

Review

Insights of maize lethal necrotic disease: A major constraint to maize production in East Africa

Fatma Hussein Kiruwa, Tileye Feyissa and Patrick Alois Ndakidemi*

Department of Sustainable Agriculture, Biodiversity and Ecosystem Management, Nelson Mandela African Institution on Science and Technology, P. O. Box 447, Arusha, Tanzania.

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Maize Lethal Necrotic Disease (MLND) is a new disease in East Africa, first reported in Kenya in 2011 and then spread to Tanzania, Uganda and Rwanda. The disease is caused by *Maize Chlorotic Mottle Virus (MCMV)* in combination with viruses of genus *Potyvirus*, mostly *Sugarcane Mosaic Virus (SCMV)*. The co-infection is the one that results in intensive to complete yield loss. Diagnosis of MLND based on symptoms is reported ineffective because symptoms like stunting and chlorosis resembles nutrient deficiencies or maize mosaic. Detection and characterization of MLND causing viruses have been done by techniques such as enzyme-linked immuno-sorbent assay (ELISA), polymerase chain reaction (PCR) and next generation sequencing. Relatively little work has been done to characterize MLND causing viruses in Tanzania prior to those techniques. The disease can be managed through the use of certified seeds, sanitation, quarantine, crop rotation, the use of resistant/tolerant maize varieties and other cultural practices. The use of resistant maize varieties is considered the most reliable, eco-friendly, effective and economical way of managing MLND.

Key words: Enzyme-linked immuno-sorbent assay (ELISA), etiology, *Maize Chlorotic Mottle Virus*, Maize lethal necrotic disease, nucleic acid based methods, resistant maize varieties, *Sugarcane Mosaic Virus*.

INTRODUCTION

Maize (*Zea mays*) is important staple crop in east Africa (FAOSTAT, 2013) and is one of the most widely cultivated gramineous plants in the regions (Acland, 1977) due to its ability to grow in diverse climates (Agbonifo and Olufolaji, 2012). In 2011, a disease with virus like symptoms (chlorotic mottle on maize leaves, mild to severe mottling and necrosis) were reported in east Africa causing dramatic maize damage in farmers

fields (Wangai et al., 2012a,b). The disease was identified as Maize Lethal Necrotic Disease (MLND) (Wangai et al., 2012b; Adams et al., 2013), a new disease in Africa and perhaps the worst enemy of the maize crops in recent times. This review discusses MLND in east Africa, including its importance, diagnostics, etiology, managements and therefore highlights the future research needs.

*Corresponding author. E-mail: patrick.ndakidemi@nm-aist.ac.tz. Tel: +255 757 744 772.

MAIZE LETHAL NECROTIC DISEASE

Causative agents/pathogens

MLND is caused by *Maize Chlorotic Mottle Virus* (MCMV) as a single virus infection or in combination with other Potyviridae family like *Sugarcane Mosaic Virus* (SCMV), *Wheat Streak Mosaic Virus* (WSMV) or *Maize Dwarf Mosaic Virus* (MDMV) (Bockelman et al., 1982). The double infection (co-infection) which is more severe than single infection (Niblett and Claflin, 1978; Scheets, 1998) occurs mostly with two viruses; MCMV and SCMV and this gives rise to what is known as MLND, also referred to as Corn Lethal Necrosis (CLN) (Uyemoto et al., 1980; Uyemoto et al., 1981).

