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Key Factors Responsible for the Xanthomonas Wilt Epidemic on Banana in East and Central Africa

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Abstract

Xanthomonas wilt of banana, caused by *Xanthomonas campestris* pv. *musacearum*, is a serious threat to sustainable banana production in East and Central Africa. The disease has been confirmed in Uganda, Rwanda, Democratic Republic of Congo, Burundi, Kenya and Tanzania and is continuing to spread. Surveys were carried out between September 2006 and February 2007 in six countries to determine disease incidence and document the key factors responsible for disease spread. Farmers were randomly selected and questioned to obtain data on cultural production practices, and incidence and awareness of Xanthomonas wilt and other key pests and diseases. Incidence of Xanthomonas wilt was 12% in Kenya, 24% in Burundi, 23% in Rwanda, 16% in Tanzania and greater than 65% in surveyed areas of both Uganda and eastern Democratic Republic of Congo. The key factors for disease spread are an abundance of susceptible cultivars, a suitable environment for insect vectors, long-distance trade in bananas, lack of knowledge on disease diagnosis and management, and cultural practices that inadvertently spread disease. Over 60% of the respondents across the region indicated that they remove male buds, which can reduce the importance of insect vectors. However, less than 25% debud regularly, and more critically, less than 10% debud with the intention of managing Xanthomonas wilt, except in Uganda where awareness is higher because of a strong extension programme, well funded publicity and farmer training programmes. When establishing new plantings, more than 60% of farmers obtain suckers from their own farm while 30% also get suckers from neighbours. Knowledge of, and access to, clean planting material is a major regional constraint, except in Uganda. Harvesting of green leaves is one of the predisposing practices, especially in Uganda, western Kenya and Tanzania, where leaves are used for cooking and feeding livestock. The perception that Xanthomonas wilt is similar to Fusarium wilt, which complicates diagnosis and slows down the initiation of an appropriate response, has also contributed to disease spread. Banana trade from epidemic zones is an additional factor requiring intervention. Overall levels of knowledge on practices for disease management are low.

INTRODUCTION

Banana and plantain are key crops for food security and income generation for over 20 million people in East and Central Africa. In addition to local consumption and value addition, there is a significant regional export trade in bananas (Tushemereirwe et al., 2006). Xanthomonas wilt of banana is currently a serious threat to productivity in the region. The disease is caused by *Xanthomonas campestris* pv. *musacearum* and was first

reported in Ethiopia on *Ensete ventricosum* (Yirgou and Bradbury, 1968). For many years, the disease was only found in Ethiopia until outbreaks occurred in Central Uganda in 2001 (Tushemereirwe et al., 2003). The disease is now found in Kenya, Tanzania, Burundi, Rwanda and the Democratic Republic of Congo (D.R. Congo) (Mwangi et al., 2007). The disease is transmitted by insect vectors, contaminated tools and infected planting materials (Biruma et al., 2007), and it attacks all banana cultivars grown in East Africa, although some cultivars are more affected than others. Disease symptoms are rapid yellowing and wilting of leaves, premature ripening and rotting of fruits leading to eventual death of the entire mat (Eden-Green, 2004). In Uganda, losses due to Xanthomonas wilt were estimated at US$ 34.3 million in 2005, US$ 75.6 million in 2006, and are projected to reach US$ 229 million in 2010 (Tushemereirwe et al., 2006). According to unpublished progress reports of the Crop Crisis Control Project (C3P), the disease has been devastating in Rwanda with over 750,000 infected mats already uprooted, while over 50,000 mats have been uprooted in Tanzania. Measures to reduce disease spread include removing the male flowers to avoid insect-transmitted infections, disinfecting tools and using healthy planting material. Infected mats should be uprooted to eliminate sources of inoculum and fields fallowed or put under rotation with non-host crops for at least 6 months (Turyagyenda et al., 2008).

Recent work has focused on understanding disease epidemiology, improving diagnostics technology, developing sustainable disease management methods and developing resistant cultivars through genetic transformation (Tripathi et al., 2004; Blomme et al., 2005; Mwangi et al., 2007). A major challenge has been keeping track of the disease and understanding the factors influencing its spread in different countries. Except in Uganda, functional surveillance and response systems are lacking. Responses to reported outbreaks have sometimes been inappropriate, partly due to poor understanding of the key elements affecting disease spread. C3P was a collaborative project involving government and non-government, regional and international institutions in East and Central Africa. The project aimed to improve responses to Xanthomonas wilt of banana by building the capacity of affected communities to cope with effects and prevent further disease spread. Part of the activities carried out in the C3P were geared to improve understanding of the factors that increase vulnerability to the disease, and determine appropriate response strategies.

