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Review

Approaches for the control of banana *Xanthomonas* wilt in East and Central Africa

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The livelihoods of millions of banana farmers in East and Central Africa have been threatened by the devastating epidemic of banana *Xanthomonas* wilt (BXW) caused by *Xanthomonas campestris* pv. *musacearum*. The disease is widespread and has been reported in East and Central Africa. The economic impact of the disease emanates from loss of yield and cost of control measures. All banana cultivars grown in the region are susceptible to BXW and no source of resistance has been identified. Cultural interventions are therefore the most practical and recommended practices for BXW control. A number of approaches: farmer field schools, community action, going public and top-down conventional approaches (traning of trainers, mass media and posters) have been used to mobilize stakeholders in Kenya, Uganda, Rwanda, Tanzania and Democratic Republic of Congo. Different approaches have been used in different countries with varied success in controlling BXW. This review discusses approaches, which have been successfully used in the management of BXW in some areas of East and Central Africa with a view of evaluating them individually or in combination under local conditions. This hopefully will help scale-out the promising approaches and contribute to more effective BXW control in the region.

Key words: Banana *Xanthomonas* wilt, disease management approaches, Eastern and Central Africa.

INTRODUCTION

The communities of the Great Lakes of Eastern and Central Africa have traditionally depended on a perennial banana cropping system for food and income (Karamura et al., 2008). This slow-changing farming system has ensured regional food security for many centuries. The system has come under stress due to progressive decrease in farm size, land fallow periods and production. This is mainly due to biotic threats particularly weevils, nematodes, fungal and viral diseases. On farm, such pests and diseases were traditionally managed by exploiting exisiting differences in cultivar tolerance. Although there was reduced productivity, farmers maintained reasonable levels of food and income security. However, following the arrival of banana *Xanthomonas* wilt (BXW) caused by *Xanthomonas campestris* pv. *Musacearum,* in the great lakes region in 2001, entire crop holdings were wiped out in some areas where highly susceptible genotypes were dominating the farming systems ((Tushemereiwe et al., 2004, Karamura et al., 2006). Different approaches have been used

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across the region to control BXW with varied success. For example, in the major banana growing areas in Uganda, BXW incidence remained below 5% for about 4 years (Tushemereirwe et al., 2006). In addition, in areas around the lake Victoria zone of Tanzania and Northern Rwanda, the spread of BXW was relatively reduced. Successful control of disease and pest epidemics is only possible if effective technologies are deployed together with institutional approaches that efficiently mobilise stakeholders. This review documents technological and institutional approaches that contributed to successful control of BXW in some areas, which may be validated and scaled out in the region.

Technical aspects of BXW control

There is no resistance to BXW so far reported among the local *Musa* germplasm in East and Central Africa (Ssekiwoko et al., 2006; Ndungo, unpublished). Therefore, the control strategies for BXW are based on cultural practices. However, the design and successful implementation of disease control programme based on cultural practices requires a clear understanding of the etiology and epidemiology of the disease (Thresh, 1980). Furthermore, critical factors that influence pathogen reproduction, survival, propagation, selection and evolution of more virulent strains must be understood (Jeger, 2004). This review provides a detail of the technologies used for control of BXW together with underlying epidemiological logic, which the farmers or other recipient stakeholders need in order to make informed decisions.

Prevention of introduction of BXW into uninfected fields

Introduction of pathogens to new locations and fields may be attributed to the use of pre-infected planting material or movement of vectors from remote infected sources (Cabaleiro and Segura, 1997). Currently, there are no quick screening techniques in the region for the planting materials (Karamura et al., 2008). Therefore, in locations where bananas have completely been cleared especially by BXW, strategies for large scale production of affordable clean planting materials are urgently needed to supplement the limited macro and micro-propagation technology already available.

Early removal of the malebud is an effective means of preventing the spread of BXW by insect vectors (Tinzaara et al., 2006). Removal of malebuds is recommended for both affected and unaffected fields. Using a forked stick, the malebud is removed as soon as the last cluster on banana flower is formed, that is, at about two weeks after emergence of the inflorescence. A forked stick rather than the commonly used cutting tool should be used because the stick can only contaminate should the broken bud. As such, there is no exchange of plant sap between banana plants on which the forked stick has been used and therefore no risk of spreading BXW between the plants. This technique is a preventive measure that effectively blocks the spread of BXW infection via insect vectors from within and without field.

Some banana cultivars do not have persistent neuter flowers. Other cultivars have persistent or semi-persistent bracts which do not easily break and thus escape insect vectored BXW spread. In a few extreme cases, deployment of cultivars such as scambia which do not have a male bud, but are tested for juice production, yield and farmer acceptability, may reduce the cost of removal of male buds and therefore the control of BXW cost effectively.

