



Clubroot Disease of Crucifer Crops

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Cruciferous Crops in Hawai'i

The farm-gate value in Hawai'i for cruciferous crops (Chinese cabbage, head cabbage, mustard cabbage, kale, and watercress) was estimated at \$8,295,000 in 2015. Head cabbage was the top volume-producing vegetable crop in the state in 2015, yielding over 7 million pounds. Other cruciferous crops grown in Hawai'i include arugula, bok choy, broccoli, cauliflower, choy sum, collards, daikon, mizuna, radish, tatsoi, and turnip.



Figure 1. A Chinese cabbage plant with clubroot disease.

Clubroot Disease in Hawai'i

A major disease affecting the production of cruciferous crops on the Island of Hawai'i is clubroot disease, which gets its name from the formation of club-shaped galls on the roots (Figure 1). This disease has been reported worldwide. Clubroot disease is caused by a soil-borne fungus-like pathogen, *Plasmodiophora brassicae*. This organism was once considered a slime mold but is now classified in a group of protists called Phytomyxea. Cool, wet, and acidic soils provide the most favorable environ-

ment for the pathogen. In acidic soils, the temperature range for infection is between 50 and 95°F, the optimum being between 68 and 77°F. In alkaline soils, the temperature range is lower. Once a field is infested with the pathogen, the resting spores can remain viable for many years.

Clubroot disease had been noted in Hawai'i from around 1940. On Hawai'i Island, clubroot disease is known to occur in the Glenwood, Volcano, and Waimea vegetable-farming areas. In Waimea, the pathogen has quickly spread among farms in re-

cent years. Some growers have estimated a 50-percent reduction in yield of crops such as Chinese and head cabbages and broccoli. In severely affected areas (usually poorly drained areas), it may not be feasible to harvest.

Hosts

Plasmodiophora brassicae has the potential to infect all 330 genera and 3,700 species in the *Brassicaceae* family. Cabbage, broccoli, kale, cauliflower, Brussels sprouts, mustard, radish, and turnips are some of the

Table 1. Crops listed by susceptibility to *Plasmodiophora brassicae* (Zitter 1985)

Susceptibility	Crops
Highly susceptible	Brussels sprouts, cabbage, Chinese cabbage, some turnip varieties
Moderately susceptible	Broccoli, cauliflower, collards, kale, kohlrabi, rutabaga, some turnip and radish varieties
Mildly susceptible	Black mustard, rape (canola), some turnip and radish varieties

economically important crops commonly affected. Table 1 includes selected crops listed by susceptibility. *Plasmodiophora brassicae* can also infect cruciferous weeds and some grasses.

Symptoms

The initial symptoms of clubroot disease will most likely be abnormal wilting during the warmer period of the day and recovering when temperatures drop. Later symptoms can include signs of nutrient stress, such as stunted growth (as compared to uninfected plants), yellowing and dropping of leaves, and the failure of older plants to reach market size.

Clubroot disease has a variety of symptoms on roots. Infected root symptoms can range from small knots to enlarged, club-shaped roots (Figure 2). Some hosts, in-



Figure 2. Close-up picture of clubs on root system of affected Chinese cabbage plant

cluding turnips and radishes, do not exhibit the clubbing of the roots but will have black, sunken lesions on the root surface. This is because in addition to forming the large galls and inhibiting root ability to uptake water and nutrients, infected root tissue lacks the normal protective outer layer. This makes roots susceptible to invasion by secondary organisms, such as soft-rot bacteria.

Disease Cycle

In the soil with no host, *P. brassicae* exists as resting spores which can survive for 18 or more years. These resting spores germinate into single-celled zoospores that have two flagella (whip-like appendages) that enable them to swim through moist soil, which encourages infections. When a susceptible host is present, the zoospores enter the roots of the host plant through wounds or root hairs. From each of these infections, a plasmodium (a structure that contains many nuclei that are not divided into individual cells) is produced. These infections encourage the abnormal growth of the host tissue that results in the characteristic galls or clubs. When the root matures and breaks down, resting spores that have been produced in the plasmodia (Figure 3) are released into the soil.

Prevention and Management

Prevention

The resting spores of *P. brassicae* can be spread through the transport of infested soil by means of tools, vehicles, equipment, infected transplants, other planting material (such as potato tubers with soil), animals, and humans. Always thoroughly clean farm equipment and shoes after working in a field suspected of having the disease. Resting spores can also be transported in water runoff from infested fields.