History and geographical distribution of MLND

In September 2011, the first outbreak of MLND was reported in east Africa along rift valley regions of Kenya (Wangai et al., 2012a, b). Regions that were reported to have the disease includes; Bomet, Naivasha, Narok, Chepalungu, Sotik, Transmara, Bureti, Nakuru, Konoin, South Narok, Mathira East, Imenti South Districts and Nyeri (Wangai et al., 2012c). In August 2012, this disease was also reported in Tanzania around border regions especially Northern zone and along Lake Zone (Makumbi and Wangai, 2013). Northern zone includes Arusha (Karatu, Mlangarini, Longijave and Ngaramtoni), Kilimanjaro (Hai district in Nshara and lower Moshi) and Manyara in Kiru, Babati, Mbulu and Simanjiro. Lake Zone includes Mwanza, Mara and Shinyanga. In Uganda, the disease was first reported in October 2012 in Busia then in border district of Tororo, Mbale and Kapchorwa (ASARECA, 2013). MLND was first reported in February 2013 in Gisesero site, Musanze District in Northern Province of Rwanda and it then spread to western Province (Adams et al., 2014; ASARECA, 2013). This disease is not reported yet in Burundi (ASARECA, 2013).

This disease is new in east Africa but not new in the other parts of the world as it was identified as corn lethal necrosis in 1976 in Kansas (Niblett and Claflin, 1978; Uyemoto, 1983), Peru (Castillo, 1977; Uyemoto, 1983), Hawaii (Kaua'i) in the early 1990s (Nelson et al., 2011), Nebraska in 1976 (Uyemoto, 1983), Argentina (Gordon et al., 1984), Texas and Brazil (Uyemoto, 1983). The possibility of spreading to other areas cannot be ruled out and hence need to quantify its distribution in a wider context.

The extent of yield loss due to the impact of the disease

MLND is a big threat to maize production in East Africa as it can cause intensive to complete yield loss (Wangai

et al., 2012b). Maize is susceptible to this disease at all stages of development specifically from seedling stage to near maturity (CGIAR Research Program MAIZE, 2012). The loss is due to infected maize plants with small ears, distorted and set little or no grains. On the other hand maize production costs are increasing as farmers use herbicides and insecticides to control weeds and insect vectors transmitting the disease. Furthermore, seed production costs also increases as extra cost of seed treatment is incurred by the seed companies. Therefore, proper solution must be found to properly manage the MLN disease to reduce the losses and maximize production.

Diagnosis of the disease

The best method of controlling plant diseases is proper identification of the causative agents (Webster et al., 2004; Adams et al., 2013) and this is supported by the best diagnostic tools. Several methods have been used to diagnose plant viral diseases. These methods include; serological methods, nucleic acids based methods (Singh and Singh, 1995; Naidu et al., 2003; Webster et al., 2004; Punja et al., 2007; Trigiano et al., 2008), electron microscopy (EM) (Singh and Singh, 1995), physical properties of a virus (that is, thermal inactivation point, dilution end point, and longevity *in vivo*) (Trigiano et al., 2008), transmission tests, and symptomatology (Naidu et al., 2003). In this review, only three methods viz; symptomatology, serological and nucleic acids based methods mostly used in the diagnosis of plant virus diseases specifically MLND are discussed.

Symptomatology: Diagnosis based on symptoms

Symptoms are one of the indications of plants being affected either by biotic (pests and pathogens) or abiotic (environmental conditions) factors in fields (Agrios, 2005). They are important in disease management as some of the management practices such as rouging are based on the observed symptoms.

Symptoms of MLND

Symptoms of MLND includes; elongated yellow streaks parallel to leaf veins, streaks may coalesce to create chlorotic mottling, chlorotic mottling may be followed by leaf necrosis (Nelson et al., 2011; Makone et al., 2014) which may lead to "dead heart" symptom and plant death (Wangai et al., 2012a), premature aging of the plants (Gordon et al., 1984), failure to tassel and sterility in male plants, malformed or no ears (Uyemoto et al., 1981; Gordon et al., 1984), failure of cobs to put on grains and rotting of cobs (Wangai et al., 2012a).

Diagnosis of MLND causative agents based on observation of symptoms has been reported to be less accurate because some of the symptoms like stunting and chlorosis may not be virus infection but nutrient deficiencies or maize mosaic (Nelson et al., 2011). Additionally, factors like unfavorable environmental conditions, damage by pests, air pollution, herbicides applications, and infection by non-viral pathogen can also induce virus like symptoms (Naidu et al., 2003). Furthermore, symptoms may be very slight and inconclusive, infected plants may be symptomless (Lima et al., 2012) or different viruses may cause similar symptoms in a plant (Webster et al., 2004). Therefore, to be certain and to avoid misdiagnosis, other confirmatory tests must be done to ensure accurate diagnosis of virus infection (Bock, 1982).

