International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 04 Issue 10 October 2021
DOI: 10.47191/ijcsrr/V4-i10-11, Impact Factor: 5.825
IJCSRR @ 2021
www.ijcsrr.org

The Effects, Distribution and Management Options for Major Banana Diseases in Tanzania

Kennedy Elisha Jomanga[1], Shija Shilunga Lucas[2]
[1]International Institute of Tropical Agriculture (IITA)
[2]Africa Inland Church Tanzania, Diocese of Mara and Ukerewe

ABSTRACT: Emergences of Fusarium wilt, Bacterial wilt and Black Sigatoka diseases have caused banana yield loss of up 100% in Tanzania. Though there have been accumulated empirical data on yield decline due to diseases, lack of disease knowledge and selection of appropriate control methods has been a limiting factor in improving banana production. Therefore, this review focused on identifying different management options for major banana diseases, for purpose of providing reference and decision making tools to farmers, extension officers, researchers and decision makers. Using online resources, we identified several methods which are affordable, applicable and reliable for disease management in the country. These includes sanitation, intercropping, crop rotation, prevention, irrigation, drainage improvement, quarantine, use of silicon/calcium and awareness campaigns. Other method was biological control, which need further research on its applicability and impact on the environment. Moreover the use of resistant cultivars though being important, there is little achievement which have been made on breeding for resistance, because banana are polyploidy, parthenocarpic, have long generation time, loss of resistance and poor acceptability of new cultivars. We also found that, no single method is perfect for management of diseases; this is due to the fact that, in agricultural system, disease challenges rarely occur singly. So the approach to disease management should be pragmatic and geared towards integration of several appropriate methods. We hereby conclude that, researches should focus on identifying the best and feasible combination of control methods that can be used by Smallholder farmers.

KEYWORDS: Bananas, Bacterial wilt, Black sigatoka, Fusarium wilt, Resistant cultivars.

1. INTRODUCTION

1.1 General Background

Bananas including plantains are the fourth most important dietary staple food after rice, wheat and maize (Nelson *et al.* 2006; Perrier *et al*. 2011; Li *et al*. 2013). It is estimated that, about 30% of Tanzania's population derive their carbohydrates from bananas, with annual production of approximately 4 MMT (FAOSTAT, 2017; FEWS-NET, 2018). The crop provides households with both food and income, while leaves are used for thatching houses and as animal feeds as pseudostem is (MAFC, 2009). Banana ranks first as a major food staple and second or third as a cash crop in the banana and/or coffee based farming systems of Kagera, Arusha, Kilimanjaro, and Mbeya regions (Nkuba *et al*. 2003). According to reports maize, rice, banana, grain legumes and cassava are the most popular staple for many Tanzanians, followed by sorghum, millet, sweet potato and wheat (MAFC, 2009).

Despite its importance, there are fluctuations marked by declining trend of banana production in the country from 18 t/ha in 1960s to 5-7 t/ha/year (Kilimo trust, 2012; FAOSTAT, 2017). Many authors reported that, pests and diseases played a major role as production constraints to smallholder farmers and export banana production (Jones 2000a; Ploetz, 2003; Van Asten *et al*. 2005; Swennen *et al*. 2013). In East Africa, emergence of diseases like Fusarium wilt, Bacterial wilt and Sigatoka disease has reduced banana production (Swennen and Vuylsteke, 2001; Karamura *et al*. 2008; Viljoen *et al*. 2016). A loss of up to 100% occurs caused by epidemics of diseases in perishable horticultural crops have been reported (de Lapeyre de Bellaire *et al*. 2006; Muchuruza and Melchior, 2013; Ochola *et al*. 2014; Brito *et al*. 2015).

Though there have been empirical data on yield decline and accumulated information on the impact of diseases on crop performance, lack of disease knowledge, proper management options and selection of appropriate disease control methods are limiting factors in improving banana yield in Tanzania. Therefore, this review focused on identifying different management options for major banana diseases, for the purpose of providing readily available reference and decision making tools to farmers, extension officers and researchers for banana production resilience.

Major banana diseases

There are three major banana diseases that are considered of agricultural economic importance in Tanzania namely Fusarium wilt, Banana Xanthomonas wilt and Black sigatoka diseases.

1.0 Fusarium wilt disease

Fusarium wilt of banana, popularly known as Panama disease, is highly destructive and lethal caused by the soil-borne fungus *Fusarium oxysporum* f. sp. *cubense* (*Foc*) (Siddhesh *et al*. 2015; Ploetz, 2015; Dita *et al*. 2018).The disease originated in Southeast Asia (Panama) (Ploetz, 2006) and it's pathogen exists in different races, race 1, race 2, race 3 and race 4 (Tropical race 4- TR4) (Sutherland *et al*. 2013; Siddhesh et al. 2015; Ploetz, 2015; Ordonez *et al.* 2015; Siamak and Zheng, 2018). Mbwana and Rukazambuga, (1998), reported that, the disease was first recorded as race 1 in Kaagya Ward, Kagera Region, Tanzania in the mid of 1970s.

1.1. Effects of the disease

Fusarium wilt disease in Tanzania, as in other banana producing countries was and has remained among the major threats in banana industry despite the endeavour to manage the disease (Viljoen *et al*. 2016). This is due to the fact that, the disease is only controlled by using resistant cultivars and prevention (Nel *et al*. 2007). In Tanzania, increase in land population pressure has resulted into continous growing banana on the same infected fields, thus led to increased inoculum pressure (Baijukya, 2005; Shen *et al*. 2017).Therefore, the disease has remained the most serious and devastating banana fungal worldwide (Rong *et al.* 2013) and can result in yield losses up to 100% (Pushpavathi, 2014). Posing great challenge to banana production with serious repercussions on the livelihoods and food security of millions small holder producers and workers, and the banana value chain (Jackson, 2014; FAO, 2017). Moreover, there are potential environmental degradation as uncontaminated land would be cleared for cultivation, and important susceptible varieties are abandoned (Jackson, 2014).

