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Biology, Epidemiology, Economic Importance and Management of Maize Lethal Necrosis Disease (MLND) in Ethiopia: A Review

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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Review Article

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Abstract

Maize (*Zea mays* L.) is an economically, nutritionally, and industrially pivotal cereal crop globally. Ethiopia is the second-largest maize producer in Sub-Saharan Africa, where the crop serves as a primary staple for millions of smallholder farmers across diverse agro-ecologies. Despite its importance, production is severely constrained by a complex matrix of biotic and abiotic factors. Among the biotic constraints, Maize Lethal Necrosis Disease (MLND) has emerged as the most destructive transboundary viral threat to maize productivity in the region. This review aims to assess the occurrence, biological mechanisms, epidemiology, economic impact, and management strategies of MLND in Ethiopia. Data were consolidated from peer-reviewed journals, doctoral dissertations, technical reports, and international symposia proceedings. Findings indicate that MLND causes catastrophic grain yield losses ranging from 50% to 100%. The disease is driven by a unilateral synergistic co-infection where SCMV suppresses the host's innate immune system via RNA silencing interference, leading to hyper-accumulation of MCMV. Epidemiology is primarily governed by

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thrips (*Frankliniella* spp.) and aphid (*Rhopalosiphum* spp.) vectors, supplemented by low-rate seed transmission, which facilitates long-distance dissemination. Effective mitigation requires an Integrated Disease Management (IDM) framework involving rigorous phytosanitary protocols, synchronised crop rotation, targeted vector control, and the deployment of resistant hybrids developed through marker-assisted breeding. This review concludes that while MLND poses a critical threat to national food security, its impact can be mitigated through the strategic integration of host resistance and optimised cultural practices.

Keywords: Integrated disease management; maize chlorotic mottle virus; synergism; sugarcane mosaic virus; yield loss.

1. Introduction

According to Vavilov (1926), the centre of origin for maize (*Zea mays* L.) is the Mesoamerican region, specifically Mexico, where it was domesticated approximately 9,000 years ago from its wild progenitor, Teosinte (*Zea mays* ssp. *parviglumis*). It is popularly known as the "Queen of cereals", "Contingent crop", "Miracle crop" and an emerging industrial crop, belonging to the grass family commonly known as Poaceae (Hazarika et al., 2025). Unlike barley or wheat, which were domesticated in the Fertile Crescent, maize adapted to the diverse climates of the Americas before spreading globally. Today, maize is cultivated worldwide, with major producing countries including the United States, China, Brazil, and Argentina. In the context of Africa, maize was introduced in the 16th century and has since become the most important staple food crop, providing over 30% of the caloric intake for the population in Sub-Saharan Africa (McCann, 2005; Shiferaw *et al.,* 2011). Its adaptability allows it to thrive in tropical, subtropical, and temperate agro-climatic environments, making it a crucial part of agricultural systems across the continent (Diro & Yadesa, 2022). In 2021, maize production in Ethiopia reached approximately 10.6 million metric tons, cultivated across 2.53 million hectares, with an average yield of 4.2 t ha^{-1}. Ethiopia ranks second in maize yield among Sub-Saharan African countries, surpassed only by South Africa (Asfaw et al., 2026).

In Ethiopia, maize has been grown as one of the most important staple food crops in the mid-lands and lowlands, ranking first in total production and productivity among all cereals, surpassing indigenous staples such as teff, wheat, and sorghum (Ethiopian Statistics Service, 2022; Shiferaw *et al.,* 2011). The crop has immense value in the social and food habits of the Ethiopian people, being utilised for preparing various traditional foodstuffs such as *injera*, porridge (*genfo*), bread, and local beverages. Ideally, the crop is cultivated across a wide range of agro-ecologies, from the moisture-stressed Rift Valley to the humid western highlands. However, maize productivity in the country (approx. 4 t ha^{-1}) remains lower than the global average of 5.78 t ha^{-1} and the crop's genetic potential (Diro & Yadesa, 2022). This yield gap is attributed to a complex matrix of biotic and abiotic factors, including low soil fertility, erratic rainfall, and pest pressure.

Of the various biotic constraints, viral diseases have historically been considered less economically damaging than fungal diseases like Grey Leaf Spot (*Cercospora zeae-maydis*) or Turcicum Leaf Blight (*Exserohilum turcicum*) (Legesse *et al*., 2012). This perception changed drastically with the emergence of Maize Lethal Necrosis Disease (MLND). MLND is a serious disease of maize causing severe symptoms, such as leaf necrosis, premature ageing, small cobs, and even plant death, which dramatically reduce maize (corn) yield (Zhan et al., 2022; Johnmark et al., 2022). First identified in Kansas, USA, in 1976 (Niblett and Claflin, 1978), the disease remained a localised problem in the Americas for decades. However, in 2011, it emerged as a continental epidemic in Kenya (Wangai *et al.,* 2012) and subsequently in Ethiopia in 2014 (Bekele *et al.,* 2017; Mahuku *et al.,* 2015). As detailed by Mekureyaw (2017) and Diro and Yadesa (2022), the disease was first reported in the Upper Awash Valley, causing 100% yield loss before spreading to Oromia, Amhara, Benishangul-Gumuz, SNNP, and Tigray regions (Fig. 1).