Management of initial inoculum from the banana field

Once BXW infection has been detected in a banana field, infected plants are the source of inoculum. In addition to removal of malebuds, farmers are advised to remove infected plants and disinfect tools that have had contact with infected plants (Tushemereirwe et al., 2004). Some farmers rouge the whole stool once they find an affected plant on them. Others remove the only infected plants from the affected stool. At the beginning of the BXW epidemic in Uganda, rouging the whole affected stool was recommended (Tushemereirwe et al., 2004). Overtime the recommendation changed to single stem removal (that is, removing infected plants only from the stool). This was after it became evident that the process of rouging whole stools was extremely labour intensive and it was possible to only remove infected plants from the affected stool and save the remaining uninfected plants from disease infection on the same stool. This was possible because most BXW infection starts from the upper parts of the plant on the inflorescence and takes some time to get to the lower parts of the plant (Ssekiwoko et al., 2006). If the infected plant is carefully removed from the stool before infection gets to the corm, it is possible to save other plants on the stool from BXW infection (Turyagyenda et al., 2006). Single stem removal has also been evaluated and found to be effective in control of BXW in Kenya and DRC (Kubiriba et al., 2014). Furthermore, after cutting infected banana plants, farmers may leave banana refuse on the ground. It had been previously recommended to burry all banana refuse (Tushemereirwe et al*.,* 2004). However, no *Xcm* was isolated from refuse of infected banana plants after 5 days even when they were left on the ground (Mwebaze et al., (2006). As long as rotting conditions are created, Xcm seems to compete poorly with other organisms involved in the rotting process of the banana refuse. This suggests that formerly affected fields can be replanted after 3months without risk of reinfection from old inoculum. However, a minimum of 6 months have been recommended to completely remove the risk of reinfection in previously infected fields. It is impotant to note that the survival of the bacterial is dependent on ecological conditions of different areas therefore it may be necessary to validate this recomendation before its application.

Management of incubating BXW infection

In tool-mediated infection, movement of the disease within the plant is dependent on the site of infection and this can be the roots, leaves, the inflorescence or the stem. During the incubation period, suspending the use of cutting tools in infected fields was key in the control of BXW (Tushemereirwe et al., 2006). The epidemiological basis for this practice is that, when a plant is infected with BXW, it shows symptoms within 3 months. Meanwhile, if infected plants are continuously removed, the number of infected plants will gradually reduce until no more infected plants are identified. During the 3 months incubation period, if pruning is discontinued, *Xcm* will not spread from infected plants with incubating BXW infection to unaffected plants. As a result, the disease outbreak is then effectively controlled. However, all preventive measures have to be applied continuously to prevent reintroduction of the bacteria.

Disinfection of tools

Disinfection of cutting tools used for pruning trash off the plants or after removing infected plants limits mechanical spread of BXW. The Xcm was detected on cutting tools kept at room temperature up to 22 days (Buregyeya, 2010). During that period, BXW is spread from the tools to banana plants up to 18 days. This implies that if traders who collect bananas from fields that are hundreds of kilometres apart do not disinfect the tools between plants and farms, they can spread BXW over long distances. Cutting tools may be disinfected by burning directly on a fire flame or cleaning with commercial JIK (sodium hypochloride).

Institutional approaches for stakeholder mobilisation

Conventional approaches

Every stakeholder in the banana value chain should be engaged in the battle against BXW. Subsistence farmers, who form the majority of farmers in the region, have substantial difficulty in managing plant diseases (Sherwood, 1997). This is partly because they cannot see the organisms that cause the plant diseases (Nelson et al., 2001). It is therefore important to package the message in a clear and concise manner stating the epidemiological underpinnings, negative impact of failure to implement the intervention as well as the benefits of such interventions to the individual farmer and the larger community. The choice and design of the communication strategies should take into account the dynamics of the target area such as literacy levels, numbers of radio receivers and availability of extension support. The strategies would include training of trainers, posters, pamphlets, leaflets, brochures and billboards designed to suit the levels of literacy and other socio-economic dynamics in the target community. Whereas this approach, which is widely used in the region is instrumental in swiftly raising awareness of stakeholders about the disease across countries, it is ineffective in triggering actions to control the disease (Tushemereirwe et al., 2006).