1.1.0 Symptoms

The fungus infects susceptible cultivars by penetrating the roots and rapidly colonizing the xylem vessels (O'Donnell *et al*. 1998; Ploetz 2006; Dita *et al*. 2018), then progresses into vascularized portions of the rhizome (Viljoen, 2002; Ploetz, 2015). Ultimately, the vascular bundle is plugged, thereby impeding water and nutrient transport (Viljoen, 2002; Ploetz, 2015).The infection may or may not pass into young budding suckers or mature 'daughter' suckers. The disease expressses both internal and external symptoms in susceptible cultivars (Plates 1, 2 and 3).

1.1.1 Internal symptoms

The vascular bundles show pale yellow discoloration in the early stages to dark red or almost black in later stages, most pronounced in the rhizome (Viljoen, 2002; Daly and Walduck, 2006). In the pseudostem, brown discolored vascular stands and sometimes the bunch stalk occurs (Viljoen, 2002; Moore *et al*. 1995).The advances in the internal symptoms influences the appearance of external symptoms (Ploetz *et al*. 1994).

1.1.2 External symptoms

Externally, the disease symptoms appears first on the older leaves by becoming yellow, beginning with patches at the leaf margin from the older to the younger leaves, the petiole may collapse and skirting, and sometimes longitudinal cracking of pseudostem (Moore *et al*. 1995; Jackson, 2014; Ploetz, 2015; Viljoen *et al*. 2016). The disease typically shows symptoms of wilting followed by death (Jeger *et al*. 1995; O'Donnell *et al*. 1998). *Plates 1, 2 and 3*

1.2 Distribution and host cultivars

The disease is widely distributed throughout all banana growing areas of Tanzania (FAO, 2009). Karangwa *et al*. (2016) reported that, among the East and Central African countries Tanzania is the country with highest disease incidence (63.6%) in many farms. *Fusarium oxysporum* f. sp. *cubense* exclusively attacks sweet banana cultivars, including Gros Michel – AAA, kayinja (Pisang awak – ABB), kanana (Kisukari Ndizi) and kishubi (Ney Poovan – AB) (Moore *et al*. 1995; Tushemereirwe *et al*. 2004). Kisukari Ndizi the favourite cultivar of banana to many farmers in Tanzania is almost devastated by the disease (IITA, 2016). It was also observed and confirmed to attack important banana varieties like the Mchare varieties in Arusha, Kilimanjaro and Mbeya (IITA, 2016).

1.3 Dispersal mechanisms

The fungus is commonly spread through movement of infected planting material, infested soil, furrow irrigation andsurface run-off water (Davis, 2005; Daly and Walduck, 2006; Jackson, 2014). The spread can also occur through infested soil attached to vehicles, tools and shoes (Daly and Walduck, 2006). Untreated soil used as a potting medium can transmit the fungus and animals can also move around fungal spores present in soils.The fungus can persist in soil as chlamydospores in the absence of the host for more than 30 years and germinate in the presence of host roots (Ploetz 2006; Paul *et al*. 2011; Dita *et al*. 2018).

1.4.0 Management options

Managing *fusarium oxysporum* f. sp. *cubense* with its soil-borne nature, long latency period and persistence once established, makes it difficult to control without drastic strategy changes (Wibowo *et al*. 2013; Ordonez *et al*. 2015). Several feasible control measures have been employed to manage this disease, which include, prevention, sanitation, use of disease free planting materials, resistant or tolerant cultivars, use of biological agents, burning of infected materials, use of silicon and calcium (Nel *et al*. 2006; Ploetz, 2006; Ploetz, 2015). Depending on the circumstance, the use of integrated approaches in controlling the disease is advocated in this review in order to curb the weaknesses of different methods.

1.4.1 Prevention

Applying disease preventive measures such as planting in fields not infected with *Fusarium oxysporum* f. sp. *cubense* using disease free propagation materials, is considered effective in managing this disease (Nel *et al*. 2006). Another means is restriction on the free movement of suckers, tools and boots from one farm to another if of doubtful quality or disinfect all equipment before and after use (Ssebunya, 2011). It has been reported earlier that, Fusarium race 1 is distributed everywhere in banana growing areas in Tanzania, so the method is limited unless in a newly opened farms. Fusarium wilt disease is difficult to eradicate once established in the field due to the fact that, exclusion of the pathogen from the soil is impossible (Davis, 2005; Ploetz, 2015). Therefore, there is a need for campaigns to create awareness to all stakeholders on the disease symptoms, potential effects and impose quarantine on movement of banana plant related materials from place to place.

1.4.2 The use of resistant or tolerant cultivars

The use of host resistance and tolerance cultivars makes a major contribution towards world food production and is the most effective and sustainable management option for fusarium wilt disease (Ploetz and Pegg, 2000; Moore *et al*. 2001;Companioni *et al*. 2006; Paul *et al*. 2011 Bohra *et al*. 2014). Both innate and induced resistance have been reported to significantly reduce the effects due to fusarium wilt disease (Wibowo *et al*. 2013; Siamak and Zheng, 2018). However, achievement in breeding for resistance to fusarium wilt disease has been slow,due to the fact that, breeding is time consuming, expensive, and constrained by sterility of most cultivated bananas, polyploidy nature of the plant, negative correlation between yield and resistance, and resistant breaking isolates (Novak, 1992; Fortunato *et al*. 2012; Chen *et al*. 2013; Hu *et al*. 2013; Nabi and Chodhary, 2015).

