mottling or mosaic, depending on virus strain, potato cultivar and weather conditions. Symptoms are intensified by cloudy, cool weather. Symptoms caused by a combined infection of potato virus A and potato virus X are more severe than those resulting from infection by either pathogen alone. There are no tuber symptoms.

Causal agent Potato virus A is a potyvirus with filamentous particles, 750 by 15 nm. Potato virus A infections can be identified by specific monoclonal antibodies utilized in enzyme-linked immunosorbent assay (ELISA) procedures involving extracts from infected leaf tissue.

Disease cycle Potato virus A overwinters in infected tubers. It is transmitted in a non-persistent manner by aphids, mostly by the potato aphid and the green peach aphid. The pathogen is not transmitted in sap because of virus instability. For this reason, potato virus A is not likely to be spread by seed tuber cutting or by foliar contact. Aphids acquire the virus on their mouthparts (stylets) during feeding. Virus retention on the stylets usually is limited to the time between its acquisition and the first feeding on a mosaic-free plant.

Management (See aphids, 16.40-16.43, for control of individual species.)

Cultural practices — Growers should plant Certified or a higher class of seed.

Selected references
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De Bokx, J.A. 1981. Potato virus A. Pages 71-72 *in* W.J. Hooker, ed., *Compendium of Potato Diseases.* APS Press, St. Paul, Minnesota. 125 pp.

(Original by N.S. Wright, R. Stace-Smith and P.J. Ellis)

Potato virus M

Potato virus M, although widespread and important in eastern Europe, is very rare in North America. In addition to potato, some other solanaceous plants, including tomato, and a few species in the families Chenopodiaceae and Leguminosae are suceptible.

Symptoms Foliar symptoms are a slight to severe mottle, mosaic, crinkling or rolling of leaves, the stunting of shoots, and leaflet deformation. Severity of symptoms is influenced by virus strain, potato cultivar and weather. Temperatures of 24°C or higher tend to mask symptoms.

Causal agent Potato virus M is a carlavirus with filamentous rods, 650 by 12 nm. The pathogen can be transmitted by rubbing leaves of healthy plants with sap from infected plants. The virus can readily be detected by serological methods.

Disease cycle Potato virus M overwinters in infected tubers. It is transmitted in a non-persistent manner by several aphid species, including the potato aphid and the green peach aphid. As with most viruses, some strains are more readily transmitted by aphids than others.

Management (See individual aphid species, 16.40-16.43, for their control.)

Cultural practices — Growers should plant Certified or a higher class of seed.

Selected references
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Hiruki, C. 1981. Potato virus M. Pages 74-75 *in* W.J. Hooker, ed., *Compendium of Potato Diseases.* APS Press, St. Paul, Minnesota. 125 pp.
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(Original by R. Stace-Smith, N.S. Wright and P.J. Ellis)

Potato virus S

Potato virus S is the most widespread potato virus and occurs even in pedigreed seed in many areas. It appears to have been eradicated from the Pemberton Seed Potato Control Area in British Columbia as a result of a control program that began in 1967. Yield losses of up to 20% caused by potato virus S have been reported.

Symptoms Potato virus S infection is virtually symptomless in most potato cultivars. However, some strains cause a deepening of veins, and mottling, bronzing or rugosity of the foliage. There are no tuber symptoms.

Causal agent Potato virus S is a carlavirus with slightly curved, filamentous particles, 650 by 12 nm. The pathogen is strongly antigenic, so infections may be detected by most serological methods, especially in mid-season when virus concentration in plants is highest.

Disease cycle Potato virus S overwinters in infected tubers. It is readily transmitted in sap and extensive spread may occur if seed cutting knives are contaminated, if sprout contact occurs, or if the foliage of growing plants rubs together. Some strains are transmitted by the green peach aphid in a non-persistent manner.

Management (See individual aphid species for their control.)

Cultural practices — Growers should plant Certified or a higher class of seed. Cutting knives should be thoroughly disinfested between seed lots.

Selected references
Bagnall, R.H. 1981. Potato virus S. Pages 75-77 *in* W.J. Hooker, ed., *Compendium of Potato Diseases.* APS Press, St. Paul, Minnesota. 125 pp.
Wetter, C. 1972. Potato virus S. CMI/AAB Descriptions of Plant Viruses, No. 60. Commonw. Mycol. Inst./Assoc. Appl. Biol., Kew, Surrey, England. 3 pp.
Wright, N.S. 1988. Assembly, quality control and use of a potato cultivar collection rendered virus-free by heat therapy and tissue culture. *Am. Potato J.* 65:181-198.

(Original by N.S. Wright, R. Stace-Smith and P.J. Ellis)

Potato virus X *Fig. 16.27a*

Since 1967, when clones of virus-free potato cultivars first became available in Canada, potato virus X has declined from high to low levels in commercial seed stocks. The yield reduction caused by this pathogen in many cultivars can be 15% or more.

Symptoms Depending on strain of virus, cultivar and weather conditions, potato virus X can cause a very mild to severe mottle of the foliage *(16.27a).* Symptoms are most visible under cool, cloudy growing conditions. There are no tuber symptoms.

Causal agent Potato virus X is the type member of the potexvirus group. It has filamentous particles that measure 515 by 13 nm. The pathogen is strongly antigenic, and infections may be detected by serological methods.

Disease cycle Potato virus X overwinters in infected tubers. It is readily spread from infected to healthy potato plants by cutting knives, sprout contact before planting, and by contact of foliage or roots during the growing season. Biting or chewing insects may spread the virus but not piercing and sucking insects, such as aphids.

Management

Cultural practices — Growers should plant pedigreed seed. Cutting knives and machinery should be thoroughly disinfested between seed lots.

Selected references

Koenig, R., and D.-E. Leseman. 1989. Potato virus X. AAB Descriptions of Plant Viruses, No. 354. Assoc. Appl. Biol., Inst. Hort. Res., Wellesbourne, Warwick, U.K. 5 pp.

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(Original by N.S. Wright, R. Stace-Smith and P.J. Ellis)

Potato virus Y *Figs. 16.27b; 3.11a-c*

Potato virus Y occurs commonly on solanaceous plants (see also Tomato, 18.20) worldwide. In North America, most potato virus Y infections involve common strains of the virus (designated PVY°), but occasional infections by necrotic strains (designated PVY^N) have been found (see Introduced diseases and pests, 3.11). The necrotic strains cause weak mosaic symptoms, if any, on potato foliage but induce a bronzing and necrotic reaction on tobacco *(3.11a,b).* These strains occur in Europe and their possible importation to Canada is a concern. In 1990, a strain of PVY^N that causes systemic veinal necrosis in tobacco was discovered in seed potatoes in eastern Canada. Potato virus Y° is one of the most damaging potato viruses in terms of yield loss. In combination with potato virus X, it causes an even more destructive disease known as rugose mosaic *(16.27b).*

Symptoms Symptoms in potato vary with virus strain and potato cultivar and range from a mild mottle to severe foliar necrosis. Some European strains of PVY^N can cause brown rings on the skin of tubers.

Causal agent Potato virus Y is the type member of the potyvirus group; it has long filamentous rods, 730 by 11 nm. The pathogen is antigenic, and serological detection, especially with enzyme-linked immunosorbent assay (ELISA) procedures, is quite effective.

Disease cycle Potato virus Y overwinters in infected tubers and is readily sap-transmissible. Ground cherry *(Physalis heterophylla* L.) *(3.11c)* has been found to be infected with a strain of PVY^N in Ontario. The spread of potato virus Y depends mainly on the presence of winged aphids. Many species of aphids are vectors, but the green peach aphid is probably the most efficient. Potato virus Y is transmitted in a non-persistent manner.

Management

Cultural practices — Growers should plant only carefully selected seed of Certified or a higher class. Aphids should be controlled (see buckthorn aphid, 16.40, and green peach aphid, 16.41).

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Singh, R.P. 1992. Incidence of the tobacco vecual necrotic strain of potato virus Y (PVY^N) in Canada in 1990 and 1991 and scientific basis for eradication of the disease. *Can. Plant Dis. Surv.* 72:113-119.

(Original by N.S. Wright, R. Stace-Smith and P.J. Ellis)

▶ 16.28 Spindle tuber *Figs. 16.28a,b*

Potato spindle tuber viroid

Before 1980, spindle tuber had been reported from several provinces and was of concern to seed growers and breeders. However, as a consequence of rigorous control measures, spindle tuber has not been found in Canadian seed potatoes since 1980. The spindle tuber viroid can infect potato, tomato, eggplant, tobacco and several other species of broadleaved plants.

Symptoms The characteristic symptoms of spindle tuber are long spindly tubers *(16.28b)* that often are deformed by cracking and generally are smaller than those from healthy plants. Russet skins may become smooth and colored skins may lighten. Eyes may be more numerous and heavily indented with pronounced brows. Necrotic spots often appear around lenticels and in the flesh of infected tubers. Not all tubers from an infected plant may display symptoms.

In the field, infected plants are more upright and have fewer stems than do healthy plants. Leaves are folded upward with a ruffled margin and are smaller in size *(16.28a).* The leaves on affected plants often are attached to the stem at sharp angles, and the main petiole does not drop or curve as in viroid-free plants. Symptoms may vary with cultivar and environmental conditions. High temperatures early in the growing season favor the development of symptoms.

Causal agent Potato spindle tuber viroid is a circular ribonucleic acid molecule. It is smaller than a virus and devoid of the protein coat commonly associated with viruses. Conventional serological techniques will not detect this viroid. Biochemical techniques, particularly the return-polyacrylamide gel electrophoresis and nucleic acid hybridization procedures, are used for large-scale detection. For individual tests, inoculation to indicator plants can be employed. Potato spindle tuber viroid occurs in many strains.

Disease cycle Potato spindle tuber viroid can be transmitted by sap, direct contact, grafting and through true seed. It spreads in the field largely by mechanical means, such as seed cutting and handling, and cultivation practices. The viroid is important in breeding programs because it is transmitted in pollen and true potato seed. Insects capable of spreading the viroid include the Colorado potato beetle, grasshoppers, green peach and potato aphids, potato and other flea beetles and leaf beetles, and *Lygus* bugs.

Management

Cultural practices — Growers should plant high-quality, disease-free seed. Maintaining seed stock of new cultivars viroid-free will prevent the introduction of the pathogen into the seed-production system. Since 1980, the Canada Seeds Act has had a zero tolerance for potato spindle tuber viroid in all classes of seed potatoes.

Selected references

De Bokx, J.A., and P.G.M. Piron. 1981. Transmission of potato spindle tuber viroid by aphids. *Neth. J. Plant Pathol.* 87:31-34.

Hiruki, C., D.K. Lakshman and G. Figueiredo. 1989. A comparative study of the sensitivity of dot hybridization assays using cRNA and cDNA for the detection of potato spindle tuber viroid. *Proc. Jpn. Acad.* 65, Ser. B:76-79.

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(Original by R.P. Singh and I.R. Evans)

▶ 16.29 Witches'-broom *Figs. 16.29a,b*

Potato witches'-broom mycoplasma-like organism

Witches'-broom is a minor disease on potato. It occasionally is transmitted to potato crops that are grown near alfalfa, clover or other legumes that have the disease, or which are growing among grasses and other hosts that sustain the leafhopper vectors.

Symptoms Natural infections in potato usually occur too late in the season for foliage symptoms to develop or to influence tuber size. When tubers from infected plants germinate, however, they produce an unusually large number of stems *(16.29a,b)* and are somewhat chlorotic. These symptoms may appear at emergence or later during the growing season. Such plants produce numerous small tubers. In successive years, the degeneration usually continues until no plants or tubers are formed. However, complete recovery from witches'-broom has been observed three years after initial infection in the cultivar White Rose. Apparently the pathogen failed to remain fully systemic in all tubers and some eyes produced normal stems and tubers.

Causal agent Witches'-broom is associated with an organism that resembles the one associated with aster yellows. As with aster yellows, there is no proof that the mycoplasma-like organism is the cause. Three strains, all of which are associated with the same symptoms in potato, have been distinguished by symptoms induced by graft transmission to tomato and tree tomato (*Cyphomandra betacea* (Cav.) Sendtn.).

Disease cycle The witches'-broom pathogen can be transmitted to potato from other hosts by leafhoppers *(Scleroracus* spp.) but not from potato to potato because it is an unsuitable host for these leafhoppers. In nature, inoculum probably is acquired from infected legumes and is transmitted to potato when the leafhoppers migrate into potato fields.

Management

Cultural practices — Growers should use Certified or a higher class of seed grown in areas where witches'-broom has not been found. In affected areas, leafhopper migration into potato fields should be controlled by modifying cultural practices and by using insecticides, particularly on field margins.