MLND is biologically unique because it is caused by the synergistic interaction of two viruses: *Maize chlorotic mottle virus* (MCMV) and a potyvirus, typically *Sugarcane mosaic virus* (SCMV). Recent metagenomic studies in East Africa have also identified other viruses in the MLN complex, including *Maize streak virus* (MSV), *Maize yellow mosaic virus* (MaYMV), and *Maize-associated totivirus* (MATV) (Jiao *et al.,* 2022; Tonui *et al.,* 2020). In Ethiopia, despite the critical economic importance of maize, most smallholder farmers lack fundamental knowledge regarding the survival mechanisms of the viral pathogens, the modes of insect vector transmission, and the specific environmental factors that favour epidemics. Consequently, the management of MLND remains reactive rather than preventive.

While scholars have conducted valuable epidemiological research, including Regassa *et al.* (2021), Bekele *et al.* (2017) and Mengesha *et al. (*2017), these findings are often fragmented across various journals and technical reports. There is an urgent need to synthesise these disparate datasets into a holistic framework that guides sustainable production. This review was undertaken to bridge this information gap. It is designed to benefit a wide range of end-users: researchers will identify critical gaps for future molecular breeding; agricultural extension agents will gain a consolidated evidence base to formulate robust management packages; and policy-makers will find data to support strengthened quarantine and seed certification protocols. Ultimately, this synthesis aims to translate complex virological data into actionable strategies that safeguard the livelihoods of millions of maize-dependent households in Ethiopia.

The Objectives of the review are – To 1) assess the economic impact and yield losses attributed to MLND in the Ethiopian context; 2) elucidate the biology and synergistic mechanisms of the causative pathogens—Maize chlorotic mottle virus (MCMV) and Sugarcane mosaic virus (SCMV); 3) examine the epidemiological drivers of the disease, with an emphasis on vector dynamics and alternative host reservoirs; and 4) synthesize sustainable management strategies.

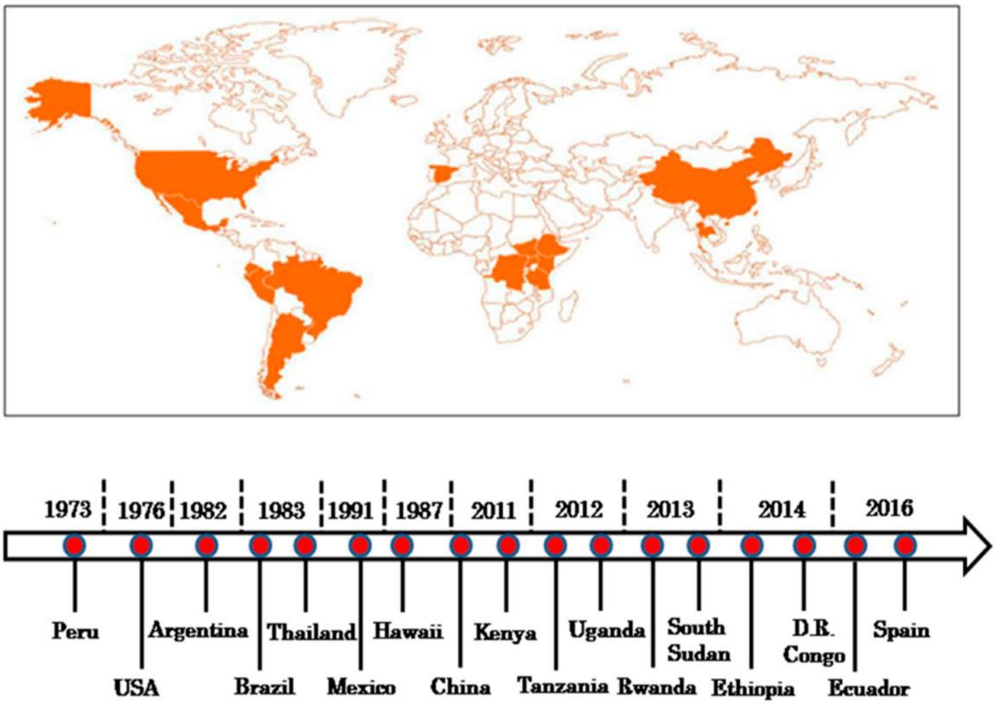

Fig. 1. Chronological and geographical distribution of Maize Lethal Necrosis Disease. (A) Global spread from USA (1976) to China (2009) and East Africa (2011). (B) Map of Ethiopia showing initial outbreak zones in the Rift Valley and subsequent spread to the Western Highlands. Source: Adapted from Mahuku et al. (2015) and Diro and Yadesa (2022)

2. Biology and Ecological Requirements for Maize Production

2.1 Biology of Maize

Maize (*Zea mays* L.) belongs to the tribe *Maydeae of* the grass family *Poaceae.* It is a tall, robust, monoecious annual grass, a biological trait that distinguishes it from other cereals. Unlike barley or wheat, which have a spike inflorescence, maize has separate male and female inflorescences on the same plant; the male inflorescence (tassel) produces pollen, while the female inflorescence (ear) produces the grain (Fig. 2). This biological feature makes maize highly cross-pollinated, which has profound implications for breeding and the maintenance of genetic purity (Diro & Yadesa, 2022). The biology of the maize plant, specifically its broad leaves and succulent stem with a high sugar content, makes it highly attractive to sap-sucking insects like aphids and thrips. These insects find refuge in the leaf whorls and leaf sheaths, which are the primary feeding sites and, consequently, the sites of viral inoculation (Kusia *et al*., 2015).