Participatory approaches

In the conventional approaches of stakeholder mobilization, pest and disease epidemic control programmes begin with generation of technologies and most often stop at dissemination of information to the farming communities, hoping that the recipients will use the information to control the epidemics (Hawkins et al., 2009). The awareness campaign deployed in Uganda was successful with more than 85% of the banana farmer knowing how to identify BXW, how it spreads and how it is controlled (Bagamba et al., 2006). However, only 30% of the farmers were undertaking BXW control (Tushemereirwe et al., 2006). It is possible to improve on the proportion of farmers that adopt control measures at community level using participatory approaches.

Participatory development communication

Participatory development communication (PDC) is the use of communication to facilitate community participation in a development initiative such as control of BXW (Bessette, 2004). Deploying PDC facilitates dialogue among the different stakeholders around a common problem has the aim of developing and implementing an action plan to solve the problem. The approach follows the following steps:

1. Members of the community and their leaders are brought together to discuss the BXW problem with facilitation of a PDC resource person.
2. The community members explore and discuss alternative ways of controlling BXW and identify the appropriate practices they can implement.
3. The community members develop an action plan to tackle the BXW problem.
4. The community agrees on the mechanism for implementing the formulated action plan.
5. The action plan is executed with various stakeholders in the community given roles and responsibilities to see

that the agreed action plan is properly implemented in time and space.

6. The community also agrees on how to monitor and evaluate activities for disease control as part of the action plan.

7. The community agrees on how to share successful outcomes.

The key output of the above process is the formulation and implementation of an action plan for the control of BXW (Table 1). The action plans may be at community level, sub-county, district and national levels. In locations where PDC approaches were religiously implemented, the incidence of BXW was drastically reduced (Figure 1). In the communities of Lake zone, Tanzania, PDC or its modification was also used with some success in controlling BXW (Mgenzi et al., 2006).

Farmer field schools (FFS)

Farmer field schools empower farmers to learn in an informal setting within their own environment. The FFSs are schools without walls where groups of farmers meet weekly with facilitators. It is a participatory method of learning, technology development and dissemination based on adult learning principles. The approach uses experiential learning and a group approach to facilitate farmers in making decisions, solving problems and learning new techniques. The concept is based on farmer participatory discovery approach for improving decision-making capacity of farming communities and stimulating local innovation for sustainable agriculture. The school involves 25 – 30 farmers. The group dynamics contribute towards team building and organizational skills. The FFS approach has successfully been used in Kenya, Uganda and Tanzania (Davis, 2008)

Farmer field schools with BXW control

The FFS approach was employed in controlling BXW in Uganda between 2006 and 2008. The process started with training of trainers (TOT). In this TOT, it was emphasized to the facilitators that:

1. It is not possible to improve banana production with their farmers' groups unless BXW was eradicated. It was agreed that BXW is enemy number one to the banana crop; which should be eradicated quickly to allow the FFS time to deal with other banana constraints.
2. The cultural package for control of BXW is effective, giving experiences of successful control.
3. The farmers should know how to identify infected plants and how BXW is spread through Agroecosystem analysis (AESA). This then would help them to explain the logic behind the recommended practices, not only for enhanced adoption but also modification of the practices where applicable.

The FFS were thereafter established in 50 subcounties in five banana growing districts of Mbarara, Kiboga, Mukono, Kamuli and Lira. By April 2008, BXW had been significantly reduced in all the groups of participating farmers (Figure 2). In subcounties or districts hosting FFS, other farmers soon started controlling BXW thus spreading the efforts. In areas such as Lira district, where control of BXW had been difficult for the national disease control efforts, FFS were islands of effective control in a sea of no compliance in BXW control. The FFS approach is invaluable where some recommended technologies may not work in new locations and therefore must first be tested, validated and adapted locally. The FFS approach has potential benefits because it is cheap, flexible, incorporates farmers' aspirations and empowers them. In addition, FFS approach has an in-built monitoring and evaluation mechanism and it can be integrated with other research/development approaches.

DISCUSSION

Effective disease control is possible if effective technologies are generated and promoted together with institutional approaches that effectively mobilise stakeholders who use the technologies (Kubiriba et al., 2012). The cultural practices reviewed in this paper were formulated with information generated from epidemiological studies in Uganda with participation of various partnerships from both local and International Research Institutes and Universities (Tushemereirwe et al., 2006). Other stakeholders from Government and Non-Government Organisations involved in rural development also contributed to the planning, generation and promotion of these technologies. In some locations, farmers sometimes modified recommended practices to suit their conditions (Bagamba et al., 2006). Experiments were established to scientifically validate such technologies and valuably improved development of appropriate technology e.g. single stem removal (Ssekiwoko et al., 2006). The technologies for the control of BXW proved effective in all areas where they have diligently and consistently been deployed (Tushemereirwe et al., 2006). Although most of the recommended practices may have region-wide applicability, most of them were ecology specific and may therefore need to be validated for customization to the local ecological conditions.