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(Original by N.S. Wright)

NON-INFECTIOUS DISEASES

A large number of non-infectious disorders can affect potatoes. These result from stresses such as mechanical damage, nutritional imbalances, temperature and moisture effects, poor soil aeration, chemical injury and air pollution. The common problems are described in the following sections.

▶ 16.30 Blackheart *Fig. 16.30*

Blackheart is primarily a disorder of stored potatoes. It is often seen in tubers stored in closed bins or in deep piles that lack adequate aeration. Blackheart develops when oxygen is limited or excluded from stored potatoes, particularly at temperatures above 15°C. It is seen occasionally in potato fields that were excessively wet before harvest, resulting in the internal tuber tissues having insufficient oxygen for respiration.

Symptoms Affected tubers develop an intense, blackish, irregular discoloration in the center *(16.30).* The blackened tissue is initially firm, but later becomes soft and watery.

Management

Cultural practices — Growers should avoid storing potatoes in closed containers or bins, or in deep piles that lack adequate ventilation. Storage temperatures should be reduced as soon as possible after harvest. Potato should not be grown on land that is subject to flooding or has poor drainage.

Selected references

Bennett, J.P., and E.T. Bartholomew. 1924. The respiration of potato tubers in relation to the occurrence of blackheart. *Calif. Agric. Exp. Stn. Tech. Paper*. 14. 41 pp.

Stewart, F.C., and A.J. Mix. 1917. Blackheart and the aeration of potatoes in storage. *New York Agric. Exp. Stn.* (*Geneva*) *Tech. Bull.* 436:321-362.

(Original by I.R. Evans and R.J. Howard)

▶ 16.31 Growth cracks *Fig. 16.31*

Several types of growth cracks can occur in potato tubers and can reduce quality. Thumbnail cracks result from rough handling and drying of the skin during or after digging. This disorder is aggravated by dry storage conditions. Cracks may also result from mechanical pressure or impact during harvest. Factors such as cultivar type, frost damage, top-killing and harvesting during cold soil conditions can induce growth cracking.

Symptoms Thumbnail cracking appears as if a thumbnail has been pressed into the skin of the potato *(16.31).* The cracks are usually shallow but tubers may be rendered unmarketable. Tubers may also split from internal pressure following excessively rapid growth, which usually occurs along the longitudinal axis of tubers. They may heal during the growing season and be of little consequence. Cracked tubers in the field and in storage are much more liable to be infected by bacteria and fungi that may cause them to rot.

Management

Cultural practices — Producers should follow good soil and crop management practices, especially when fertilizing, irrigating and spacing plants. Tubers should be handled as little and as gently as possible from harvesting to storage. Following storage, the tubers should be warmed prior to handling. Tubers should be stored at high humidity to minimize thumbnail cracking.

Selected references
Jefferies, R.A., and D.K.L. Mackerron. 1987. Observations on the incidence of tuber growth cracking in relation to weather patterns. *Potato Res.* 30:613-623.
Sparks, W.C. 1970. Thumbnail cracks in potatoes. *Idaho Agric. Exp. Stn. Bull.* 136. 4 pp.

(Original by I.R. Evans and R.J. Howard)

▶ 16.32 Hollow heart *Fig. 16.32*

Hollow heart is a common disorder in oversized or rapidly growing, early maturing tubers. Up to half of the tubers of some cultivars may be affected. It is most severe under conditions that favor rapid tuber enlargement, such as unbalanced fertilization, dry soil conditions followed by high moisture levels, and soils with a low organic matter content, especially those that are well-drained and in areas where the annual rainfall may exceed 750 mm. Wide plant spacing or loss of hills can increase incidence of hollow heart. Potassium deficiency also has been implicated in this disorder.

Symptoms Tubers with hollow heart lack external symptoms. They usually are detected only after the potatoes have been cut in half. Initially, affected tubers exhibit a brown area at or near the center. Later, tan- to brown-walled angular cavities, up to 5 cm in diameter, develop at these sites *(16.32).*

Management

Cultural practices — Specific gravity tests or X-rays can be used to detect affected tubers. Close and regular spacing of hills, maintenance of uniform soil moisture levels, adequate potassium fertilization, and the planting of highly susceptible cultivars, such as Kennebec, closer together in the row will reduce hollow heart incidence.

Selected references
Finney, E.E., Jr., and K.H. Norris. 1978. X-ray scans for detecting hollow heart in potatoes. *Am. Potato J.* 55:85-105.
Crumbly, I.J., D.C. Nelson, and M.E. Duysen. 1973. Relationships of hollow heart in Irish potatoes to carbohydrate reabsorption and growth rate of tubers. *Am. Potato J.* 50:266-274.

(Original by I.R. Evans)

▶ 16.33 Jelly end rot

This disorder is most common in western Canada, particularly in the cultivar Russet Burbank. Affected tubers are unmarketable. Conditions that interfere with starch deposition, such as high soil temperatures and drought, followed by abundant mositure, are usually responsible for this problem. Jelly end rot is prevalent in misshapen tubers, particularly those with secondary growth. Because this disorder is strongly influenced by growing conditions, it tends to be seasonal in occurrence.

Symptoms The flesh at the stem end of the potato becomes glassy and jelly-like and then shrivels and dries up.

Management

Cultural practices — Consistent and adequate moisture conditions must be maintained during the growing season, particularly during tuber formation.

Selected references
Iritani, W.M., and L. Weller. 1973. The development of translucent end tubers. *Am. Potato J.* 50:223-233.

(Original by I.R. Evans)

▶ 16.34 Other physiological disorders *Figs. 16.34a-n*

Genetic abnormalities
Herbicide injury
Internal black spot
Internal sprouting
Nutritional disorders
Secondary tubers
Stem-end browning
Tuber greening
Miscellaneous disorders

Genetic abnormalities

Wildings are potato plants that are characterized by the production of foliage that is darker green than normal, numerous stems, and many small tubers. Affected plants rarely flower and yield is reduced. Feathery wildings are another variation of this problem and can result in multiple stems and reduced yields. The causes are unknown and control is by roguing these plants during the seed certification process.

A condition known as “giant hill” causes potato plants to mature later than normal, grow to be extremely large and vigorous, and produce numerous flowers. Tubers are usually few and rough. The cause is unknown and control is by roguing during the inspection of seed fields. The cause of pink discoloration in the flesh of white-fleshed tubers *(16.34a)* is also unknown.

Selected references

Dearborn, C.H. 1963. “Stitched end,” “giant hill,” and fasciated stem of potatoes in Alaska. *Am. Potato J.* 40:357-360.

Herbicide injury

The drift onto growing crops of specific herbicides may cause severe damage and significant yield and quality losses. Potatoes are sensitive to soil-borne residues of herbicides such as picloram, clopyralid, chlorsul- furon and dicamba. If potato is grown on land that has been recently treated with these chemicals, particularly picloram *(16.34b)*, severe yield losses, tuber malformation (*16.34c*) and stem-end discoloration may result. These chemicals can be taken up by seed tubers and subsequent crops may show typical herbicide injury symptoms. Potato foliage is sensitive to picloram at levels of less than one part per billion. Drift of picloram onto potato crops or soil residues of this herbicide may adversely affect potato yield and quality.

Internal black spot

Grayish spots develop just under the skin, particularly at the stem-end of tubers. Bruising and potassium deficiency are thought to cause this condition.

Internal sprouting

Tubers can sprout internally to the extent that they split and small tubers form inside *(16.34d)*. Storage temperatures above 16°C, which physiologically ages the tuber, and insufficient concentrations of CIPC (isopropyl-m-chlorocarbanilate), a sprout inhibitor, may induce this disorder.

Nutritional disorders

Nitrogen, phosphorus, potassium, sulphur, calcium and magnesium are the major nutrients essential for normal potato growth. An absence or shortage of any of these can cause severe yield reduction. Magnesium deficiency is common on coarse-textured, acidic soils in eastern Canada.

Micronutrients generally considered essential for potato are boron, chlorine, copper, iron manganese, molybdenum and zinc. Some or all of these elements may be in short or limiting supply on coarse-textured (sandy) soils that are otherwise favorable for growing potato. Deficiency symptoms may resemble specific infectious or non-infectious diseases *(16.34e,f)*. Excesses of micronutrients such as boron, aluminum and manganese also may cause considerable yield loss, particularly on acidic soils with a pH of around 5.0.

Nutritional disorders can generally be corrected by applications of fertilizers containing the missing elements. Most fertilizers are applied at or before planting, but applications can also be made in irrigation water (fertigation) or by spraying directly onto the foliage. It is advisable to use the results of soil and/or tissue analyses to properly gauge the amount of fertilizer necessary to correct the problem.

Selected references

Collier, G.F., D.C.E. Wurr and V.C. Huntington. 1980. The susceptibility of potato varieties to internal rust spot. *J. Agric. Sci.* **(***Cambridge***)** 94:407-410.

Dyson, P.W., and J. Digby. 1975. Effects of calcium on sprout growth and sub-apical necrosis in Majestic potatoes. *Potato Res.* 18:290-305.

Secondary tubers

In storage or following planting, tubers may form secondary, bead-like tubers but no shoots *(16.34g,j)*. Storing tubers above 16°C or planting tubers into cold, dry soil will induce this disorder. The result may be hills with missing plants. Physiologically old seed tends to form more secondary tubers than fresh seed brought out of cold storage.

Selected references

Van Schreven, D.A. 1956. On the physiology of tuber formation in potatoes. 1. Premature tuber formation. *Plant Soil* 8:49-55.

Stem-end browning

Brownish streaks at the stem end of the tuber (*16.34k*) are often associated with rapid killing of potato tops by chemicals or frost. To minimize the risk of this disorder, growers should apply slow-acting top killers at least two weeks before harvesting the crop. Alternatively, reduced rates of chemical, higher rates of water to enhance coverage of vines, and two applications spaced one week apart should be considered. This will kill the vines more gradually. While these practices may prevent or reduce stem-end browning, they can increase the incidence and severity of infectious diseases that affect the tubers. Late blight, leafroll and rhizoctonia scurf are examples of diseases that may have more time to affect the maturing potato crop.

Selected references
Halderson, J.L., D.L. Corsini and L.C. Haderlie. 1985. Potato vine kill: stem-end discoloration effects on Russet Burbank. *Am. Potato J.* 62:273-279.

Tuber greening

Greening (formation of chlorophyll in the leucoplasts of tubers) results from exposure of tubers to sunlight or to artificial light in storage *(16.34h).* This disorder is serious in potatoes intended for consumption, since exposure to light also simultaneously increases levels of glycoalkaloids. Low levels of steroid glycoalkaloids (solanine and chaconine) are present in all potato tubers, but potatoes are considered unfit for consumption when glycoalkaloid levels exceed 20 mg/100 g fresh weight. Glycoalkaloids may impart a bitter taste, are toxic at concentrations over 40 mg/100 g and may be teratogenic. They are not decomposed or removed by normal cooking or food processing methods. Other factors that may induce high levels of glycoalkaloids in potatoes in the absence of greening are rough handling, Colorado potato beetle attack, and harvesting under very cold conditions.

Greening can be controlled by proper hilling, by avoiding cultivars that set tubers near the soil surface, by applying sufficient moisture to avoid soil cracking, and by storing tubers in darkness.

Selected references
Poapst, P.A., I. Price and F.R. Forsyth. 1978. Controlling post storage greening in table stock potatoes with ethoxylated mono- and diglyceride surfactants and an adjuvant. *Am. Potato J.* 55:35-42.
Rizk, A.F.M. 1991. *Poisonous Plant Contamination of Edible Plants.* CRC Press, Boca Raton, Florida. 183 pp.

Miscellaneous disorders

There are many other non-parasitic disorders of potato that are caused by such factors as air pollutants (sulphur dioxide and ozone), toxins from feeding by various insects, wet soil (enlarged lenticels, *16.34m),* low or high air and soil temperatures (sprouting, *16.34i;* tuber necrosis, *16.34n),* and wind, hail and lightning injury. In Ontario, atmospheric ozone levels of 70 ppb for one or two days have caused significant injury to potato foliage. Research there has shown that ozone, an indirect by-product of automobile exhaust, can defoliate susceptible cultivars, such as Norland, while tolerant cultivars, such as Kennebec, may hardly be affected. (For more information on these disorders, see Additional references.)

(Original by I.R. Evans and B. Otrysko)

NEMATODE PESTS

▶ 16.35 Northern root-knot nematode *Fig. 16.35*

Meloidogyne hapla Chitwood

Symptoms In potato, root-knot nematodes penetrate root and tuber lenticels. Scab-like lesions on tubers may make them unmarketable. For a complete description and management strategies, see Carrot, 6.20; see also Management of nematode pests, 3.12.

