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Status, Prevalence and Management of Maize (*Zea mays L.*) Lethal Necrosis Disease in Ethiopia: A Review

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Abstract: The most important and the first rank crop in production and productivity in Ethiopia is maize which is also the second-largest crop in terms of area coverage after teff. However, viral infections that were introduced during the 2013/2014 growing season in the area of the Upper Awash Valley are severely limiting its productivity in Ethiopia. Later the virus was identified as Maize Lethal Necrosis Disease (MLND); this disease can induce varying degrees of harm, from a low infection rate to a complete crop failure. The disease is highly prevalent in Ethiopia's main maize-producing provinces, including the Amhara, Benishangul-Gumuz, Oromia, Southern Nation, Nationality and Peoples (SNNP), and Tigray regions. In contrast to the main growing season, the disease pressure was greatest during the off-season, due to maize grown under irrigation is probable the only green plant in the area, it attracts a lot of insects and provides a better environment for their migration and reproduction, which speeds up the spread of viruses that cause MLN. Four years of data on MLN prevalence showed a general decrease in the disease's prevalence from 2015 to 2018. The yields were devastated; as the infected plants frequently produced no seed at all, undersized or malformed ears, or both. The factors responsible for the spread of MLND are vectors, infected soil, and infected seed. Some of the management options used to manage MLND are: using clean Seed and non infected soil, host resistant, control vectors of the virus, and Integrated Disease Management.

Keywords: Maize Lethal Necrosis, MCMV, Prevalence, SCMV, Status

1. Introduction

Maize (*Zea mays* L.) is an adaptable crop with greater genetic variability that can thrive in tropical, subtropical, and temperate agro climatic environments all over the world. In Sub-Saharan Africa, it is a crucial part of agricultural systems and a staple food crop [34]. It is widely consumed in Africa by both animals and humans with a wide range of socioeconomic status and dietary preferences. Since the native people can quickly become used to its taste, it is replacing traditional starchy food like cassava. Additionally, this crop is necessary to feed nations with low income [41].

Special attention should be paid to maize's nutritional value. Given that it provides billions of people worldwide, especially in Africa, South America, and Asia, with essential sources of proteins, calories, and some crucial vitamins and minerals, it has been termed a poor family nutrient cereal [42]. When it comes to production yield, distribution, and adaptability, maize dominates Ethiopia's cereal crops. With a total annual production of 10.6 million tons, the crop is produced on 2.3 million hectares (17.7% of the total area given to cereals), and a second next to teff (Eragrostis tef) in terms of area covered but first in terms of productivity (4.7 t ha1) [11]. Wegulo SN, tated that the Western, Southern, Southwestern, Eastern, as well as some Northwestern, are the main production areas of the country [60]. Despite the importance of maize as a crucial crop for food security, Ethiopia's average yield of 4.179 t/ha [11] is still below the global average of 5.78 t/ha [17].

An important portion of this yield difference can be attributed to biotic and abiotic factors and the poor use of varieties that are tolerant to or resistant to these factors [1]. Insect pests like maize weevils, stem borers, and fall armyworms, diseases like Gray leaf spot (GLS), Turcicum leaf blight (TLB), Common leaf rust (CLR), Maize streak disease (MSD), Maize lethal necrosis (MLN), Gibberella ear rot (GER), Fusarium ear rot (FER), and Striga parasitic weed are among the major biotic stresses that have been identified [26, 50]. Since 2014 cropping season, the production of maize in Ethiopia has also been threatened by the disease known as Maize Lethal Necrosis Disease (MLND), which is brought on by a concurrent infection of the maize Chlorotic mottle virus (MCMV) and the cereal Potyvirus [7, 14, 45] The disease was initially reported in the Rift Valley area of Ethiopia and it is a devastating viral disease that is widely spreading in the country [45].

Domestic regulation that can be used to stop the movement of maize products from diseased areas to disease-free regions, cultural control strategies like closed seasons, crop rotation, and crop diversification, vector control using seed treatment followed by foliar sprays, host-plant resistance, and integrated pest management techniques are all component of the most effective method of controlling MLND [43]. The objective of this review is to explore the status, prevalence and management of maize lethal necrosis disease in Ethiopia.

