

Occurrence, Distribution, Economic Importance and Management of Maize Chlorotic Mottle Virus: A Review

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Abstract

Plant virus diseases are serious constraints to the production and productivity of a wide range of crops among which maize chlorotic mottle virus (MCMV) is a serious problem in maize production and productivity. The virus is primarily originated in South America (Peru) and later distributed into many countries of all the continents except Australia and Antarctica. It is transmitted from location to location, and from plant to plant mechanically, through seed, insect vectors, and/or soil. The virus has many host ranges of agricultural crops (Maize, Sorghum, Sugarcane and Finger millet) and wild species (*Dinebra retroflexa*, *Setaria verticillata*, *Cyperus assimilis*, *Digitaria ternta* and *Oplismenus hirtellus*). MCMV alone causes 10-15% crop loss and up to 100% loss when it co-infects maize plants with other maize viruses such as maize dwarf mosaic virus, Sugar cane mosaic virus or Wheat streak mosaic virus. No any single disease control measure alone is effective in controlling the MCMV. However, an integrated virus disease management options (the use of disease-resistant crop varieties, proper field sanitation, removal of infection sources, use of virus-free seeds and chemical pesticides to indirectly control insect vectors) play a critical role in controlling the virus. Since the current status of the disease is wide spreading and on increasing trend, intensive MCMV employment, combined with integrated disease management, requires ongoing practice in countries where the virus is prevalent and in those countries that have not yet reported MCMV.

Keywords: Integrated management; Insect vector; plant residue; Soil transmission; *Zea mays*

DOI: 10.7176/ALST/87-03

Publication date: April 30th 2021

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 crop production and productivity 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 origin, distribution, host range, transmission mechanism, economical importance and management options of MCMV.

2. Body of the Text

2.1. Taxonomy of Maize Chlorotic Mottle Virus (MCMV)

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 (Wangai., *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).

Symptoms of MCMV

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).

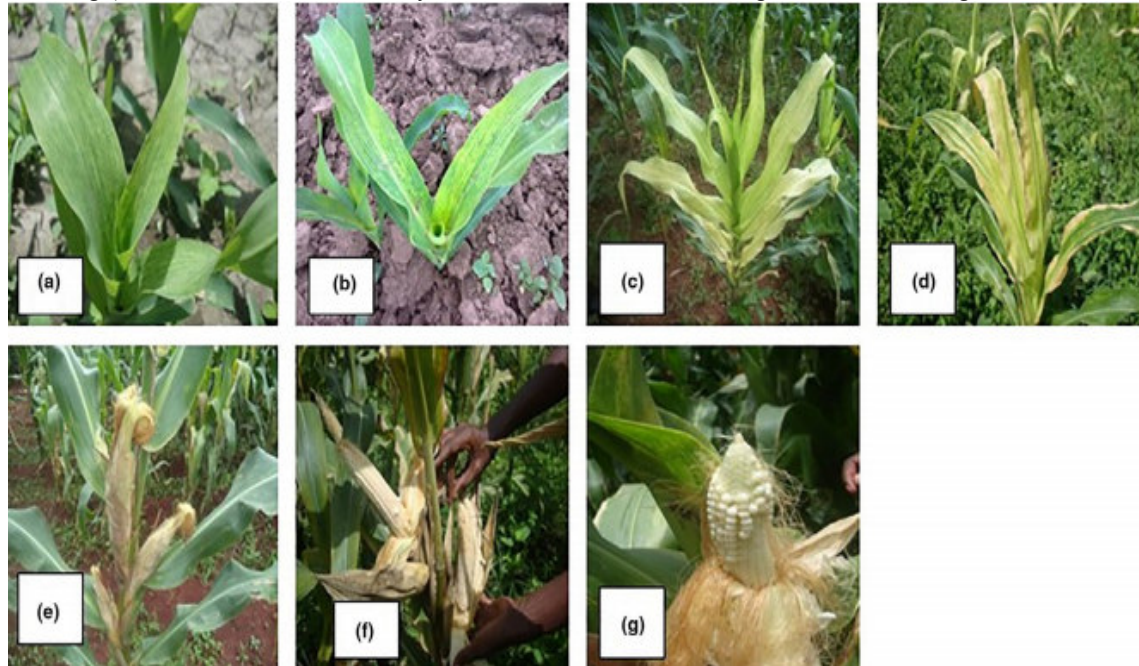


Fig 1. MCMV co-infection with SCMV and symptoms commonly observed under natural field condition: (a) chlorotic, (b and c) mild to severe leaf mottling, (d) necrosis of leaf margins, (e) drying cob, (f and g) poor or no grain filling. **Source:** Regassa *et al.* (2021).