MATERIALS AND METHODS

Surveys were carried out between September 2006 and February 2007 in Burundi, Rwanda, Uganda, western Kenya, the Kagera region of Tanzania and the eastern D.R. Congo, targeting areas known to be affected or threatened by Xanthomonas wilt of banana. The survey was undertaken in two stages, both designed to capture information on factors that could accelerate disease spread or increase vulnerability of farming communities to the disease. Stage 1 involved the administration of a questionnaire in an oral interview to a group of farmers in the survey area. Farmers with plantations of at least 2 years old, near the homestead for easier access and with a minimum of 60 mats for adequate sampling were selected randomly in each area. There were 167 farmers selected in Kenya, 594 in Tanzania, 165 in Burundi, 196 in Rwanda, 600 in D.R. Congo and 358 in Uganda, with each farmer being counted as one respondent (Table 1). The questions addressed presence of Xanthomonas wilt and other diseases, farmer awareness of management practices, banana cultivars grown and sources of planting material, cultural practices (e.g. trashing, weeding, desuckering, debudding and intercropping) and any

other issues of that could be of relevance to disease spread and management. There was a minimum distance of 5 km between farms and GPS locations. Sampling was more concentrated in areas with Xanthomonas wilt, with fewer farms being sampled as number of farms with disease in an area reduced. Stage 2 involved visiting the banana plot to physically inspect plants for disease symptoms. In each farm, 30 plants were randomly selected by making two diagonal transect walks. In each country, the number of farms sampled was equal to the number of respondents indicated in Table 1. The cultivar type was identified and plants assessed for infection by Xanthomonas wilt and any other diseases and pests.

RESULTS AND DISCUSSION

Xanthomonas wilt of banana was found in the six countries, with the disease being confirmed officially in Kenya and Burundi in October 2006. In Kenya, Xanthomonas wilt was only present in Bungoma, Busia and Teso districts, with the affected farms spread over an area spanning about 100 km aligned along the common border with Uganda (Table 1). Most of the plants infected in western Kenya had symptoms on the inflorescence, indicating insect-transmitted infection (Eden-Green, 2004), though it is possible the initial inoculum was introduced through infected bunches or suckers brought from affected districts in Uganda. In Rwanda, most of the diseased farms were found in Rubavu district where the original outbreak occurred in 2005. In Uganda, incidence was highest (>85%) in the eastern and central districts of the country close to Mukono where the initial outbreak occurred in 2001 (Tushemereirwe et al., 2003). Disease was least in the western district with only 6.9% of diseased farms in Mbarara. In D.R. Congo, Xanthomonas wilt was observed in more than 65% of the farms in Masisi, Rutshuru and Watalinga (Table 1). Compared to data taken approximately 1 year earlier, these surveys revealed a dramatic increase in the area affected by disease in Nord Kivu province, and contests the previously held view that Xanthomonas wilt is spreading at a slow rate of less than 10 km/year (Blomme et al., 2005). In Burundi, most of the farms with disease had few mats infected (<30%), except Cibitoke where a few farms with up to 100% of mats infected were found. In Tanzania, Xanthomonas wilt was found in Biharamulo and Karagwe districts, adjacent to Muleba district where the initial outbreak was reported in January 2006. While 74% of infected farms in eastern and central districts of Uganda became infected between 2001 and 2004, the western districts (Mbarara and Ntungamo) were infected in 2005.

There is increasing evidence that epidemics of Xanthomonas wilt can be contained. In this study, 10.6% of respondents in districts in East and Central Uganda reported they had successfully eradicated Xanthomonas wilt from their farms over the past 2 years, while another 18% had managed to keep the disease out of their farms, after implementing recommended control measures, based on principles discussed below.

