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Review

Maize streak virus: A review of pathogen occurrence, biology and management options for smallholder farmers

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Maize streak disease is a major threat to cereal crops amongst smallholder farmers in sub-Saharan Africa causing up to US$480 million losses annually. It is caused by *Maize streak virus* (MSV), a geminivirus that is indigenous to Africa. The virus is transmitted by at least 11 *Cicadulina* species, with *Cicadulina mbila* being the main vector. In addition to cereals, the virus also infects wild grasses. There are 11 known MSV strains, designated with the letters A to K, according to alphabetical order. MSV-A is the most severe and economically important strain that attacks maize. The other strains attack cereal crops other than maize. The control of MSV is most effective when cultural and chemical methods are integrated with plant breeding for resistance. While host plant resistance is the best method of MSV management, it is not usually easy to conventionally produce resistant cultivars. Genetic engineering has been successfully employed in producing MSV-resistant maize. However, opponents of genetic engineering have prevented the adoption of the technology by most African countries. This means that smallholder farmers have to continue growing susceptible cultivars or buy the slightly more expensive conventionally-bred cultivars.

Key words: *Cicadulina*, host range, integrated disease management, pathogen strains, symptoms.

INTRODUCTION

Maize streak virus (MSV) is one of at least eight viruses that cause significant agronomic losses in maize (*Zea mays* L.) worldwide (Redinbaugh et al., 2004). It is the causative agent for maize streak disease (MSD), a major maize disease in sub-Saharan Africa (Ininda et al., 2006; Magenya et al., 2008; Martin and Shepherd, 2009) where it manifests from sea level to 2000 m above sea level (Welz et al., 1998). MSV is indigenous to Africa, including the adjacent Indian Ocean Islands of Reunion, Mauritius and Madagascar (Willment et al., 2001; Fajemisin, 2003). The first record of MSD was by Claude Fuller in 1901 in South Africa's Natal province (now KwaZulu-Natal) (cited by Shepherd et al., 2010). Serious MSV epidemics have been reported in at least 20 African countries including Angola, Benin, Burkina Faso, Cameroon, Democratic Republic of Congo, Ghana, Kenya, Malawi, Mozambique, Nigeria, Zambia and Zimbabwe (Wambugu and Wafula, 2000; Lagat et al., 2008; Magenya et al., 2008). MSD is

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the most important maize disease in Zimbabwe where it occurs in every natural farming region. The disease is more prevalent on the Highveld (1219 to 1675 m above sea level) and Middleveld (600 to 1200 m above sea level) where farmers grow maize and winter cereals in rotation.

Yield losses by MSV are estimated from trace to 100% depending on cultivar and time of infection (Alegbejo et al., 2002). This translates to between US$120 million and US$480 million per year (Martin and Shepherd, 2009). In Kenya, food security in the smallholder sector is greatly compromised as annually, up to one million metric tonnes of maize grain is lost to MSD (Ininda et al., 2006). The smallholder farmers are particularly vulnerable to MSV because many of them grow susceptible traditionally open-pollinated varieties because they cannot afford to buy MSV-resistant hybrids. Often, such varieties are killed if infection occurs within three weeks after emergence.

This paper reviews the biology and control of MSD. It characterizes the MSV pathogen, its vectors, host range and symptoms. In view of the significance of the smallholder agricultural sector to sub-Saharan Africa, the paper evaluates the different control options available to farmers for dealing with the disease. The strengths and limitations of each control option are highlighted.