Serological methods

Detection and diagnosis of plant viruses have included serological tests since the 1960s (Martin et al., 2000). These tests are believed to be the best in identification of large number of field samples (Wu et al., 2013). They are reported as one of the most specific and easiest methods for rapid and precise identification (Naidu et al., 2001; Astier et al., 2007). Such tests include enzyme-linked immuno-sorbent assay (ELISA) which includes (triple antibody sandwich ELISA (TAS-ELISA), double antibody sandwich ELISA (DAS-ELISA) and direct antigen coating-ELISA (DAC-ELISA) (Kumar et al., 2004), dot-immuno-binding assay (DIBA), and immuno-capture reverse transcription-polymerase chain reaction (IC-RT-PCR) by using the MAb 4B8 that is developed for sensitive, specific, and rapid detection of MCMV in fields (Wu et al., 2013). Other serological tests include; tissue blot immunoassays, immuno-electron microscopy (trapping and decoration), western blots, double immune diffusion and lateral flow rapid tests (Lima et al., 2012). These serology tests are based on antigen-antibody reaction (Lima et al., 2012).

Among serological methods, ELISA has been extensively used in many studies to identify viral diseases of plants (Punja et al., 2007). The reason being relatively high sensitivity and specificity (highly strain specific) (Lima et al., 2012), low cost and simple for routine diagnosis (Webster et al., 2004; Kimar et al., 2004). This test is based on the basic principle in which the virus antigens are recognized by their specific antibodies (IgG) in association with colorimetric properties (Lima et al., 2012). ELISA method have been used to identify WSMV in wheat (Montana et al., 1996; Ilbagi et al., 2005), MCMV in maize (Jensen et al., 1991; Xie et al., 2011; Adams et al., 2013; Lukanda et al., 2014), SCMV in maize (Louie, 1980; Adams et al., 2013; Lukanda et al., 2014) and MDMV in maize (McDaniel and Gordon, 1985; Giolitti et al., 2005). DAS-ELISA has been used to identify

MLND causing viruses in Kenya but gave negative results (Adams et al., 2013) probably due to low sensitivity and poor specificity for unusual or variant isolates (Adams et al., 2013). Similar study was done to identify MCMV and SCMV by ELISA (DAS-ELISA and Indirect ELISA) with polyclonal antibodies produced against the East African strains of MCMV and SCMV and it was successful. (Mahuku et al., 2015a, b).

In spite of serological methods such as ELISA being less accurate in identifying unusual or variant isolates because of being too specific to a particular species or even strain of a virus as reported by Adams et al. (2013), still it can be used in identification because it is the easiest method associated with low cost. Furthermore, it is rapid and can be used in the identification of large number of samples and that is why it is intensively used in quarantine/movement of seeds and plants across countries to identify diseases of quarantine importance including MLND (Mezzalama et al., 2015). However, there must be proper selection of good reagents and ensuring the level of antibodies' sensitivity and specificity toward the pathogen under study, proper handling, storage of reagents and incubation time and temperature must be done carefully as these factors have been reported by Hewings and D'Arcy (1984) to affect ELISA results.

Nucleic acid based methods

Nucleic acid based methods have been used in identification and characterization of many viral diseases of plants (Henson and French, 1993; Hadidi et al., 1995; Lopez et al., 2003). Polymerase chain reaction (PCR) and next generation sequencing (NGS) are among nucleic acid based methods used in the diagnosis of many plant virus diseases including MLND (Zhang et al., 2011; Wangai et al., 2012b; Adams et al., 2013; Lukanda et al., 2014; Mahuku et al., 2015a, b).

