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Cucumber Mosaic Virus in Hawai'i

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Cucumber mosaic virus (CMV) is one of the most widespread and troublesome viruses infecting cultivated plants worldwide. The diseases caused by CMV present a variety of global management problems in a wide range of agricultural and ecological settings. The elevated magnitude of risk posed by CMV is due to its broad host range and high number of arthropod vectors.

Plant diseases caused by CMV occur globally. Doolittle and Jagger first reported the characteristic mosaic symptoms caused by the virus in 1916 on cucumber. The pandemic distribution of cucumber mosaic, coupled with the fact that it typically causes 10–20% yield loss where it occurs (although it can cause 100% losses in cucurbits) makes it an agricultural disease of major importance (Zitter et al. 2009).

The virus causes numerous plant diseases in Hawai'i that range from mild to severe. These mosaics occur in various settings: large-scale agriculture, smaller market gardens, home gardens, landscapes, and agroforestry and forestry ecosystems. Here we describe this viral pathogen, its transmission among plants, and its host range and disease symptoms, and we discuss integrated practices for the best management of diseases caused by CMV in Hawai'i.

Mosaic symptoms associated with *Cucumber mosaic virus* on a naupaka leaf.

Pathogen

The pathogen causing cucumber mosaic disease(s) is *Cucumber mosaic cucumovirus* (Roossinck 2002), although it is also known by other names, including *Cucumber virus 1*, *Cucumis virus 1*, *Marmor cucumeris*, *Spinach blight virus*, and *Tomato fern leaf virus* (Ferreira et al. 1992). This plant pathogen is a single-stranded RNA virus having three single strands of RNA per virus particle (Ferreira et al. 1992). CMV belongs to the genus *Cucumovirus* of the virus family *Bromoviridae*. There are numerous strains of CMV that vary in their pathogenicity and virulence, as well as others having different RNA satellite virus particles that modify pathogen virulence and plant disease symptoms.

Virus Transmission

Arthropods. CMV is vectored and transmitted by cucumber beetles and more than 60 species of aphids (Zitter et al. 2009). 'Cucumber beetle' is a common name given to members of two genera of beetles, *Diabrotica* and *Acalymma*, both in the family Chrysomelidae. Notable aphid vectors include the cotton or melon aphid (*Aphis gossypii*) and the green peach aphid (*Myzus persicae*), both of which transmit CMV in a non-persistent manner.

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Such transmission indicates that CMV can be acquired by an aphid within 5–10 seconds of probing a plant and then transmitted to another feeding site in less than 60 seconds. The ability of CMV to be successfully transmitted declines after about 2 minutes post-acquisition and is usually lost from vectors within 2 hours (Ferreira et al. 1992). In addition, isolates of CMV vary in transmissibility by aphids: Some isolates can lose their transmissibility by one aphid species but not by other aphid species (Francki et al. 1979). Typically, young plants and new growth are the most susceptible plant tissues for infection by CMV, because these organs and tissues frequently are the preferred feeding sites for aphid vectors.

Mechanically. CMV is readily transmitted between plants via plant sap and by mechanical inoculation via pruning tools.

Seeds. Transmission to new plants through seeds occurs to varying degrees for 19 host species, including some important weeds. The geographic dispersal by and the durable persistence of CMV in weed seeds are important factors in the dynamics and epidemiology of some diseases caused by CMV (Zitter et al. 2009).

Parasitic seed plants. This virus can also be transmitted between plants by parasitic seed plants such as dodder (*Cuscuta* spp.), whose vine-like stems bridge the hosts aerially or at the ground surface (Ferreira et al. 1992).

Host Range of CMV

CMV has an unusually large and broad host range that includes over 1,200 plant species belonging to hundreds of plant families (Zitter et al. 2009). Many of these plants are important agricultural crops and landscape plants, while many others are uncultivated plants and weeds. Host plants include monocots and dicots, and herbaceous, woody, or semi-woody species (Zitter et al. 2009). This wide variety of hosts means the disease can be a persistent problem in both agricultural and non-agricultural settings.