Tools and Disease Spread

Tools are used for removing leaves, weeding, harvesting and removing excess suckers and dry fibres. When a machete or knife is used on an infected plant and subsequently on another healthy plant without disinfecting first, the pathogen is propagated further. The equipment used to remove contaminated leaves is one of the key factors of Xanthomonas wilt spread in Uganda and Tanzania, and increasingly in Kenya. In these countries, leaves have various domestic uses, feeding livestock, providing mulch and generating income. Table 2 shows the number of farmers that engage in leaf removal

in different countries. In Uganda, farmers prune leaves to avoid plant toppling during strong winds as plants near maturity, to reduce shading or to clean the plant of senescent and diseased leaves. The East African highland banana cultivars (AAA genome) can withstand pruning every 7-10 days without reduction in yield (Holderness et al., 1999). In central Uganda, fresh banana leaves of 'Kayinja' (ABB, syn. 'Pisang Awak') are used daily in almost every household for steaming matooke. In this area, green leaves have a ready market, especially in urban centres. In a recent study in Luwero district, leaf removal was observed to be the second most practiced operation, representing 25-30% of the time spent in banana farms in six villages (Ssenyonga et al., 2005). After losing plantations to Xanthomonas wilt, some farmers have been reported to maintain their plantations for the sole purpose of harvesting leaves for sale (Bagamba et al., 2006). The risk of disease spread is therefore significantly increased due to use of tools on fresh plant parts that are likely to be more receptive to the pathogen once it is introduced.

Banana Cultivars and Disease Spread

Although there is considerable diversity of banana germplasm in East and Central Africa, a recent review suggests that all cultivars are susceptible to Xanthomonas wilt though those grown for juice extraction seem to succumb faster to the disease (Biruma et al., 2007). Therefore, where outbreaks occur, the disease has a continuous belt of susceptible hosts, which complicates efforts to prevent spread.

The existence of ecological conditions suitable for insect vectors is also believed to influence infection (Mwangi et al., 2006). It has been suggested that the exotic cultivars 'Pisang Awak', 'Kivuvu' (ABB genome, syn. 'Bluggoe'), 'Bogoya' (AAA genome, syn. 'Gros Michel') and 'Sukari Ndizi (AB genome) have higher sugar content in their nectar which makes them more attractive to insect vectors (Kagezi et al., 2006).

One key trait that influences disease spread in different varieties is the male bud. In varieties that have dehiscent male buds, all known insect transmission of Xanthomonas wilt occurs through the scars that are left behind when the male flowers fall. Varieties that have persistent male flowers and bracts do not get infected through the male flowers (Biruma et al., 2007). For varieties with dehiscent male flowers, the risk of infection is believed to be reduced when male bud removal is practiced, as it is in the cultivation of some cooking cultivars in western districts of Uganda (Bagamba et al., 2006). However, this study found that a majority of the farmers in the six countries are not practicing debudding (Table 2) as has been recommended for control. In a previous study in central Uganda, Kagezi et al. (2006) reported inconsistencies in implementation of debudding, with most farmers debudding sporadically or when the bud is already too old for the practice to be effective. Some farmers are reluctant to remove male buds, citing traditional customs or a belief that debudding affects juice quality or because of a lack of time (Bagamba et al., 2006).

In some regions of Ethiopia and central Uganda where 'Pisang Awak' is abundant and debudding is rarely practiced, higher rates of Xanthomonas wilt spread have been noted at altitudes below 1700 m above sea level (Addis et al., 2004; Blomme et al., 2005; Kagezi et al., 2006). Abundance of these cultivars with minimal debudding could accelerate disease spread where insect vectors thrive. During this survey, all countries were found to have mid-altitude regions (850-1400 m) that are suited to insect vectors. Above 1700 m, as in Rwanda and Masisi (east D.R. Congo), Xanthomonas wilt infection through flowers is less, even when 'Pisang Awak' is abundant (Mwangi et al., 2006), which indicates a reduced role for insect vectors.

Where disease spread is predominantly through tools, susceptibility of cultivars is also important, as observed in Ntungamo and Mbarara districts of Uganda where cooking East African highland banana cultivars are more abundant. Although farmers in this area vigorously practice debudding, some of the recent outbreaks were difficult to eradicate due to use of contaminated tools (Tushemereirwe et al., 2006). During this survey, a few cultivars were identified that do not succumb to infection through the inflorescence thanks to their persistent male flowers and bracts, which restrict insect access to infection sites. These cultivars are mostly East African highland types, e.g. 'Mbwazirume', 'Nakitembe' and 'Gonja' in Uganda, and 'Inkazikamwa' and 'Incakara' in Rwanda, but they are not preferred by many farmers and thus are unlikely to have much impact.

