Introduction

The kumara disease known as black rot is caused by the fungus *Ceratocystis fimbriata* Ell. & Halst. This fungus was originally identified from kumara or sweetpotato (*Ipomoea batatas* (L.) Lam.) crops in 1890, with the first New Zealand recording in 1907. The pathogen was recognised as the cause of a significant disease problem for New Zealand kumara growers from 1947 when it was recorded at Kaitaia, and then over subsequent years was recognised within other kumara producing regions of Northland, Auckland and the East Coast. Kumara production entered a period of depression following these black rot outbreaks, which for some growers caused severe and occasionally complete crop loss. However, following the industry's adoption of a strict crop hygiene protocol, introduced by the New Zealand Department of Agriculture, kumara production increased, as black rot ceased to be a problem and was rarely observed. The New Zealand kumara industry has continued to grow over the decades, with changes to the personnel involved and the crop management systems used. In recent years the black rot disease has been found more frequently. As this pathogen is highly transmittable and can cause severe economic losses within production beds, fields and storage, the disease and management strategies are described.

Management strategies for kumara black rot

The disease

Storage roots

Black rot infection in storage roots generally takes place through openings in the skin such as damaged lateral roots, lenticels or wounds. Lenticels are pores in the root surface that assist with air exchange, and can become more pronounced when roots are grown under wet conditions. Wounds may be caused by environmental conditions as seen in growth-cracks, or by mechanical injury at harvest. Pests such as crickets, white-fringed weevil, black beetle, grass grub, wire worm, caterpillars, slugs, mice, rats, pukeko and pheasants can all wound the roots.

Significantly infected storage roots initially show circular brown lesions which are slightly depressed. The lesions become grey-black in colour, but when wet are green-black. Lesions are initially small, but increase in size with distinct edges until they merge. The infected tissue is firm and dry, with the periderm (skin) usually remaining intact (Figure 1). Lesions do not generally penetrate below the vascular ring unless a secondary infection takes place (Figure 2). A cluster of perithecia (minute black bristles) often forms and these produce ascospores at the centre of the lesion. Infected roots may produce a strong fruity smell, which is thought to attract insects, which help spread the sticky ascospores. Although badly diseased roots are often noticed and discarded at harvest, those without visible symptoms may be retained and produce a general infection during storage.

Plants

As for storage roots, small black lesions form then enlarge and merge on buried portions of the plant stems. Sometimes the underground stem may become completely girdled with lesions. The leaves of infected plants in propagation beds may turn yellow, wilt and shed, while plant growth may be stunted or

Figure 1: Black rot lesion on a kumara storage root, cultivar 'Owairaka Red'. Note dark central spot, where perithecia (fruiting bodies) have formed.

Figure 2: A cross sectional view of a black rot lesion within a kumara storage root, cultivar 'Beauregard'. Note the location of the vascular ring, indicated by arrows.

show signs of collapse. Severe infection pressure may cause the death of new sprouts before they can emerge from the soil.

Dispersal

The black rot fungus, *Ceratocystis fimbriata,* has many specialised strains, each with a different host plant range. The kumara strain appears to be a specific disease pathogen for the Convolvulaceae family.

Fungal infection may occur via fragments of mycelia, or through the various types of spores the fungus produces: ascospores, chlamydospores, and conidia. Mycelia are the filamentous threadlike hyphae that spread out from an infection site to form a lesion. The fungus also develops structures called perithecia, which to the naked eye look like short hairs or bristles. The perithecia produce large numbers of sticky ascospores at their tips these, together with the insect-attracting aroma induced by the fungus, aids in insect dispersal. Ascospores are distinctly shaped, looking somewhat like a bowler hat under the microscope. The chlamydospores are thick-walled, durable, resting or survival spores. These approximately oval spores are generally formed within the host tissue and enable the fungus to survive for 1 to 2 years in crop debris. Conidia are approximately cylindrical and may be produced in large numbers, contaminating surfaces on which they settle.

The different forms of spores can be scattered by wind, water, soil, insects, rodents, people, farm equipment, farm structures, tools, the movement of stored roots and handling in preparation for market.

Management strategies

The black rot disease can be limited to economically insignificant levels by an integrated approach to plant hygiene, which encompasses the entire cropping cycle.

Seed root selection

Use only disease-free seed roots within the propagation bed. Seed root selection is generally visual, but is also based on a knowledge of the propagation, performance and storage history of the crop from the previous season. Care should be taken when receiving propagation material from other properties if the cropping history is not known.

A hygienic planting stock system should ensure that seed roots are produced from healthy bed or field cuttings (not pulled plants with attached roots), which have been dipped in fungicide then planted in disease-free soil. The seed root crop should be inspected for disease symptoms throughout the season, harvested under dry conditions with clean machinery, and cured then stored in disinfected crates. To minimise cross-contamination from workers and their clothing, the seed crop could be harvested following a weekend break and the issuing of new gloves.

International reports on the use of virus-free kumara seed stock suggest a reduction in the incidence of black rot, due to both lower contamination with the pathogen and generally higher plant health.

Propagation beds

Propagation beds should be established annually on a new site, to avoid inter-seasonal disease carry-over due to bed location. The propagation site and soil used to cover the beds should not have been exposed to kumara for 3 to 4 years and should be free of plant debris. There should be no discarded kumara material in the vicinity, as that may provide a disease source.