▶ 16.36 Potato cyst nematodes *Fig. 16.36*

Golden nematode *Globodera rostochiensis* (Wollenweb.) Behrens
Pale cyst nematode *Globodera pallida* (Stone) Behrens

These two species of potato cyst nematodes have been introduced into Canada (see Introduced diseases and pests, 3.11). Both species occur in Newfoundland, and the golden nematode also occurs on Vancouver Island. Hosts of both species are potato, tomato, eggplant and other solanaceous plants.

Symptoms Foliage of affected plants appears pale and may wilt under dry conditions. Nematodes in large numbers can cause stunting, early senescence and root proliferation. In heavy infestations, plants look as though they are under water stress or suffering from a nutrient deficiency. Yield loss varies with nematode density and resistance level of the potato cultivar.

Identification *Globodera* spp. (order Tylenchida, family Heteroderidae) are morphologically similar and related to the sugarbeet cyst nematode *Heterodera schachtii.* In *Globodera*, the female body is subspherical to round before turning into a brown cyst; the genital opening (vulva) is a transverse slit between finely papillated, crescentic areas; and the cuticle surface between the anus and vulva is arranged in parallel ridges.

These two potato cyst nematodes differ in color before encystment. In *G. rostochiensis,* the female's cuticle is golden yellow, whereas in *G. pallida* it is white. Identification must be confirmed by a specialist. In the field, the non-specialist needs to know that a spherical white or golden- yellow cyst, about 1 mm in diameter, can be seen on potato roots if potato cyst nematodes are present *(16.36).*

Life history Eggs, stimulated by root exudates, hatch while encysted in the soil. Second-stage juveniles leave the cyst, migrate through the soil, and invade roots to feed. They molt three times before becoming adult. Juveniles penetrate the roots to feed near the vascular bundles, inducing large multinucleate cells. While the rest of the female's body, which is white or yellow at this stage, enlarges and erupts through the root epidermis, the head remains inserted. Males feed and mature, then leave the root tissues, migrate through the soil, and mate with protruding females. Fertilized females fill with as many as 500 eggs. The body becomes a sub-spherical, hard, dark cyst that retains the eggs, which may remain viable for twenty years or more. The cyst may adhere to the roots or eventually become free in the surrounding soil.

Management

Cultural practices — Movement of potatoes and other solanaceous crops, soil, contaminated machinery, tools, and storage containers from quarantined areas is prohibited in Canada (see Introduced diseases and pests, 3.11).

Resistant cultivars — Races of both *Globodera* species vary in their ability to multiply on potato clones and hybrids, which has encouraged breeding for resistant potato cultivars to use in Newfoundland.

Selected references

Evans, K., and A.R. Stone. 1977. A review of the distribution and biology of the potato cyst-nematodes *Globodera rostochiensis* and *G. pallida. Pans* 23:178-189.

Mulvey, R.H., and A.M. Golden. 1983. An illustrated key to the cystforming genera and species of Heteroderidae in the Western Hemisphere with species morphometries and distribution. *J. Nematol.* 15:1-59.

Stone, A.R. 1973. *Heterodera rostochiensis.* CIH Descriptions of Plant Parasitic Nematodes, Set 2, No. 16. Commonw. Agric. Bureaux, England. 4 pp.

Stone, A.R. 1973. *Heterodera pallida.* CIH Descriptions of Plant Parasitic Nematodes, Set 2, No. 17. Commonw. Agric. Bureaux, England. 2 pp.

(Original by B.A. Ebsary and I.A. MacLatchy)

▶ 16.37 Potato-rot nematode *Fig. 16.37*

Ditylenchus destructor G. Thorne

This nematode is a serious pest of potato in many countries, but it has not been reported in Canada since the 1960s. For a description, see Foreign diseases and pests, 3.10.

▶ 16.38 Root-lesion nematode *Figs. 16.38; 16.38T1*

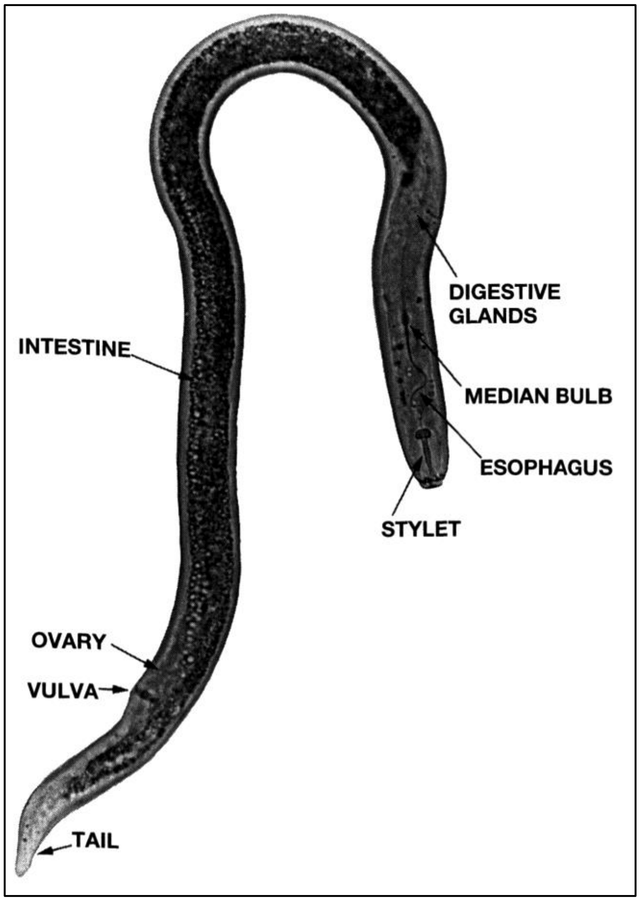
Pratylenchus penetrans (Cobb) Filip. & Stek.

The root-lesion nematode affects most of the major vegetable crops grown in Canada. Yield reductions of 10 to 40% have been observed in commercial potato fields and experimental plots in Ontario and Prince Edward Island.

Symptoms Plant growth is stunted in heavy infestations. Affected plants occur in patches, usually extending along the rows, or elongated in the direction of cultivation. Plants wilt readily on hot days and leaves become progressively yellow. Older leaves may die prematurely. Secondary roots are necrotic with dried areas. Yields of leaf vegetables are lowered. Tap root maturation is delayed and they may be smaller and branched. Tubers and bulbs are smaller and may be commercially down-graded *(16.38)*. However, stunting, chlorosis and early senescence also are caused by other infectious and non-infectious diseases. Small lesions on feeder roots and black rotting are indicative of root- lesion nematode damage, but may not be sufficient evidence to conclude that nematodes are the sole problem.

Identification *Pratylenchus* spp. (order Tylenchida, family Pratylenchidae) are difficult to separate because of the small number of diagnostic characters at the species level and intra-specific variability.

Adults of *P. penetrans* are about 0.8 mm long. The head is low and broad. Stylet and labial sclerotization are well developed. The oesophageal glands overlap the intestine ventrally. In females (*16.38T1*), the genital opening (vulva) is posteriorly situated and the posterior branch of the ovary is reduced to a post-uterine sac. In males, the tail is pointed with a well-developed genital pouch (bursa).



16.38T1 Root-lesion nematode; female.

Life history *Pratylenchus penetrans* migrates through the soil and infects developing roots, preferentially in the root- hair zone. Second-stage juveniles through to the adults are migratory endoparasites, penetrating roots and migrating through the cortical tissue while feeding. To feed, they push their stylet through a cell wall, inject digestive enzymes secreted from the oesophageal gland, and ingest the cell contents. By repeatedly thrusting the stylet through the cell wall, they make a slit-like opening and move forward to feed on the next cell. The females lay eggs as they move through the tissues. A second-stage juvenile hatches from each egg and starts feeding on adjacent cells, progressively enlarging the zone of necrosis. Lesions enlarge and coalesce as the nematodes feed. The nematodes leave a decaying root when they become over-crowded. Soil bacteria and fungi can grow rapidly in the lesions and accelerate the decomposition of cortical root tissues. In soil, the nematodes are attracted to newly formed roots and to uninfested parts of the same root.

The life cycle on most crops varies with the type of host and soil temperature, ranging from 40 to 90 days at 25 to 15°C, respectively. When soil conditions become unfavorable for nematode migration or root growth, many juveniles and adults become quiescent for several months. Approximately 50% of the nematodes can survive two years in soil at 4°C. This nematode is also a moderate anhydrobiote, being able to enter a coiled, dehydrated state and survive in moderately dry soil for several months.

Management

Monitoring — Low to medium densities of nematodes in soil or roots (50 to several hundred per 100 mL of soil or per gram of roots) at mid-season do not generally constitute a serious threat to susceptible crops. However, when soil sampling reveals high populations (100 or more per 100 mL of soil) of root-lesion nematodes before planting, significant damage may result.

Cultural practices — In gardens, interplanting with certain marigolds *(Tagetes patula* L. and *Tagetes erecta* L.) and the use of solarization are effective. See also Management of nematode pests, 3.12.

Selected references

Ferris, J.M. 1962. Some observations on the number of root lesion nematodes necessary to cause injury to seedling onions. *Plant Dis. Rep.* 46:484-485.

Kimpinski, J., and K.B. McRae. 1988. Relationship of yield and *Pratylenchus* spp. population densities in Superior and Russet Burbank potato. *Ann. Appl. Nematol.* 2:34-37.
Olthof, T.H.A., and J.W. Potter. 1972. The relationship between population densities of *Pratylenchus penetrans* and crop losses in summer maturing vegetables in Ontario. *Phytopathology* 63:577-582.
Potter, J.W., and T.H.A. Olthof. 1977. Analysis of crop losses in tomato due to *Pratylenchus penetrans. J. Nematol.* 9:290-295.
Townshend, J.L. 1962. The root-lesion nematode, *Pratylenchus penetrans* (Cobb, 1917) Filip. & Stek. 1941, in celery. *Can. J. Plant Sei.* 42:314-322.

(Original by T.C. Vrain and J. Kimpinski)

▶ 16.39 Stubby-root nematodes

Paratrichodorus allii (Jensen) Siddiqi
Paratrichodorus pachydermus (Seinhorst) Siddiqi
Paratrichodorus spp.
Trichodorus spp.

This group of nematodes is not well established in Canada and has caused only minor damage to a few gardens in southern Alberta. Reports of damage to onion by *P. allii*, and of the transmission of corky ringspot disease of potato by *P. pachydermus* and possibly other species, are open to question. Several species of *Paratrichodorus* and *Trichodorus* induce the same symptoms and have the same common name. Stubby-root nematodes attack many types of vegetables, including bean, cabbage, corn and tomato. These nematodes are most prevalent and damaging in sandy loam or sandy soils; they are heat and drought tolerant.

Symptoms When stubby-root nematode density is high, which is rare in Canada, affected plants become stunted and chlorotic. Roots proliferate abnormally but appear not to grow in length and their extremities may be somewhat swollen. In potato, there is very little direct damage; however, large necrotic lesions form in tubers affected by these nematodes, which vector tobacco rattle virus, the cause of corky ringspot disease of potato (see corky ringspot, 16.25).

Identification Stubby-root nematodes (order Dorylaimida, family Trichodoridae) are short, thick nematodes with a non-axial, dorsal curved stylet (onchiostyle). Extraction and identification from representative soil and/or root samples are necessary to confirm that stubby-root nematodes are the cause of disease.

Life history Stubby-root nematodes are strictly ectoparasitic, feeding aggressively on epidermal cells and devitalizing root tips. They develop and multiply in the root zone without ever entering the plant roots. When new roots emerge, the nematodes immediately feed upon them. The roots stop growing and remain damaged, swollen and short.

Management ***Cultural practices*** — Solarization is effective in small areas to reduce numbers of stubby-root nematodes, which tend to be shallow feeders.

(Original by T.C. Vrain)

INSECT PESTS

▶ 16.40 Buckthorn aphid *Figs. 16.40a,b*

Aphis nasturtii Kaltenbach
(syn. *Aphis abbreviata* Patch)

The buckthorn aphid occurs from Manitoba eastward in Canada. The overwintering host is any of several species of buckthorn, such as the alder-leaved buckthorn (*Rhamnus alnifolia* L'Hér.), the European buckthorn (*R. cathartica* L.) and alder buckthorn (*R. frangula* L.). Secondary hosts include species of Solanaceae and some species of Cruciferae, Labiatae and Polygonaceae.

Damage The buckthorn aphid infests the lower leaves of potato. It rarely increases in numbers sufficiently to weaken a crop or reduce potato yields. Summer populations usually are localized within a field, where nevertheless this may be the most abundant species of aphid; in a dry year, it can spread throughout the field.

The buckthorn aphid is an effective vector of potato virus Y.

