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Maize Chlorotic Mottle

Scot Nelson,[1] James Brewbaker,[2] and John Hu[1]
[1]Department of Plant and Environmental Protection Sciences
[2]Department of Tropical Plant and Soil Sciences

Maize (*Zea mays* L., corn) ranks as the second largest crop in the world, according to the Food and Agriculture Organization of the United Nations. The annual yield of maize in 2009 exceeded 800 million tons, and its value exceeded $51 billion (FAOSTAT 2009). Maize has become an integral part of modern society: It is a staple food for humans and livestock and has a variety of other uses. Corn has also become Hawai'i's most valuable crop.

Seed crops are Hawai'i's most valuable farm commodities. In 2008, seed corn made up 95% of the seed market and was valued at $213.6 million (Statistics of Hawaii Agriculture 2009). Eleven farms grew corn seed crops that year on over 6,300 acres. Farmers also grew 400 acres of sweet corn, valued at more than $1.23 million. With ever more acres being devoted to sweet corn, forage, feed grain, biofuel, and popcorn, maize has become essential to Hawai'i's modern agricultural economy.

Disease symptoms on a tasseling corn plant in Hawai'i infected with *Maize chlorotic mottle virus* (MCMV): pale green stripes or blotches running parallel to leaf veins, mosaic, and severe stunting (reduced distance between leaf internodes).

A range of important insects, weeds, and plant pathogens cause damage to corn in Hawai'i. Among the pathogens, fungi and viruses cause yield-limiting diseases to which temperate-climate field corn and sweet corn often lack resistance. Pathogens that cause fungal diseases include southern rust and a viral disease, maize mosaic, caused by *Maize mosaic virus* (MMV), both of which have been targeted for decades by the corn-breeding program at the University of Hawai'i's College of Tropical Agriculture and Human Resources (UH-CTAHR). Open-pollinated varieties such as Hawaiian Supersweet #9 (yellow) and Hawaiian Supersweet 'Silver' (white) are among the few sweet corn varieties available with a high level of resistance to MMV and southern rust. All sweet corn and field corn hybrids derived from these varieties and released by CTAHR are highly resistant (www.ctahr.hawaii.edu/hfs).

A newly emergent viral disease of corn, maize chlorotic mottle, appeared on Kaua'i in the early 1990s. *Maize chlorotic mottle virus* (MCMV) now poses a significant threat to temperate-zone seed corn crops and some of the locally developed tropical corn varieties. This disease was controlled for several years on Kaua'i by destroying infected crops, but it has since spread to other islands, including O'ahu and Maui. Most of the temperate-zone seed corn produced in Hawai'i is

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Typical mosaic symptoms on corn leaves (left) caused by MCMV in Hawai'i. Nearly asymptomatic leaves are shown at right.

highly susceptible to MCMV, and locally bred sweet corn varieties often show some genetic susceptibility. Producers of corn seed on all Hawaiian islands now spray regularly after planting to control the insects that spread of the virus.

In Hawai'i MMV, transmitted by the leafhopper, *Peregrinus maidis*, is more damaging than MCMV (Ming et al. 1997). However, the former disease can be effectively controlled by regular insecticide applications. MMV resistance in corn is monogenic and rare among temperate-zone corn varieties but common in all Hawai'i germplasm. MMV resistance in corn does not provide resistance to MCMV. When both viruses are present in a plant, in fact, the plants often age prematurely. The condition is called corn lethal necrosis (CLN).

The level of MCMV resistance varies widely among pure lines that have been tested in Hawai'i, so it is considered a quantitative trait. Almost all temperate climate inbreds and hybrids are highly susceptible to the virus. As a result, growers in Hawai'i's seed industry routinely spray insecticides on their predominately temperate-zone seed stock to control the thrips that are the vector of MCMV. In contrast, many tropical field corn lines and varieties are fully resistant. In CTAHR breeding nurseries at Waimanalo Research Station, the disease was first observed in early 2011. Maize chlorotic mottle is not widespread, but an epidemic occurred at a Kahuku sweet corn farm in 2010, causing severe yield loss. Preliminary inheritance studies on the inheritance of traits suggest a polygenic control of the disease, with resistance being partially dominant. This encourages the commercial production of hybrids only if both parents are resistant to the pathogen.