Currently in Tanzania, the commonly grown and preferred cultivars (Mchare and Kisukari Ndizi) by community consumers are susceptible to fusarium race 1 (Kangire *et al*. 2001a). Introduction of new resistant cultivars to curb some production challenges like diseases, the acceptability of cultivars has been with difficult (Kilimo trust, 2012). Karamura *et al*. (2016) and Nabuuma *et al*. (2018) reported that sensory reasons, cost, accessibility, loss of resistance to pests and diseases, and reliability of variety types from trusted sources are some of the major reasons for less acceptability.

The banana breeding program should therefore focus on breeding hybrid cultivars of Mchare, Kisukari and other preferred local cultivars, which will cut across many consumers' preferences and needs.

1.4.3 Sanitation

The importance of effective sanitation method for the control of Fusarium wilt disease of banana has been highlighted many times by many authors (Moore *et al*. 1999b; Viljoen, 2002; Daly and Walduck, 2006). Sanitation includes procedures like cleaning of footwear, treatment of vehicles and machinery, disinfection of tools and use of footbath with surface disinfectants such as sodium hypochlorite and formaldehyde (Ssebunya, 2011; Ghag *et al*. 2015). It is highly recommended to destroy and remove all infected

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IJCSRR @ 2021
www.ijcsrr.org

banana plants and their corms, chop, dry and compost them (Ssebunya, 2011). The procedures aredirected to inoculum reduction, eliminating infected plants and delimitation of infected areas (Viljoen, 2002; Daly and Walduck, 2006; FAO, 2014).

Therefore, there is a need for agricultural extension officers to conduct training campaigns related to sanitation issues to limit spread of the disease to new areas and reduce inoculum in infected areas.

In some researches the use of chemicals has been reported to be effective but their disadvantages outweighs their advantages, this calls for further research to identify chemicals which are effective and environmental friendly.

1.4.4 Biological agents

The use of biological control agents such as predators, parasites and pathogens have been proved to be an environmental friendly disease management strategy (Xue *et al*. 2015; Ghag *et al*. 2015; Deltour *et al*. 2017; Fu *et al*. 2017).The appropriateness of biocontrol approach depends on the pathosystem (Kidane, 2008). The biocontrol approach is targeting to manage the pathogen's inoculum, protect the plant surfaces from infection, and to cross protect or induced resistance (Cook and Baker, 1983). The control mechanism is achieved in the rhizosphere by competing with *Fusarium oxysporum* f. sp. *cubense* for essential nutrients, adhesion sites on the plant surface, production of secondary metabolites and enzymes (Ghag *et al.* 2015). Again, these biocontrol agents act as regulators of plant growth providing an added advantage in durable resistance against pathogens (Kidane, 2008; Ghag *et al*. 2015). Researches have shown that,intrinsic microbial communities or specific sub-populations have the potential to suppress 50%-80% pathogen infectivity to host plants (Thangavelu 2002; Thangavelu *et al*. 2004). Many researches have reported fungi and bacteria being important biocontrolfor *fusarium oxysporum* f. sp. *cubense*in banana, *Trichoderma spp*. (Kidane, 2008; Alabouvette, 2009; Behera, 2016), *Bacillus spp.* (Farhana *et al*. 2011; Govindasamy *et al*. 2011; Tan *et al*. 2013; Gang *et al*. 2013; Behera, 2016), *Pseudomonas fluorescens* (Belgrove, 2007; Mohammed *et al*. 2011), *Streptomyces* (Lian *et al*. 2009; Thangavelu and Mustaffa, 2012), Non-pathogenic *Fusarium oxysporum* (Belgrove, 2007). Contrary to the reported importance of biological agents in controlling *Fusarium oxysporum* f. sp. *cubense*, Zhang *et al*. (2013), reported that biological control have been with little success.The reasonmight be due to little field research on evaluation of biocontrol efficacy for Fusarium wilt disease of banana (Ploetz, 2004).

In order to effectively utilize the biocontrol agents, there are need to understand the biology, epidemiology and interaction within the pathosystem. We therefore, recommend researches on biocontrol agents to focus on the results of specific interaction within the pathosystem.

1.4.5 Intercropping

Intercropping is reported to play a big role in disease management, by altering vector dispersal, changes in moisture, host morphology and physiology, and pathogen inhibition (Boudreau, 2013). Studies in China have shown that, intercropping and rotating banana with Chinese chive (Allium spp.) resulted in a significant reduction of banana fusarium wilt disease (Zhang *et al*. 2013; Wibowo *et al*. 2015). Huang *et al*. (2012), working with banana and chinese leek (*Allium tuberosum*), observed highest reduction of fusarium wilt incidence and disease severity index by 97 % and 96 %, respectively. The reduced incidence of fusarium wilt in the presence of Chinese chives could be due to inhibitory effects on *Fusarium oxysporum* f. sp. *cubense* mycelial growth and spore germination (Nadarajah *et al*. 2016).

There are few researches reported on the effects of intercropping of banana and other crops as a disease management tool. We therefore recommend that, intercropping research should focus on rhizospheric interaction effects so as to come up with an intercrop that can inhibit growth and spore germination of the pathogen.