In Burundi, 'Pisang Awak' is grown by 34.4% of farmers while in western Kenya, the susceptible dessert cultivar 'Sukari Ndizi' is grown by 59% farmers. In Rwanda, ABB brewing cultivars have been reported to be the most dominant (Gaidashova et al., 2005), but our findings show that the highly susceptible dessert cultivar 'Kamaramasenge' is grown by 48% farmers. In Tanzania, over 80% of the bananas produced in the Kagera region are cooking varieties, but 'Pisang Awak' is still grown by 15% farmers. In the central and eastern region of Uganda, 'Pisang Awak' is popular for brewing and is widely grown (in some areas by >75% of the farmers). The regional distribution of banana cultivars is influenced by market opportunities, dietary preference and food security roles, as well as adaptation to prevailing biotic and abiotic stresses (Gaidashova et al., 2005).

Planting Materials and Disease Spread

In East Africa, the demand for suckers has recently increased drastically as farmers seek to re-establish plantations lost to Xanthomonas wilt. In a participatory study in central Uganda, Ssenyonga et al. (2005) found suckers to be an important source of income, with 26% of the suckers produced being sold locally. However, suckers are an important means of spread for systemic bacterial diseases of banana (Hayward, 2006).

In the six countries surveyed, over 90% farmers were obtaining suckers from their own or neighbours' fields. Due to the latent nature of Xanthomonas wilt infection, especially in the early stages, farmers often transplant already diseased materials. The danger of using infected suckers was observed in early 2007 in Tanzania where an outbreak occurred in the north-eastern Tarime area of Mara district. The source of the infection was traced to infected suckers that had been transported by boat over Lake Victoria from Bukoba district in the Kagera region. A similar risk apparently faces Rwanda and Burundi where refugees returning from camps in Tanzania have been observed to carry with them suckers of the cultivars they liked in the Kagera region, which could be potentially infected.

Within the C3P project, macropropagation is being promoted as an alternative cost-effective method for producing clean suckers.

Removal of Infected Mats

Removal of infected mats is recommended so as to reduce sources of inoculum (Eden-Green, 2004) and also free up the affected land for alternative use. This study identified difficulties in uprooting as one of the key challenges in Xanthomonas wilt management. In Rwanda, recent experience showed that one man could only uproot and bury two mats per day. In addition to the physical difficulties, farmers lack motivation to remove mats since there is no immediate gain. The C3P is addressing these challenges by

organising support in terms of a 'Food-for-Work' programme and providing seeds of alternative crops to be planted where banana is removed.

The importance of banana and availability of land for alternative enterprises is an important factor in determining how farmers handle infected mats. In western Kenya, where bananas have less economic importance, almost all farmers have abandoned the diseased mats without effort to uproot them. In parts of eastern D.R. Congo, where land is scarce, farmers have been making efforts to remove the plants by cutting down the stems and cultivating sorghum, cocoyam or beans in the space between the banana stumps. Some have even been putting soil on top of the stumps on which they grow beans. The major challenge is the continued resprouting of the stumps, which continue to harbour inoculum.

Across the region, most farmers that have experienced Xanthomonas wilt appreciate that diseased mats serve no purpose and should be removed. However, very few farmers have made attempts to uproot, despite the fact that many indicated they would (50% in Burundi, 82% in Kenya, 79% in Rwanda). In Tanzania, the involvement of local government authorities ensured the community was fully mobilised to remove all infected mats. In Uganda, Xanthomonas wilt has been eradicated in at least 15 sub-counties due to effective mobilisation of farmers to remove infected plants as soon as an outbreak is spotted (Tushemereirwe et al., 2006).

Disease Diagnosis and Disease Spread

In the Great Lakes region, Xanthomonas wilt is a fairly new disease that is not well understood, with many farmers yet to experience its impact. There is thus considerable lack of knowledge about the disease in the region, which is coupled to non-existent or inadequate capacity for disease diagnosis. The failure to appreciate the threat of Xanthomonas wilt has resulted in a slow response from the responsible institutions. The lag period between initial outbreak and intervention allows the disease to spread further.

The presence of other banana diseases that manifest symptoms resembling those of Xanthomonas wilt has complicated correct diagnosis, sometimes leading to incorrect decisions on measures to be taken and as such contributing to disease spread. Fusarium wilt, caused by *Fusarium oxysporum* f. sp. *cubense* and widely spread in the Great Lakes region (Fig. 1), is the disease that is most commonly confused with Xanthomonas wilt (Ploetz, 1990). Both diseases cause similar leaf yellowing and wilting symptoms. But the management measures required for these two diseases are not the same. While plants infected with Fusarium may continue to yield, albeit with reduced productivity, management of Xanthomonas wilt would involve removal and appropriate disposal of all infected plants. Failure to correctly identify Xanthomonas wilt may thus lead to disease spread if plants are not destroyed, while misdiagnosis of Fusarium wilt as Xanthomonas wilt may lead to unnecessary uprooting.