Polymerase chain reaction (PCR)

PCR is a molecular technology that facilitates the amplification of rare copies of specific nucleic acid sequences to produce a quantity of amplified product that can be analyzed (Coleman and Tsongalis, 2006). This method is used in many applications (Doughari et al., 2009) including diagnostics of plant virus diseases (Henson and French, 1993; Hadidi et al. 1995; Lopez et al., 2003) because of its speed, specificity, sensitivity, and versatility (Naidu et al., 2003). Apart from detection of viruses, PCR products (amplicons) can be sequenced to provide further data on strain types (Webster et al., 2004). There are several PCR variants including basic PCR, reverse-transcription-PCR (RT-PCR) common for

RNA viruses, real-time PCR (Lopez et al., 2003; Kumar et al., 2004; Rao et al., 2006; Punja et al., 2007; Hardingham et al., 2012), Multiplex PCR, Nested PCR (Lopez et al., 2003; Webster et al., 2004; Rao et al., 2006; Punja et al., 2007; Hardingham et al., 2012), immunocapture PCR (IC-PCR), competitive fluorescence PCR (CF-PCR) and fluorescence RT-PCR using Taqman[®] technology (Webster et al., 2004). These PCR variants are designed to increase sensitivity, alter specificity or allow automation of detection (Webster et al., 2004).

PCR has been used in diagnosis of many viral diseases of plants including detection of MCMV by real-time PCR in maize seeds (Zhang et al., 2011) and in maize leaves (Adams et al., 2014). Real-time PCR is considered as the best confirmatory test and for routine diagnosis and it is species specific (Adams et al., 2013). Additionally, RT-PCR has been used to detect/verify MCMV and SCMV in maize (Wangai et al., 2012b; Mahuku et al., 2015a), MCMV in sugarcane (Wang et al., 2014) and in maize (Xie et al., 2011), SCMV, *Sorghum Mosaic Virus* (SrMV), *Sugarcane Streak Mosaic Virus* (SCSMV) and *Sugarcane Yellow Leaf Virus* (SCYL) in sugarcane (Xie et al., 2009), and SCMV in maize and sorghum (Rafael et al., 2014).

PCR results can be affected by a number of factors including improper handling and storage of reagents, PCR contaminants, quality of enzyme (that is, Taq polymerase), type of primers and annealing temperature and the presence of inhibitors that can affect amplification of the target DNA which may be the result of improper purification of DNA/RNA (Viljoen et al., 2005). These inhibitors may lead into false negative results and contaminated amplicons may lead to false positive results. Therefore, considerable care is required throughout the process. It is essential to include proper positive and negative control reactions to guard against systematic contamination of PCR reagents and to ensure that the desired amplicon is produced in positive reaction (Coleman and Tsongalis, 2006). Moreover, Rao et al. (2006) reported on non-uniform distribution of most viruses in plant and even less in the plot, orchard or nursery, therefore studies on sampling methodologies and sample processing is urgently needed in to avoid false negative results.

Nevertheless, PCR is considered as the best confirmatory and reliable method for routine diagnosis. However, the need of expertise and high costs of reagents hinders it to be used extensively in detection and identification of viral diseases of plants such as MLND especially in low income-developing countries including east Africa, thus affecting proper diagnosis of viral diseases of plants in regions.

Sequencing

Sequencing is a very reliable technique for virus

identification and has led to development of strain specific probes and primers from extensive sequence data available from many viral isolates (Punja et al., 2007). Next-generation sequencing (NGS) is one of modern techniques that have been used in the diagnosis of new unidentified viral plant diseases. This technique involves generation of sequences in non-specific fashion and identification is based on similarity searching against GenBank (Adams et al., 2013). It has been used in several studies to identify and characterize plant viruses including MLND (Adams et al., 2013, 2014; Mahuku et al., 2015a, b). Among those studies includes characterization of MCMV and SCMV in Kenya whereby MCMV showed a similarity of more than 96% to the Yunnan strain from China but different from US strains while SCMV was found most similar to a strain from China (Adams et al., 2013). Other similar study, complete nucleotide sequence of MCMV isolates in Nebraska was done, whereby sequences of MCMV-NE (Nebraska isolates) and MCMV-KA (Kansas isolates) were closely related sharing 99.5% nucleotide sequence identity suggesting that the two virus isolates share a very recent common ancestor (Stenger and French, 2008). However, in spite of NGS being the most modern and effective method for detection of novel unidentified viral plant diseases, it is not used extensively because of high associated cost. This has severely affected proper diagnosis of plant diseases (including MLND) in the region's leading to very low level of molecular diagnosis. Therefore, there is a need of capacity building and enhancing developing countries in plant disease diagnostics.