1.4.6 The use of silicon and calcium

Improvement of plant nutrition is suggested as an important integrated control method to fight banana diseases (Datnoff *et al*. 2007; Atim *et al*. 2013). Elements like Silicon and calcium are known to decrease the severity of diseases of many economically important crop species through induced resistance (Datnoff *et al*. 2007; Zhang *et al*. 2014; Rodrigues *et al*. 2015). Silicon application induces broad spectrum stress tolerance in many plant species without the occurrence of resistance trade-offs on growth and yield penalties (Guo, 2006; Bockhaven, 2011). Adequate application of Calcium inhibits the formation of pectolytic enzymes produced by fungi and bacteria (Gupta *et al*. 2017) and interferes with spore production and their behavior (Sugimoto *et al*. 2008).

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DOI: 10.47191/ijcsrr/V4-i10-11, Impact Factor: 5.825
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www.ijcsrr.org

Currently in Tanzania there are no significant researches which have been undertaken to assess the silicon and calcium induced resistance effect in the banana. we therefore recommend researches on the use of Silicon and Calcium as a component of disease management tool.

2.0 BANANA XANTHOMONAS WILT/BACTERIAL WILT

Banana Xanthomonas Wilt (BXW) is one of the major threat to the banana production and livelihoods of millions of people (Kagezi *et al*. 2006; Biruma *et al*. 2007; Karamura *et al.* 2008;Ochola *et al*. 2015). The disease is caused by *Xanthomonas campestris pv. musacearum*a member of *Xanthomonadaceae* (Biruma *et al*. 2007; Shimelash *et al*. 2008; Tripathi *et al*. 2009; Ochola *et al*. 2015). The bacteria is a motile, gram-negative, rod-shaped bacterium possessing a single polar flagellum (Tripathi *et al*. 2009). In Tanzania BXW disease was first recorded in september 2005 at Kabale village, Muleba District in Kagera Region (Mgenzi *et al*. 2006; Carter *et al*. 2010; Shimwela *et al*. 2016).

2.1 Effects of the disease

BXW is a complex problem that is rooted in a multitude of challenges and has shown to be persistent and recurrent (McCampbell *et al*. 2018). The disease is among the most destructive bacterial pathogens, causing up to 100% yield loss (Muchuruza and Melchior, 2013; Ochola *et al*. 2014; Ochola *et al*. 2015). Yield losses are associated with early ripening and rotting of fruits (Rugalema and Mathieson, 2009).The affected fruits have no economic value because they cannot be consumed by humans or livestock (Ochola *et al*. 2014).

The effect due to this has led to severe falls in banana production in areas where the disease was well established, area under banana production and consumption reduced, farmers diversified into other crops or livestock in order to cope with the situation imposed by the disease (Karamura, 2006; Nkuba *et al*. 2015). The disease reduced food security and income at the household level, on families that depended on banana while bunch prices unpredictably doubled (Kubiriba *et al*. 2012; Muchuruza and Melchior, 2013; Nkuba *et al*. 2015; McCampbel *et al*. 2018).

2.2 Symptoms

Banana and plantain plants infected with BXW shows symptoms of folding and yellowing of leaves, the fruits; show premature and scattered ripening, with either blackening or staining of the fruit pulp, whereas the male bud; shrinks and at times falling off (Tripathi *et al.* 2009; Ochola *et al*. 2014; Nakato *et al*. 2016; Tinzaara *et al*. 2016). Upon cutting open any part, pockets of pale yellow ooze or bacterial exudate appears within 5-15 minutes (Nakato *et al*. 2016; Shimwela *et al*. 2016; Tinzaara *et al*. 2016) (Plate 4, 5 and 6).

2.3 Distribution and host cultivars

Banana Xanthomonas wilt disease has surged over from Muleba District, to Bukoba rural, Karagwe, Misenyi, Ngara, Biharamulo districts in Kagera region, Tarime district in Mara region and Ukerewe district in Mwanza (Mgenzi *et al*. 2006). The disease indiscriminately attacks all cultivated banana genotypes (Muchuruza and Melchior, 2013), Kalyebara *et al*. (2006), Smith *et al*. (2008) and Vigheri *et al*. (2009) reported that, upon the arrival of the Xanthomonas wilt of banana entire farms were wiped out by the disease.

2.4 Dispersal mechanisms

Generically, *Xanthomonas campestris* pv. *musacearum* is spread bypollinating insectsvectors, (Tushemereiwe *et al*. 2006; Tripathi *et al*. 2009; Shimwela *et al*. 2016), infected suckers used for setting up new plantings,birds and bats (Biruma *et al.* 2007; Nakakawa *et al.* 2017).Use of contaminated garden toolsduring different operations in the farm have been reported facilitate spread of the pathogen(Tushemereiwe *et al.* 2006).Plant infection can occur through soil-borne bacterial inoculum in the roots (Biruma *et al.* 2007; Tripathi *et al.* 2009). The major sources of *Xanthomonas campestris* pv. *Musacearum*inoculum includes; plant residues, contaminated soils and water, infected mats and traded products including fruits, leaves and planting materials (Eden-Green, 2004). Spread of the disease depends on the survival of the bacterium, its mode of transmission and whether the pathogen is carried internally or externally by one or a few specific vectors (Agrios, 2005).

In order to prevent resurgence and or introduction of *Xanthomonas campestris* pv. *musacearum* in new areas, researches should focus on designing simple, cheap and rapid diagnostic test that can be used by farmers and people in border areas to restrict the movement of infected banana related materials and or help in identifying areas for imposition of quarantines.