MAIZE STREAK VIRUS (MSV) BIOLOGY

Pathogen characterization

MSV is one of at least nine currently known grass infecting "African streak virus" species, a group that includes *Panicum streak virus*, *Sugarcane streak virus*, *Sugarcane streak Egypt virus*, *Eragrostis streak virus*, *Sugarcane streak Reunion virus, Urochloa virus* (cited by Martin and Shepherd, 2009), *Eragrostis minor streak virus* (Martin et al., 2011) and *Axonopus compressus streak virus* (Oluwafemi et al., 2014). It belongs to the genus *Mastrevirus* in the family *Geminiviridae*. It is a DNA virus with monopartite genome consisting of circular single-stranded DNA encapsidated in a characteristic geminate morphology (Muhire et al., 2013). Virion particles have a quasi-icosahedral shape, 27 x 38 nm (Shepherd et al., 2010). MSV is the reference species of the genus *Mastrevirus* whose other important species include *Bean yellow dwarf virus* (BeYDV), *Chloris striate mosaic virus* (CSMV), *Digitaria streak virus* (DSV), *Tobacco yellow dwarf virus* (TYDV) and *Wheat dwarf virus* (WDV).

MSV is the only species known to cause MSD. There are 11 known strains of MSV namely MSV-A to MSV-K (Shepherd et al., 2010; Monjane et al., 2011). The MSV-A strain causes the most severe and economically relevant form of MSD. It has five strain variants namely: MSV-A_1, MSV-A_2, MSV-A_3, MSV-A_4 and MSV-A_6. These variants have different geographical ranges. MSV-A_1 is the most widely distributed, occurring in every part of sub-Saharan Africa. Zimbabwe has MSV-A_1 and MSV-A_4 variants while South Africa has MSV-A_1, and MSV-A_4, in addition to MSV-B, MSV-C, MSV-D and MSV-E (Martin et al., 2001; Varsani et al., 2008). The MSV-A_1 and MSV-A_2 variants produce the severest symptoms; MSV-A_3 and MSV-A_6 produce intermediate symptoms and MSV-A_4 produces the mildest symptoms (Magenya et al., 2008). The MSV-B to MSV-K strains infect crops other than maize (Willment et al., 2002).

Vectors

MSV is obligately transmitted by several species of leafhoppers of the genus *Cicadulina* (Cicadelidae: Homoptera) in a persistent manner (Bosque-Perez et al., 2000). The most important vector is *Cicadulina mbila* (Naude) which has a wider geographical range and greater capacity to transmit the virus than any of other leafhopper species. The other confirmed vectors are *Cicadulina storeyi* China, *Cicadulina arachidis* China, *Cicadulina bipunctata* (Melichar), *Cicadulina latens* (Fennah), *Cicadulina parazeae* Ghauri, *Cicadulina similis* China, *Cicadulina triangular* Ruppel, *Cicadulina ghauri* China (Lett et al., 2002; Fajinmi et al., 2012), *Cicadulina chinai* Ghauri (www.grainsa.co.za) and *Cicadulina dabrowskii* Webb (Oluwafemi et al., 2007). The *Cicadulina* species are generally considered as grassland species. They are present in wild and pasture throughout the year, but can migrate in large numbers to maize (Page et al., 1999). Female leafhoppers are two to three times more capable of transmitting the virus than males (Oluwafemi et al., 2007). Fertilized leafhoppers prefer wild grassed for oviposition. MSV is neither seed borne nor mechanically transmissible.

Host range

Besides maize, MSV infects other crops such as rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.), barley (*Hordeum vulgare* L.), rye (*Secale cereale* L.), finger millet (*Eleusine coracana* L.), pearl millet (*Pennisetum typhoides* L.), sorghum (*Sorghum bicolor* L.) and sugarcane (*Saccharum officinarum* L.) (Damsgeegt, 1983; Willment et al., 2001; van Antwerpen et al., 2011). Maize is a staple food crops in Africa, while sorghum, finger and pearl millet are major food crops especially in marginal areas of sub-Saharan Africa. Sugarcane is an important cash crop in a number of countries including Mauritius, South Africa and Zimbabwe. Wheat, barley and oats are grown as winter cereals in southern Africa thereby ensuring that the virus has favourable hosts throughout the year. MSV also attacks a wide range of grasses in the genera *Axonopus,*

Figure 1. Maize plants infected by *Maize streak virus.* Photograph by Charles Karavina.

Brachiaria, Coix, Eleusine, Paspalum, Imperata, Rottboellia, Eragrostis and *Setaria* (Willment et al., 2001; Lett et al., 2002; Fajemisin, 2003). Most of these grasses grow naturally in vleis and irrigation schemes.