1.1. Some Importance of Maize Crop

Maize is a crop with numerous uses, including those for food, medicine, pharmaceuticals, industry, and other purposes. Thus, it is utilized to relieve human hunger [6, 13] Protein, crude fiber, ether extract, and carbohydrates are all present in maize's nutritional value. It contributes a significant amount of energy to both human and animal diets [3]. The author also stated that, despite lacking some essential amino acids like lysine and tryptophan, maize serves as a source of amino acids for the body. According to research by [15], selenium found in maize stimulates the thyroid gland and boosts human immunity. According to [40], maize silk has been used as a source of therapy materials in herbal medicine.

1.2. Historical Perspective of Maize Lethal Necrosis Disease (MLND)

Maize Chlorotic Mottle Virus (MCMV) and any number of viruses in the Potyviridae group, such as the Sugarcane Mosaic Virus (SCMV), Wheat Streak Mosaic Virus (WSMV), or Maize Dwarf Mosaic Virus, combine to infect maize, causing Maize Lethal Necrosis Disease (MLND) (MDMV). The double infection of the two viruses, resulting in MLND, also known as Corn Lethal Necrosis (CLN). It was firstly reported in Peru [20], states of Kansas, USA [38], Argentina [49], Mexico [18], China [61]. Similar to this, the disease was found on the African continent in Kenya in 2012 [56], then in Rwanda [2], and in the Democratic Republic of the Congo (DRC) [31]. Similar to a pattern observed in Ethiopia in 2014, cropping seasons have resulted in varying degrees of damage to some maize fields in the rift valley area of East Shewa Zone in Oromia Region, ranging from a low infection rate to complete crop failure [32, 14, 45].

1.3. Economic Importance of MLND and Maize Yield Loss

According to what was previously stated, MCMV was initially identified in Peru in 1973 (Hebert and Castillo, 1973), where losses in types of floury and sweet maize ranged from 10 to 15%. Depending on the maize varieties and the year, crop losses in Kansas because Maize Lethal Necrosis were reported to range from 50% to 90% [38, 54]. Because it might lead to severe to full yield loss, MLND faced a significant challenge to the production of maize in East Africa [56]. Farmers in Kenya suffered significant or total crop loss in regions where MLND was quite severe [57]. The diseased plants are typically barren; the developed ears are small, malformed, and produce no seeds, greatly lowering the yield. According to [24], the yield losses and infection rates were both significant during the recent outbreak in Kenya, reaching up to 100% in some cases. The disease's detrimental consequences are already noticeable at the national levels. Affected farmers have lost all of their crops on their individual farms. Because of concerns about fungal toxicity, livestock cannot consume the leftover leaves, which worsens the situation. Karanja *et al.,*'s results show that FAS/national Nairobi's estimations for the production years 2014/2015 indicate that the disease has devastated around 60,000 hectares [25].

Demissie *et al*., report that in Ethiopia's Upper Awash Valley in July 2014, maize plants with noticeable yellowing and chlorotic mottle symptoms were found [14]. According to some respondents, there were incidences of maize lethal necrosis symptoms in 2013, which equated to 15.12% of crops being damage. Prevalence grew to 65.1 and 80.7%, respectively, in 2014 and 2015. The SNNP region, followed by Oromia, Benishangul Gumuz, Tigray, and Amhara regions, had the highest yield loss, as the report stated. Additionally, according to the report, the average yield drop caused by MLND in SNNP, Oromia, Benishangul Gumuz, Tigray, and Amhara was 65%, 50%, 45%, 25%, and 15%, respectively. Keno *et at.,* also stated that maize lethal necrosis disease also has impacts, but on the other side, the cost of producing maize is rising as farmers employ herbicides and insecticides to manage weeds and insect vectors that spread the disease [27]. In addition, when seed producers pay more expenses for seed care, the cost of producing seeds likewise rises.