Some hosts of CMV are of great agricultural importance to Hawai'i. Table 1 lists the number of acres of these crops farmed in Hawai'i and their respective production values. In addition to the agricultural crops shown in Table 1, there are a number of specialty food crops and ornamentals that are susceptible to CMV (Table 2). Other plants recently reported as hosts globally include *Agave* (Florida Dept. of Ag. and Consumer

Table 1: Agricultural Crops Affected by CMV in Hawai'i

Crops	Acreage (year)	Number of Farms	Value of Crop (x1000)
Banana	1,300 (2011)	240	$11,310
Cucumber	310 (2008)	N/A	$2,736
Onions	130 (2011)	N/A	$3,267
Green Pepper	160 (2007)	N/A	$1,242
Sweet Potato	1,100 (2011)	N/A	$7,348
Italian Squash	170 (2011)	N/A	$1,014
Tomatoes	740 (2007)	N/A	$9,867
Watercress	35 (2011)	N/A	$1,451
Watermelon	540 (2011)	N/A	$3,930
Celery	20 (2008)	N/A	$137
Lettuce	140 (2011)	N/A	$5,453

Information from USDA National Agriculture Statistics Service (*USDA: Nat. Ag. Statistics Service*).

Services, 2013), globe artichoke (*Cynara scolymus*) (Ergün et al. 2013), and maize/corn (*Zea mays*) (Wang et al. 2013). Therefore, where these plants are cultivated in Hawai'i they may be susceptible to infection by CMV. Growers of such plants might consider this susceptibility when deploying these species in crop rotations, in inter- or polycropping systems, or if these plants are present in neighboring fields or hedges or as weeds.

Symptoms of CMV Infection on Crops Important to Hawai'i

Symptoms of mosaic diseases caused by CMV in the squash family, or cucurbits, consist of chlorotic mosaic patterns on leaves, stunted growth, leaf distortion, mottling, and color breaking of fruits (Zitter et al. 2009). On tomato, CMV can cause "shoestring" symptoms, in which leaf blades do not fully develop and expand normally, rendering the petioles nearly bare except for the small, narrow, and deformed leaf blades. This symptom on tomato is also known as "fernleaf" (Ferreira et al. 1992).

On kava (*Piper methysticum*), leaves display chlorotic mosaic patterns that may resemble a fertilizer element deficiency, or they may display rugosity, blackened veins, or ringspots. Affected plants can exhibit stunting, chlorosis, and wilting and display cane or plant dieback. Necrotic black or brown lesions on stalks or leaf nodes, or blackened stumps, roots, and basal stems may also occur (Nelson 2000).

Table 2: Host plants for *Cucumber mosaic virus*

Landscapes & floral gardens	Members of the family *Convolvulaceae* (morning glory)[2] Members of the following genera: Canna, Celosia, Chrysanthemum[2], Datura, Delphinium, Gilia[2], Gladiolus[2], Lilium (lily)[2], Musa (bananas and plantains)[3], Passiflora (passion fruit or lilikoi)[4], Pelargonium (geranium)[2], Petunia[2], Phlox[2], Salvia[2], Scaevola (naupaka)[4], Tulipa (tulip [only at high altitudes])[2], Tropaeolum (nasturtium)[2], Zinnia[2] Other species: *Callistephus chinensis* (China aster)[2], *Delphinium ajacis* (larkspur)[2], *Tagetes patula* (marigold)[2], *Vinca major*, *V. minor*, and *V. rosea* (periwinkle)[2], *Antirrhinum majus* (snapdragon)[2] *Heliotropium arborescens* (heliotrope)[32], *Hyacinthus orientalis* (hyacinths)[2]
Market & home gardens	Members in the family Cucurbitaceae (cucurbits)[1] Members of the following genera: Capsicum (chili pepper)[1], Musa (bananas and plantains), Phaseolus (beans)[1], Solanum (tomato, potato)[1], Passiflora (passion fruit or lilikoi) Other species: *Beta vulgaris* (beets/chard)[2], *Foeniculum vulgare* (fennel)[2], *Allium cepa* (onion)[2], *Ipomoea batatas* (sweet potato)[2], *Solanum melongena* (eggplant)[5], *Nasturtium officinale* (watercress)[2], *Rheum rhabarbarum* (rhubarb)[2], *Petroselinum crispum* (parsley) [2], *Spinacia oleracea* (spinach)[1], *Lactuca sativa* (lettuce)[1], *Anethum graveolens* (dill)[2], *Pastinaca sativa* (parsnip)[2], *Apium graveolens* (celery)[1], *Commelina diffusa* (honohono grass)[2], *Piper methysticum* (kava or 'awa)[4]
Commercial agricultue (monocrops, polycrops)	All of the hosts listed under market gardens/home gardens, as well as plants of the genera Celosia, Canna, and Datura, which are commonly found around banana and plantain plantings
Agroforestry	Members of the genera Celosia[3], Canna[3], and Datura (these three are found commonly around Musa plantings)[3], Musa (bananas and plantains), Passiflora (passion fruit or lilikoi), *Piper methysticum* (kava or 'awa), *Commelina diffusa* (honohono grass)