Because of low level of molecular diagnosis of plant diseases in east Africa (specifically Tanzania), virus strains causing MLND are not well known. Therefore, there is a need of using modern techniques to identify and characterize viruses causing MLND across regions of east Africa and hence set strategic plans to manage the disease and thereby secure food and alleviate poverty.

Etiology of pathogens causing MLND

Sufficient knowledge of causative agents of a disease, their origin, their disseminations and survival properties usually results in adequate control of the disease.

Taxonomy of the pathogens

Maize Chlorotic Mottle Virus (MCMV): MCMV is the only species in the genus *Machlomovirus* family Tombusviridae (Stenger and French, 2008; King et al., 2011), closely related to members of the genus *Carmovirus*. It is an isometric single component particle containing 4.4 kb single stranded positive sense genomic RNA (ssRNA) (Goldberg and Brakke, 1987; Lommel et

al., 1991) and has a smooth spherical or hexagonal shape with a capsid protein of 25 kDa (Lommel et al., 1991).

Sugarcane Mosaic Virus (SCMV): SCMV is one of the major viruses in the genus *Potyvirus*, family Potyviridae. The virus is not enveloped having filamentous flexuous particles (700-760 nm long and 13-14 nm in diameter) of single stranded positive sense RNA (Teakle et al., 1989).

Wheat Streak Mosaic Virus (WSMV): WSMV is one of viruses in genus *Tritimovirus*, family Potyviridae (Kumar et al., 2004). It is single stranded positive sense RNA (ssRNA) approximately 9.4 to 9.6 kb sizes with a 3'-poly A terminus. It has a filamentous particle of 15 nm diameter and 690 to 700 nm long (Kumar et al., 2004; Wegulo et al., 2008).

Maize Dwarf Mosaic Virus (MDMV): MDMV belongs to genus *Potyvirus*, family Potyviridae (Giolitti et al., 2005). The virus is a single stranded positive sense RNA (ssRNA) with a flexuous filamentous viral particle of 750 nm long and 13 nm wide (Williams and Alexander, 1965; Bancroft et al., 1966; Autrey, 1983).

Life cycle of the pathogens

Survival between cropping seasons: MLND causing viruses can survive in infected maize residuals and contaminate soil, alternative hosts like sorghum, (Toler, 1985), millet, (Bockelman et al., 1982; ASARECA, 2013), Johnson grasses (Knoke et al., 1974; Toler, 1985; ASARECA, 2013) and other grasses in the family Poaceae (Scheets, 2004) can also harbor MLND viruses and act as source of inoculums in the next seasons of maize production.

Transmission

MCMV is transmitted by vectors mainly beetles (Nault et al., 1978; Gordon et al., 1984; Jensen et al., 1991) rootworms (Nault et al., 1978; Uyemoto, 1983; Jiang et al., 1992) thrips (Jiang et al., 1992) and stem borers. SCMV is transmitted by several species of aphids in non-persistent manner (Brandes, 1920; Pemberton and Charpentier, 1969; Zhang et al., 2008). WSMV is transmitted by mites in persistent manner (Kumar et al., 2004; Wegulo et al., 2008). MCMV is transmitted by aphids in non-persistent manner (Knoke et al., 1974; McDaniel and Gordon, 1985; Toler, 1985; Simcox et al., 1995). Additionally, infected soil (Nelson et al., 2011) and seeds have been reported as a reservoir and a means of viruses' transmission (Jensen et al., 1991; Delgadillo Sánchez et al., 1994). Human activities such as using utensils in infected field without thorough washing can

transmit the disease causing viruses from infected to uninfected fields.

