Review on Maize Chlorotic Mottle Virus: Distribution, Host Range, Transmission Mechanisms and Management Options

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Abstract
Plant virus diseases are serious constraints to the productivity and profitability of a wide range of crops. Epidemics of existing plant virus diseases and the emergence of novel virus diseases have become a serious threat to subsistence and commercial agriculture. The knowledge of virus transmission and its survival helps to understand how the disease transmits from infected plant to healthy, where it reserved, and this will lead to identify the most important variables and focus efforts to develop sustainable management strategies.

Maize chlorotic mottle virus (MCMV) is transmitted from location to location, and from plant to plant through various mechanisms (mechanically, seed, insect vectors, and soil) and many kinds of wild grass and cultivated crops, maize residue are used as its reservoirs. Different weed species and cultivated plants used as alternate hosts, and soil and seed transmissibility of MCMV are epidemiologically important and contribute to maintaining virus inoculum available in the absence of maize in the field and increase the chances of continuing its survival. Integrated disease management approach, regular field monitoring, assessment of virus symptoms, and rouging-out diseased plants are recommended to prevent further spread by insect vectors. Apart from this, because the disease is still widespread in various countries, intensive MCMV recruitment, combined with integrated disease management, requires ongoing practice in countries where MCMV is prevalent and in those countries that have not yet reported MCMV.

Keywords: Integrated management; Insect vector; plant residue; Soil transmission; Zea mays
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1. Introduction
Maize (Zea mays L.) is the main staple food in Latin America and Sub-Saharan Africa (Iken and Amusa, 2004). The crop is ranked the third most important cereal plant after wheat and rice (Khalili et al., 2013). Presently maize is cultivated throughout the year in almost every part of the world. The potential yield of maize per unit land area is highly dependent upon fertility levels, plant population, management practices, and the inherent potential of the variety adapted to that area.

Plant viruses are among the major factors that affecting food production worldwide and cause vast economic losses. It results in the loss by limiting plant produce quality and quantity (Thresh, 2006; Van der Vlugt, 2006) and have an estimated economic impact of more than $30 billion per year (Sastry and Zitter, 2014). Globally, there are more than 32 maize infecting viruses recorded on maize. Among them, Maize chlorotic mottle virus (MCMV) is one of the most devastating maize productions worldwide. Hence the objective of this paper is to overview the MCMV global distribution, host range, transmission mechanism, and its management options.

Discussion
2.1. Maize chlorotic mottle virus (MCMV) and its strains
MCMV is the only identified member of the genus Machlomovirus in the family Tombusviridae (King et al., 2011). There are several strains of MCMV have been identified. MCMV-NE is the isolate from Nebraska (Stenger and French, 2008), MCMV-K and MCMV-P are isolated from Kansas and Peru, respectively (Uyemoto, 1983) while MCMV-YN the Chinese isolate from Yunnan (Xie et al., 2011). The US isolates (K and NE) share 99.5% Nucleotide sequence identity, a clear indication the two isolates are related (Nutter et al., 1989’ Stenger and French, 2008). MCMV isolates from Thailand were closely related to China strains with 98-99.6% sequence similarity (Wu et al., 2013). The nucleotide sequence similarity of MCMV isolates from East African countries is 99% (Mahuku et al., 2015), that the whole region has similar MCMV viruses interacting mainly with SCMV. Kenyan isolates had 95-98% sequence similarity (Wangat., et al., 2012). Ethiopia isolate was similar to East Africa isolate with 99% similarity (Mahuku et al., 2015). Rwanda, Kenya, China isolates were identical with 99% and 96-97% with USA isolates (Adams et al., 2014).