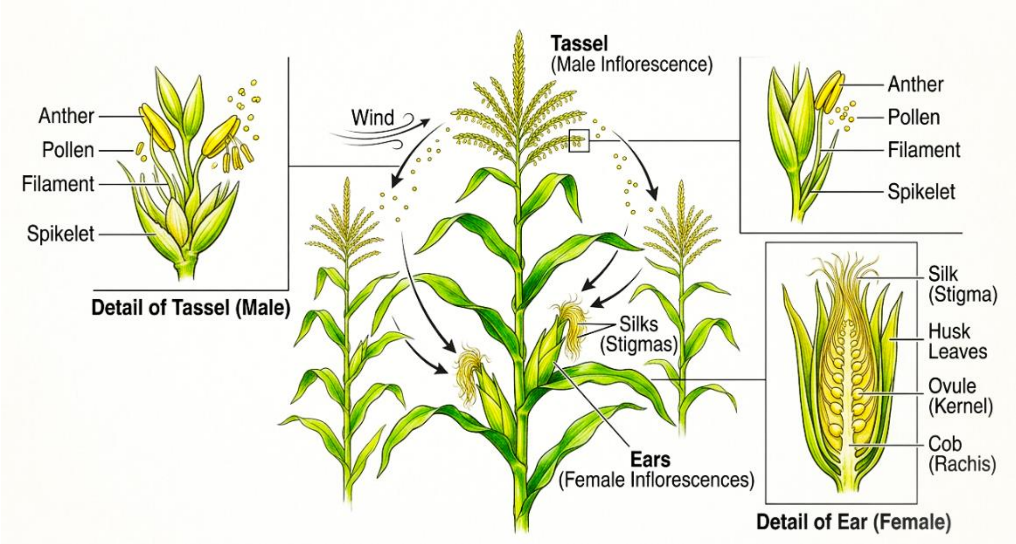

Fig. 2. Reproductive anatomy of the maize plant (*Zea mays* L.) illustrating the separate male (tassel) and female (ear) inflorescences that facilitate high cross-pollination. Source: Adapted from Purseglove (1972) and Ritchie *et al.* (1993)

2.2 Ecological Requirements and Vector Favorability

Maize is a versatile crop, but has specific ecological requirements that inadvertently overlap with the optimal conditions for MLND vectors. It grows best in warm climates with temperatures ranging from 20°C to 30°C. In Ethiopia, it is predominantly grown at altitudes ranging from 1,000 to 2,400 meters above sea level (m.a.s.l), requiring 500 to 1200 mm of well-distributed rainfall during the growing season (Diro & Yadesa, 2022). The major maize-producing regions in the country include Oromia, Amhara, and the Southern Nations, Nationalities, and Peoples' Region (SNNP). However, the ecological conditions that favour maize, particularly the warm temperatures of the Rift Valley and the continuous cropping seasons permitted by bimodal rainfall (Belg and Meher seasons) or irrigation, also favour the reproduction of insect vectors.

Epidemiologically, the Ethiopian context presents unique challenges. While early literature focused on beetle transmission, the primary drivers in East Africa are *Frankliniella williamsi* (thrips) and *Rhopalosiphum maidis* (aphids) (Kusia *et al.,* 2015; Redinbaugh & Stewart, 2004). The presence of maize year-round, particularly during the off-season under irrigation, creates a "green bridge" that sustains these vector populations. During dry periods, irrigated maize may be the only green vegetation available, attracting high concentrations of thrips and aphids from surrounding desiccated vegetation (Diro & Yadesa, 2022). Warm soil and air temperatures shorten the life cycle of these vectors, exponentially increasing the rate of viral transmission (Zhan *et al.,* 2022; Mengesha *et al.,* 2017). Furthermore, climate change models suggest that elevated temperatures may negatively affect plant antiviral responses, such as RNA silencing, while simultaneously increasing vector reproduction rates, thereby exacerbating MLN outbreaks (Kiruwa *et al*., 2010).

3. Economic Importance of Maize Lethal Necrosis Disease

3.1 Yield and Economic Losses

Viral diseases, unlike fungal leaf spots, which reduce photosynthetic area through localised lesions, often attack the systemic machinery of the plant. Chlorotic mottling, severe systemic necrosis, and “dead heart” symptoms characterise MLND, leading to total plant death. Consequently, MLND causes yield losses ranging from 50% to

100%, far exceeding the 20-30% losses typically associated with fungal diseases (Wangai *et al*., 2012; De Groote *et al.,* 2016). The timing of infection is the critical determinant of loss; if infection occurs at the seedling stage (V2 to V6), the loss is total (100%), as the plant produces no cob and often dies before tasseling (Fig. 3).

Late infection leads to "chaffy" cobs with shrivelled, poor-quality grain that is often unmarketable due to malformation and reduced seed set (Diro & Yadesa, 2022).