SYMPTOMS

MSV symptoms have been described in detail by various researchers (Ward et al., 1999; Shepherd et al., 2010). Symptoms vary according to the MSV isolate. The symptoms are characterized by broken to almost continuous chlorotic stripes centred on the tertiary leaf veins (Pinner et al., 1988). They first manifest as minute pale circular spots on the lowest exposed part of the leaf. Only new leaves develop the symptoms of virus infection while leaves below the point of infection remain healthy (Hill and Waller, 1998). The spots develop into discontinuous pale yellow streaks, up to several millimetres in length, along the blades, parallel to the veins or broken chlorotic streaks on secondary or tertiary veins with primary veins being less affected than secondary and tertiary veins. The longitudinal chlorotic streaking causes a concomitant reduction in photosynthetic area, growth and yield of the plant. The streaks often fuse laterally to give narrow broken chlorotic stripes which may extend over the entire length of fully affected leaves. In highly susceptible genotypes, chlorotic streaks tend to coalesce to form an almost uniform chlorosis. The chlorosis is caused by failure of chloroplasts to develop in the tissue surrounding the vascular bundles and this results in reduced photosynthesis and increased respiration leading to reduction in leaf length and plant height. Thus maize plants infected within the first three weeks after emergence become severely stunted producing considerable abnormal cobs or giving no yield at all. If infection occurs more than eight weeks after plant emergence, the virus does not normally cause significant economic loss (Page et al., 1999). Figure 1 shows typical MSV symptoms on maize plants.

MANAGEMENT OF MAIZE STREAK DISEASE

Numerous options have been recommended for the management of MSD. Current management strategies rely on the employment of cultural, chemical and host plant resistance measures. The availability, feasibility and cost-effectiveness of each method differ with production regions and settings, that is, commercial or subsistence (Pratt et al., 2003). Farmers are encouraged to combine at least two different tactics in dealing with the disease, a concept called Integrated Disease Management (IDM).

Cultural control

Various cultural practices are currently employed in the management of MSV. These include crop rotation, field hygiene, early planting and cultivar choice. Rotation should be practiced with broadleaved crops because MSV does not infect broadleaved plants at all (Damsteegt, 1983; Shepherd et al., 2010). Smallholder farmers commonly grow broadleaved crops like groundnuts (*Arachis hypogeae*), beans (*Phaseolus vulgaris*), cowpeas (*Vigna unguiculata*), cotton (*Gossypium hirsutum*) and pumpkin (*Cucurbita pepo*). Recently, more and more Zimbabwean smallholder farmers have diversified their production into tobacco (*Nicotiana tabacum*) and soybean (*Glycine max*) which are non-hosts of MSV. A major impediment to the implementation of crop rotation amongst smallholder farmers is the land sizes which average 0.5 to 1.5 ha per farmer. With such small pieces of land, farmers tend to prioritize the growing of staple crops over MSV management. A better alternative to crop rotation is intercropping. Farmers can grow cereal food crops intercropped with legumes and cucurbits. However, intercropping reduces the yield of the main cereal crop (Page et al., 1999).

Common field hygienic measures for MSD management are roguing and the destruction of weeds, volunteer and ratoon crops. Infected crops should be rogued and buried as soon as they are identified during the growing season. Grassy weeds and cereal volunteer crops should also be destroyed. Normally, smallholder farmers are tempted to maintain ratoon and volunteer crops because they do not have adequate financial resources to purchase certified seed every season. If these are infected, then they act as sources of inoculum for MSV.

In the commercial farming sector, farmers maintain a buffer zone of five to ten meters around the field to reduce the movement of leafhoppers and subsequent virus spread. This zone has to be sprayed regularly with insecticides; or the grass in the buffer has to be kept short by regular mowing. A similar zone can be maintained between early and late planted crops. The smallholder farmer does not have the luxury of maintaining such a buffer zone because of limited land size. Neither can the farmer afford to purchase insecticides to spray onto the buffer. However, should they opt for such a buffer zone, they can use it to grow MSV non-host crops like groundnuts, beans and cucurbits in order to maximize land use.