1.4. Distributional Status of Maize Lethal Necrosis Disease in Ethiopia

Since the first outbreak was detected in Ethiopia's Upper Awash valley in June 2014, the spread of Maize Lethal Necrosis (MLN) in the areas where maize is grown has accelerated. Later evaluations were carried out in Ethiopia's principal maize-growing regions, including the Amhara, Benishangul-Gumuz (BSG), Oromia, Southern Nation, Nationality and Peoples, and Tigray regions [14]. According to their findings, the prevalence rose to 65.1% and 80.7%, respectively, in 2014 and 2015. Bekele *et al.,* revealed that MLN disease was widespread in Ethiopia, by the fact that

MCMV was frequently identified in the majority of leaf and grain samples collected from the several assessment sites [7]. This implies that the necessity for efficient control measures to be implemented is being driven by the increasing prevalence of disease in the country. Additionally, the authors suggested that in contrast to the main growth season, the disease pressure were most significant during the off-season, due to maize grown under irrigation may be the only green plant in the area that draws many insects and offers a better environment for their migration and reproduction, which aids in the rapid spread of viruses that cause MLN. According to [26], the regular use of insecticides to manage the fall army worm, which has since 2017 become into a significant problem for the production of maize, may have indirectly managed insect vectors of MLN-causing viruses, greatly decreasing the disease's spread. Regassa *et at.,* Claim that MLN disease was prevalent throughout Ethiopia's major maize-growing areas particularly in the central, western, southern, and southwestern parts of the country [45]. However, their report on MLN prevalence over a four-year period indicated that the disease's prevalence generally decreased from 2015 to 2018. As a result of MLN awareness campaigns started throughout time by various government agencies and maize stakeholders, maize growers now have a greater understanding of MLN problems and its management.

1.5. Life Cycle and Mode of Spread of Maize Lethal Necrosis Disease

A carrier is necessary for the virus to transmit from plant to plant and from field to field, as is the case with many viruses. The lack of molecular machinery prevented plant viruses from replicating. They must therefore switch from infected to uninfected plants in order to survive; otherwise, they risk not doing so. Because of the thick cell walls of plants, viruses cannot enter and cause harm inside. For viruses to enter a body, there must be wounds caused by outside causes [58, 62].

Even though there are reports from other parts of the world, various insects were discovered in Ethiopian fields near the infected maize plants. In Ethiopia, however, insects are not examined for their capacity to spread MCMV and SCMV effectively. According to global experience, MCMV is mostly transmitted by beetles, rootworms, and thrips, as well as stem borers [21, 22]. In particular, [10] found that thrips transmit MCMV after acquisition times of 3h, with no clear indication of latent periods; both larvae and adults can continue to spread the virus for up to 6 days following acquisition. A number of species of aphids non-persistently transmit SCMV [62]. Mites persistently transmit the WSMV [28, 59]. Furthermore, it has been shown that infected soil and seeds can act as a reservoir for viruses and a mode of transmission [21, 48]. Prasanna *et al*., revealed that potyviruses that infect maize are frequently carried by both grass-eating and polyphagous species of aphids worldwide, as well as maize thrips, which are present in several maize crops each year, are a problem in every tropical and subtropical area where MCMV is a problem [43]. According to [32] seed transmission is epidemiologically significant even though it occurs at a low rate since maize is usually propagated by seed, which results in the introduction of virus into new areas through seed. According to [27], human activities like using supplies in infected fields without thoroughly washing them can spread disease-causing viruses from those fields to fields that are not infected. Since the virus may persist in plant residues, the virus may also spread through soil and through infected plant debris [39]. The incidence of viruses and their vectors is greatly increased by the practice of monoculture.

1.6. Host Range and Survival Mechanism of MLND

Weeds and other alternative natural hosts are used by plant viruses as a source of inoculum from which economically significant crop plants can catch the infection [55]. Likewise, [32] reported that some of the weed species that have been previously identified in Ethiopia as MCMV hosts are also members of the Poaceae family. Asala *et al*., revealed that these weeds allow viruses survive in the absence of their intended hosts and serve as a significant initial source of virus inoculum that can spread to other weed plants as well as the main host crops following harvesting seasons [4]. The presence of MLND was reported in numerous possible alternate host plants in Ethiopia, including Johnson grass, unidentified grass species, Digitaria sp., sedge grass, Setaria sp., and sugarcane. This shows that grass families are the most diverse hosts for viruses that cause MLND [7]. According to [44], the majority of the MCMV-inoculated grasses and sedges weeds showed positive reactions. The majority of these weed species are often and strongly linked to the maize crop, according to the authors, and they may play a significant epidemiological role as alternate hosts and viral reservoirs where the virus can survive in the absence of the maize crop. This reveals that disease manifestation and secondary cycles spread to alternate hosts (such as sorghum, millet, sugarcane, and Johnson grasses, etc.) and so sustain repeated cycles throughout the year with the help of vectors.