[1]Zitter et al. 2009, [2]Ferreira et al. 1992, [3]Webster et al. 1994, [4]Melzer 2014, [5]Susheel et al. 2014

Naupaka and *Passiflora* infected with CMV may exhibit chlorotic spots and mosaic on their leaves (McRitchie et al. 1981, Teakle et al. 1963).

In banana (*Musa* spp.), some strains of CMV cause severe symptoms such as leaf distortions and mosaic. Sometimes banana may become infected yet display no apparent or obvious symptoms (Hu et al. 1995). This may either be a latent, unexpressed infection, or infection by a strain of CMV that causes only mild symptoms. Such plants may be slightly reduced in size, which could be confused with symptoms caused by adverse environmental conditions or other factors (Hu et al. 1995, Webster et al. 1994). Because young or immature tissues are still developing, symptoms of cucumber mosaic tend to manifest more in early stages of plant organ development, rater than in mature tissues or more advanced phenological stages (Webster et al. 1994).

Detection of CMV in Plant Tissues

CMV infections can be confirmed by serological (antibody-based) or molecular (RNA/DNA) technologies.

The simplest serological method for detecting CMV is the lateral flow assay. In this method, antibodies specific to CMV are present on a strip of paper-like material, which is then dipped into pulverized plant tissue. If CMV is present, antibodies on the strip bind to the virus and produce a specific pattern to indicate a positive reaction. If CMV is absent, a different pattern appears. This method is the most practical and least expensive for small-scale use. Other serological methods may be more efficient on a larger scale, such as enzyme-linked immunosorbent assay (ELISA). With ELISA, antibodies bind to the virus particles and induce an enzymatic reaction that results in a color change for positive samples. ELISA is usually used in diagnostic laboratories and not by growers.

Common molecular methods used to detect CMV include variations of the polymerase chain reaction (PCR), as well as isothermal amplification methods such as loop-mediated isothermal amplification (LAMP). These methods amplify specific sequences of RNA from CMV that can be detected by gel electrophoresis or fluorescence-based chemistry. Hybridization-based methods, such as the Northern blot and microarray,

Cucumber mosaic virus **on banana (left), swiss chard (center), and long bean (right) leaves.**

are also available for CMV detection but are rarely used for diagnostic purposes due to their higher cost and more advanced technical requirements (Hu et al. 1995). Gardeners or farmers generally do not use most molecular methods, as they require special equipment, chemicals, and sterile environments that are only practical in diagnostic laboratories. A possible exception would be LAMP; a knowledgeable practitioner can use LAMP in a field setting. It also requires less expensive equipment and fewer procedural steps.

Disease Management

Plan your garden, farm, or landscape to take into consideration wind direction, upwind diseases, sunlight distribution, soil drainage and slope direction, previous crops that were grown in this soil, previous diseases extant at this site, and compatible plants for your growing system. Having the most optimal growing conditions for your plants is important for sustained plant health and avoidance of disease. After planning your garden or growing system, construct a suitable IPM program, considering all of the actions you can take that will influence the health of your plants. Below we provide some IPM guidelines.

- **Manage infected weeds and alternate hosts for CMV and vectors before planting.** Eliminate weed hosts of CMV in and around cultivated fields by use of herbicides, mechanical removal (manually or by machine), or by grazing livestock. Weed management has proved successful in reducing the incidence of CMV infections in both cucumber and celery and may benefit other crops as well (Ferreira et al. 1992).
- **Exclude CMV from production houses.** Exclusion in a production house means physically preventing CMV from infecting susceptible hosts. For example, use vector-proof screening to isolate disease-free transplant crops from other plants that may harbor CMV. Scout for the development of mosaic symptoms within a production house and remove symptomatic plants promptly.
- **Manage aphids and CMV in production houses before outplanting.** Establish host-free zones around production houses by using cement, mulch, rocks, or herbicides to reduce nearby vector and virus populations. Apply insecticides within production houses to minimize vector numbers.