2.5.0 Management options

For proper and effective BXW disease management, a well-defined and integrated approach is needed. This is because; managing diseases in perennial crops such as banana is difficult due to uninterrupted relationship of host and inoculum over a long period of time (Tripathi *et al.* 2009). Integrated approach can reduce bacterial wilt disease by 20–100% in the field or under laboratory conditions, and typically combines two or three methods among cultural practices and chemical and biological methods (Yuliar *et al.* 2015). BXW disease is managed by employing several methods which includes the following; sanitation, prevention and quarantine, crop rotation, chemicals, use of resistant cultivars and awareness campaigns (Tushemereirwe *et al.* 2006; Okurut *et al.* 2006; Tinzaara *et al.* 2009; McCampbel *et al.* 2018).

2.5.1 Prevention and quarantine

In areas where BXW is absent, careful selection of healthy planting material, using suckers from trusted sources are important means of avoiding introducing this pathogen to new areas (Jogo *et al.* 2011; Yuliar *et al.* 2015; Yemataw *et al.* 2017). Avoiding overflow of water from infected to uninfected fields by creating trenches or drains, removing alternate hosts around plants, and controlling leafhoppers, aphids and mole rats that may transmit (Muchuruza and Melchior, 2013; Yemataw *et al.* 2017).Another way of preventing the spread was through customized laws which were enacted by the local councils or community leaders and reinforced to farmers (Nkuba *et al.* 2015). Quarantines are imposed to restrict movement of banana related materials and products at farm, national and international levels, from infected areas to area where the disease is absent (Etebu and Young-Harry, 2011). Routine surveillance, reporting and continuous information update of the disease are necessary control strategies (Biruma *et al.* 2007; Kubiriba *et al.* 2012).

2.5.2 Sanitation

The method involves several strict sanitary procedures that are used on the farm to avoid transmission of *Xanthomonas campestris* pv. *musacearum* inocula, from plant to plant and farm to farm. Methods like; sterilization, burning, burying, male bud and corm removal aim at reducing the amount of inoculum and preventing their spread.

2.5.2.1 Sterilization

BXW disease spread through cutting tools can be managed by sterilizing tools with fire or JIK (Sodium hypochloride) or suspending the use of cutting tools for at least 3 months (Tushemereirwe *et al.* 2006; Blomme *et al.* 2014).The objective of sterilizing is to keep the tools used for cutting banana fruit bunches and leaves clean and free from bacteria. Installation of footbaths is important, since is an easy and effective way of removing pathogens adhered on shoes (Tesoriero *et al.* 2010).

2.5.2.2 Corm removal, Burning and burying

Reduction of inocula is done through uprooting all the plants by chopping, drying and burningusing manual or herbicides to kill infected symptomatic plants (Okurut *et al.* 2006).Other management practices recommended for BXW include whole affected mat removal, burying or burning of infected materials (Kubiriba *et al.* 2012; Blomme *et al.* 2014; Nakato *et al.* 2017; Blomme *et al.* 2017). Blomme et al., (2008) and Kubiriba *et al.* (2014) showed that Roundup and 2-4-D are effectivein destroying infected plants comparable to manual removal andhas the advantage of reducing labour costs.

2.5.2.3 Male bud removal

Removal of male bud using forked stick immediately after formation of the last hand eliminates inflorescences that attract insects (Tinzaara *et al.* 2006; Biruma *et al.* 2007).The male bud removal has proven effective in preventing the disease incidence (Biruma *et al.* 2007). It has been reported that, the use of forked stick in male bud removal reduces the risk of moving bacteria on cutting tools (Biruma *et al.* 2007). Timing of male buds removal is important and need to be done quickly after the fruit has been set (Blomme *et al.* 2014). The drawbacks are that the method is time-consuming and some farmers consider the male bud is an essential source of juice production (Blomme *et al.* 2014).

Researches should focus on alternative use of male bud, since they are an excellent source of both macro and micro nutrients, are a good source of fiber and protein, phytochemicals known as saponins and flavonoids (Swe, 2012). This will motivate farmers to timely remove the male bud as source of food and cash.

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DOI: 10.47191/ijcsrr/V4-i10-11, Impact Factor: 5.825
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2.5.3 Use of resistant cultivars

The growth of cultivars that are resistant to bacterial wilt is considered to be the most economical, environmentally friendly, and effective method of disease control (Yuliar *et al.* 2015. Breeding for resistance to BXW is of economic importance and sources of resistance have been reported in diploid parents of the edible bananas(Musa balbisiana) and in other crop plants such as pepper (Tripathi *et al*. 2009). IITA in partnership with NARO-Uganda and African Agriculture technology foundation (AATF), managed to identify 65 transgenic plants that exhibited strong resistance against BXW under laboratory and screen-house tests that are in confined field trials (Lopez, 2011). Similarly, Namukwaya *et al.* (2012) reported that, transgenic bananas with ferredoxin-like protein gene under the regulation of the constitutive CaMV35S promoter were completely resistant to BXW under laboratory conditions and in the screen-house. Mudonyi *et al.* (2018) working with banana screening in the field identified heritable traits that confer resistance to BXW in Musa balbisiana, Mbwazirume, M9 and Musa zebrina, and recommended Mbwazirume and M9 should be promoted for farmers growing to complement cultural controls against BXW.

Despite the fact that, resistant cultivars have been identified conventional banana breeding to transfer resistance to farmers preferred cultivars is still difficult and length process. The reasons behind this are, banana are polyploidy with high sterility, long generation time and is costly. We therefore recommend Governments and non-Governmental organizations and other stakeholders should come together; mobilize resources for research on resistant cultivars preferred by the community consumers.