In Kenya, the 2012 epidemic resulted in an estimated direct financial loss of $52 million USD in a single season (De Groote *et al.,* 2016). In Ethiopia, following the 2014 outbreak, yield losses in the Upper Awash and West Gojjam zones were catastrophic for smallholder farmers. A field survey conducted by Bekele *et al*. (2017) in major maize-growing belts of Ethiopia confirmed incidence levels of up to 100% in susceptible varieties in the Rift Valley, East Shewa, West Wollega, and Kamashi zones. Similarly, Mekureyaw (2017) reported that farms in the Upper Awash basin experienced total crop failure, forcing farmers to abandon maize for other crops like vegetables or pulses. According to Demissie *et al*. (2016), yield losses were highest in the SNNP region (65%), followed by Oromia (50%) and Benishangul Gumuz (45%). Recent simulations predict that MLN can cause up to 73% grain loss for susceptible varieties under current climatic conditions (Kiruwa *et al.,* 2010). This level of loss devastates household food security, forcing farmers to purchase food at inflated prices.

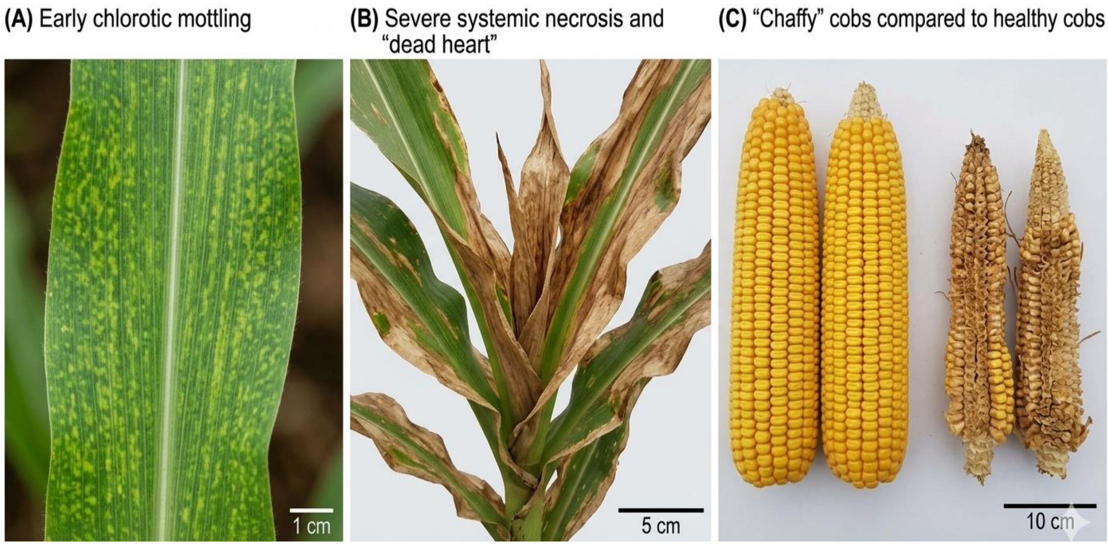

Fig. 3. Symptomatology of MLND at different growth stages. Source: Wangai et al. (2012)

3.2 Geographical Distribution

Maize Lethal Necrosis Disease is caused by the synergistic infection of MCMV and one of several cereal-infecting potyviruses. While the associated viruses in the *Potyviridae* family are ubiquitous worldwide, different species predominate in different geographical regions. *Sugarcane mosaic virus* (SCMV) is found globally, while *Maize dwarf mosaic virus* (MDMV) is distributed widely in Europe and the United States (Mahuku *et al.,* 2015; Redinbaugh & Stewart, 2004). In the African context, although *Johnsongrass mosaic virus* (JGMV) and MDMV are present, SCMV is the predominant potyvirus associated with the disease (Wangai *et al.,* 2012; Mahuku *et al*., 2015).

Since SCMV and MDMV are widely distributed, the geographical expansion of MCMV is the crucial factor for the occurrence of MLND. MCMV was first identified in Peru in 1971 (Castillo and Hebert, 1974). The first outbreak of MLND occurred in Kansas, United States, in 1976 (Niblett and Claflin, 1978). In recent years, the disease has emerged as a major threat in Asia and Africa. In 2009, MCMV was detected in the Yunnan Province of China, inducing MLND through co-infection with SCMV (Xie *et al.,* 2011). The first outbreak of MLND on the African continent was reported in 2011 in Kenya (Wangai *et al.,* 2012). Currently, MLND has been identified across several African countries, stretching from Ethiopia in the north to Tanzania in the south (Diro

& Yadesa, 2022; Mahuku *et al.,* 2015). In Ethiopia, the disease is highly prevalent in Amhara, Benishangul-Gumuz, Oromia, SNNP, and Tigray regions, with prevalence rates reaching over 80% (Demissie *et al.,* 2016).

4. Biology of the Pathogens and Viral Synergism

4.1 The Causative Viruses

The aetiology of Maize Lethal Necrosis Disease (MLND) is biologically distinct because it is not caused by a single pathogen but is the result of a complex viral synergism. The disease is driven by the co-infection of two taxonomically distinct RNA viruses: *Maize chlorotic mottle virus* (MCMV) and a member of the family *Potyviridae*, predominantly *Sugarcane mosaic virus* (SCMV) in the Ethiopian context (Bekele *et al.,* 2017; Mekureyaw, 2017).

MCMV acts as the primary driver of this complex. It is the type species of the genus *Machlomovirus* within the family *Tombusviridae*. MCMV virions are non-enveloped, isometric (spherical) particles measuring approximately 30 nm in diameter. The genome is a single-stranded, positive-sense RNA (+ssRNA) of approximately 4.4 kb (Jiao *et al*., 2022; Adams *et al.,* 2013). Phylogenetic analyses of East African isolates, including those from Ethiopia, revealed that they share >99% nucleotide identity with the "Yunnan" strain from China, distinguishing them from older American isolates. This genetic uniformity suggests a recent, single introduction event of MCMV into East Africa, likely via contaminated seed or trade (Mahuku *et al*., 2015; Adams *et al.,* 2013).