2.2. Yield loses caused by MCMV
MCMV infects maize plants and causes significant losses in maize production. Under natural field conditions, MCMV causes 10-15% crop loss and up to 59% loss under inoculated conditions (Castillo and Loayza, 1977). When MCMV co infects maize plants with other maize viruses from the family Potyviridae, such as maize dwarf
mosaic virus (MDMV) (genus: *Potyvirus*), Sugar cane mosaic virus (SCMV) (genus: *Potyvirus*), or Wheat streak mosaic virus (WSMV) (genus: *Tritimovirus*), their synergistic effect causes a more severe disease called Maize lethal necrosis (MLN), previously known as Corn Lethal Necrosis which leads to almost 100% field loss (Uyemoto *et al.* 1980; Goldberg and Brakke, 1987; Xie *et al.*, 2011). When MCMV co-infects maize with any potyvirus infecting maize plants, a synergistic interaction occurs, causing a severe disease (Fig. 1) and yield losses. MCMV can cause 91% yield loss occurs in co-infection with either MDMV or *Wheat streak mosaic virus* (WSMV) (Niblett and Claflin, 1978). In Africa, MCMV is a serious disease of maize from its first outbreak in Kenya (Wangai *et al.*, 2012) to the present (Regassa *et al.*, 2020; 2021). In Africa 30-100% loss in co-infection with SCMV (Wangai *et al.*, 2012, Mahuku *et al.*, 2015; Guide *et al.*, 2018; Regassa *et al.*, 2020).

![Fig. 1. MCMV co-infection with SCMV causing severe damage on maize under natural field condition](image1.jpg)

2.3. MCMV symptoms

Depending on the host genotype, MCMV infection symptoms range from mild to severe chlorotic mottle, leaf necrosis, stunted growth, a shortened male inflorescence with few spikes, malformed or partially filled ears, and premature death of plants (Niblett and Claflin, 1978; Uyemoto *et al.*, 1981; Regassa *et al.*, 2021).

When MCMV co-infects maize with a potyvirus infecting maize, the infected maize plants under field condition show a various range of symptoms, such as chlorotic mottling of the leaves (Fig 2 a and b), typically starting from the base of the young leaves in the whorl and extending upwards toward the leaf tips. The leaves can experience necrosis at the leaf margins that progress to the mid-rib resulting in drying of the whole leaf (Fig 2 d). Other symptoms include premature aging of the plants and mild to severe leaf mottling. Severely affected plants form small cobs with little or no grain set (Fig 2 f and g). The entire crop can frequently be killed before tasseling (Niblett and Claflin, 1978; Uyemoto *et al.*, 1980, 1981; Wangai *et al.*, 2012; Regassa *et al.*, 2021).
Fig 2. MCMV co-infection with SCMV and symptoms commonly observed under natural field condition: (a) chlorotic, (b and c) mild to severe leaf mottling, (d) necrosis of leaf margins, (e) drying cob, (f and g) poor or no grain filling. Source: Regassa et al. (2021).

2.4. History and Global distribution of MCMV

MCMV was first described in maize from Peru in 1973 and reported in 1974 (Castillo and Hebert, 1974) and thereafter was reported on maize plants in different countries of South America, North America, Europe, Asia and Africa. In Africa, MCMV was first occurred in Kenya in 2011 and reported in 2012 (Wangai et al., 2012), since then have been reported and widespread in other East African countries. The following Table (Table 1) provides the year in which samples first tested positive for MCMV in each country it has reported in.

Table 1. MCMV global distribution

| Continent/Country          | Earliest report | Reference                          |
|----------------------------|-----------------|------------------------------------|
| SOUTH AMERICA              |                 |                                    |
| Peru                       | 1973            | Castillo and Hebert (1974)          |
| Argentina                  | 1982            | Teyssandier and Bo (1983)           |
| Ecuador                    | 2015            | Quito-Avila et al. (2016)           |
| NORTH AMERICA              |                 |                                    |
| USA                        | 1976            | Niblett and Claflin (1978)          |
| Mexico                     | 1984            | Gordon et al. (1983)                |
| Hawaii                     | 1990            | Jiang et al. (1992)                 |
| Kansas                     | 1977            | Nault et al. (1978)                 |
| Nebraska                   | 1981            | Doupnik et al. (1982)               |
| Texas                      | 1978            | Kessler (1979)                      |
| EUROPE                     |                 |                                    |
| Spain                      | 2015            | Achon et al. (2017)                 |
| ASIA                       |                 |                                    |
| Thailand                   | 1982            | Klinkong and Sutabutra (1983)       |
| China                      | 2011            | Xie et al. (2011)                   |
| Yunnan                     | 2014            | Wang et al. (2014)                  |
| Taiwan                     | 2014            | Deng et al. (2014)                  |
| AFRICA                     |                 |                                    |
| Kenya                      | 2011            | Wangai et al. (2012)                |
| Tanzania                   | 2012            | Mahuku et al. 2015b                 |
| Uganda                     | 2013            | Mahuku et al. 2015b                 |
| Rwanda                     | 2013            | Adams et al. (2014)                 |
| Democratic Republic of Congo| 2013        | Lukanda et al. (2014)               |
| Ethiopia                   | 2014            | Mahuku et al. (2015a)               |
| South Sudan                | 2014            | Mahuku et al. 2015b                 |
2.5. MCMV host range