2.2. Origin and 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 202 (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 <i>et al.</i> (2016)
NORTH AMERICA		
USA	1976	Niblett and Clafin (1978)
Mexico	1984	Gordon <i>et al.</i> (1983)
Hawaii	1990	Jiang <i>et al.</i> (1992)
Kansas	1977	Nault <i>et al.</i> (1978)
Nebraska	1981	Douppnik <i>et al.</i> (1982)
Texas	1978	Kessler (1979)
EUROPE		
Spain	2015	Achon <i>et al.</i> (2017)
ASIA		
Thailand	1982	Klinkong and Sutabutra (1983)
China	2011	Xie <i>et al.</i> (2011)
Yunnan		Wang <i>et al.</i> (2014)
Taiwan	2014	Deng <i>et al.</i> (2014)
AFRICA		
Kenya	2011	Wangai <i>et al.</i> (2012)
Tanzania	2012	Mahuku <i>et al.</i> 2015b
Uganda	2013	Mahuku <i>et al.</i> 2015b
Rwanda	2013	Adams <i>et al.</i> (2014)
Democratic Republic of Congo	2013	Lukanda <i>et al.</i> (2014)
Ethiopia	2014	Mahuku <i>et al.</i> (2015a)
South Sudan	2014	Mahuku <i>et al.</i> 2015b

2.3. MCMV host range

2.3.1. Natural alternative hosts

Earlier, maize was reported as the only known natural hosts of MCMV (Scheets, 2004) however, recent studies, 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). The most recent study (Regassa *et al.*, 2021) showed that the *Poaceae* family had the highest number of grass species and *Cyperaceae* family (*Cyperus cyperoids* and *Cyperus cyperoides*) species were alternate hosts for 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.

Table 2. Natural alternate hosts of MCMV identified

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

Source: Regassa *et al.* (2021)

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

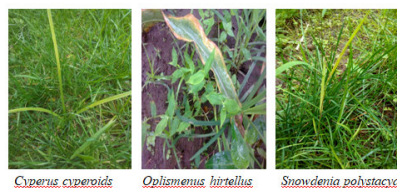


Fig. 2. *Maize chlorotic mottle virus* (MCMV) on naturally infected different alternate hosts shows yellowing and mosaic symptoms.

2.3.2. 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).

Table 3. Plants tested for susceptibility to strains of MCMV (Sheets, 2004)

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

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, G and H).



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 = *Oplismenus hirtellus*, F = *Sorghum arundianaceum*, G = wheat, H = barley).

Table 4. MCMV experimental host (Weed species) identified by artificially inoculation in greenhouse

Family name	Species name	Life cycle	Type of weed
Cyperaceae	<i>Cyperus assimilis</i> Steud.	Annual	Sedges
Cyperaceae	<i>Cyperus esculentus</i> L.	perennial	Sedges
Cyperaceae	<i>Cyperus rotundus</i> L.	Perennial	Sedges
Poaceae	<i>Cenchrus ciliaris</i> L.	perennial	Grasses
Poaceae	<i>Cynodon nlemfuensis</i> Vanderyst.	Perennial	Grasses
Poaceae	<i>Andropogon abyssinicus</i> (Fresen.) R. Br.	Annual	Grasses
Poaceae	<i>Cynodon dactylon</i> (L.) Pers.	Perennial	Grasses
Poaceae	<i>Denebra retroflexa</i> (Vahl.) panzer	Annual	Grasses
Poaceae	<i>Digitaria abyssinica</i> (A. Rich) Stapf	Perennial	Grasses
Poaceae	<i>Digitaria ischaemum</i> (Schreb.) muhl.	Annual	Grasses
Poaceae	<i>Digitaria ternate</i> (A. Rich.) Stapf	Annual	Grasses
Poaceae	<i>Echinochloa colona</i> (L.) Link	Annual	Grasses
Poaceae	<i>Eleusine indica</i> L. Gaertn.	Annual	Grasses
Poaceae	<i>Eragrostis cilianesis</i> (All.) Lut.	Annual	Grasses
Poaceae	<i>Pennisetum ramosum</i> (Hochst.) Schweinf.	Annual	Grasses
Poaceae	<i>Phalaris paradoxa</i> L.	Annual	Grasses
Poaceae	<i>Setaria pumila</i> (poir.) Roem. & schult.)	Annual	Grasses
Poaceae	<i>Setaria verticillata</i> (L.) P.Beauv.	Annual	Grasses
Poaceae	<i>Snowdenia polystachya</i> (Fresen.) pilg	Annual	Grasses
Poaceae	<i>Sorghum arundinaceum</i> (Desv.) Stapf	Annual	Grasses

Source: Regassa et al. (2021)

Source of Inoculum

MCMV infested soil, infected maize residue and alternative host weed species are an important survival, inoculum source and spread of MCMV.

2.4. Mechanisms of MCMV transmission

2.4.1. Mechanical Transmission

MCMV is transmitted mechanically by sap (Regassa *et al.*, 2021). 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.