2.5.7 Awareness campaigns

Shimwela *et al.* (2016), reported that, BXW has continued to spread in Tanzania despite an intensive symptomatic plant removal campaign. Jogo *et al.* (2018), demonstrates that a significant number of farmers were still not aware of the potential danger posed by cutting tools in transmitting the disease both in-field and across fields. McCampbel *et al.* (2018) this is due to lack of awareness and knowledge about disease transmission, diagnosis, and disease management. It is further noted that untimely actions, ineffective surveillance methods, and lack of resistance genotypes have been named to hamper the endeavor to prevent the spread and minimize the effect due to the disease (Jogo *et al.* 2018).

Tripathi *et al.* (2009), suggested that, for proper control of diseases of quarantine importance like BXW, awareness campaigns, advocacy, support from policy makers and the donor communities are critical. We therefore propose that, future awareness campaigns need to emphasize on enhancing farmer knowledge on different control practices and early warning on the disease incidence.

2.5.8 Crop rotation

Crop rotation no doubt has been used with benefit of either reducing or completely impeding the growth of pathogens and development of diseases. Sequeira, (1962), reported that, banana rotation with sugarcane plus fallow reduced incidence of bacterial wilt by 48%. There are also several reports on different crops that indicated reduced bacterial wilt diseases by 60% to more than 90% (Katafiire *et al.* 2005; Zhang *et al.* 2013; Wibowo *et al.* 2015). The reason is that, mono-cropping using susceptible host lead to pathogenic population establishment, whereas crop rotation avoids this detrimental effect resulting in reduction of plant diseases (Kurle *et al.* 2001; Janvier *et al.* 2007; Yemataw *et al.* 2017).

There is a need for more researches to identify suitable crops that can be used in banana crop rotation with maximum reduction of pathogen populations, within a shortest period possible. The focus should be on non-host crops that produces chemical inhibitors like *Allium spp*.

3.0 BLACK SIGATOKA DISEASE

Black sigatoka is a leaf spot disease of banana plants, caused by ascomycete airborne fungus *Mycosphaerella fijiensis* (Morlet) (Anamorph *Pseudocercospora fijiensis*) (Henderson *et al.* 2006; Jimenez *et al.* 2007; Churchill, 2011; Viljoen *et al.* 2016; Alakonya *et al.* 2018). The fungus is a sexual, heterothallic, haploid and hemibiotrophic ascomycete within the class Dothideomycetes, order Capnodiales and family Mycosphaerellaceae (Churchill, 2011). The pathogen was identified for the first time in Fiji in the year 1963 (Henderson *et al.* 2006; Churchill, 2011). Over sixty distinct strains with different pathogenetic potentials have been isolated (Bhamare and Kulkarni, 2015).In Tanzania, the disease was first reported in 1987 along the coastal regions; Tanga, Morogoro, Coast and Pemba-Zanzibar (Mourichon *et al.* 1997; Frison *et al.* 1998).

3.1 Effects of the disease

Black Sigatoka is more aggressive, destructive and it has displaced yellow Sigatoka as the predominant leaf spot on banana in most of its range (Ploetz *et al.* 1992; Tushemereiwe and Waller, 1993; Ploezt, 2000). The pathogen infects the plantby both conidia and ascospores, which attacks the leavescausing necrosis either partially or entirely leading to disruption of photosynthesis process that feed the bunch (Ploezt, 2000; Etebu and Young-Harry, 2011; Alvindia, 2012). As the result of infection, diseased plants produce fewer and smaller fruits, have delayed harvest and lower quality fruit due to few number of functional leaves (Alvindia, 2012). Banana plants with leaves damaged by this disease may have up to 50% lower yield of fruit (Etebu and Young-Harry, 2011; Viljoen *et al.* 2016). Estimates of losses due to Black Sigatoka for dessert bananas and plantains ranges from 20 to 80% in the absence of fungicides (Maciel and Pires de Matos, 2003), and production losses of up to 100% in susceptible varieties such as *M. acuminata* Cavendish Grande Naine (*Musa* cv. AAA) and Prata (*Musa* cv. AAB) (de Lapeyre de Bellaire, *et al.* 2006; Jimenez *et al.* 2007; Ganry *et al.* 2012; Brito *et al.* 2015).

3.2 Symptoms of the disease

The first sign of the disease is the appearance of small, dark brown streaks on the lower surface of leaves (Meena, 2017). These streaks enlarge and coalesce forming necrotic lesions with light grey centres and yellow perimeters, the leaves of banana then drops and collapse (Etebu and Young-Harry, 2011; Meena, 2017). Large areas of leaf can be damaged causing a lowering of photosynthetic ability, premature ripening of the fruit and reduction in yield (Meena, 2017).

Stover and Simmonds, (1987) described black sigatoka symptoms into stages as follows; **Stage 1:** Faint, minute, reddish-brown specks on the lower surface of the leaf. **Stage 2:** Specks elongate, becoming slightly wider to form narrow reddish-brown streaks. **Stage 3:** Streaks change colour from reddish brown to dark brown or black, sometimes with a purplish tinge, clearly visible at the upper surface of the leaf. **Stage 4**: The streaks broaden and become more or less fusiform or elliptical in outline, and a water-soaked border appears around each lesion. **Stage 5**: The dark brown or black centre of each lesion becomes slightly depressed and the water-soaked border becomes more pronounced. **Stage 6**: The centres of the lesions dry out becoming light grey, with a bright yellow zone forming between them and the normal green colour of the leaf. The lesions remain clearly visible after the leaf has become necrotic because of their light-coloured centre and dark border.

Jones *et al.* (2000), reported that, black sigatoka symptoms varies, depending on leaf age, physiology, developmental stage of the plant, leaves at the time of infection, level of plant stress, disease pressure, environmental conditions and cultivar.The symptoms of Black Sigatoka are sometimes not distinguishable from those of Yellow Sigatoka, especially in the advanced stages of necrosis, which are very similar (Churchill, 2011; Alvindia, 2012).