Early planting is also recommended for MSV management (Magenya et al., 2008; Shepherd et al., 2010). An early planted crop grows past the susceptible stages before leafhopper population has built up sufficient levels to spread the virus. Also, the crop also grows vigorously as it is able to access high heat units in the early months of the summer season. However, planting dates are largely determined by the onset of the rainy season, especially in the smallholder sector where there are no irrigation facilities. So, with climate change, it is difficult to recommend this option because smallholder farmers are normally forced to plant with the first effective rains. In Zimbabwe, for example, the rainy season is now effectively starting in early December as opposed to early or mid-November. By this time, some non-effective early rains would have led to the emergence of wild grasses, ratoon and volunteer crops. If these are infected with the virus, then they provide MSV inoculum for the cereal crop to be planted at the onset of the rainy season.

In areas where MSD pressure is high, it is better to plant short season varieties as they are exposed to the disease over a shorter time than long season varieties. Farmers should avoid planting maize downwind of older cereal crops. Leafhoppers will be easily carried downwind and infect the new crop.

Chemical control

The application of insecticides is aimed at controlling the vectors. Insecticides like aldicarb, carbofuran, carbosulfan, dimethoate, endosulphan and imidacloprid are available for use against leafhoppers. The most commonly used insecticides are carbofuran and imidacloprid. Carbofuran can be applied as seed dressing, in planting farrows or as conventional sprays (Magenya et al., 2008). It also controls other maize pests like maize stalk borer (*Busseola fusca* (Fuller)), termites (*Microtermes spp* and *Macrotermes spp*), white grubs (*Adoretus spp*), and wireworms (*Agriotes obscurus* L.). With a residual activity of up to seven weeks, carbofuran protect the maize crop past the susceptible stages.

Imidacloprid is mainly applied as seed dressing when controlling leafhoppers. It is another broad spectrum insecticide that has many formulations. It is marketed as Gaucho, Confidor, Admire or Conguard. In Zimbabwe, Gaucho is used for seed treatment while Confidor is formulated for foliar sprays. Two organophosphorus insecticides dimethoate and endosulphan are commonly applied as foliar sprays to control leafhoppers in the field and buffer zone. Sometimes, farmers spray herbicides like glyphosate and paraquat in the buffer zone to kill the grass thereby creating bare ground that repels the leafhoppers.

There are several challenges associated with chemical control of MSD. Pesticides like aldicarb, paraquat and carbofuran are extremely poisonous to both humans and the environment. Aldicarb and paraquat are part of the “Dirty Dozen”, a list of chemicals that have been banned in the developed world (www.legacy.library.ucsf.edu). However, they are still in use most developing countries where technically and economically feasible alternatives with acceptable health and environmental effects are not available.

Besides their effects on humans and the environment, foliar pesticide sprays quickly break down during the growing season. So, they need to be repeatedly applied throughout the growing season for effective leafhopper control. Most smallholder farmers are financially constrained to buy pesticides. Even when they have the pesticides, they usually do not have adequate protective clothing and technical knowhow on correct pesticide application techniques. As a result, there have been many deaths due to pesticide poisoning. The World Health Organization estimates that one million people are poisoned annually with 20,000 cases resulting in deaths (Matthews et al., 2003). In most cases, smallholder farmers are usually far away from medical services in case there is accidental poisoning. Sometimes, the medical services are poorly equipped to handle cases of pesticide poisoning.

Host plant resistance

By far the most effective, economically viable and environmentally friendly method of MSV management is the growing of resistant cultivars (Lagat et al., 2008). Resistant cultivars are produced through either conventional breeding or genetic engineering.