The co-infecting partner is SCMV, a member of the genus *Potyvirus*. Unlike MCMV, SCMV virions are flexuous filaments, 700-750 nm in length, containing a significantly larger genome (~10 kb) (Fig. 4). SCMV is endemic to Ethiopia and is widespread in maize and sorghum fields, often causing mild mosaic symptoms that local maize varieties tolerate well (Bekele *et al.*, 2017). The presence of this endemic virus essentially "primed" the Ethiopian maize agro-ecology for the MLND epidemic once the exotic MCMV was introduced.

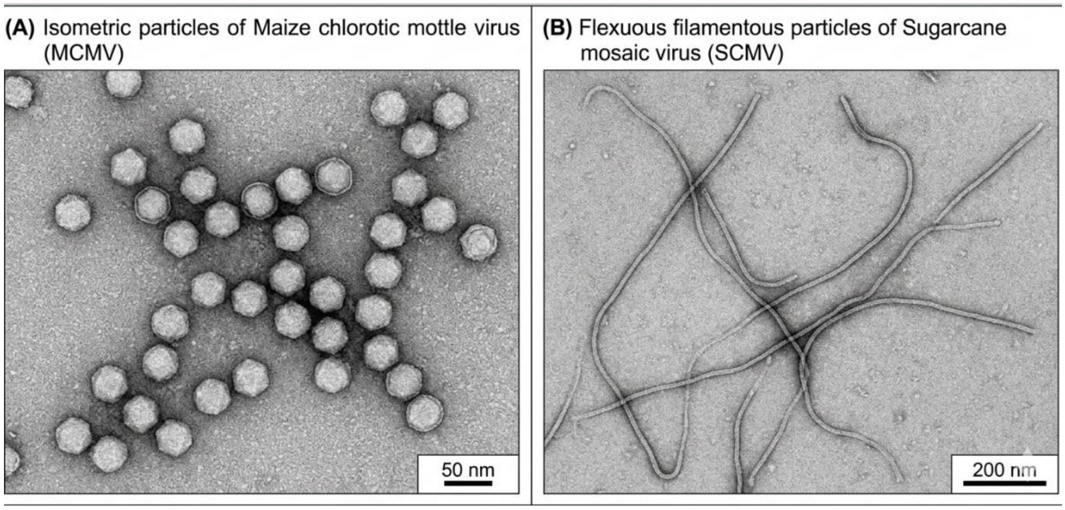

Fig. 4. Electron micrographs showing the morphology of the causative agents. Source: Adams et al. (2013)

4.2 Molecular Mechanism of Synergism

The biological basis of the MLND epidemic in Ethiopia is fundamentally rooted in the "unilateral synergism" between MCMV and SCMV. While MCMV acts as the spark, the "lethal" phenotype of MLND is triggered only when it co-infects a host already harbouring a potyvirus. The interaction is a classic example of unilateral synergism, where the presence of the potyvirus facilitates the hyper-accumulation of MCMV, while the titer of the potyvirus itself remains relatively unchanged (Jiao *et al.,* 2022; Xia *et al.,* 2016).

The molecular mechanism underlying this lethality is centred on the suppression of the host plant's innate immune system, specifically RNA silencing (Post-Transcriptional Gene Silencing, PTGS) (Fig. 5). Maize plants naturally produce small interfering RNAs (siRNAs) to degrade viral RNA via the Dicer-like (DCL) and Argonaute (AGO) protein pathways. However, potyviruses like SCMV encode a multifunctional protein known as the Helper Component-Proteinase (HC-Pro). HC-Pro acts as a powerful viral suppressor of RNA silencing (VSR) by binding to siRNAs or interfering with the plant's Argonaute proteins, effectively "blinding" the plant's immune system (Jiao *et al.,* 2022; Redinbaugh & Stewart, 2004).

In a mixed infection, the SCMV-derived HC-Pro suppresses the maize defence machinery not only for itself but also for the co-infecting MCMV. In this immunocompromised environment, MCMV replicates to titers 10 to 50 times higher than in a single infection (Jiao *et al.,* 2022; Xia *et al.,* 2016). This explosive viral replication leads to the massive destruction of chloroplasts and cellular integrity, manifesting as systemic necrosis and premature death.