3.3 Distribution and host cultivars

By 1990 black sigatoka disease have been reported in all the Cavendish cultivars in regions particularly Coast region, Tanga and Morogoro (Frison *et al.* 1998). Kimunye *et al.* (2018) confirmed the presence of black sigatoka in Mbeya and Kagera regions. A hotspot of black sigatoka disease has also been reported in Arusha at Tengeru Horticultural Research Institute (IITA Plant pathology report, 2018). The disease is considered among the most damaging and costly disease of banana (Alvindia, 2012), which is also reported to be most economic threat in the banana industry in the world (Henderson *et al.* 2006). The definite symptoms of black sigatoka have been recorded on cultivated banana (Musa), plantain (Musa paraduisaca), wild banana (Musa acuminate and their inter-specific hybrids) and subspecies bantesii and zebrina (Maciel and Pires de Matos, 2003; Etebu and Young-Harry, 2011; Alvindia, 2012; Brito *et al.* 2015).

3.4 Dispersal mechanisms

The pathogen reproduces both sexually (ascospores) and asexually (conidia) and are both important for its dispersal (Henderson *et al.* 2006; Bhamare and Kulkarni, 2015). Due to their greater abundance and small size, ascospores are most important in spreading the disease within plants and plantations (Ploetz, 2000). The conidia are mainly spread byrain and irrigation water to short distances, while ascospores are carried by wind to more remote places (Jones and Alcorn, 1982; Mourichon *et al.* 1997; Ploetz, 2000; Bhamare and Kulkarni, 2015). Long distance spread is through the movement of germplasm (infected suckers, diseased leaves) (Jones and Alcorn, 1982; Mourichon *et al.* 1997; Ganry *et al.* 2012).

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 04 Issue 10 October 2021
DOI: 10.47191/ijcsrr/V4-i10-11, Impact Factor: 5.825
IJCSRR @ 2021
www.ijcsrr.org

3.5.0 Management options

Eradication of black sigatoka is based on the principle of early detection; the earlier the detection the more likely are the chances of eradication, otherwise the next best option remains management of the disease (IICA, 2006).The fungus is known to develop rapidly and the time from infection of the leaf tissue to the appearance of spotting is between 8-10 days than other banana leaf spot diseases (Young and Conie 2001). The pathogen produces fast and abundant ascospores, leading to greater infection potential; therefore controls must be geared to cope with the short interval infection (IICA, 2006).

The following are feasible control methods that can be used by smallholder farmers either singly or in combination depending on the goal and environment.

3.5.1 Sanitation

Pruning based on eliminating necrotic leaf tissue, prevents the disease from spreading, this helps to reduce the amount of inoculum available to infect neighbouring plants(Stover, 1972;Jones and Alcorn, 1982; Pérez-Vicente, 1996; Jimenez *et al.* 2007; Etebu and Young-Harry, 2011 Ganry *et al.* 2012). After pruning, the leaves should be placed on the soil underside down, piled one on top the other to reduce ascospores release by windblown and aid decomposition (Gauhl, 1994; Pérez-Vicente, 1998).

Proper plant spacing, control of weeds and removal of diseases suckers facilitates air circulation that will reduce spore lending time on the plant (Henderson *et al.* 2006).

Personnel working and visiting infected farms and premises are required to wear disposable paper coveralls and plastic shoe covers (IICA, 2006).Processing waste and infected plants or parts by compositing help in reduce the pressure of inoculum in the next growth cycle (IICA, 2006).

3.5.2 Nutrient management

Application of balanced nutrition of Potassium, Silicon, Magnesium, Calcium, Nitrogen, have been reported to increase tolerance and possible escape from the effects of black sigatoka disease (Bernstein *et al.* 2011; Pérez-Vicente, 2012; Kablan *et al.* 2012). Nutrients plays an important role in essential biochemical and physical processes in inhibiting pathogen growth, multiplication and ultimate infections (Cakmak, 2005; Jimenez *et al.* 2007; Kablan *et al.* 2012). The nutrients have also been reported to induce resistance in banana (Kablan *et al.* 2012; Rodrigues *et al.* 2015).

Nutrients have been confirmed by many researches to be among important disease management tool but there are fewer researches in the country probably due to negligence or lack of funds. Banana stakeholders need to come together and discuss on enhancing banana nutrient research.

3.5.3 Irrigation

The duration of leaf wetness has a direct influence on the epidemiology of black sigatoka and other banana diseases (Wielemaker, 1990).Moisture film is essential for spore germination, germ tube growth and penetration, sporulation and dispersal (Agrios, 2005). The use of surface irrigation is the best method that avoids wetting of the leaves and creating high humidity (Wielemaker, 1990).

3.5.4 Drainage improvement

Wielemaker, (1990) and Jimenez *et al.* (2007), reported that, two weeks after rain or storms, there is a severe outbreak of black sigatoka disease, so improving drainage is essential to reduce high humidity on the air and duration of leaf wetness. This agrees with Marín *et al.* (1992) and Carlier *et al.* (2000), who also reported that installation of efficient drainage system, facilitate drying and help reduce the relative humidity.

3.5.5 Use of resistant cultivars

The use of resistant cultivar is the only feasible and practical method for black sigatoka disease control for small-scale and subsistence growers (Marín *et al.* 2003). It has been reported that, resistance in this fungus is mainly the result of the interaction between the recessive allele at a major locus and those of at least two independent minor genes with additive effects (Ortiz and Vuylsteke, 1994). These genes have a strong dosage effect at the tetraploid level, which results in higher level of resistance in tetraploid than in diploid hybrids (Etebu and Young-Harry, 2011). Currently in Tanzania, breeding and release of sigatoka resistant genotypes is slow due to the nature of the crop and lack of banana breeding programs in many research centres. Again, some introduced resistant cultivars like FHIA hybrids have faced acceptability and loss of resistance (Kilimo Trust, 2012).