Identification The buckthorn aphid is the smallest of the potato-colonizing aphids. Adults range from 1.2 to 2.0 mm in length, the body is flattened, egg-shaped, lemon-yellow or green, the tip of the abdomen (cauda) has fewer than 10 hairs (setae), and the antennae do not have prominent tubercles. Winged adults have a conspicuous, dark brown to black head and thorax (*16.40b).*

Life history The buckthorn aphid overwinters as an egg on buckthorn, although in warm regions adult females also may survive the winter on weeds. In spring, the buckthorn aphid migrates from the overwintering host, at first colonizing weeds and by mid-July potato crops, *(16.40a).* Late in the summer, winged males and females appear and migrate to buckthorn. The winged females give birth to wingless sexual forms, which mate and lay the overwintering eggs.

Management

Monitoring — Abundance of the buckthorn aphid is estimated by counting the number of aphids on leaves. A sequential sampling plan, using 100 plants and a count of 0.6 or more aphids per plant, provides a satisfactory estimate of the distribution of aggregations of the buckthorn aphid. In central and eastern Canada, it is rarely economical to apply control measures to prevent direct damage to the plants. For that reason, the empirical threshold is set very high. In New Brunswick, for example, the action threshold is 150 aphids per plant and 80% of the plants infested.

Cultural practices — To reduce the spread of potato virus Y, mineral oil should be applied to seed-potato fields at weekly intervals at the first appearance of the buckthorn aphid (or other aphid vectors). Eradicating buckthorn shrubs from areas where potato is grown has been suggested, but the impact of this practice has yet to be evaluated.

Chemical control — Any recommended insecticide should be applied whenever sudden, rapid and significant increases in buckthorn aphid occur. The buckthorn aphid is susceptible to a wider range of insecticides than are other potato-colonizing aphids. However, because of its preference for the undersides of lower leaves, it may be more difficult to control. Nevertheless, chemical insecticides are the only means available for control of the buckthorn aphid when its populations are sufficiently high to affect yield or to increase the spread of virus diseases. No resistance to insecticides has been recorded in Canada.

(Original by G. Boiteau)

▶ 16.41 Green peach aphid *Figs. 16.41a,b*

Myzus persicae (Sulzer)

The green peach aphid occurs worldwide and is transcontinental in Canada, being present in all vegetable-producing areas. It is thought to be Asian in origin. In British Columbia and most of southern Ontario, the green peach aphid is the most abundant and potentially damaging potato-colonizing aphid. In the rest of Canada, it is secondary to other aphids, such as the potato aphid and the buckthorn aphid, because it colonizes potato late in the season and its populations rarely increase sufficiently to weaken the crop and reduce yields.

The overwintering hosts are peach *(Prunus persica* (L.) Batsch.), Canada plum *(P. nigra* Ait.) and black cherry *(P. serotina* Ehrh.). Although Canada plum is endemic along the southern border of Canada from Manitoba to New Brunswick, the green peach aphid rarely overwinters successfully on this host in New Brunswick. In some areas of the Prairie provinces, no overwintering host has been found.

Summer hosts number in the hundreds, belong to many plant families and include vegetable crops in the Solanaceae, Chenopodiaceae, Compositae, Cruciferae and Leguminosae. Among the vegetable crops, potato is a preferred summer host.

Damage The green peach aphid affects mainly the lower leaves of potato, but flowers and shoot tips also are subject to attack. The green peach aphid is the most important vector of potato leafroll virus, and it is an effective vector of potato virus A, potato virus S, and potato virus Y (including the tobacco necrotic strain).

Identification The adult green peach aphid is 1.2 to 2.5 mm in length and egg-shaped. The body has paired abdominal projections (cornicles) that are slightly swollen toward the tips, and the bases of the antennae have prominent, inwardly directed tubercles. Wingless adults *(16.41a)* are light green and almost translucent. Winged adults (*16.41b*) have a black or dark brown head and thorax, and a dark dorsal patch in the center of the abdomen.

Life history The green peach aphid gives birth to live young without mating (parthenogenesis) during the growing season. Later, in response to changing daylength and low fall temperatures, sexual forms appear, mate and lay eggs. The green peach aphid can overwinter in the warmer areas of Canada, such as southern Ontario and British Columbia, either as adult females on weeds and woody shrubs or as eggs on peach trees. This is why early planted potato in British Columbia and southern Ontario can be colonized by the green peach aphid soon after plant emergence in late May or early June. Almost everywhere else in Canada, early colonization of potato occurs less frequently because the aphids move from bedding plants or overwintering sites in greenhouses; in that case, colonization usually occurs later in the season and the aphids are thought to originate from the United States or from local weed hosts around greenhouses or storage areas.

In late summer, winged males and females are produced, but their numbers on potato dwindle as they seek overwintering hosts. Adults may survive in storage areas.

Management It is important to manage populations of the green peach aphid to prevent or reduce the spread of virus diseases in the potato crop.

Monitoring — The green peach aphid is usually located on the lower leaves of potato. The technique for monitoring the abundance of this and other potato-colonizing aphids is to count the number of aphids (winged and wingless) on 100 plants chosen at random while walking in a pattern (“X” or “W”) through the field. Counts are based on three compound leaves per plant, which should be taken from the upper, middle and lower parts of the plant because the different species of aphids do not distribute themselves evenly over the entire plant. This procedure often must be modified to suit the requirements of a given region. It may be necessary to adjust the counts for plant size in order to compare aphid populations on different potato cultivars or on potato crops grown under different conditions. If the plants are very small, they can be beaten over a tray, in which case all aphids are counted.

In general, the need for control is based on the occurrence of sudden and significant increases in the number of green peach aphids on potato plants or in monitoring traps. Traps provide information that can be related to the dispersal and redistribution of aphids. Because yellow traps attract aphids, they are used to monitor the time of aphid flights. Yellow water-pan traps are used in Prince Edward Island, New Brunswick and Ontario. Yellow sticky traps have been used in British Columbia. In Quebec and New Brunswick, estimates of the aerial population are obtained by using suction traps at heights of 1.5 and 12 m. Landing rates in the crop can be estimated by using leaf-green water-pan traps.

The empirical threshold for the green peach aphid on potato in New Brunswick is 25 aphids per plant, using a sampling unit of three compound leaves per plant, and 10% of all plants being infested; monitoring is continued until mid- to late August, after which control usually is not required. In British Columbia, the threshold is 30 aphids per compound leaf per plant and 20% of all plants infested.

In areas where seed-potato crops are grown, top-killing is recommended as soon as possible after the onset of flights of the green peach aphid. To indicate when leafroll may begin to spread within the crop, a threshold of five cumulative catches in any yellow water-pan trap is used in New Brunswick; in British Columbia, a significant increase in aphid catches serves as an indicator.

Cultural practices — To prevent or reduce the spread of virus diseases, growers should plant only Certified seed, and rogue and top-kill to eliminate infected plants as soon as possible after aphid flights begin. Mineral oil may be applied to seed-potato crops at weekly intervals to reduce the spread of mosaic. To limit the spread of virus diseases, some provinces establish mandatory dates each year for top-killing, which should be done as soon as tubers are suffficiently mature to escape injury.

Chemical control — To keep field populations of the green peach aphid low, thereby preventing the formation of winged forms that might spread virus diseases, growers usually have to apply chemical insecticides. In areas where early colonization from overwintering hosts or greenhouse colonies is likely, a systemic insecticide at planting will be effective for seven weeks or longer. This sometimes eliminates the need for further control measures. Resistance to pesticides has been reported for the green peach aphid in coastal British Columbia.

(Original by G. Boiteau)

▶ 16.42 Potato aphid *Figs. 16.42a-c*

Macrosiphum euphorbiae (Thomas)

The potato aphid is worldwide in distribution and probably Asian in origin. In Canada, it is transcontinental and the most abundant aphid on potato in eastern Canada and possibly across Canada. In Atlantic Canada, this is the first aphid to appear on potato. It usually can be found in June in most fields. It shows a preference for the middle and upper part of the plant, which is where the winged forms usually settle. High numbers can weaken the crop and reduce yields.

Overwintering hosts are Rosaceae, such as shining rose *(Rosa nitida* Willd.), swamp rose (*R. palustris* Marsh.) and rough rose *(R. rugosa* Thunb.). Summer hosts include a variety of vegetable crops and various other plants; potato is one of the preferred summer hosts.

Damage General characteristics of high numbers of the potato aphid include wilting of the plants and honeydew on the leaves. Mainly flowers and shoots are attacked.

The potato aphid transmits potato virus Y in tobacco, but almost never in potato. It is considered to be a poor vector of potato virus A and potato leafroll.

Identification Wingless potato aphid adults are 1.7 to 3.6 mm in length, which makes them the largest of the potato-colonizing aphids in Canada. The body is elongate, wedge-shaped, yellowish-green to pink and darker along the middle of the back *(16.42a,b).* The head has prominent antennal tubercles that are directed outwards. Winged adults have a pale yellow- brown, green-brown or dark brown head and thorax *(16.42c).* The potato aphid is quite restless and will drop when disturbed.

Life history The potato aphid overwinters as nymph-producing females in sheltered sites, such as greenhouses, and as eggs on rosaceous plants. The eggs hatch in the spring as the buds begin to swell. Two to six generations of females are produced on the overwintering host, during which time winged females mature and migrate to various weeds and to potato plants. Population build-up occurs between 5 and 25°C. Aphid numbers continue to increase in July and winged forms are produced. By early or mid-August, the population of *M. euphorbiae* on potato declines, mainly because winged males and females start to move to their overwintering hosts.

Management

Monitoring — Abundance of the potato aphid is estimated by counting aphid numbers on leaves (see green peach aphid). A sequential sampling plan, using 100 plants and a level of one or more aphids per plant, gives a satisfactory estimate of the distribution of the aphid. In eastern Canada, management is not necessary unless the potato aphid becomes sufficiently abundant to affect yields, which is why the empirical threshold is set fairly high. For example, in New Brunswick, the threshold is 50 aphids per compound leaf per plant and 40 to 60% of plants infested. In western Canada, management of the potato aphid rarely is required.

Biological control — Of the potato-colonizing aphids, the potato aphid is most subject to control by naturally occurring parasites, predators and fungi, but these biocontrol agents generally are not being used. In some integrated pest management programs in British Columbia, beneficial insects are a major component of aphid management strategies, especially in areas where the use of broad spectrum insecticides against other insect pests has been reduced or eliminated.

Chemical control — Any recommended insecticide can be applied whenever sudden, rapid and significant increases in abundance of the potato aphid occur. However, chemical control of the potato aphid is probably not economical in western Canada and may only be needed occasionally in central and eastern Canada.

(Original by G. Boiteau)

▶ 16.43 Other aphids *Figs. 16.43; 16.43T1, T2*

Black bean aphid *Aphis fabae* Scopoli
Bulb and potato aphid *Rhopalosiphoninus latysiphon* (Davidson)
Crescent-marked lily aphid *Aulacorthum circumflexum* (Buckton)
Foxglove aphid *Aulacorthum solani* (Kaltenbach)
Melon (cotton) aphid *Aphis gossypii* Glover

Black bean aphid —

The black bean aphid occurs worldwide and throughout Canada. It visits potato fields in eastern Canada and occasionally colonizes potato in western Canada. It has a very large host range.

Bulb and potato aphid —

The bulb and potato aphid occurs in British Columbia but has only rarely been reported on potato. It affects mainly tulip and gladiolus bulbs, and it infests the roots of many plants in the field. It may attack potato tubers in storage.

Crescent-marked lily aphid —

The crescent-marked lily aphid, also called the mottled arum aphid, occurs in British Columbia, where it is common on potato crops. It has a wide host range, but no overwintering hosts are known in Canada.

Foxglove aphid —

The foxglove aphid *(16.43)* is virtually worldwide in distribution. It occurs across Canada, extending into the Northwest Territories. It is only occasionally present on potato crops in eastern Canada and the Prairie provinces, but it can be as abundant as the potato aphid in British Columbia. Where the climate permits, it overwinters as eggs on a variety of hosts, such as common foxglove *(Digitalis purpurea* L.), plantain *(Plantago maritima* L.), red clover *(Trifolium pratense* L.), hawkweed *(Hieracium* spp.) and strawberry *(Fragaria* spp.). During the summer, it is found on numerous mono- and dicotyledonous plants, including potato.