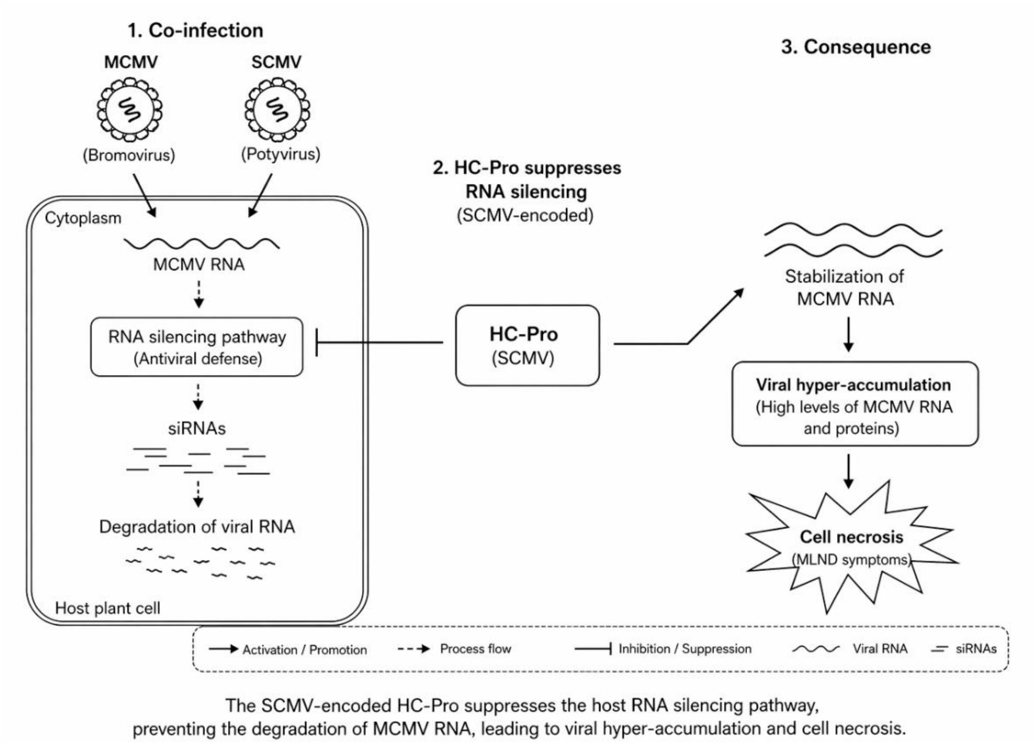

Fig. 5. Schematic representation of the molecular mechanism of viral synergism. The diagram illustrates how SCMV-encoded HC-Pro suppresses the host RNA silencing pathway, preventing the degradation of MCMV RNA, leading to viral hyper-accumulation and cell necrosis. Adapted from Xia et al. (2016)

5. Epidemiology of Mlnd

5.1 Transmission Vectors

The primary driver of the MLND epidemic is vector-mediated transmission, illustrated in the epidemiological cycle (Fig. 6). MCMV is transmitted in a semi-persistent manner by thrips (Order: Thysanoptera). In the Ethiopian context, Kusia *et al.* (2015) identified the maize thrips, *Frankliniella williamsi*, as the predominant and most efficient vector in the Central Rift Valley. Unlike transient vectors, *F. williamsi* can acquire the virus after feeding on an infected plant for just 3 hours and can remain infectious for up to six days.

Zhan *et al.* (2022) highlighted that *F. williamsi* exhibits cryptic feeding behaviour, preferring to hide deep within the leaf whorls. This behaviour facilitates efficient viral transmission into the most metabolically active tissues and protects the thrips from contact insecticides. Simultaneously, SCMV is transmitted in a non-persistent (stylet-borne) manner by various aphid species, most notably the corn leaf aphid, *Rhopalosiphum maidis*. Aphids can acquire the virus within seconds of probing and transmit it to a healthy plant just as quickly (Redinbaugh & Stewart, 2004).