Initial infection on maize plants

Generally, plant cells have a robust cell wall and viruses cannot penetrate them unaided. Therefore, they penetrate through wounds created by the feeding mode of insect vectors (Ellis et al., 2008) or mechanical injury by human activities. The feeding insect deposits/injects MLND causing viruses rapidly when feeding on a non-infected plant. Such a relationship is termed "non-persistent" and this is common transmission for Potyvirus by aphids (Zhang et al., 2008; Trigiano et al., 2008). Beetles spread a layer of pre-digestive materials known as regurgitant on the leaves as they feed, when viruliferous beetles spread this layer they also deposit virus particles in the wound at the feeding site (Trigiano et al., 2008). Once inside the cell, the viral protein coat is removed and nucleic acid enters the nuclear membrane and alters the maize DNA machinery so as to produce many of its copies. Since MLND causing viruses are RNA viruses, they first change their RNA to complementary DNA (cDNA) to mimic its host maize DNA. When more copies of viral particles have been synthesized, their movement between cells is through plasmadermata and the whole maize plant through phloem (Ellis et al., 2008). This results in disease manifestation and secondary cycles to alternative hosts (sorghum, millet, sugarcane and Johnson grasses etc.) and therefore continue repeated cycles during seasons and off seasons by the aid of vectors.

Disease management

Disease management is the selection and use of appropriate techniques to suppress disease to a tolerable level (Fry, 2012). The goal of plant disease management is to reduce the economic and aesthetic damage caused by plant diseases (Maloy, 2005). Proper disease management is achieved when the causation and the effect that the disease could cause are known. Disease management in this context is described based on basic principles of disease control by Whetzel (1929) with modifications as explained by Maloy (2005) and other studies (<http://www.apsnet.org/edcenter/advanced/topics/EpidemiologyTemporal/Pages/ManagementStrategies.aspx>)

Reduction of initial inoculums

Pathogen exclusion/strict quarantine: Pathogen exclusion is the prevention of disease establishment in areas where it does not occur. This is a major objective of

plant quarantine procedures throughout the world. Maize seeds are inspected before entering and going out countries and within country regions to prevent transmission of the disease especially by seed transmission. Plant quarantine is a national service and is organized within the framework of Food and Agriculture Organization (FAO) (Kumar et al., 2004). It is considered as one of the best procedures of controlling movement of MCMV, rather than attempting to control the endemic SCMV (Adams et al., 2014). This is because MCMV is new in East Africa, reported in Kenya in 2011 (Wangai et al., 2012a, b) but SCMV is not and was reported in East Africa in 1973 (Louie, 1980). Enforcement of this practice will have significant effects in limiting the introduction of MLND into other areas and prevent their spreading and hence reducing threats of food security.

Pathogen eradication: This method reduces pathogen from infected areas before it becomes well established (Maloy, 2005). Pathogen eradication includes sanitation which involves cleaning of tools such as tractor and clothing used in infected fields, removal of infected maize plant debris that will act as source of inoculums in the next season, rouging of diseased maize plants (Mawishe and Chacha, 2013), eliminating weeds and other alternative hosts (insect vectors) which serve as reservoir for viruses (Webster et al., 2004; Maloy, 2005; Trigiano et al., 2008). Crop rotation can be done by planting a non-host crop, this can reduce (but not eliminate) density of the viruses and manage MLND (Uyemoto, 1983). Non-host crops include Irish potatoes, sweet potatoes, cassava, beans, bulb onions, spring onions, vegetables and garlic (Wangai et al., 2012a). Additionally, the use of techniques that disfavor vectors/movement for example, reflective mulches for aphids and sticky cards for other insect vectors that feed on maize can be used to reduce vectors for transmission and thereby reducing density of inoculums.