Conventional breeding

Breeding for MSV resistance is done by the private sector, international research centers and national programmes (Pratt et al., 2003). The International Maize and Wheat Improvement Centre (CIMMYT) and International Institute of Tropical Agriculture (IITA) are the major international research centers involved in breeding for MSV resistance in Africa. They have identified germplasm that has high tolerance to MSV, with the *msv-1* gene responsible for conferring the resistance (Kyetere et al., 1995). Private companies and government programmes involved in breeding MSV-resistant hybrids get germplasm from these international research centers. CIMMYT has regional offices in Harare (Zimbabwe) and Nairobi (Kenya) servicing southern and East Africa, respectively. IITA has its offices in Nigeria, and it services West Africa.

In view of the severity of MSV in sub-Saharan Africa, all maize breeding programmes incorporate resistance to MSV. To date, several MSV-tolerant cultivars have been released throughout the sub-Saharan region. In Zimbabwe, for example, SeedCo (a private company) has released the cultivars SC403, SC411, SC621, SC713 and SC719 which are being marketed in a number of countries in the region (SeedCo Manual, 2010-2011). The yield and quality of the tolerant cultivars are comparable to those of susceptible cultivars. However, they tend to be slightly more expensive than susceptible ones. Therefore, farmers should be prepared to pay slightly more for tolerant cultivars. In most African countries though, the price of maize seed is subsidized by government to make it affordable even to the poorest farmers.

There are several challenges in producing conventionally bred maize genotypes with a high degree of resistance. The MSV resistance reported so far relies heavily on the *msv-1* gene. If MSV were to evolve and yield strains capable of overcoming the *msv-1* gene, all currently resistant germplasm would be rendered ineffective (Redinbaugh et al., 2004; Olaoye, 2009). Also, resistance may be associated with undesirable traits like low yield and poor taste. Thus, farmers have to make choices between MSV resistance versus desirable agronomic and nutritional traits. Another major challenge is that resistance genes are scattered amongst different chromosomes. This makes it difficult to transfer them to agronomically favourable genotypes because of linkage drag (Martin and Shepherd, 2009). In most sub-Saharan countries, there are no effective seed multiplication and distribution systems for the resistant cultivars (Thresh, 2003).

Genetic engineering

Genetic engineering is the direct manipulation of an organism's genome using biotechnology. In this instance, either natural resistance genes or resistance genes from other sources are inserted into a crop host to produce a genetically modified plant. The concept of pathogen derived resistance (PDR) proposed by Sanford and Johnston (1985) has been effectively used to produce MSV-resistant maize in South Africa. Shepherd et al. (2007) used dominant negative mutants of the MSV replication-associated protein gene (rep) to develop resistance in maize. This was the first time maize with transgenic MSV-resistance was developed anywhere in the world (Sinha, 2007). There are several drawbacks with genetic engineering for producing MSV-resistant maize; the main one being the unfavourable perception on genetically engineered foods the world over (Arthur, 2011; Adenle et al., 2014). In Africa, only Burkina Faso, Egypt, South Africa and Sudan permit genetically modified (GM) crop farming (James, 2013). Zimbabwe, like most other sub-Saharan countries, banned GM cropping despite regularly importing agricultural products like maize mealie-meal and cooking oil from South Africa, a country that has embraced the GM technology. The imports are necessitated by food deficits caused by frequent droughts and a decline in domestic agricultural output. While there have been no major reported MSV epidemics in the last twenty years, it does not mean that the MSD problem has been overcome. Disease epidemics are likely to occur in future, especially if the *msv-1* gene is overcome. As such, farmers should be allowed to choose between susceptible conventionally-bred maize and transgenic resistant maize varieties. While not advocating for conventional breeding to be scrapped out, it is my view that transgenic maize should be given a chance to be on the market. Most of the fears about GM crops are based on perceptions rather than true scientific facts.

CONCLUSION

MSD remains an important disease in sub-Saharan Africa. In spite of no major, widely reported epidemics having occurred in the last two decades, the disease is there to stay in the region. With climate change and more land being utilized for cereal cropping, it is most likely that the next major epidemic is just around the corner. The smallholder farmer who is mainly dependent on cereal crops for food is more exposed to such epidemics when they occur. In the meantime, an integrated approach to MSV management is the best way of dealing with the disease.

Conflict of Interest

The authors have not declared any conflict of interest.

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