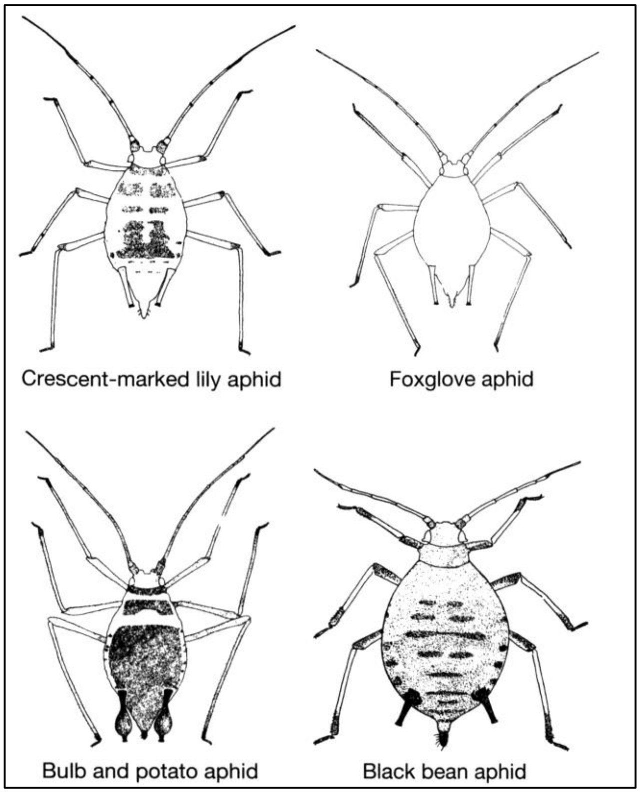
Melon aphid —

The melon (or cotton) aphid attacks many crops (see Greenhouse cucumber, 22.33). Recently, it has been a problem in commercial potato crops in British Columbia.

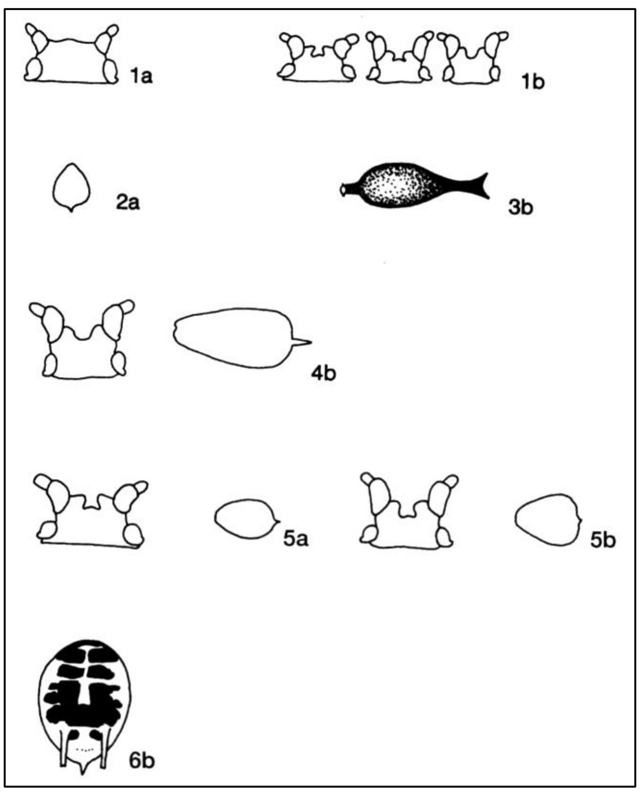
Damage The foxglove aphid can cause discoloration and irregular curling of the leaves, especially unfolding leaflets.

Table 16.43 Key to wingless female aphids colonizing potato in Canada

1a	Antennae shorter than body, antennal tubercles absent or weak	2
lb	Antennae as long as, or longer than, body, antennal tubercles prominent	3
2a	Body yellow to green, without dark marks on dorsum, cauda of abdomen with fewer than 10 setae	Buckthorn aphid *Aphis nasturtii*
2b	Body color variable with dark marks on dorsum (easily confused with *Aphis nasturtii*)	Melon aphid *Aphis gossypii*
2c	Body dull black, without dark marks on dorsum, cauda of abdomen with more than 10 setae	Black bean aphid *Aphis fabae*
3a	Cornicles brown to yellow-green, slightly swollen or not at all	4
3b	Cornicles shiny black, extremely swollen	Bulb and potato aphid *Rhopalosiphoninus latysiphon*
4a	Body ovoid or pear-shaped, antennal tubercles convergent inward or parallel sided	5
4b	Body elongate or wedge-shaped, antennal tubercles sloping outward	Potato aphid *Macrosiphum euphorbiae*
5a	Body pear-shaped, abdomen pigmented	6
5b	Body ovoid, abdomen unmarked	Green peach aphid *Myzus persicae*
6a	Thorax unmarked, abdomen pigmented at base of cornicles only	Foxglove aphid *Aulacorthum solani*
6b	Thorax with transverse bands or patches, abdomen with large black patch	Crescent-marked lily aphid *Aulacorthum circumflexum*



16.43T1 Aphids; four species that occasionally infest potato.



16.43T2 Aphids; body parts of wingless females described in Table 16.43.

Other aphids usually are not sufficiently abundant to be damaging, but they may cause loss of vigor in plants or sprouts. In general, none of these aphids has an economic impact on potato as a standing crop.

The foxglove aphid and the crescent-marked lily aphid transmit potato leafroll. Their scarcity excludes them as vectors of any importance, except in British Columbia. The black bean aphid transmits both leafroll and mosaic, but it is not a major factor in the spread of these diseases. Were it not for its rare occurrence, the bulb and potato aphid could be important as a vector of leafroll to potato in storage.

Life history The black bean aphid prefers young leaves and shoots. It overwinters as eggs on weed hosts. The bulb and potato aphid will breed continuously in storage areas. The foxglove aphid is seldom abundant on potato except in British Columbia, where it is most abundant during mid- to late August. It overwinters as eggs on weeds or as nymph- producing females inside greenhouses and other protected places. It prefers potato leaves close to the ground and occasionally it is found on sprouting tubers. The crescent- marked lily aphid overwinters either as an egg on weeds or as nymph-producing females.

Identification (see key to wingless female aphids, Table 16.43, and Figs. *16.43T1*, *T2***)**

Black bean aphid — The wingless adult is dull black. Winged forms are variably striped. The tip of the abdomen (cauda) characteristically has more than 10 hairs (setae).

Bulb and potato aphid — The wingless adult is shiny, dark or olive- green, and its paired abdominal projections (cornicles) are shiny, black and swollen in appearance. The nymph is paler green but it also has shiny, black, swollen cornicles. The winged forms have shiny, olive-green to black, dorsal abdominal marks.

Crescent-marked lily aphid — No winged adults are produced. The adult is shiny, white to bright-green, and has a horseshoe- or crescentshaped patch on the back (dorsum) of the abdomen.

Foxglove aphid — The wingless adult is shiny, light yellow-green to dark green, and darker at the base of the cornicles. It is pear-shaped, globular, and widest just in front of the cornicles. The foxglove aphid is larger than the green peach aphid and smaller than the potato aphid.

Melon aphid — The adult varies in color but has black marks on the back of the abdomen, which helps distinguish it from other potato-colonizing aphids. The melon aphid may be confused with the buckthorn aphid. (For more on the melon aphid, see Greenhouse cucumber, 22.33.)

Management

Monitoring — These aphids rarely require control and there are no empirical thresholds.

Chemical control — No resistance to insecticides has been reported in Canada for any of the above species. Any recommended insecticides can be applied if needed.

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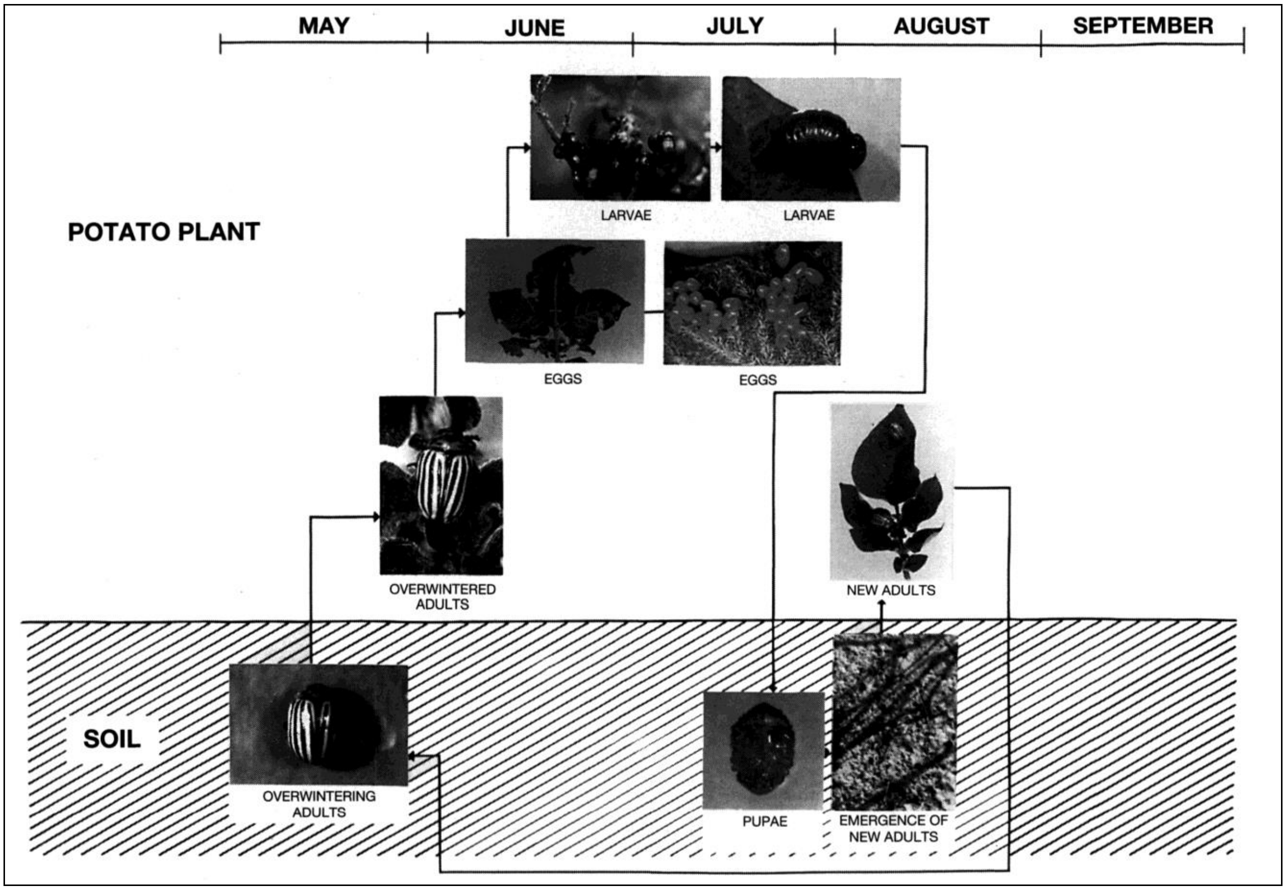
(Original by G. Boiteau)

▶ 16.44 Colorado potato beetle *Figs.16.44a-d; 16.44T1*

Leptinotarsa decemlineata (Say)

THE COLORADO POTATO BEETLE

LEPTINOTARSA DECEMLINEATA (SAY)



16.44T1 Colorado potato beetle; life cycle in regions with one generation.

The Colorado potato beetle probably entered Canada first in Ontario in 1870, reaching Prince Edward Island by 1883 and British Columbia by 1919. To date, it is absent from insular Newfoundland, and from coastal British Columbia and Vancouver Island. It is the most important insect pest of potato from New Brunswick and Prince Edward Island to Manitoba and in Alberta. In Nova Scotia, Saskatchewan and interior British Columbia, it is a secondary or rare pest.

Hosts of the Colorado potato beetle are limited to the Solanaceae. The beetle prefers potato but it also attacks eggplant, tomato and weeds, such as ground cherry *(Physalis* spp.) *(3.11c),* wild tomato *(Solanum triflorum* Nutt.), and bittersweet or climbing nightshade *(S. dulcamara* L.).

Damage The adult and all larval stages feed mostly on foliage, chewing irregular holes in and along leaf margins, but they also may attack stems. High populations can completely defoliate plants (*16.44c*) throughout large portions of a field. Extensive feeding at any time during the season, especially when the crop is in bloom, can reduce yield. Generally, a reduction in leaf surface decreases the ability of potato plants to produce nutrients for storage in the tubers.

The suggestion that the Colorado potato beetle might be a vector of certain bacterial and viral diseases of potato has not been confirmed, but mechanical transmission is likely.

Identification The Colorado potato beetle (family Chrysomelidae) adult is about 10 mm long and 7 mm wide, and somewhat rounded. Its head and anterior thorax (pronotum) are brown-orange to yellow and covered with variously shaped black markings. Ten black lines run the length of the forewings (elytra), which otherwise are pale yellow *(16.44a).* Females can be recognized by their greatly distended abdomen and the absence of a depression in the last abdominal segment when viewed from below. The eggs are elongate and yellow to orange, and usually they are laid on the underside of leaves of the host plant in clusters of about 30 (*16.44b).* The larva is humpbacked, and red-orange with two rows of black spots along the sides of the body (*16.44c,d).*

The Colorado potato beetle cannot be confused with any other beetle in Canada. It most resembles *Leptinotarsa juncta* (Germar), a similar species limited to an area southeast of Pennsylvania in the United States.