Reducing the rate of infection

Avoidance: This method aims at avoiding contact between host (maize) and pathogen (viruses) by planting maize in field with no history of the disease, provide adequate plant spacing and avoid crowding, avoiding injury to the maize plants because viruses penetrates the plants through wounds and avoiding the use of recycled maize seeds by using certified seeds (Trigiano et al., 2008; Wangai et al., 2012a), planting maize on the onset of the main rainy season and not during the short rain season so as to create a break in maize planting seasons (Wangai et al., 2012a). This will reduce the population of vectors and hence low rate of infection and disease severance.

Plant protection: This method involves protection of the host (maize) from invading pathogens (viruses). It is

achieved by spraying chemicals and modification of plant nutrient (the use of manure and fertilizers) and environment. MLND viruses cannot be controlled by the use of chemicals, but chemicals can be used to kill vectors that transmit/spread those viruses. Several insecticides, formulated either as granules or spray applications can be used to manage vectors (e. g. aphids, rootworms, stem borers, mites, thrips) that transmit MLND. Such insecticides include Imidacloprid, Thiamethoxam, Deltamethrin, Abamectin, Permethrin, Endosalphon and Dimethoate (TPRI, 2011). For effective control of vectors, appropriate insecticides must be sprayed once every 1 to 2 weeks and there should be rotation of multiple chemicals every month to avoid immunity development of the target vector (Mezzalama et al., 2015). The use of chemicals has been reported insufficient in the management of plant virus diseases (Satapathy, 1998; Perring et al., 1999). Other protection techniques include the use of manure, basal and top dressing fertilizers to strengthen the resistance of plants to disease and pests (Wangai et al., 2012a).

Resistant or tolerant varieties: This is the most reliable, effective, environmental friendly and economical way of controlling plant diseases (Kumar et al., 2004). This is because it is durable, reduces crop losses due to disease and no or little use of chemicals (pesticides) that could affect human and the environment. Many Efforts are being done to produce resistant varieties of maize in eastern Africa (ASARECA, 2014). For example, strong collaboration between CIMMYT and National maize programs has been established to effectively tackle the MLN challenge in eastern Africa (CGIAR Research Program MAIZE, 2012; IRIN, 2013). This resulted in establishment of a centralized MLN screening facility for eastern Africa at the KALRO Livestock Research Farm in Naivasha (CGIAR Research Program MAIZE, 2012; IRIN, 2013). Additionally, Ngotho (2013), reported on the funding from the Bill and Melinda Gates Foundation and Syngenta Foundation for Sustainable Agriculture that will be used to develop fast tracking maize varieties that are tolerant to the disease and drought by scientists and researchers within Pan-Africa and the eleven ASARECA countries, Kenya, Uganda, Tanzania, Rwanda, Burundi, Ethiopia, Sudan, Eritrea, DRC Congo, Madagascar and South Sudan.

If proper management of this disease is not taken seriously, the disease will spread throughout Africa where maize is produced as there are reports of MLND in Democratic Republic of Congo (Luanda et al., 2014) South Sudan (FAO REOA, 2013; ASARECA, 2013), Ethiopia (Mahuku et al., 2015b) and Somalia. This may result in serious economic impacts, food insecurity as well as affecting livelihoods and well-being of Africa.

FUTURE RESEARCH NEEDS

In order to manage MLND effectively in east Africa, the

following questions needs to be answered: How do the virus strains causing MLND present in regions of east Africa differ in the rate of infection? What insect vectors are responsible for transmission of MLND causing viruses in EA? What is the relationship between MLND causing viruses and their insect vectors? How can these insect vectors be managed? How much seeds can contribute to transmission of the viruses causing MLND? What genes are responsible for host resistance? How can these genes be incorporated into seed stocks by breeders? What is the prevalence/incidence of MLND in each region of EA? And what is the contribution of climate change to the spread of MLND? Therefore, there is a need to conduct studies to address these questions to properly manage MLND.

Conflict of interests

The author(s) did not declare any conflict of interest.

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