There are a number of important unanswered questions about MCMV and its vectors, as well as about maize chlorotic mottle. Here we discuss these ques-

tions, the pathogen, vectors and virus transmission, and the disease epidemiology and symptoms. We suggest integrated practices for its successful management and also identify areas of future research needed to gain a fuller understanding leading to better management of epidemics of maize chlorotic mottle.

Pathogen

Maize chlorotic mottle virus is the only species in the genus *Machlomovirus* (family *Tombusviridae*). The virions of this single-stranded RNA virus are isometric, and the single-component particles have a smooth spherical or hexagonal shape (Scheets 2010). The virus was first reported to infect *Z. mays* in Peru (Hebert and Castillo 1973). MCMV is not widespread in the United States, having been reported only in Nebraska, Kansas, and Hawai'i. Globally, the virus occurs in Argentina, Mexico, and Peru. At least two genetically and geographically distinct strains of MCMV have been reported, MCMV-P (Peru) and MCMV-K (Kansas) (Nyvall 1999).

Transmission

MCMV transmission occurs through insect vectors, mechanically, and by seed at very low rates (Jensen et al. 1991). MCMV is possibly also transmitted though infested soil, as the virus can survive in corn residue (Nyvall 1999). Continuous maize production in a field greatly increases the incidence of maize chlorotic mottle.

The following insect species can transmit MCMV (Nyvall 1999):

- Corn thrips (*Frankliniella williamsi*)
- Three species of corn rootworms (*Diabrotica*): the southern corn rootworm (*D. undecimpunctata*), the northern corn rootworm (*D. lonicornis*), and the western corn rootworm (*D. virgifera*)
- The corn flea beetle (*Chaetocnema pulicaria*)
- The flea beetle (*Systena frontalis*)
- The cereal leaf beetle (*Oulema melanopa*)

Corn thrips is the only widely distributed vector of MCMV in Hawai'i and is likely the primary vector. It transmits MCMV in a non-persistent manner. Although maize is the preferred host, corn thrips can survive on a number of plants, including cassava, beans, maize, sorghum, onions, various grasses, rice, peppers coriander, peas, and the weedy species *Bidens pilosa* and *Tithonia diversifolia* (Capinera 2008; ICPEI Thrips 2011; Frison and Feliu 1989; King and Saunders 1984).

Plant host range for MCMV

Maize is the only natural host reported for MCMV. Hosts that can be infected experimentally are limited to the grasses in the family *Poaceae* (Scheets 2004). Among these grasses, 73 plant species in 35 genera have been tested for susceptibility to virus strains MCMV-Kansas, MCMV-Peru, or both (Table 1).

Table 1. Plants tested for susceptibility to strains of MCMV (Scheets 2004).

Immune genera[1]	Susceptible genera	Genera with both immune and susceptible species
Axoponus	*Andropogon*	*Agropyron*
Chloris	*Avena*	*Bromus*
Elymus	*Bouteloua*	*Cenchrus*
Festuca	*Buchloe*	*Cynodon*
Lolium	*Calamovilfa*	*Dactylis*
Oryza	*Eleusine*	*Digitaria*
Paspalum	*Eragrostris*	*Echinochloa*
Poa	*Euchlaena*	*Panicum*
Saccharum	*Hordeum*	*Phalaris*
	Secale	*Setaria*
	Sorgastrum	*Zea*
	Sorghum	
	Spartina	
	Tripsacum	
	Triticum	

[1]Status of hosts listed in this table are a result of experimental inoculations, not natural field infection.