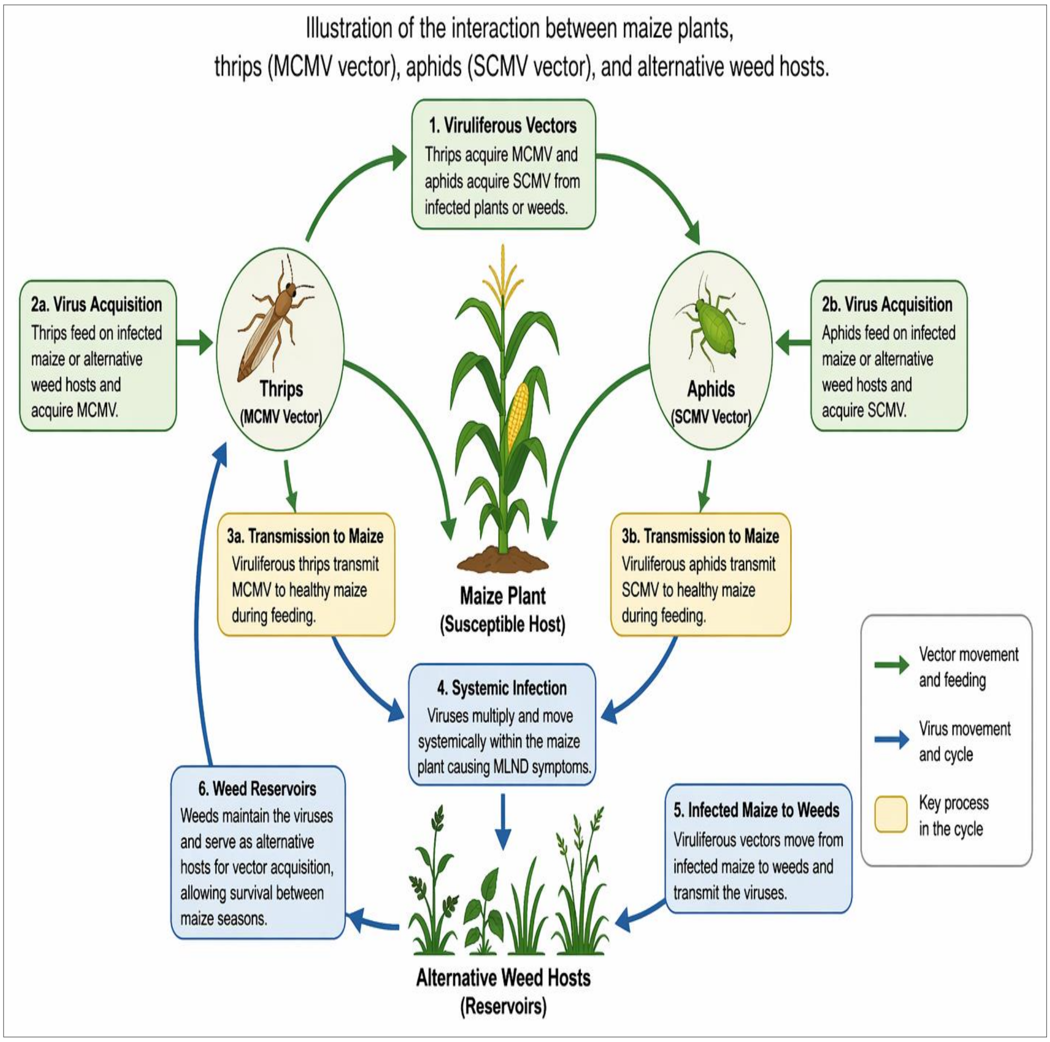

Fig. 6. The MLND Epidemiology Cycle. Illustration of the interaction between maize plants, thrips (MCMV vector), aphids (SCMV vector), and alternative weed hosts. Adopted from Redinbaugh and Stewart (2004)

5.2 Seed Transmission

Recent and rigorous investigations in the East African context have redefined the risk of seed transmission. Bekele *et al.* (2017) detected MCMV in commercial seed lots in Ethiopia, with transmission rates as high as 6.5% in some samples. While percentages may appear low, a transmission rate of just 0.1% results in roughly 50 infected seedlings per hectare, acting as primary inoculum sources or "patient zero" (Redinbaugh & Stewart, 2004). Consequently, seed transmission is now recognised as the primary mechanism for the long-distance dissemination of MLND into virgin fields, while vectors drive the localised explosive spread.

5.3 Alternative Hosts (Green Bridge)

Surveys by Bekele *et al.* (2015) and Regassa *et al.* (2021) established a distinct inverse correlation between altitude and disease severity, with pressure highest in low to mid-altitude zones (1,000 to 1,800 m.a.s.l). Crucial to the persistence of MLND is the "green bridge" effect provided by alternative hosts. In Ethiopia, identified reservoirs include Johnsongrass (*Sorghum halepense*), Napier grass (*Pennisetum purpureum*), and broadleaf weeds like *Commelina benghalensis* (Regassa *et al*., 2021). These hosts ensure that viruliferous vectors are present to initiate the epidemic cycle when new maize seedlings emerge.

6. Management Options

6.1 Cultural Practices and Phytosanitation

Sustainable mitigation requires a holistic Integrated Disease Management (IDM) approach (Diro & Yadesa, 2022; Adams *et al.,* 2013). This is visualised in the IDM pyramid (Fig. 7). Effective strategies for mitigating the impact of Maize Lethal Necrosis Disease focus on disrupting the viral life cycle and reducing vector density through rigorous cultural practices. One of the most successful methods is crop rotation, which involves alternating maize cultivation with non-host crops such as legumes or tubers to effectively deprive the viruses of a reproductive host (Diro & Yadesa, 2022). Additionally, the implementation of a synchronised maize-free window, or a community-based "closed season," serves to starve vector populations by ensuring no susceptible host tissue is available in the landscape for a set period (Wangai *et al.,* 2012). Comprehensive weed management is also critical, particularly the targeting of alternative reservoirs like *Commelina* and *Cyperus* species; in fact, research by Mengesha *et al.* (2017) demonstrated that the strategic combination of hand weeding and insecticide application could reduce disease severity by over 60%.

6.2 Host Plant Resistance

Host plant resistance forms the top tier of the IDM pyramid. Initial screening revealed that most commercial Ethiopian varieties, such as BH-660 and Melkassa-2, were highly susceptible (Bekele *et al.,* 2017; Regassa *et al*., 2021). However, tolerant inbred lines (e.g., CML444) are being used to develop second-generation hybrids (Bekele *et al.,* 2017). Molecular breeding using Marker-Assisted Selection (MAS) is now targeting major resistance loci like *Scmv1* and *Scmv2* on chromosomes 6 and 3 (Jiao *et al.,* 2022; Redinbaugh & Stewart, 2004).