3.5.6 Prevention and quarantine

Prevention and quarantine involves imposition laws and bylaws in the community that will regulate movement of banana related materials within and without. Jones and Alcorn, (1982) and Jones, (1991) reported that prevention reduced the spread of black sigatoka disease into new areas through imposing barriers.The laws and bylaws recommended the following procedures to be followed; 1.restriction of movements of plant material from infected zones, 2.the establishment of quarantine stations, 3.forbidding the use of leaves to protect fruits in vehicles during transport, 4.disinfection of vehicles, 5.inspection of banana plantations and 6.grubbing up the most severely affected fields (Orozco-Santos *et al.* 2002; IICA, 2006).

CONCLUSION

We hereby conclude that, researches should focus on identifying the best and feasible combination of management methods that can be used by farmers. The approach should be pragmatic and geared towards integration of several appropriate methods. Provisions of knowledge on diseases, rapid and accurate diagnostic procedures on plant diseases in the field are essential for effective disease management.

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International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 04 Issue 10 October 2021
DOI: 10.47191/ijcsrr/V4-i10-11, Impact Factor: 5.825
IJCSRR @ 2021
www.ijcsrr.org

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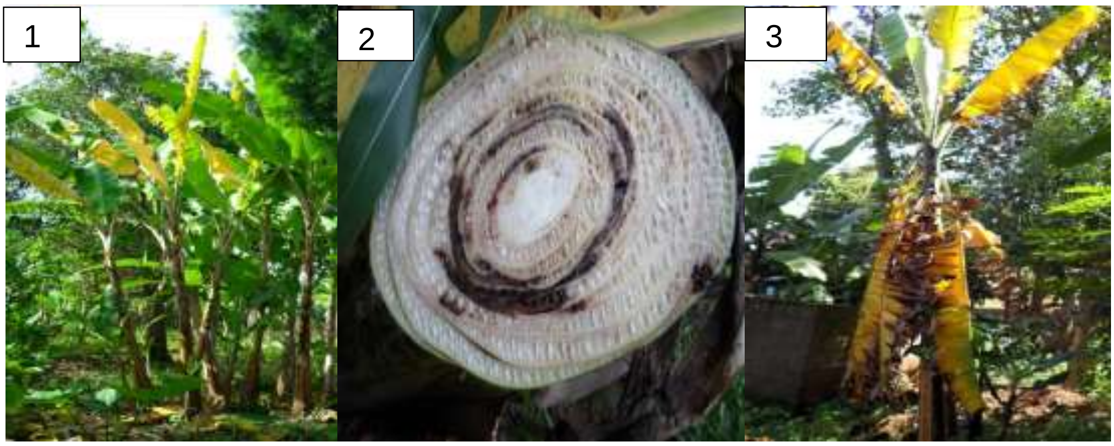
International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 04 Issue 10 October 2021
DOI: 10.47191/ijcsrr/V4-i10-11, Impact Factor: 5.825
IJCSRR @ 2021
www.ijcsrr.org

APPENDIX



Plates 1, 2 and 3: External symptoms of Fusarium wilt on Mchare (left-Arusha), Kisukari Ndizii (between-Mbeya) and to the right internal symptom of Fusarium wilt in pseudostem. **Source**: IITA-Plant pathology Arusha office, May 2016 report.

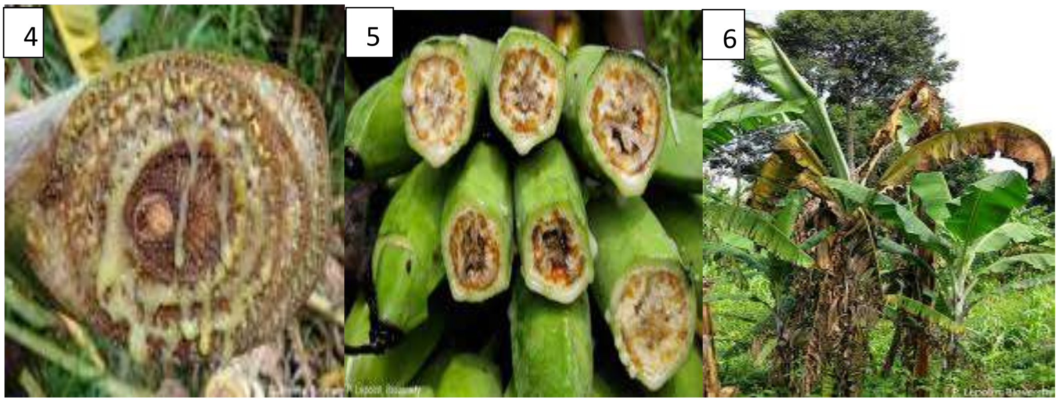


Plate 4, 5 and 6: Symptoms of Banana Xanthomonas wilt disease
(**Source:** https://www.google.com/search?q=banana+xanthomonas+wilt%2Bimage)

Plate 7 and 8: Symptoms of Black sigatoka disease on Mchare and Williams respectively (Jomanga and Lucas, field visit Hort Tengeru (Plate 7) and Mbeya (Plate 8)

Cite this Article: Kennedy Elisha Jomanga, Shija Shilunga Lucas (2021). The Effects, Distribution and Management Options for Major Banana Diseases in Tanzania. International Journal of Current Science Research and Review, 4(10), 1276-1295