Life history The adult overwinters in the soil of the previous year's potato fields (*16.44T1*). As the temperature increases in the spring, the beetles move upward in the soil. They first appear in the last week of May or early June, and immediately seek host plants. They feed for a few days, after which mating (*16.44a*) and egg laying occur. Individual females lay 300 to 500 eggs from

June to late July. During this period, they may move from older to younger plants. The extended oviposition period means that larvae may be present in the field for three to five weeks, although larval development from hatch to pupation requires only two to three weeks. Pupation occurs in the soil and new adults appear after a further one to two weeks. In most regions of Canada the poor quality of the host food, the short daylength (photoperiod), and relatively low temperatures during the emergence period prevent the new adults from mating. Instead, they feed and prepare for overwintering (reproductive diapause). Thus, there is only one generation of the beetle throughout most of Canada except in southern Ontario, where there are two generations. Occasionally in New Brunswick, Nova Scotia and Prince Edward Island, some of the new adults emerge early enough to mate and lay some eggs, creating a partial second generation. However, these mated adults soon stop producing eggs and start preparing for overwintering. The partial second generation usually develops too late in the season to have a significant impact on potato yield in those provinces. In southern Ontario, however, the second generation is complete and in some years there is even a partial third generation.

Management

Monitoring — The density of egg, larval, and adult stages can be estimated by visual counts on a fixed number of whole plants or plant stems chosen randomly from different parts of the field. For medium-maturing potato cultivars, a sequential sampling plan for larvae in their third and fourth instar assumes an economic threshold of 20 large larvae per plant. As many as 40 plants must be examined to obtain a valid estimate of beetle density. Sampling by sweep net is not suitable for estimating numbers. Currently, there are no specific economic thresholds. Recommendations to commence control are based solely on empirical observations: leaf damage exceeding 10% in Manitoba; an average of two larvae per plant in 12 m of row in Atlantic Canada; and, in Quebec, 3.5 overwintering adults per plant, 10 larvae per plant before 90% bloom, or 20 adults per plant toward the end of the season. In Manitoba, the economic injury level ranges from 0.14 to 0.82 larvae per plant on the potato cultivar Norland. There is on-going research in New Brunswick, Manitoba and Quebec to establish economic thresholds. Present information suggests that only very low levels of Colorado potato beetle do not justify control, and that the economic threshold is affected by the intensity of other factors stressing the crop.

Cultural practices — Apart from the use of insecticides, crop rotation is one of the few control techniques currently available to potato growers. Rotation can significantly reduce beetle numbers, and it also results in the initial localization of incoming beetles at the periphery of the potato field, where insecticides can then be applied as a spot treatment. Not all growers can use this strategy, because they may not have the land needed for rotation and alternative crops tend to be less profitable than potato. In these cases, it is best to avoid planting in fields where high numbers of adult beetles were present at the end of the last growing season.

Resistant cultivars — None of the present commercial cultivars of potato is resistant to the Colorado potato beetle. Research is in progress to develop cultivars with low to moderate levels of resistance, which might then be used along with chemical and other control techniques.

Biological control — Populations of native predators, which include the ground beetles *Lebia* and *Pterostichus* spp., the two-spotted stink bug *Perillus bioculatus* (Fabricius) and the spotted lady beetle *Coleomegilla maculata* (DeGeer), and the parasite *Myiopharus doryphorae* (Riley) (syn. *Doryphorophaga doryphorae* (Riley)) rarely have a significant impact on the abundance of the Colorado potato beetle. Strains of the bacterium *Bacillus thuringien- sis* Berliner have been registered and have good potential for commercial use because of their specificity to Colorado potato beetle.

Chemical control — An array of systemic and foliar insecticides is available. Growers are encouraged to spray only when necessary and to alternate their choice of insecticides from among the different chemicals available.

Resistance to organochlorine insecticides was reported as early as the 1960s in Alberta, Ontario and Quebec. More recently, Colorado potato beetles in one part of Quebec were found to be resistant to most of the currently recommended organophosphate, carbamate and pyrethroid insecticides. In New Brunswick, the genetic potential for resistance is present in many locations, although to date it has expressed itself only in a few populations. The spread of resistance has been limited, considering that populations of this insect have developed insecticide resistance on occasion in different parts of Canada. Spot treatments with foliar insecticides should be applied against adults early in the season where numbers warrant. Insecticides for control of the larval stages should be applied during bloom where numbers exceed the economic threshold, and at the end of the season for control when unusually high numbers of adults are present.

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(Original by G. Boiteau)

▶ 16.45 Potato flea beetle *Figs. 16.45a-c*

Epitrix cucumeris (Harris)

The potato flea beetle is found in all Canadian provinces except British Columbia. In the eastern United States, it extends as far south as Florida.

The potato flea beetle is primarily a pest of potato but it also attacks cucumber, eggplant, pepper, tomato and other plants, such as jimsonweed (*Datum stramonium* L.), tobacco *(Nicotiana tabacum* L.), large white petunia (*Petunia axillaris* (Lam.) BSP.), ground cherry (.*Physalis pubescens* L.), horse nettle (*Solanum carolinense* L.), bittersweet or climbing nightshade (*S. dulcamara* L.), black nightshade (*S. nigrum* L.), and Jerusalem cherry *(S. pseudocapsicum* L.).

Damage Feeding by adults on leaves in spring or late summer results in rounded feeding scars, 0.1 to 5 mm in diameter *(16.45a)*, which frequently penetrate through the leaf to form a hole. When the potato flea beetle is abundant, potato leaflets sustain numerous perforations, eventually exhibiting a "shot-hole" appearance *(16.45b).* Direct damage to tubers caused by larvae generally is minor and can be removed by peeling.

The potato flea beetle is not considered a major pest in commercial potato production in Ontario and Quebec. It is most damaging in the Maritime provinces, where yield losses of 10 to 25% have been shown. Early season feeding by adults normally is not considered significant and insecticides used against the Colorado potato beetle will kill adult flea beetles. The most significant direct damage by the potato flea beetle in Canada is from late-summer feeding by adults in crops that do not receive insecticide late in the season. In Manitoba, Norland potato can withstand a peak adult density in August of up to 100 beetles per plant, although yield declines sharply when beetle numbers exceed that density.

The incidence of the potato flea beetle and the severity of common scab have been correlated positively in Manitoba. By their feeding, larvae may directly transmit pathogens to tubers and roots and increase secondary infection of damaged tubers. Also, adults may spread pathogens when they emerge from pupation sites in the ground. Fungal diseases associated with the potato flea beetle include common scab, fusarium dry rot, rhizoctonia, and verticillium wilt. In addition, bacterial diseases and potato spindle tuber viroid may be transmitted mechanically.

Identification The potato flea beetle (family Chrysomelidae) adult is 1.7 mm long and 1 mm wide. It is black with brown legs and brown antennae *(16.45c).* The femur of the hind legs is thicker and darker than the other leg segments. The larva is small, slender and white with a dark brown head and minute legs. When fully grown, it is about 5 mm in length. As a rule, larvae inhabit the soil around potato roots. On occasion, they may enter the tubers, forming small hollows at the point of entry and tunnels, which usually are straight, about 0.8 mm in diameter and less than 6 mm long, and filled with corky tissue. This type of tuber injury contrasts with the deeper, more penetrating tunnels made by the tuber flea beetle.

Life history The potato flea beetle has one generation per year. Adults overwinter at the soil surface among litter or undergrowth either in or near the potato fields where they fed the previous summer. In spring, they move to potato fields and feed on the foliage of newly emerged potato plants. They fly and jump actively, particularly when disturbed, and they may be found on all above-ground parts of the potato plant and on the soil surface. They feed on both the upper and lower leaf surfaces, but more frequently on the upper surface. If potato plants have not yet emerged, the beetles feed on weed hosts. Females lay eggs in the soil around potato plants and then die. Usually all overwintered adults die by first bloom of potato plants.

Larvae hatch about one week after the eggs are laid. They feed primarily on the fine roots of potato plants, completing development in about four to five weeks. They pupate in the soil and become adults in about one week. These new adults emerge from the soil, usually in late July or August, and feed on potato leaves. The number of adults increases rapidly and may exceed 100 per plant in August. Adult feeding continues on potato leaves until the weather becomes too cold or the foliage becomes unsuitable. Adults that leave potato plants may feed on other favored hosts before entering overwintering sites.

Management

Monitoring — The enumeration of feeding punctures is a much better method of assessment than counting the mobile adults. A preliminary estimate of the economic threshold for the cultivar Norland in Manitoba is 65 to 75 feeding punctures per terminal leaflet from the lower third of the plant taken two weeks after the first appearance of bloom. This threshold may need to be lowered for plants that are under stress from weather or from attack by other insects or pathogens. Later in the season, however, the number of feeding punctures may exceed this threshold without signifying a need for control.

The threshold also may differ for other cultivars and in other regions of Canada. In Atlantic Canada, an economic threshold of 15 feeding punctures on the fourth terminal leaflet (counting down from the apex of the plant) has been advocated, but this number now appears to be too low.

Cultural practices — The potato flea beetle tends to be more abundant in parts of potato fields that are adjacent to uncultivated areas. Such areas often have suitable food hosts for the adult beetles and retain snow, which may enhance their survival over winter. Because the adult potato flea beetle does not readily fly, the separating of uncultivated areas from potato fields may reduce populations. Eliminating volunteer potato and other hosts also may be used to starve overwintered adults in the spring before potato crops emerge.

Resistant cultivars — None of the commercial cultivars of potato is known to be resistant to the potato flea beetle.

Biological control — Parasites do not appear to have a significant impact on the population density of the potato flea beetle. At present, no biocontrol agent is commercially available.

Chemical control — Insecticides used to control other insect pests of potato also control flea beetles. For instance, granular systemic insecticides applied at planting to kill adults of the Colorado potato beetle may be effective against the potato flea beetle for the whole season. Where systemic insecticides are not used at planting, the need for control of the potato flea beetle depends on the timing of the appearance of its immature stages relative to other insecticidal applications. For example, in Manitoba, foliar applications against the Colorado potato beetle usually are applied when the potato flea beetle is a larva or pupa in the soil, which protects it. Potato flea beetle adults emerge from the soil in large numbers over several weeks, so a foliar insecticide that is relatively persistent but which does not cause residue problems at harvest, is desirable. Insecticides recommended against emerging adults should be applied about two weeks after the first adults appear.

Resistance to currently used insecticides has not been reported. However, the potato flea beetle seems able to detect and thus avoid insecticides, such as malathion, on potato foliage sufficiently to reduce both mortality and the effectiveness of the treatments.

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(Original by N.J. Holliday and J.G. Stewart)

▶ 16.46 Potato leafhopper *Figs. 16.46a,b*

Empoasca fabae (Harris)

The potato leafhopper is found throughout the Western Hemisphere, but it does not overwinter at more temperate latitudes. Each year it migrates into Canada, dispersing from the Gulf Coast of the United States on southerly winds. From early to mid-June until fall, it usually can be found in Manitoba, southern Ontario and Quebec. It is found only occasionally in Saskatchewan, New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland.

The potato leafhopper is a pest of alfalfa and occasionally clover *(Trifolium* spp.). Vegetable crops affected include bean, celery, corn, cucumber and potato. The host range numbers over 100 broad-leaved plants, including apple and other trees.

Damage Damage by potato leafhopper depends on the density of the insects, the duration of their feeding, and the growth stage of the plants. Both nymphs and adults feed on stems and leaves, and they seriously affect seedlings. Damage to potato is characterized by yellowing and eventual death of the affected foliage. Initially, the damage consists of yellowing at the tips and margins of the leaflets. Gradually, the leaf margins die and roll inward, resulting in the typical "hopperburn" symptom *(16.46a).*

Although the potato leafhopper is present every year in Manitoba, only once in six or more years are its numbers high enough to cause hopperburn. However, in southern Ontario, the potato leafhopper has been shown to reduce potato yields by approximately 40% when it exceeded the nominal threshold (see Monitoring) and was left to feed uncontrolled for the duration of the season. If modifications to current control procedures for Colorado potato beetle were to incorporate the use of more pest-specific insecticides, natural enemies and cultural practices, the potato leafhopper likely would become a more important pest.

No disease is known to be transmitted by the potato leafhopper.

Identification Leafhoppers (family Cicadellidae) are wedge shaped, which helps distinguish them from other small insects. The adult potato leafhopper is 3-4 mm long, bright yellow-green and otherwise unmarked *(16.46b).* It is very active and flies readily when approached. Nymphs are also yellow-green. They usually remain on the foliage, moving to the opposite side of the leaf when disturbed.