2.5.1. Natural alternative hosts

Earlier, maize was reported as the only known natural hosts of MCMV (Scheets, 2004), recent studies, however, have identified MCMV from sugarcane; finger millet, sorghum, Napier grass and Kikuyu grass (Wang et al., 2014; Kusia et al. 2015; Mahuku et al., 2015; Regassa et al., 2021). Our recent study (Regassa et al., 2021) showed that the Poaceae family had the highest number of grass species that were alternate hosts for MCMV, and Cyperus cyperoides and Cyperus cyperoides from the Cyperaceae family were naturally infected by MCMV (Regassa et al., 2021). Most of the natural alternative hosts identified were annual and perennial grasses in nature (Table 2), and common in the maize growing areas.

| Family     | Species                                      | Life cycle | Type  |
|------------|----------------------------------------------|------------|-------|
| Cyperaceae | Cyperus rotundus L.                          | Perennial  | Sedges|
| Cyperaceae | Cyperus cyperoides L.                        | Perennial  | Sedges|
| Poaceae    | Snowdenia polystachya (Fresen.) plig.        | Annual     | Grasses|
| Poaceae    | Cynodon nlemfuensis Vanderyst.               | Perennial  | Grasses|
| Poaceae    | Digitaria sanguinalis (L.) Scop.             | Annual     | Grasses|
| Poaceae    | Echinochloa colona L.                        | Annual     | Grasses|
| Poaceae    | Oplismenus hirtellus L.                      | Perennial  | Grasses|
| Poaceae    | Pennisetum purpureum Schumach.              | Perennial  | Grasses|
| Poaceae    | Phalaris paradoxa L.                         | Annual     | Grasses|
| Poaceae    | Sorghum bicolor L.                           | Annual     | Grasses|
| Poaceae    | Saccharum officinarum L.                     | Perennial  | Grasses|

Source: Regassa et al. (2021)

Different types of MCMV symptoms were observed on different plant species of its alternative hosts. The symptoms observed included mosaics, mottling, yellowing, necrosis that develop from leaf margins to the mid-rib, and purple discoloration of leaves. For instance, MCMV symptoms on Cyperus cyperoides and Snowdenia polystachya were expressed as yellowing, while it showed mosaic and chlorotic symptoms on Oplismenus hirtellus (Fig.2) (Regassa et al., 2021).

![Cyperus cyperoides](image1.png)
![Oplismenus hirtellus](image2.png)

Fig. 3. Maize chlorotic mottle virus (MCMV) on naturally infected different alternate hosts shows yellowing and mosaic symptoms.

2.5.2. Experimental host range

Bockelman et al. (1982) has identified a broad range of MCMV experimental host range that includes at least 19 grass species, but it does not infect dicots. According to Sheets (2004), 73 grass species in 35 genera have been tested for susceptibility to virus strains MCMV-Kansas, MCMV-Peru, or both (Table 3).

| Immune genera | 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      | Eragrostis Euchlaena | Echinochloa                                |
| Poa           | Hordeum            | Panicum                                       |
| Saccharum     | Secale             | Phalaris                                      |
| Sorghastrum   | Sorgastrum         | Setaria                                       |
| Sorghum       | Sorgastrum         | Zea                                           |
| Spartina      | Tripsacum Triticum |                                               |

The recent MCMV experimental host range study (Regassa et al., 2021) revealed that among the 39 weed species tested for reaction to MCMV using artificial inoculation in the greenhouse, 20 species were susceptible to MCMV infection (Table 4). Cereal crops (barley and wheat) were also experimentally infected by MCMV (Fig 3,
Maize chlorotic mottle virus (MCMV) symptoms (mild chlorotic, yellowing, necrosis starting from leaf merges to mid-rib) on mechanically inoculated grass weeds and cereal crops (A = dinebra retroflexa, B = Setaria verticillata, C = Cyperus assimilis, D = Digitaria ternta, E = Opismenus hirtellus, F = Sorghum arundianaceum, G = wheat, H = barley.