Hosts of MCMV found in Hawai'i include the following plant species (common names in parentheses) (Brunt et al. 2010):

- *Bromus mollis* (soft chess; soft brome)
- *Panicum dichotomiflorum* Michx. (fall panic grass; fall panicum)
- *Panicum maximum* Jacq. (guinea grass)
- *Panicum miliaceum* (proso; broomcorn millet)
- *Zea mays* (corn)

The host status (either natural or experimental) of other

Variation in host response to infection by MCMV among inbred corn lines growing at Waimanalo, Hawai'i. Symptoms range from severe mosaic and stunting (foreground) to virtually asymptomatic (background). These corn lines express varying degrees of resistance and susceptibility to the virus, suggesting that improved varieties can be developed through traditional breeding and selection.

Bromus spp. and *Panicum* spp. found in Hawai'i for the Hawaiian strain(s) of MCMV is unknown.

Disease symptoms

Disease symptoms vary in severity depending on plant age at the time of infection, environment, and maize variety or genotype (Scheets 2004). Symptoms of maize chlorotic mottle include the following:

- Leaf mosaic with fine, chlorotic, longitudinal yellow streaks parallel to leaf veins develops about 10 days after inoculation.
- Streaks may coalesce to create chlorotic mottling.
- Chlorotic mottling may be followed by leaf necrosis, stunting, and plant death.
- Ears are short, malformed, and partially filled, often with prematurely aged husks
- Yield reductions are possible with natural infections and range up to 60% with experimental infections (Scheets 2004).
- Male inflorescences (tassels) may be shortened.

Disease diagnosis and virus detection

In maize, MCMV has been detected in leaves, pollen, female and male inflorescences, ear husks, cotyledons, and seeds (pericarps, endosperm, cotyledons, and embryo) (Scheets 2004). The most reliable methods for detecting MCMV in host tissues include ELISA (enzyme-linked immunosorbent assay), Northern blots, and polymerase chain reactions (PCR) for detection of virus RNA. There are no reliable local lesion hosts. Maize chlorotic mottle may be difficult to diagnose based on symptoms alone, because some of its symptoms (stunting, chlorosis) may resemble those caused by nutrient deficiencies or maize mosaic. CTAHR can provide diagnostic inbreds with high susceptibility or high resistance for virus-resistance testing (www.ctahr.hawaii.edu/hfs).

Disease management

The most effective management of maize chlorotic mottle is through the integration of cultural practices with insecticides and host resistance. Superior resistance to MCMV is widely available in tropical corn seed stocks and provides the best control for this disease. Most temperate-climate varieties of field and sweet corn, however, are highly susceptible. Some locally bred sweet corn hybrids are intermediate in tolerance.

The following integrated practices are recommended to control maize chlorotic mottle:

- Plant maize lines resistant to MCMV.
- Apply insecticide sprays, weekly if necessary, to control thrips vectors.
- Control alternate weed hosts, especially grassy

weeds, to reduce populations of MCMV and corn thrips.
- Scout fields regularly and remove any symptomatic plants.
- Keep unnecessary people and machines out of the field to reduce mechanical transmission and spread of MCMV.

Deployment of host resistance

The most effective management strategy is to plant MCMV-resistant varieties. Many tropical inbreds and varieties were highly resistant to MCMV in 2011 trials. For example, 30 of 40 (75%) of UH-bred field-corn inbreds tested were resistant. Complete immunity, however, has not been observed. Sweet corn developed for the Hawai‘i market often shows some susceptibility, but the level of resistance is being increased through breeding. The severity of the disease depends on the cropping environment, or location. Therefore, the best approach is to employ the integrated management practices listed above, including the use of disease-resistant plants.

Future research needs

To manage maize chlorotic mottle disease more effectively in Hawai‘i, the following questions still need to be answered. What other grassy weeds are potential hosts of MCMV? Is more than one virus strain present in Hawai‘i, and how do strains differ? What genes are responsible for host resistance, and how can these genes be incorporated into commercial seed stock? How effectively can Hawaiian strains of MCMV be spread by seed? How does the environment in which corn is grown affect the severity of disease? Are thrips the only vector of MCMV in Hawai‘i? If so, can the disease be managed by controlling them? What is the best strategy for controlling thrips in Hawai‘i? Research is needed to address these questions in order to develop improved scientific understanding and better management of epidemics.

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Young corn plants infected with MCMV in Hawai‘i showing the typical symptoms of leaf mosaic.

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