2.4.2. 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). The studies on the MLN (MCMV is the main component) distribution and factors associated with its epidemic show that the spread of 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 (*Chaetocnema pulicaria*), flea beetle (*Systema frontalis*), southern corn rootworm (*Diabrotica undecimpunctata*), western corn rootworm (*Diabrotica virgifera*) and northern corn rootworm (*Diabrotica longicornis*) (Jiang *et al.*, 1992; Nault *et al.*, 1978).

The other vector that transmits MCMV is maize/ corn thrips, *Frankliniella williamsi* 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.

2.4.3. Seed Transmission

MCMV is also transmitted by seed (Jensen *et al.*, 1991; Regassa *et al.*, 2021). 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).

2.4.4. 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% MCMV infection. The very recent study also confirmed that low soil transmission (4.24-13.5%) MCMV can be transmitted from infested soil to newly raised maize seedlings and it also reserved in maize residues (Regassa et al., unpublished data). Similar findings were previously reported on MCMV transmission through soil (Nyvall, 1999). It also reported that MCMV can be transmitted through infected plant residues that play important roles in the survival of the virus especially when maize is planted during the off-season (Uyemto, 1983; Montenegro and Castillo, 1996).

2.5. Economic importance of 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. 4. MCMV co-infection with SCMV causing severe damage on maize under natural field condition

2.6. Management of MCMV

MCMV has been known on many crops including maize in many countries for many years but few studies have been conducted on its management since the potential threat of the disease to production. The disease is widespread on maize with high rates of incidence and severity in the maize growing countries since most farmers have limited knowledge about the virus and were therefore indifferent towards its control resulting in increasing disease incidence and severity.

2.6.1. Host Resistance

Disease control by use of resistance variety is one of the disease management components in integrated disease management. Diseases resistant varieties not only have the potential to reduce the cost of production but also offer an environmentally safe disease management approach. 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 virus. 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. The Author concluded that 75% of UH-bred field corn inbred lines are highly resistant to the virus.

2.6.2. Cultural Practices

Use of improved cultural practices can play a role in managing the disease below economic threshold level. 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 potatoes, sweet potatoes, cassava, beans, bulb onions, spring onions,

vegetables and garlic. Also the uses of cultural practices like crop sanitation and removal of infection sources, use of virus-free seeds should help prevent the disease. 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). Manure and basal/top dressing fertilizers can be applied to boost plant vigor.

2.6.3. Chemical Control Measure

It is intrinsically difficult to manage MCMV directly by measures such as direct use of chemical pesticides, however insecticides such as seed treatment and foliar spray to indirectly control vector insects is used to minimize further transmission of the virus by vectors (Nelson *et al.*, 2011). Alford (2000) concluded that pre-planting application of seed treatment by clothianidin, thiamethoxam and imidacloprid against thrips and beetles are effective in minimizing the yield loss due to MCMV.

2.6.4. Integrated Management of MCMV

Plant virus diseases including MCMV are intrinsically difficult to manage directly by a single disease control measures. Therefore an integrated virus management options play a critical role in controlling the virus which include the use of disease-resistant crop varieties, the uses of crop sanitation, removal of infection sources, use of virus-free seeds and chemical pesticides to indirectly control vector insects is the most feasible option (Nelson *et al.*, 2011).

3. Summary and Conclusions

The highest level of damage caused by MCMV and its potential to wide spread cause tremendous yield losses in most major maize growing countries. The virus is the main component of MLN. It 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.

The virus is transmitted from location to location, and from plant to plant through various mechanisms (mechanically, seed, insect vectors, and soil). Agricultural crops such as Maize, Sorghum, Sugarcane and Finger millet and many kinds of wild grass (*Dinebra retroflexa*, *Setaria verticillata*, *Cyperus assimilis*, *Digitaria ternita* and *Oplismenus hirtellus*). Maize residues are used as its reservoirs.

Under natural field conditions, MCMV causes 10-15% crop loss and up to 59% loss under inoculated conditions. However when it co infects maize plants with other maize viruses such as *Maize dwarf mosaic virus*, *Sugarcane mosaic virus*, or *Wheat streak mosaic virus*, their synergistic effect causes a more severe disease called maize lethal necrosis which leads to 100% crop loss.

Many management options developed to minimize the yield loss caused by MCMV, but no any single disease control measure alone is effective in controlling the virus. However, an integrated virus management options (the use of disease-resistant crop varieties, the uses of crop sanitation, removal of infection sources, use of virus-free seeds and chemical pesticides to indirectly control vector insects) play a critical role in controlling the virus.

4. The Way Forward

Since the current status of the disease is wide spreading and on increasing trend, intensive MCMV employment, combined with integrated disease management, requires ongoing practice in countries where the virus is prevalent and in those countries that have not yet reported MCMV.

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