Trade in Bananas and Disease Spread

The economic importance of banana derives largely from profitable trade with markets often far from the production areas. The long-distance movement of bananas presents a considerable risk for Xanthomonas wilt spread. For example, dessert bananas ('Gros Michel' and 'Sukari Ndizi') exported from Uganda to Kenya are routinely wrapped in pseudostem sheaths to protect fruits from blemishes. If contaminated with bacteria, such packaging residues could provide primary inoculum for Xanthomonas wilt.

Quite often, there are no well structured procedures for handling banana residues at destination markets, and some farmers collect and use them as mulch. In a recent study, Tumushabe et al. (2006) demonstrated the ability of freshly infected banana residues to provide inoculum when they are thrown into farms where banana roots are injured, either mechanically (during weeding) or by pests.

Xanthomonas wilt could also be carried in latently infected bunches. In Rwanda, it is speculated that the outbreaks in Rubavu district were caused by bacteria introduced in a latently infected bunch imported for brewing from D.R. Congo. In Tanzania, the initial Xanthomonas wilt outbreak in Muleba district is reported to have started in a farm where male buds used to cover jerry cans of banana beer imported from Uganda were discarded (S. Gaidashova [ISAR] and B. Mgenzi [ARDI], pers. commun). Hayward (2006) has pointed out the need to limit transportation of bananas from diseased areas because exudates from infected bunches could be transmitted by insects, machetes or other means. Regulating trade in bananas for Xanthomonas wilt management has largely been unsuccessful, mostly due to the economic implications and associated sensitivities. In Tanzania, for instance, over 150 tonnes of bananas are transported by boat to Mwanza every week from Bukoba. This route could be easily monitored to ensure infected bananas are not transported. However, earlier efforts to impose quarantine failed because local government councils needed the revenue levied from banana trade.

CONCLUSIONS

This study has identified several factors that could be targeted with interventions to prevent Xanthomonas wilt spread. Recommended control measures include timely removal of male buds, disinfection of tools and planting suckers from certified sources. Some of these factors, e.g. germplasm, would be addressed sufficiently through investment in technology development, while others require specific policy interventions, e.g. spread through traded products. Farmers need to be involved in finding solutions to Xanthomonas wilt and they should feel that the benefits of implementing the recommended interventions outweigh the costs. It will be important to increase efforts to raise awareness so that farmers and other stakeholders know how to recognise the disease and take appropriate control measures.

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Tables

Table 1. Percentage of farms with Xanthomonas wilt of banana in Rwanda, Tanzania, Uganda, Burundi, Kenya and D.R. Congo.

Rwanda			Tanzania			Uganda		
Region	n	%	Region	n	%	Region	n	%
Karongi	17	0.0	Biharamulo	44	34.0	Nakaseke	27	48.0
Kayonza	12	0.0	Bukoba	134	9.7	Mukono	15	66.7
Kirehe	19	0.0	Karagwe	91	28.6	Luwero	43	88.4
Ngoma	10	0.0	Kasulu	60	0.0	Kayunga	39	89.7
Nyamasheke	10	0.0	Kibondo	34	0.0	Iganga	31	87.0
Rubavu	72	68.0	Kigoma	40	0.0	Kamuli	10	0.0
Rulindo	8	3.0	Misenyi	17	29.4	Mbale	44	88.6
Rusizi	16	0.0	Muleba	99	29.3	Sironko	27	100
Rutsiro	17	0.0	Ngara.	59	0.0	Hoima	31	77.4
Rwamagana	16	0.0				Mbarara	29	6.9
						Ntungamo	21	47.6
						Kabarole	22	86.4.
Burundi			Kenya			D.R. Congo		
Region	n	%	Region	n	%	Region	n	%
Bubanza	6	50.0	Busia	20	5.0	Masisi	130	68.4
Bujumbura	6	50.0	Teso	21	61.9	Rutshuru	120	63.3
Bururi	14	14.3	Bungoma	14	14.0	Mutwanga	80	42.5
Cankuzo	12	8.3	Butere	17	0.0	Mahagi	150	50.0
Cibitoke	12	50.0	Kuria	11	0.0	Watalinga	100	67.0
Gitega	8	25.0	Migori	19	0.0	Goma	20	75.0
Karuzi	6	0.0	Kisii	11	0.0			
Kayanza	12	8.3	Nyamira	15	7.0			
Kirundo	13	38.5	Rachuonyo	12	0.0			
Makamba	11	27.3	Gucha	9	0.0			
Muramuya	8	37.5	Vihiga	10	0.0			
Muyinga	12	25.0	Siaya	5	0.0			
Mwaro	5	0.0						
Ngozi	12	25.0						
Rutana	12	66.7						
Ruyigi	15	0.0						