Life history Potato leafhopper adults generally arrive in southern Ontario in early June and are often found on alfalfa, which is their preferred host for laying eggs. The nymphs hatch in about 10 days and feed on alfalfa foliage until they mature. The adults from this generation then invade potato and initiate one or more generations on that crop. There are two generations on potato in southern Ontario, but usually only one in the rest of Canada.

Females may lay three to five eggs per day and up to 35 eggs in a lifetime. The eggs are inserted into the plant stem. There are five nymphal instars, of which the last two cause more damage than the earlier stages or the adult. Nymphal development requires 10 to 25 days. Maximum development occurs at 30°C.

Management

Monitoring — A nominal threshold of 10 nymphs per 100 mid-plant leaves has been established. Leafhopper populations above this threshold for two or more growth stages of the plant, such as vegetative through flowering or flowering through senescence, or feeding for more than three or four weeks can cause a significant yield loss. On a commercial scale, no monitoring programs are in effect in Canada.

Cultural practices — At present, alternative approaches to control the potato leafhopper are not available.

Biological control — There are no important natural enemies of the potato leafhopper in Canada, at least none that appreciably affects the growth of its populations.

Chemical control — In Canada, control of the potato leafhopper has not progressed beyond the use of chemical insecticides intended for control of the Colorado potato beetle. Several foliar organophosphate and pyrethroid insecticides are effective against the potato leafhopper. The choice usually is dictated by materials that are most effective against the Colorado potato beetle but which also control other pests, including the potato leafhopper. Suggestions include better timing of foliar insecticide applications during the season and the use of systemic granular insecticides at planting. No information is available on resistance to insecticides in potato leafhopper populations.

(Original by M.K. Sears)

▶ 16.47 Potato stem borer *Figs. 16.47a,b; 12.22b*

Hydraecia micacea (Esper)

The potato stem borer, popularly known as the rosy rustic moth in Europe, was introduced into North America in Nova Scotia and New Brunswick in the early 1900s. It now occurs in eastern Canada, including Newfoundland, and in the mid-western United States. To date, there are no confirmed records from western Canada.

The potato stem borer is an occasional pest of a variety of cultivated vegetables, including corn *(12.22b),* onion, pea, potato, tomato and rhubarb. In Canada, the main vegetable crop hosts are potato in Newfoundland, corn and other vegetables in New Brunswick and Nova Scotia, corn in Prince Edward Island, corn and potato in Quebec, and corn and rhubarb in Ontario. Other hosts include strawberry, sugar beet, barley, wheat, *Gladiolus,* wild plants such as dock *(Rumex* spp.) and plantain *(Plantago* spp.), and grasses.

Damage Problems occur most frequently in newly established fields with weedy grasses. Plants are attacked when young. In late spring, the larva enters and feeds within the stem, causing the stem to wilt and die, and eventually killing the plant. Generally, larval feeding kills or severely damages the plant or, in the case of rhubarb petioles, makes the crop unmarketable. Although a variety of crops may be severely affected in individual fields, widespread reductions in crop yield seldom occur. This insect makes production costs marginally higher because of increased seeding to compensate for damage near fencerows and the need for additional plowing.

In New Brunswick, the potato stem borer has been associated with blackleg of potato, of which it may be a vector.

Identification The potato stem borer is a moth (family Noctuidae). It lays eggs that are finely ribbed and shiny. The larva has a pale brown head and pink body (*16.47b; 12.22b).* The pupa has two slender spines at the anal end. The moth itself measures about 42 mm across the wings *(16.47a).* It has dark, olive-brown shading on an otherwise pale brown forewing, and a dark median band that curves inward at the leading edge. The hindwing is yellow-brown with a diffuse, central, gray spot and a darker transverse line.

Life history Eggs are laid in August in parallel rows on leaf blades, usually on grasses, on which they overwinter. The larvae hatch in early May and feed on grasses in and around cultivated fields. As the larvae mature, they move to larger plants and feed inside the stem or root crown. They become fully grown by mid-July and pupate in the soil. The moths are active from late July to late September. Migration is suspected but the patterns are not known. Hay that is cut in the fall is a potential medium for the spread of eggs of the potato stem borer and may be how it was introduced to North America.

Management

Monitoring — A sex pheromone has been identified and is very effective in trapping male moths. The pheromone could be used as a monitoring tool, although present procedures are limited to scouting for damage during July.

Cultural practices — Populations of the potato stem borer are best controlled by clean cultivation, either by plowing or by the use of herbicides to remove weedy sites and reduce egg numbers on wild plants. New ground for crops should be plowed immediately after haying, and seeding should be at a higher rate in the border rows to offset seedling mortality.

Biological control — In North America, the tachinid fly *Lydella radicis* Townsend parasitizes potato stem borer larvae. Several wasps are known to parasitize the eggs, larvae *(3.7u)* and pupae.

Chemical control — Contact insecticides are unsuitable for use against the potato stem borer, because its larvae generally feed inside the plant. Systemic insecticides are not cost-effective.

(Original by R.J. West)

▶ 16.48 Tuber flea beetle *Figs. 16.48a-c*

Epitrix tuberis Gentner

The tuber flea beetle is the most serious insect pest of domestic and commercial potato crops in British Columbia. It has been found recently in home gardens in Alberta, and it also occurs in the United States.

The preferred host of the tuber flea beetle is potato, although feeding and reproduction occur on tomato and other solanaceous plants.

Damage Feeding by adults is seldom of economic concern. However, large numbers of adults can defoliate and kill young potato plants, especially in small potato fields and home gardens. Commercial potato crops are invaded in a number of ways. For instance, in second-year potato fields, overwintered beetles may emerge directly from the soil and infest volunteer potato plants or the emerging crop. In first- and second-year potato fields, tuber flea beetles from surrounding headlands tend to migrate mostly into the outer rows. Thus, damage to potato crops is usually greatest in the border rows. Even small populations early in the year are considered potentially dangerous to late-harvested potato cultivars.

Larval feeding on the developing tubers is a major economic concern to commercial growers. Although potato yields usually are not affected, the larvae cause cosmetic tuber damage in the form of pimpling, surface channels and shallow networks of fine tunnels *(16.48a,b).* Early potato crops generally escape serious injury because they are harvested before the populations have increased to economic levels. Mid- and late-season potato crops are subject to severe damage from second- and third-generation larvae in August and September, when the tubers are maturing. Should significant tuber damage occur, the crop might be considered unmarketable, or the grade may drop from Canada No. 1 to Canada No. 2.

The relationship between feeding by the tuber flea beetle and disease incidence in potato crops has not been established as it has for the potato flea beetle.

Identification The tuber flea beetle (family Chrysomelidae) adult is small, 1.5 to 2.0 mm in length, black and shiny *(16.48c).* Feeding by adults gives potato leaves a characteristic "shot-hole" appearance. Other insects, such as caterpillars and springtails (Collembola), also cause holes in potato leaves, making observation necessary. Larval feeding is restricted to the roots or developing tubers. Their presence is not conspicuous above ground.

Life history The tuber flea beetle overwinters as an adult in the soil in and around potato fields. Winter survival is highest in elevated, grassy headlands that are free from flooding. There are two to three generations per year, starting between mid-May and early June when the overwintered adults emerge. Adults feed and mate on the upper surfaces of the leaves of potato plants from morning until dusk. They rapidly jump from the plant if disturbed, and they can fly. Mating and egg laying may continue for a month. First-generation larvae feed from early June to mid- July, second-generation larvae from mid-July to mid- September, and third-generation larvae after mid-August. The larval stage is completed within three weeks and is followed by a pupation period of about two weeks. One complete life cycle normally takes about six weeks.

The potential for population increase is high; theoretically, a single female that emerges in May can give rise to thousands of progeny by fall. Soils that have high moisture levels and relatively high temperatures, such as organic soils, favor population growth. Thus, potato crops in muck soils are usually at greater risk than those in mineral soils.

Management

Monitoring — Monitoring the adult tuber flea beetle throughout the growing season ensures efficient and cost-effective control. Because beetle populations are higher in outer rows than in inside rows, these two areas usually are sampled separately. Plants must be inspected on a weekly basis from the time of early emergence until the crop is 30 cm tall. The procedure requires that 35 samples of 10 consecutive plants be thoroughly inspected, each sample being taken at intervals of 40 paces along the perimeter rows of the field. An equivalent number of samples should be taken along randomly selected rows inside the field. If an average of one beetle per 60 inspected plants is observed, a spray should be applied to the inner rows or to the perimeter rows, as required.

Thorough application of control measures early in the season will eliminate the need to spray later for tuber flea beetle. Moreover, late-season spraying may damage plants and may result in aphid outbreaks. When plants are taller than 30 cm, samples must be taken on a weekly basis with a sweep net. Sweeping is done by striking the tops of the plants vigorously with the net while walking, taking 20 consecutive 180° sweeps at 30-pace intervals along the outside rows. An equivalent number of samples is required along arbitrarily selected inner rows of the field. A spray is required if an average of more than one beetle per 10 sweeps is observed in either the outer or the inner rows, using a 30 cm diameter sweep net.

In new fields of potato, an inexpensive and effective strategy for routine sampling is to plant about 20 perimeter rows earlier than the main crop. These perimeter rows can be treated with a systemic granular insecticide or can be sprayed if the number of beetles reaches the threshold determined by the monitoring program. Sampling for flea beetles and other pests inside the field must still be performed, but sprays need only be applied when necessary. This procedure should not be attempted without a monitoring program.

Cultural practices — In British Columbia, yearly crop rotation is the key cultural practice, because beetle populations build up in fields planted repeatedly to potato. Furthermore, volunteer potato plants are host to the beetle early in the season, providing a source of infestation for later spread to the main crop. New fields of potato also may be invaded, but the beetles will be fewer and usually will be confined to the outer rows.

Chemical control — Normally, only mid- and late-season potato cultivars require chemical control of the tuber flea beetle. The most effective procedure for commercial plantings is to apply systemic insecticides to the seed furrow in May and June. Uptake of the insecticide into the leaves, upon which the overwintered adults feed, can provide excellent control before the adults lay eggs. The systemic insecticides work best in soils low in organic matter. Foliar sprays can be applied routinely or timed according to the results of population sampling, which must be done on a weekly basis from crop emergence until harvest.

In the interior of British Columbia, the tuber flea beetle has shown some degree of resistance to chlorinated cyclodiene insecticides.

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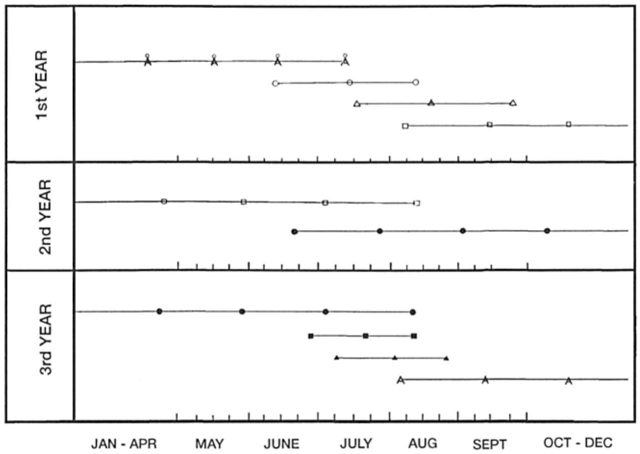
(Original by R.S. Vernon)

▶ 16.49 White grubs (June beetles) *Figs. 16.49a-e; 16.49T1, T2*

Common June beetle *Phyllophaga anxia* (LeConte)
Other June beetles *Phyllophaga* spp.

White grubs, the larvae of June beetles, spend up to three years in the soil while developing from egg to adult. The common June beetle is one of many *Phyllophaga* species that are native to North America. Adults are referred to as May or June beetles, and the larvae as white grubs. The common June beetle occurs throughout Canada and almost everywhere in the United States. It and several other June beetles may cause economic damage to horticultural crops, but *Phyllophaga anxia* is the species most likely to cause damage in Canada.

16.49T1 White grubs; larvae under sod.



16.49T2 White grubs; life cycle of the common June beetle *Phyllophaga anxia;* Å adult; O egg; A larva, 1st instar; □ larva, 2nd instar; # larva, 3rd instar; ■ prepupa; A pupa; A adult, ten- eral. Reprinted from Lim, Yule and Stewart (1981).

The larvae are best known for their damage to the fibrous roots of lawn grasses (*16.49T1*), but they have a broad host range that includes cereal crops, young evergreens and root crops. Adults feed mainly on the foliage of deciduous trees. Adult feeding also has been observed on leaves of weeds, vegetable crops and flowers.