1.7. Infection and Symptom of MLND

According to [16], viruses enter plant hosts through wounds caused by insect vectors' feeding mechanism and mechanical damage since plant cells have a strong cell wall, which prevents viruses from penetrating them. When eating on a healthy plant, the feeding insect rapidly injects MLND-causing viruses. According to [62], aphids frequently transmit the Potyvirus in such "non persistent" relationships. Additionally, [51] stated that virus particles are injected into the wound at the feeding site when viruliferous beetles generate regurgitant layer on the leaves while they feed. The authors also stated that as the beetles feed, they deposit a layer of regurgitant, or pre-digestive substances, on the leaves. The viral protein sheath is disintegrated once inside the cell, and nucleic acid enters the nuclear membrane where it alters the machinery of the maize DNA to create an enormous number of copies of the original. For the purpose of mimicking the host maize DNA, RNA viruses, which are responsible for MLND, first convert their RNA to complementary DNA (cDNA). Viral particles migrate between cells through plasmadermata and throughout the entire maize plant through phloem once more copies have been created [16].

Chlorotic mottle, which alternates between light and dark green patches on the leaves and typically begins at the base of new leaves in the whorl and progresses upward toward the leaf tips, is one of the most common symptoms; likewise, mild to severe leaf mottling, dwarfing and early plant aging, necrosis of young leaves in the whorl before expansion resulting in the "dead heart" symptom, and drying up of the entire plant are some of the symptoms [37, 33, 56]. According to [14] assessment in Ethiopia, their report revealed that decaying, bad-smelling, yellowing, wilting, and eventually drying of leaves was observed), failure to tassel and sterility in male plants, malformed or no ears, and premature aging of the plants; similarly, those plants affected after silking had problem with seed setting. According to [12], infected plants display a variety of symptoms depending on the variety, the number of viruses attacking the plant at a given time, the part of the plant affected, the timing of infection, and the local ecological conditions. Beyene *et al.,* stated that maize plants are susceptible to MLN disease from the seedling stage through the maturation stage [8]. A mature plant may eventually die towards the end of the season, usually from the top down, as leaves begin to die inward from the margins [56]. Due to misinterpretation of some symptoms, symptoms brought on by unfavorable environmental conditions, pest damage, air pollution, herbicide applications, late planting season, a lack of nutrients, and other infections by non-viral pathogens, confirmatory tests must be performed to ensure accurate diagnosis [14]. Additionally, different viruses can cause the same symptoms in a plant, and viruses might infect a plant without causing any symptoms [58, 30].

2. Management Options

2.1. Cultural Practices and Crop Rotation

Infected plants served as a bridge between different cropping seasons due to the maize crop's year-round presence in the field, which created a suitable environment for the preservation of insect vectors and MLN causative viruses [45]. According to [53], MLN disease intensity is typically lower in areas that were planted with crops other than maize the previous year. According to [24], poor weed control techniques may have given alternate hosts to MCMV and SCMV. Eliminating alternative hosts for a potential development of insect vectors and viral load by proper field hygiene, such as effective weed management, helps reduce MLN [57, 23]). Similarly, [19] reported that the lower weed infestation led to the lower MLN severity because hand weeding practices showed high disturbance of alternate hosts and may have preventable effects on disease development and insect infestations, which helped the crop be robust and resistant to disease suppression.

2.2. Chemical Control

Using chemical protects maize from invasive viruses. It can be used to get rid of the MLND viruses' vectors of spread and transmission, but the method is unable to control the viruses themselves. There are a number of pesticides that can be used as spray treatments or as granule preparations to combat MLND vectors such aphids, rootworms, stem borers, mites, and thrips. There are a number of pesticides that can be used to control MLND vectors such aphids, rootworms, stem borers, mites, and thrips, either as spray treatments or as granules. Imidacloprid, Thiamethoxam, Deltamethrin, Abamectin, Permethrin, Endosalphan, and Dimethoate are a few of these pesticides [52]. In order to effectively control vectors, [36] noted that the proper insecticides need to be sprayed once every one to two weeks, and there should be a rotation of different chemicals every month to prevent the target vector from developing immunity. Additionally, [56] found that alternative methods exist for enhancing plants' resistance to pests and disease, including the application of manure, basal fertilizers, and top-dressing fertilizers. In Ethiopia, pesticides can be used to control the vectors, much like in other country. Diazinon 60% EC (1-1.5 lit/ha), Malathion 50% EC (2 lit/ha), and Lambda-cyhalothrin 5% (0.2-0.4 lit/ha) are a few examples of the pesticides that are readily available [29]. Likewise, [47] stated that controlling MLND vectors requires the use of insecticides with systemic, Imidacloprid (Tata mida 200SL) and contact, Lambda-cyhalothrin (Lambda-cyholothrin Duduthrin 1.7 EC), modes of action.