Different manifestations of *Cucumber mosaic virus* on honohono grass.

- **Avoid vegetative propagation of CMV-infected plants.** Do not use symptomatic or CMV-infected plants to propagate new plants.

- **Avoid planting CMV-infected plants.** Screen plants before transplanting. Plants can be visually inspected, or a testing regime can be put into place before transplanting. Using disease-free seed is a good way to avoid disease, as CMV is seed-transmitted in a number of hosts (Zitter et al. 2009). When transplanting from production houses, avoid areas near CMV-infected crops or non-cultivated areas where there may be weeds harboring the virus (Agrios 2005).

- **Plant CMV-resistant host varieties.** Resistant plants are the best management practice, because they require fewer inputs, are easy to use, and don't have adverse effects on the environment. Both transgenic plants (Ntui et al 2013) and selective breeding (Zitter et al. 2009) have been used to manage CMV. Because of CMV's genetically variable population (e.g., the high number of strains), however, effective management has been generally difficult to achieve using host resistance. There are plant varieties on the market that are resistant to CMV and will offer a better chance of disease control than non-resistant varieties (Zitter et al. 2009). There are a number of CMV-resistant crops on the market derived from traditional breeding. The seeds of these varieties can be purchased online after a simple Internet search for "CMV-resistant seeds." They can also be purchased from seed company catalogs. Seeds developed specifically for strains of CMV in your area will offer the greatest protection against the disease. Choose crops for cultivation at your location that are not hosts of CMV (i.e., are immune to the virus), if possible. In general, plants that are suggested for your area or type of growing area will be healthier and show less disease than those meant for other habitats.

Manifestations of *Cucumber mosaic virus* on kava ('awa) (left and center) and nasturtium (right).

- **Scout fields for symptom development and rogue diseased plants.** A scouting program will help you be aware of the current vector and disease situation in your growing area. Scouting often is advisable because the life cycles and development of the disease, vectors, and hosts are all constantly changing, as are the environmental conditions that can encourage disease. Rogue all diseased plants promptly.

- **Manage aphids within gardens and fields.** Install insect exclusion nets or floating row covers over susceptible hosts. These nets can be removed for pollination, depending on the crop that is being grown.

Avoid over-fertilization of plants to reduce the populations of insect vectors of CMV. Prune and discard aphid-infested leaves and stems, if aphid populations are clustered. If entire plants are infested with vectors, it may be useful to rogue the entire plant. Employ aluminum foil or reflective mulches to deter aphids from landing on plants, and spray streams of water to physically knock aphids off of plants (University of California Ag. and Natural Resources 2014). Control ant populations, because ants tend and protect aphid vectors of CMV to feed on the sweet aphid excrement known as "honeydew." To control ants effectively, the particular ant species must be identified, because different species have different habits. Two common examples are the Argentine ant and the long-legged ant (Nelson 2014). If necessary, submit ant samples to the University of Hawai'i's Agricultural Diagnostic Service Center for proper identification, and then consult this service or your local agricultural Extension agent for the names of proper ant baits and for other ant-management recommendations.

Often, when an aphid outbreak is anticipated, insecticides are used to suppress their populations. These pesticides will help reduce populations of aphids that colonize plants and do not migrate much. Aphid species

Manifestations of *Cucumber mosaic virus* on passion fruit (left and center) and loofah (right).

that are more mobile, however, will not be controlled as effectively by pesticides, as they often fly in and out of growing areas frequently, and insecticide sprays are only active for short periods of time. This makes it important to identify which species of aphids may be a problem in your field. Extension agents, agricultural diagnostic services, and the entomologists at the University of Hawai‘i at Manoa are useful resources for aphid identification and for information about vectors of CMV in your area.