Damage The grubs may damage potato crops in fields that recently have been in sod. If white grub feeding on potato is severe, damage is indicated by dwarfing or wilting of the plants. White grubs chew deep cavities in potato tubers, making them unmarketable *(16.49a,b).*

Identification Adults of these beetles (family Scarabaeidae) are light to dark brown and measure about 20 mm in length and 11 mm in width *(16.49c).* Eggs are pearly white, about 2.5 mm long and 2.0 mm wide *(16.49d).* The larva is a C-shaped white grub with three pairs of anteriorly located legs and a red-brown head (*16.49d,e*). When mature, larvae are about 30 mm long. Pupae are yellow-white.

Life history All June beetles have similar life histories and habits (*16.49T2*). In most parts of Canada, the insects have a three-year life cycle. The adults are nocturnal. They remain in the soil during the day and on warm evenings fly to nearby trees, where they feed on the foliage. Flight activity begins in May after the accumulation of about 176 degree-days above 5°C, measured from April 1, coinciding with bud break on such trees as trembling aspen *(Populus tremuloides* Michx.). Adult activity may continue for a month on evenings when the temperature is 10°C or higher, during which time mating occurs and egg laying begins. Eggs are laid in the soil at a depth of about 17 cm, usually in grassy areas. The larvae hatch within 30 days and first-instar larvae are commonly found in July. They feed on decaying vegetation, fungi and plant rootlets, usually to a depth of 5 cm or more on plants other than sod; they move from plant to plant as they consume the roots. They molt in mid-August, and the second-instar grubs feed until late fall, then move downward in the soil to overwinter. The second year of the life cycle is known as the “white grub” year. During that time, the second-instar larvae feed and molt into the third (final) instar around the third week of June. Third-instar grubs are most injurious, feeding at a depth of 5 to 25 cm, depending on the soil and the type of food plants. Again, the larvae move downward in the soil to overwinter and, in the third growing season, those that were not fully grown continue to feed before pupating. Most of the grubs form cells in the soil 20 to 25 cm below the surface during July, and pupate. Adults emerge the same year but remain in their earthen cells until the following spring, which is the beetle “flight” year.

Management Information is not available specifically for potato, but the following remarks apply.

Monitoring — Black-light traps fitted with a collection funnel are used to monitor June beetle flights. The traps are set with the rim of the funnel 1.2 m above the ground. Estimates of the density of the soil-inhabiting stages are done by taking sample units of 0.09 m^2 (one square foot) of soil to a depth of 30 cm. The soil samples are examined and larvae counted. No economic threshold is available for vegetable crops. However, tolerance for white grubs in root crops would probably be much lower than in sod or in new forest plantations, such as those in Quebec, where an average of 0.5 grubs per 0.09 m^2 is suggested as a threshold, based on 50 samples at 5 m intervals.

Cultural practices — Planting vegetable crops in recently cultivated sod should be avoided. Summer tillage usually is beneficial, because the grubs are killed by physical injury or exposed to natural enemies and the elements. Tillage should be timed between early May and late June to kill second- and third-year grubs, and from late July to early September to kill first-year grubs. If vegetables are rotated with other crops, then legumes or corn are best in a beetle “flight” year. In other years, oat or barley crops may be used.

Biological control — Natural control agents include insect parasites and predators, nematodes, protozoa, bacteria, fungi, viruses, birds, small mammals and toads. The nematode *Steinemema carpocapsae* (Weiser) (syn. *Neoaplectana car- pocapsae*

Weiser and *Steinemema feltiae* (Filipjev) in earlier literature) is effective against white grubs in pastures. The fungus *Metarhizium anisopliae* (Metsch.) Sorokin has proven effective against white grubs in field studies.

Chemical control — Resistance to organochlorine insecticides was indicated in 1971, when white grubs completely destroyed a crop near Nicolet, Quebec; the field had been treated with chlordane specifically for white grubs.

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(Original by K.P. Lim and J.C. Guppy)

▶ 16.50 Wireworms *Figs. 16.50; 12.21a,b, T1*

Dusky (or European) wireworm *Agriotes obscurus* (L.)
Eastern field wireworm *Limonius agonus* (Say)
Wheat wireworm *Agriotes mancus* (Say)

Wireworms attack potato planted in newly broken land following permanent sod. Several indigenous species are major or minor pests of commercial or domestic potato across Canada. In eastern Canada, the most troublesome species is the eastern field wireworm. The dusky wireworm and the wheat wireworm are the primary pests in central and western Canada. The dusky wireworm, which was accidentally introduced into British Columbia about 1900, has caused major economic damage to potato crops in recent years. It is advisable to identify the species of concern before taking control action, because the host preference and biology of each species varies.

Damage Wireworms tunnel into potato seed-pieces and the developing roots and shoots in the spring. With heavy infestations, a potato crop may be weakened and spotty. Wireworms also feed on the developing tubers *(16.50)* later in the growing season, producing tunnel-like holes 3 mm in diameter and up to 4 cm deep. These holes become lined with periderm, and subsequent tuber growth may be severely distorted.

Identification (see Maize, wireworms, 12.21)

Life history Wireworm larvae in potato fields spend much of the growing season in the upper 10 cm of soil. If mid-summer soil temperatures exceed 27°C, the larvae move downward into cooler zones. Wireworm larvae generally overwinter deep in the soil to avoid freezing.

Management

Monitoring — Annual monitoring is recommended for potato to determine the degree of infestation and the probable success of control methods. If a wireworm problem is suspected, the field should be monitored, using any of the following procedures. The simplest way to determine the presence or absence of wireworms is to follow the cultivator in early spring or fall when soil temperatures are above 10°C and wireworms are near the surface. After cultivating and before planting, baits of whole wheat flour can be used to determine the level of infestation more accurately. This is done by placing about 30 g of flour at a depth of 10 cm in the soil, using an ordinary corn planter or a shovel, and marking each bait station with a stake. For reliable results, 30 to 50 bait stations per hectare should be used. After three or four days, the baits can be uncovered and the wireworms counted. If an average of one or more wire- worms is encountered per station, damage to potato can be severe. Baiting is effective in the warmer spring and summer months, but not if the soil contains a lot of plant residue or if the weather is cold, wet, or very dry. Carrot pieces, buried in the same manner as flour baits, also can be used to sample wireworms (see Carrot, carrot weevil, 6.24).

Cultural practices — Where wireworm population levels are high, careful consideration must be given to proper crop rotation. Wireworms thrive in sod, in red clover and sweet clover, in small grains such as barley and wheat, and in truck crops, all of which should be avoided in rotations with potato. Alfalfa in rotations has the potential to reduce wireworm populations because it is a soil-drying crop and wireworms do poorly under these conditions. Alfalfa can be cropped in infested fields for three or four years and is suitable for rotation with potato as long as appropriate weed control measures are performed. Corn is another option in rotations, because some effective chemicals are registered for use against wireworms on corn. Where wire-worm populations exceed economic thresholds, growers should grow alfalfa or corn in the affected fields for at least three years before again planting potato.

Chemical control — A limited number of chemicals are directed against wireworm larvae. For best control, if potato must be planted in an infested area, granular insecticides may be broadcast and worked into the soil to a depth of 12 to 15 cm, or applied as a band treatment in the furrow with the potato seed-pieces. When soil temperatures are below 10°C, such as in the early spring, efficacy is usually reduced where organic matter is high and chemicals with short residual activity should not be used.

(Original by R.S. Vernon and A.T.S. Wilkinson)

▶ 16.51 Other insect pests *Figs.: see text*

Aster leafhopper *Macrosteles quadrilineatus* (Forbes) (syn. *Macrosteles fascifrons* of authors, not Stål)
Blister beetles
Cutworms
European corn borer *Ostrinia nubilalis* (Hübner)
Grasshoppers
Potato psyllid *Paratrioza cockerelli* (Sulc)
Potato scab gnat *Pnyxia scabiei* (Hopkins)
Seedcorn maggot *Delia platura* (Meigen)
Stalk borer *Papaipema nebris* (Guenée)
Tarnished plant bug *Lygus lineolaris* (Palisot de Beauvois)

Aster leafhopper (see Lettuce, 11.23) The aster leafhopper *(11.23a,b)* can be important on potato because it spreads aster yellows, or purple-top wilt disease. Growers should keep potato and nearby crops free from weeds. If purple-top wilt has been found in the area, application of insecticides may be required.

Blister beetles (family Meloidae) Adults of several species of blister beetles may feed on potato. They vary in size from 0.8 to 2.5 cm and may be black, gray, brown, blue, spotted or striped, often with metallic iridescence. They usually feed in swarms and move about a great deal. Control is rarely necessary.

Cutworms Many species of cutworms may attack potato crops. Some species cut the stems at soil level, others feed on the roots and underground stems. The larvae (*6.25a-c; 18.35a-g*) are gray or brownish, hairless caterpillars, measuring 2 to 5 cm when fully grown. Most live in the top layer of soil during the day and feed at night. (For more information on cutworms, see Tomato, 18.35.)

European corn borer (see Maize, 12.16) The European corn borer (*12.16f-h*) can reduce yields in potato crops by feeding in the stems, but the likelihood of infestation is slight and control measures are rarely necessary. In Prince Edward Island in 1989, a density of 1.16 corn borer larvae per stem in untreated plots reduced total yields of Russet Burbank by 7.5% compared to plots treated with sprays of the microbial insecticide *Bacillus thuringiensis* Berliner.

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Grasshoppers may be a problem, particularly in western Canada. Several species (*12.22a*) may be found in any one locality. They damage mainly the foliage of potato, and they may spread spindle tuber viroid and possibly other pathogens. Disease transmission is purely mechanical and the pathogens can be spread by any species of grasshopper. If the grasshopper forecast indicates that their eggs are plentiful, growers should summerfallow stubble fields. Surface tillage should begin in the fall and be repeated in the spring.

Potato psyllid (family Psyllidae) The potato psyllid has been reported from British Columbia, Alberta, Saskatchewan and Quebec. Feeding by nymphs causes a disorder known as psyllid or potato yellows, which causes the outer leaves to curl and turn light green or yellow; tubers grow slowly and aerial tubers may form in the leaf axils. Growers should apply a recommended insecticide if psyllids become numerous.

Potato scab gnat (family Sciaridae) The potato scab gnat has been found in southern Ontario (confirmed from Barrie on the basis of specimens in the Canadian National Collection), and in eastern Quebec. The larvae of this small fly may attack potato seed-pieces, tubers, and sometimes stems. Eggs are laid in soft spots in tubers, on cut potato seed-pieces and in loose soil. Heavy infestations of seed- pieces may result in weak sprouts and lower yields due to larval feeding on root hairs; superficial pitting reduces the grade of the tubers. This insect is rarely a problem where clean cultivation is practiced in conjunction with good drainage and crop rotation. As a post-harvest pest, potato scab gnat can be important, because its larvae enlarge old wounds and facilitate the entry of other organisms.

Seedcorn maggot (see Bean, 15B.18) The seedcorn maggot is occasionally a pest of potato crops, chiefly in the Maritime provinces, Quebec and Ontario. Damage is greatest in cool, wet seasons. There may be two or more generations a year, depending on the season. The maggot *(12.20b,c)* attacks the seed-piece through unhealed injuries or diseased surfaces. It may spread the bacterium that causes blackleg. Seed treatment may be necessary.

Stalk borer (family Noctuidae) The stalk borer has been found in all provinces from Manitoba eastward, except Newfoundland, and occasionally in Alberta. The larvae tunnel in the stalks, causing the plant to wilt and die. The young larva has a dark brown or purple band around a cream-colored body. The fully grown larva is grayish or light purple. Clean cultivation, as recommended for the potato stem borer, also controls the stalk borer.

Tarnished plant bug (see Celery, 7.21) The tarnished plant bug *(7.21b,d,e)* feeds by piercing the plant tissues and sucking the sap. On potato, its feeding destroys flowers and may cause the leaves to curl and the new growth to wilt. This insect also can spread spindle tuber viroid. Post-harvest weed sanitation helps reduce levels of the tarnished plant bug by destroying overwintering habitats. When insecticides are required, growers should consult local spray guides.

(Original by L.S. Thompson)

OTHER PESTS

▶ 16.52 Millipedes *Fig. 12.21T1*

Sometimes mistaken for wireworms, millipedes are hard, slender, gray to purple-brown, and worm-like. Their bodies are divided into many segments, most of which have two pairs of legs (*12.21T1*). They enter potato through injuries caused by insects or disease and are especially destructive in cold, wet seasons. They tunnel into the tubers and also may feed on the planted seed. They thrive in land that is heavily manured. Growers should avoid planting potato crops too soon after manuring.

(Original by L.S. Thompson)

▶ 16.53 Slugs *Figs. 11.27a-c*

Several species of slugs (see Lettuce, 11.27) occasionally damage potato tubers. They also injure potato plants by eating the stalks and foliage. To prevent damage, it may be enough to avoid long grass and remove plant residue, old sacks and boxes on the ground, and other locations where slugs may hide in the daytime.

(Original by L.S. Thompson)

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