n = number of farms sampled; % = percentage of farms sampled with Xanthomonas wilt; Region = district for Rwanda, Tanzania, Uganda and Kenya; province for Burundi and territoire or district for D.R. Congo.

Table 2. Percentage of farmers practicing debudding and leaf harvesting to control Xanthomonas wilt in Rwanda, Tanzania, Uganda, Burundi, Kenya and D.R. Congo.

Country	Practicing debudding[3]	Debudding regularly[4]	Debudding to control Xanthomonas wilt[5]	Removing leaves	Removing leaves regularly[6]

Kenya	52.9	10.6	7	55.8	55
Uganda[1]	77.7	40	26.4	83	68
Uganda[2]	83	100	0	100	100
Burundi	79.4	36.5	0	91.5	60
Rwanda	74	24.4	3.06	88	64
Tanzania	71.8	28.7	16	>50	27
D.R. Congo	34	7	0	17	0

[1]districts in East and Central Uganda; [2]districts in West Uganda (Mbarara and Ntungamo); [3] Farmers who remove male buds, but not regularly; [4]Farmers who visit their farms at least once per month to remove male buds (for various reasons), but not always early enough or using the right method to prevent Xanthomonas wilt; [5]Farmers who debud with specific intention of preventing Xanthomanas wilt infection; [6]Farmers removing leaves at least once per week.

Figures

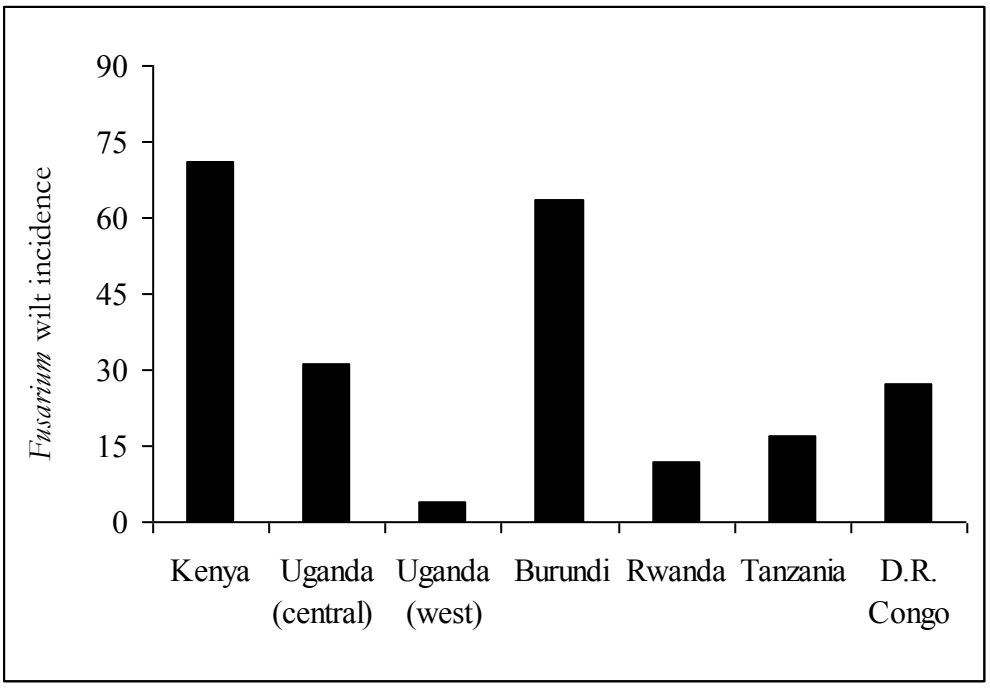

Fig. 1. Percentage of farms surveyed in Kenya, Central Uganda, West Uganda, Burundi, Rwanda, Tanzania, and D.R. Congo with Fusarium wilt.