Table 5. MCMV experimental host (Weed species) identified by artificially inoculation in greenhouse

| Family name   | Species name                              | Life cycle | Type of weed |
|---------------|-------------------------------------------|------------|--------------|
| Cyperaceae    | Cyperus assimilis Steud.                   | Annual     | sedges       |
| Cyperaceae    | Cyperus esculentus L.                      | perennial  | sedges       |
| Cyperaceae    | Cyperus rotundus L.                        | Perennial  | Sedges       |
| Poaceae       | Cenchrurus ciliaris L.                     | perennial  | Grases       |
| Poaceae       | Cydonium nemfuencis Vanderyst.             | Perennial  | Grases       |
| Poaceae       | Andropogon abyssinicus (Fresen.) R. Br.    | Annual     | Grases       |
| Poaceae       | Cydonium dactylon (L.) Pers.               | Perennial  | Grases       |
| Poaceae       | Denebra retroflexa (Vahl.) panzer          | Annual     | Grases       |
| Poaceae       | Digitaria abyssinica (A. Rich) Stapf       | Perennial  | Grases       |
| Poaceae       | Digitaria ischaemum (Schreb.) muhl.        | Annual     | Grases       |
| Poaceae       | Digitaria ternae (A. Rich.) Stapf          | Annual     | Grases       |
| Poaceae       | Echinoecia colona (L.) Link                | Annual     | Grases       |
| Poaceae       | Eleusine indica L. Gaertn.                 | Annual     | Grases       |
| Poaceae       | Ergrostis ciliates (All.) Lut.             | Annual     | Grases       |
| Poaceae       | Pennisetum ramosum (Hochst.) Schweinf.     | Annual     | Grases       |
Producers are advised to practice crop rotation for at least two seasons with alternative non-cereal crops such as shown to reduce the incidence of MCMV the following year (Phillips et al., 1982; Uyemoto, 1983). Maize thrips transmit MCMV in a non-persistent manner. Both larvae and adults of corn thrips transmitted MCMV for up to 6 days after acquisition, with decreasing rates of transmission as time progressed.

### 2.6. Mechanisms of MCMV transmission

#### 2.6.1. Mechanical Transmission

MCMV is transmitted mechanically by sap. Mechanical transmission occurs when a plant comes in contact with other plants and leaves rub together or by humans’ interferences like tools/hands/clothing. It involves the introduction of an infective virus or biologically active virus into a suitable site in the living cells through wounds or abrasions in the plant surface. Spreading viruses by the mechanical method is generally used for experimental purposes under laboratory/greenhouse conditions.

#### 2.6.2. Insect vectors

The transmissions of viruses from plant to plant by vectors provide the main method of spread in the field for many viruses including MCMV that cause severe economic loss (Hull, 2014). In Ethiopia, studies on the MLN causing viruses (MCMV and SCMV) are linked to the free movement of insect vector and continuous availability of the host plants (Regassa et al., 2020). In the United States mainland, MCMV has been reported to be transmitted by six different species of chrysomelid beetles, including the cereal leaf beetle (*Oulema melanopa*), corn flea beetle (*Chlaenomela pulicaria*), flea beetle (*Systena frontalis*), southern corn rootworm (*Diabrotica undecimpunctata*), western corn rootworm (*Diabrotica virgifera*) and northern corn rootworm (*D. longicornis*) (Jiang et al., 1992; Nault et al., 1978).

The other vector that transmits MCMV is maize/corn thrips, *Frankliniella williamsii* Hood (Thysanoptera: *Thripidae*) has been identified to be the main vector (Cabanas et al., 2013) in Hawaii, USA. Maize thrips transmit MCMV in a non-persistent manner. Both larvae and adults of corn thrips transmitted MCMV for up to 6 days after acquisition, with decreasing rates of transmission as time progressed.

#### 2.6.3. Seed Transmission

MCMV is also transmitted by seed. The rate of MCMV seed transmission observed by Jensen et al. (1991) who evaluated 42,000 seedlings and found a 0.04% transmission rate in Hawaii, USA. Quito-Avila et al. (2016) from Ecuador reported 8 and 12% seed transmission of MCMV. Zhang et al. (2011) reported MCMV seed transmission of 2 seeds in 600 (0.33%) in Chinese maize. The recent MCMV seed transmission study (Regassa et al., 2021) showed the mean seed to the seedling transmission rate of MCMV was 0.073% with a range of 0 to 0.17% among 20 different maize varieties studied. Fourteen maize genotypes had some levels of seed transmission (0.03%–0.017%) for MCMV. Seed transmission rates of the viruses were influenced by the seed lot and maize varieties used (Regassa et al., 2021).