To minimise any disease transfer within the bed, the seed roots should be placed

Figure 3: To minimise the risk of pathogen transfer it is important to cut sprouts from propagation beds at an appropriate height above soil level.

to avoid root-to-root contact. Once laid out and prior to covering, the roots are sprayed with a fungicide, to kill any spores or superficial infections indiscernible by eye.

As diseased seed roots will potentially produce diseased sprouts, as well as infecting surrounding roots, regularly inspect propagation beds during sprout growth and carefully remove and destroy roots that express disease symptoms.

Crop rotation

Ideally, kumara should be grown in a given field only once every 3 to 4 years, so providing a crop rotation suitable for limiting establishment of the black rot fungus. The fungus is reported to survive on plant debris in the field for 1 to 2 years, but rotations longer than 4 years can be required if the disease is well established.

Cuttings

The black rot fungus only affects the underground parts of the plant and kumara roots in storage; primary symptoms are not seen above ground in the growing crop. Because of this, an important hygiene measure is to take cuttings rather than pulling out sprouts from the propagation bed. The plants should be cut cleanly to encourage wound healing, at least 2 cm above soil level (Figure 3). Pulled plants are likely to be contaminated via their direct contact with an infected seed root, whereas cuttings are less likely to be infected because of their isolation. The practice of pulling plants and then cutting off the rooted zone should be avoided, as disease sources are exposed and potentially handled. Field cuttings of vines from earlier plantings are a particularly useful source of healthy propagation material, due to their position above soil level and their relative inter-plant isolation, and because they have had time to express any disease symptoms. Both bed and field cuttings should be dipped in a fungicide prior to planting out, to kill any fungal spores present on their surface. For those wishing to avoid the use of synthetic fungicides, there is some historic evidence that appropriate hot water treatment of cuttings will lower the level of fungal infection. The knives, crates and workers involved in cutting preparation should be kept free of fungal contamination throughout the process. Knives should be sterilised regularly to avoid inter-plant cross-contamination.

Curing

A key stage for disease-free kumara production is post-harvest curing. All kumara roots suffer some degree of mechanical damage at harvest, including wounding from vine removal, secondary root removal, abrasion and impact. It is important to minimise root harvest damage by appropriate modification of harvest equipment and practice. Field pests that cause wounds to the developing root should also be carefully controlled. Freshly harvested roots are cured as soon as feasible to ensure wounds are adequately healed before they provide an entry point for disease. The curing process essentially switches the harvested roots from their storage phase to an active growth phase; the roots sweeten as starch converts to sugars, sprouting initiates and a lignin layer forms to close off wounds. The curing environment is generally well aerated, at a relative humidity of 90 to 95% and a temperature of 30°C. It is important not to over-cure the harvested roots, as sprouts that develop beyond initialisation lose water at a higher rate and, being delicate, are prone to breakage, causing further wounding. If a healthy root, broken in half, is placed within the curing store, the first

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appearance of sprout initials and lignin formation on the wound can be clearly observed.

Sanitation

The key to black rot control is to avoid fungal contamination by use of strict hygiene. This involves eliminating or minimising potential for over-wintering sources of inoculum, such as plant debris in the field or piles of cull kumara roots. Any at-risk equipment such as bed frames, crates, diggers, bins, tractors and washing plant needs to be decontaminated (wash off and remove any soil and plant debris then spray with a disinfectant solution) to avoid spread of black rot spores. Storage facilities must be maintained in a clean condition. It is important that kumara roots are washed in a clean uncontaminated water supply. There is evidence from North America that some weed species of the plant family Convolvulaceae, to which kumara belongs, also host black rot, producing typical lesions and abundant spores. While these data have not been evaluated for New Zealand conditions, it may be helpful to control some of the related weed species within fields, headlands, ditches and along fence lines.

Phytoalexin

The name phytoalexin is applied to a group of naturally induced antibiotics that contribute to a plant's self defence. In kumara, living plant tissue may respond to sustained biological, chemical or physical attack by producing these phytoalexins. The first phytoalexin isolated (1943) and identified in the plant kingdom was obtained from diseased kumara roots and named ipomeamarone. Phytoalexins are not found in healthy roots, but are only induced by persistent stressors. Amongst kumara pathogens, *Ceratocystis fimbriata* is considered a high inducer of phytoalexins.

Phytoalexins make the kumara root toxic and unpalatable due to a bitter taste, but there have been no reports of human poisoning. However, there is a well established history of cattle deaths as a direct consequence of feeding livestock waste piles of diseased kumara roots. In affected cattle there was rapid onset of severe respiratory distress followed by death within days. Kumara provides a nutritious and healthy food source but, as for any other food product, requires knowledgeable and appropriate management.

Human consumption has not resulted in toxic responses due to a number of important factors. People tend to dispose of diseased or damaged produce rather than eat it. Phytoalexins accumulate within damaged tissue or its immediate surrounds, but kumara roots with slight blemishes are generally trimmed prior to cooking to leave only healthy tissue. While cooking reduces pre-existing phytoalexin levels, it does not eliminate them. Phytoalexins are only produced in living kumara tissue; fungal attacks on cooked roots do not produce these toxins.

Kumara cultivars differ in their level of phytoalexin induction. Mechanical damage that is not healed in a timely manner, within an appropriate curing regime, can itself induce phytoalexin production. Those involved in the kumara supply chain should be aware of the phytoalexin response and should take care not to market diseased or damaged produce.

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