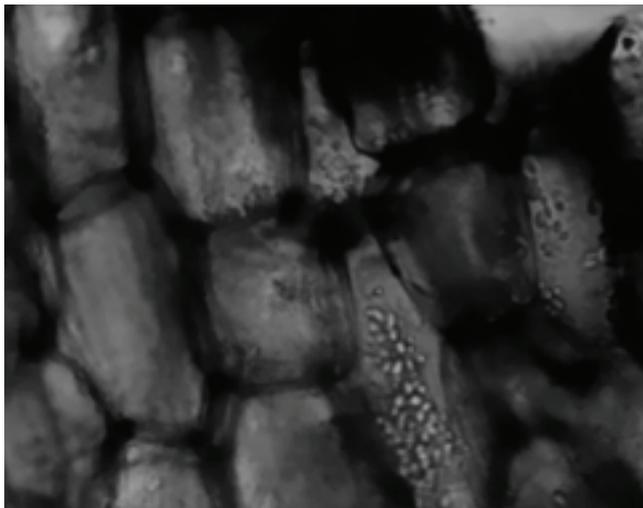


Figure 3. *Plasmodiophora brassicae* resting spores in an infected root cell.

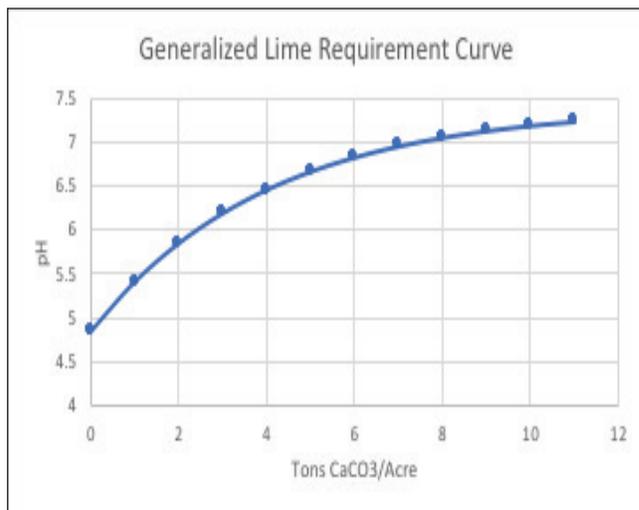


Figure 4. A generalized lime-requirement curve based on 22 Hawai'i soils.

Management

Clubroot is difficult to manage because the pathogen can persist in the soil for many years. Prevention is key. The following are several strategies growers can apply to help them manage clubroot disease once the pathogen is present in a field:

- Use clubroot disease-free transplants.
- Rotate crops: ideally, plant cruciferous crops no more than once every 3–4 years in fields where clubroot has not occurred and no more than once every 7–10 years in fields where the disease has occurred. Control susceptible cruciferous weeds such as wild mustards and shepherd's purse during the fallow period.
- Improve soil drainage in low-lying areas and avoid over-watering.
- Raise the soil pH: using lime to raise the soil pH to 7.0 to 7.2 can reduce disease incidence by creating conditions that are unfavorable for spore formation. Care needs to be taken not to over-apply lime, which could be unfavorable for the subsequent planting of non-cruciferous crops. Figure 4 shows a lime-requirement curve for a generalized Hawai'i soil. It was created by Hue and Ikawa (1994) using data from 22 Hawai'i soils.
- Plant resistant varieties. Varieties with resistance or tolerance to clubroot are available for some crops. However, replicated trials have not been conducted

Table 2.1 Examples of clubroot disease-resistant varieties

Crop	Variety
Broccoli	'Emerald Jewel'
	'Trixie'
	'Monclano'
	'Komodo'
Cauliflower	'Clapton'
	'Clarify'
	'Clarina'
Chinese Cabbage	'Apollo'
	'Chorus'
	'Jazz'
	'Marquis'
	'Prelude'
	'Spring Crisp'
	'China Gold'
	'Yuki'
	'Bilko'
'Banko'	
'Ohken 75'	
Head Cabbage	'Kilaherb'
	'Kilaton'
	'Kilaxy'
	'Kilazol'
	'Tekila'
'Kalibro'	
Red Head Cabbage	'Huzaro'

Table 2.2 Pesticides registered in Hawai'i for management of clubroot disease

Brand name	Active Ingredient	Signal Word
Blocker® 10G Agricultural Crop Fungicide	Pentanitrochlorobenzene (PCNB)	Caution
Companion® Liquid Biological Fungicide	<i>Bacillus subtilis</i> GB03	Caution
Ranman® Fungicide	Cyazofamid	Caution
Regalia® Biofungicide	Extract of <i>Reynoutria sachalinensis</i>	Caution
Sectagon-K54® Agricultural Fumigant	Potassium N-methyldithiocarbamate	Danger
Serenade® Soil	QST 713 strain of <i>Bacillus subtilis</i>	Caution
Vapam® HL Soil Fumigant	Sodium methyldithiocarbamate	Danger

in Hawai'i. Elsewhere, *P. brassicae* has been found to overcome the resistance over time by developing into new strains quite rapidly (Miller et al. 1996). Table 2 has some examples of clubroot-resistant varieties.

- Use chemical pesticides. Pesticides registered in Hawai'i for management of clubroot disease are shown in Table 2. A field trial for the efficacy of Ranman® Fungicide (cyazofamid) and Serenade® (QST 713 strain of *Bacillus subtilis*) was conducted in Waimea on the island of Hawai'i. The results will be reported in a future publication.

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