#### 2.6.4. Transmission through soil and plant residue

Transmission in soil water or crop residues has been suggested for MCMV, and there are a number of reports of increased disease pressure after heavy rainfall and in soils with a higher water capacity (Jensen, 1991; Uyemoto, 1983). Mahuku et al. (2015) found that planting clean seeds in the soil from MLN-affected areas resulted in 69% increased disease pressure after heavy rainfall and in soils with a higher water capacity (Jensen, 1991; Uyemoto, 1983). Alternatively, crop rotation with non-maize crops has been shown to reduce the incidence of MCMV the following year (Phillips et al., 1982; Uyemoto, 1983). Maize Producers are advised to practice crop rotation for at least two seasons with alternative non-cereal crops such as shown to reduce the incidence of MCMV the following year (Phillips et al., 1982; Uyemoto, 1983).
as potatoes, sweet potatoes, cassava, beans, bulb onions, spring onions, vegetables and garlic. Planting different crops each season will diversify farm enterprises. Manure and basal/top dressing fertilizers can be applied to boost plant vigor.

It is necessary to use good field sanitation methods, including weed control measures to eliminate alternate hosts for potential vectors (Wangai et al., 2012; Regassa et al., 2020, 2021). Infected foliar material should be removed from the field to reduce pathogen and vector populations. In Hawaii, USA producers of maize seed spray regularly after planting to control insects that spread the virus (Nelson et al., 2011). The use of tolerant or resistant varieties ultimately would be the most effective means of managing MCMV (Regassa et al., 2020). Superior resistance to MCMV is widely available in tropical maize seed stocks and provides the best control for this disease. The use of host resistance is the most desirable and feasible method in virus disease management. According to Nelson et al. (2011), trials performed in Hawaii in 2011 found many tropical inbred lines and varieties to be highly resistant to MCMV. Almost all temperate climate inbred lines and hybrids are highly susceptible to the virus (Nelson et al., 2011).

MCMV infected soil and infected maize residue play an important role in the survival, inoculum source and spread of MCMV. Thus, proper management of crop residues in the field after harvest is necessary to minimize the adverse effects of MCMV on maize production. Crop rotation is one of the ways of freeing the soil from MCMV disease. Therefore, as part of integrated management of MCMV, maize growers should remove all infected maize materials/residues from the field, ignore any activity that moves the soil from MCMV infected fields or infected maize residue from one place to another.

3. Conclusions and Recommendation

Because of the level of damage caused and potential of the disease to spread and cause tremendous losses in most major growing areas of the East African countries, MCMV which is the main component of MLN is currently considered as a high-risk emerging disease and given a top priority for intervention by research and crop pest regulatory authorities in the agricultural sector.

Plant virus disease management including MCMV has to be knowledge-based, and thus, it is important to know the geographical distribution and to understand the role of infected seed, alternate hosts, and insect vectors in the emergence and development of disease epidemics. MCMV transmitted from location to location, and from plant to plant through various mechanisms and many kinds of wild grasses and cultivated crops used as its reservoirs. MCMV infected seed, weed and cultivated plants are known as alternate hosts of MCMV are epidemiologically important and maintain the virus inoculum in the absence of maize crop in the field, and support the survival of the virus for continuous infection. Farmers and stakeholders involved in maize cultivation should take preventive measures by eliminating alternate host plants within and in the surrounding areas of maize fields, use virus-free and certified seed from known sources for sowing.

Different weed species and cultivated plants used as alternate hosts, and seed transmissibility of MCMV are epidemiologically important and contribute to maintaining virus inoculum available in the absence of maize in the field and increase the chances of continuing its survival. Therefore, regular field monitoring, assessment of virus symptoms, and rouging-out diseased plants are recommended to prevent further spread by insect vectors. Apart from this, because the disease is still widespread in various countries, intensive MCMV recruitment, combined with integrated disease management, requires ongoing practice in countries where MCMV is prevalent and in those countries that have not yet reported MCMV.

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