2.3. Host-Plant Resistance

The most durable method of controlling the MLN disease is assuredly the deployment of resistant or tolerant maize varieties [9]. Likewise, it is economically feasible and ecologically sound. It does, however, call for the revelation of disease-resistant genotypes and their integration into agronomically appealing variety or promotion of such genotypes for immediate commercial application [28]. According to [46], plant defense mechanisms against viruses may be mediated by resistance genes that manifest as complete or extreme resistance, and virus replication may be slowed down or rendered undetectable in infected cells. Furthermore, the authors also suggested that genes that are favorable for MLN resistance may be expressed in genotypes that exhibited a resistant reaction and limited development of disease symptoms.

2.4. Integrated Pest Management Practices

Because there is no one way to effectively address MLN, it is crucial to do research to create integrated management solutions. The removal of volunteer plants and alternate hosts, as well as the use of virus-free seeds and seeds treated with insecticides for vector management, are a some of these measures. Only when the seed coat mechanically damages the germination plumule does seed transfer take place. Masuka *et al.,* revealed that since a virus can be introduced to a new area through seed and then spread by insect vectors, resulting in a large number of infected plants, epidemiologically speaking, this low rate of transmission is significant [35]. The most effective management strategy for MLN, according to [5, 57], included integrated approaches that included cultural practices, insecticidal treatment of insect vectors, biological control, and resistant genotypes. In agreement with this, [19] showed that hand weeding followed by pesticide spraying once more resulted in the greatest values of growth and yield-related measures measured when compared to other treatments. The commercial cultivation of a virus-free maize crop may benefit from rigorous integrated insect pest and cultural control approaches [32]. In a similar manner, [45] found that planting maize at the beginning of the main rainy season, removing weeds and other potential host plants that can act as a reservoir for viruses and insect vectors, rotating crops with alternative non-cereal crops, and using tolerant/resistant varieties are all things that should be taken into account when designing MLN disease management strategies.

3. Summary and Conclusion

Maize leads Ethiopia's cereal crops in terms of yield, distribution, and adaptability. Produced on 2.3 million hectares (17.7% of the total area allocated to cereals), the crop has an annual production of 10.6 million tones and is second next to teff (Eragrostis tef) in terms of area covered but first in terms of productivity (4.7 t ha1). However, maize production has been threatening by biotic and abiotic factors. The most serious threat to Ethiopia's maize seed system and productivity, among biotic causes, is the maize lethal necrosis disease. Peru was where it was found first, before spreading to other nations. In the Oromia Region of Ethiopia's East Shewa Zone during the 2014 growing season, there was evidence of a rift valley. Insects, infected soil, and seeds are all possible routes for the virus' transmission. Clean seed and soil, host resistance, virus vector control, and integrated disease management should all be part of the control strategies. The maize seeds must be coated with both a fungicide and an insecticide in order to help manage MLND.

4. Recommendation and Future Research Prospects

It is important to implement appropriate recommendations for MLND management in Ethiopia. Establishing and enforcing quarantine inspection to prevent the movement of maize seeds from affected to unaffected areas, developing resistant varieties, conducting tests to confirm seed transmission of viruses in local cultivars, removing and discarding infected maize crops, following crop rotation schedules, vector management, recommending a routine of pesticide applications for vector control (seed and foliar), using integrated pest management techniques, and routinely monitoring MLND are all examples of preventative measures. Aside from other global experiences, Ethiopian researchers have found no natural enemies of the virus' insect vectors, thus it is important to identify the biological agents that inhibit them. The public should be made aware of the disease in addition to the aforementioned control measures.

Conflicts of Interests

The authors have not declared any conflict of interests.

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