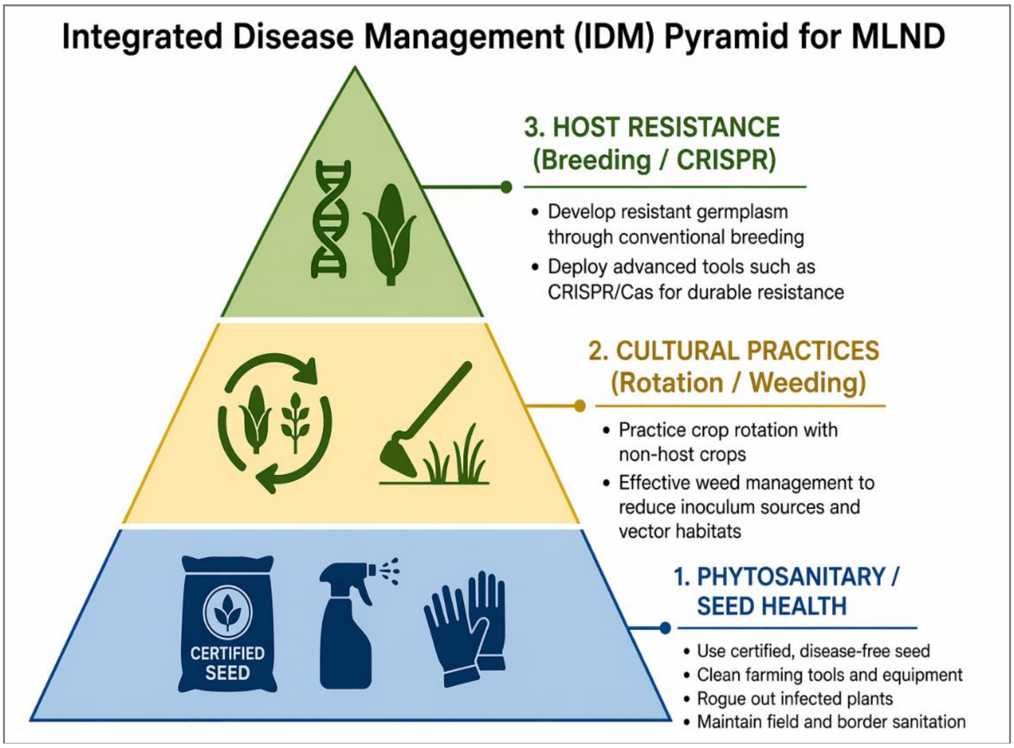

Fig. 7. Integrated Disease Management (IDM) Pyramid for MLND. Base: Phytosanitary/Seed Health. Middle: Cultural Practices (Rotation/Weeding). Top: Host Resistance (Breeding/CRISPR). Source: Adapted from Prasanna (2014)

6.3 Chemical Protection

The most effective chemical intervention is systemic seed treatment with neonicotinoids (e.g., imidacloprid), providing protection for the first 3 to 6 weeks when plants are most vulnerable (Redinbaugh & Stewart, 2004).

Foliar applications are less effective against thrips due to their cryptic behaviour, but can provide a significant advantage when combined with cultural practices (Mengesha et al., 2017; Zhan et al., 2022).

7. Conclusion

The emergence of Maize Lethal Necrosis Disease (MLND) represents the most significant phytosanitary threat to maize-based food security in Ethiopia since the crop's introduction in the 16th century. This review establishes that the "lethal" nature of the disease is not the product of a single pathogen, but a profound unilateral synergism where *Sugarcane mosaic virus* (SCMV) effectively deactivates the host's RNA-silencing defence mechanism, triggering a catastrophic hyper-accumulation of *Maize chlorotic mottle virus* (MCMV). Epidemiologically, the Ethiopian Rift Valley and mid-altitude highlands provide an ideal incubator for the disease due to warm temperatures that accelerate the life cycles of key vectors, specifically thrips (*Frankliniella williamsi*) and aphids (*Rhopalosiphum maidis*). Furthermore, the discovery of non-Poaceae "green bridge" reservoirs, such as *Commelina benghalensis*, suggests that the viral inoculum is more resilient in the Ethiopian landscape than previously understood. While the initial emergence of the disease was rapid, the recovery of the maize sub-sector has been hindered by a reliance on highly susceptible commercial hybrids and a lack of integrated management at the smallholder level. Ultimately, if left unmanaged, MLND has the potential to permanently shift farmers away from maize toward less productive alternative crops, thereby undermining national food sovereignty.

8. Limitations

This review has several limitations that include the fact that most of the available literature on MLND in Ethiopia is geographically concentrated in major maize-producing regions, potentially limiting the generalizability of the findings to all agro-ecological zones of the country. The review also depended heavily on studies conducted under controlled experimental conditions, which may not fully reflect the realities faced by smallholder farmers under field conditions.

9. Recommendations

To safeguard the future of maize production in Ethiopia, a multi-pronged, science-led strategy is required that prioritises molecular breeding and rigorous systemic adjustments. The Institute of Agricultural Research found in the country in regional and large national level should prioritize the introgression of the $Scmv1$ and $Scmv2$ resistance loci into elite Ethiopian parent lines using Marker-Assisted Selection (MAS) to shorten the breeding cycle for resistant hybrids. Parallel to breeding efforts, there is an urgent requirement for mandatory molecular screening, including the use of RT-PCR or RT-LAMP, for MCMV in all commercial seed lots before distribution, as seed transmission remains the primary mechanism for long-distance dissemination.

At the field level, extension services must facilitate the adoption of a synchronised maize-free window at the *woreda* level, implementing a minimum two-month period where no maize is grown under irrigation to effectively break the vector life cycle and reduce the environmental viral load. Farmers should also be encouraged to adopt an integrated management package consisting of early-season systemic seed treatments with neonicotinoids and aggressive control of both grassy and broadleaf weeds, specifically *Commelina* and *Cyperus* species, to eliminate "green bridge" hosts. Finally, the establishment of a national MLND surveillance database using GIS mapping is recommended to allow for the prediction of outbreaks based on climatic shifts and vector population spikes, moving the national response from a reactive to a preventive posture.

Disclaimer (Artificial Intelligence)

The author (s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Author has declared that no competing interests exist.

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