One detriment to the use of insecticides to control aphids is that the sprays may agitate viruliferous aphids, causing them to fly away to spread CMV rapidly during the period between the insecticide application and their death (Ferreira et al. 1992). Some insecticides, especially broad-spectrum insecticides, also may negatively impact populations of natural predators of aphids. Aphid populations will generally recover faster than those of the natural predators, so the use of these insecticides may be effective in the short term, but may exacerbate problems in the long term. To avoid this problem, try to use pesticides that act against the specific species that you are trying to manage, rather than using broad-spectrum pesticides.

If a pesticide is needed to reduce the population of insects transmitting CMV, be sure to read the pesticide label before purchase and application. A pesticide must be registered for use against the specific pest, on the particular plants, and in the particular intended setting (home, garden, forest, farm, etc.). Follow the instructions on the label carefully. If personal protective equipment is required for application, it will be stated on the label. If you apply pesticides routinely, rotate the sequence of use among pesticides having different modes of action. This will help reduce the risk of development of pesticide resistance in the target pest population. If you have questions about pesticide modes of action, legality of use, or anything else in reference to pesticides, ask the sales representative at the retailer where you are purchasing the pesticides, or contact the Hawai‘i Department of Agriculture or the University of Hawai‘i’s Cooperative Extension service. Table 3 lists some common pesticides that can be used to control vectors of CMV and the insects that tend them.

Table 3: Pesticides available for management of cucumber mosaic in Hawai‘i

Brand Name	Pest Controlled	Active Ingredient
ADMIRE®	Aphids	Imidacloprid
WARRIOR II WITH ZEON TECHNOLOGY®	Aphids	lambda-Cyhalothrin
BAYTHROID®	Aphids	beta-Cyfluthrin
BRIGADE®	Aphids	Bifenthrin
EIGHT®	Cucumber beetles	Permethrin
VOLIAM XPRESS®	Cucumber beetles	Chlorantraniliprole, lambda-Cyhalothrin
NUPRID®	Cucumber beetles	Imidacloprid
BONIDE BUG BEATER	Ants, Aphids	Piperonyl butoxide, Pyrethrins
CLINCH®	Ants	Abamectin
PIC®	Ants	Boric acid

The pesticides listed here are for reference only. It is the sole responsibility of the applicator to make sure that the use of these pesticides on a specified crop is permitted by the pesticide label instructions. Legality of pesticide use may vary among setting (home garden, farm, forestry, etc.), certification of an applicator, crops to which these pesticides are applied, etc. It is not the authors’ or the University of Hawai‘i’s responsibility to ensure the legal use of any pesticides listed in this article. The pesticides listed here are approved for use in Hawai‘i as of August 2014.Their registration and legal status may change over time in the state of Hawai‘i. The authors and University of Hawai‘i do not endorse the use of the products listed here over other brands or active ingredients of similar pesticides.

- **Avoid manual transmission of CMV by plant sap.** Sterilize pruning shears, cultivators, and other equipment that can potentially injure plants and move infested sap among plants. Use dilute bleach, flame, or other sterilizing methods to sanitize tools and equipment. Rogue symptomatic plants before pruning a crop. Train employees to recognize the symptoms of cucumber mosaic.

- **Apply integrated cultural management practices.** Cultivate effective border areas around fields or crops. Such border areas can help to suppress CMV and vectors. Border plants that attract natural predators may help manage aphids. Growing taller, immune hosts around the perimeter of a cultivated area can also impede disease and vector entry (Zitter et al. 2009). In addition to attracting beneficial insects, however, field border weeds may harbor vectors, so careful consideration and selection of border plants is advisable.

- **Biological control.** Some other biocontrol options such as biopesticides may be available. Many times these are fungi or bacteria mixed up into a solution that target one insect in particular. They are registered as pesticides and should be used according to the label. It is common for these types of pesticides to be available for organic production. Application of some bacterial formulations to the roots and soil around some host plants can induce host resistance to CMV (Zitter et al. 2009).

In the application of disease-management practices, bear in mind some of the differences among growing systems, such as cropping systems, landscapes, gardens, and agroforestry settings. For instance, large farms typically use monocrops having organized rows wherein machinery can move easily. This setup simplifies control practices such as pesticide applications but encourages the development of large populations of pests and pathogens. In contrast to large farms, gardens and agroforests have more crop diversity, i.e., a higher number of different plant species. This encourages competition among organisms that can reduce pests and disease.

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