Accessibility to improved technologies for disease control influences a farmers' knowledge and their decision to control plant diseases (Sherwood, 1997). The farmers should be provided with correct information that enables them to make more effective action decisions. Bentley and Thiele (1999) showed that too much information would cause needless confusion, while oversimplification of concepts would not be effective in improving disease

Table 1. Action plan executed by communities to control BXW in Rugando, Mbarara District.

Goal	Objectives	Activities	Time frame				Target	Resp. Person	Budget unit cost		
			March - June 2005	July – September 2005	October - December 2005	January - June 2006			Item	Amount	Source of funds
To eradicate BBW from Rugando Sub-county	Create awareness about BXW in Rugando	Conduct sensitization workshops	X				Technical staff/local leaders	DPC & DAO	Facilitation Stationery Announce ments	100,000= 20,000= 50,000=	District
		Training farmers	X	X	X	X	Community	AO & SC leaders	Fuel SDA Stationary Posters	60,000= 60,000= 15,000=	NGOs S/county
	Mobilize and organize farmers for community action for effective control of BXW	Formulate and enforce community bye-laws - village meetings	X	X			Affected villages	AO & Community leaders, TF	Fuel SDA Stationary	50,000= 40,000= 10,000=	S/county
		Organize farmers to effect BBW control – village meetings	X	X			Affected villages	AO & Community leaders, TF	Fuel SDA JIK Posters	100,000= 60,000= 9,000=	S/county APEP
	Effectively supervise and monitor the BXW control activities	Formulation of Taskforces	X				Affected villages	AO & community leaders, TF	Fuel SDA Stationary Posters	100,000= 30,000= 15,000=	S/County
		Supervise implementation of control measures	X	X	X		Affected villages	AO & community leaders, TF	Fuel SDA Stationary	60,000= 40,000= 10,000=	S/County APEP District
		Tracking new outbreaks/ infections	X	X	X	X	All villages	Community	-	-	-
	Ensure sharing of information	Organize exchange visits			X	X	Community and other stakeholders	Community	Fuel SDA Stationary	100,000= 80,000= 20,000=	NGOs S/County
									Total	**884,000=**	

DPC = District Production Coordinator; DAO = District Agricultural Officer; AO = Agricultural Officer; TF = Taskforce; NGOs = Non-governmental Organization; S/county = Sub-county. The action plan was totally facilitated by funds locally mobilized. To date no plant infected with BXW has been sighted in the Rugando sub-county, Mbarara for over 12 months.

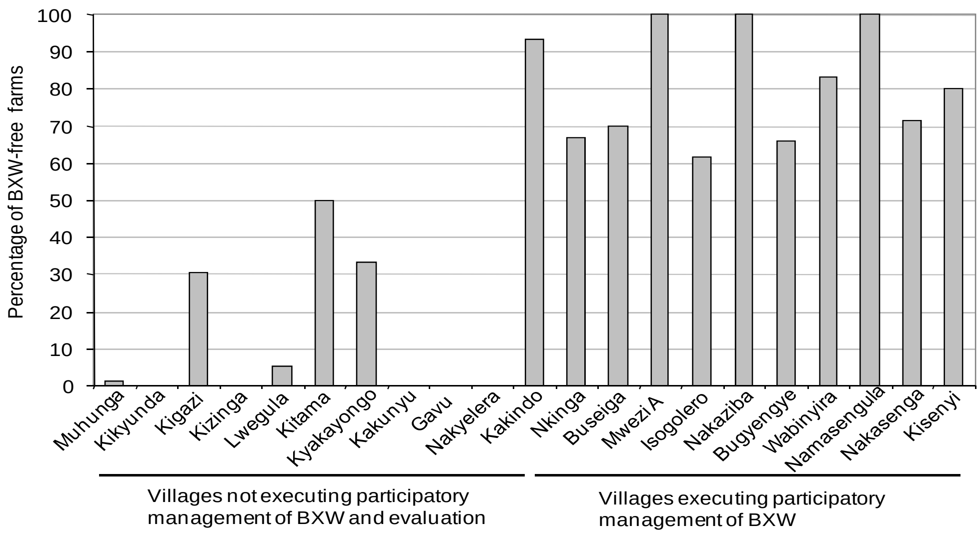

Figure 1. Success of participatory management of banana *Xanthomonas* wilt within one year in different villages in Uganda.

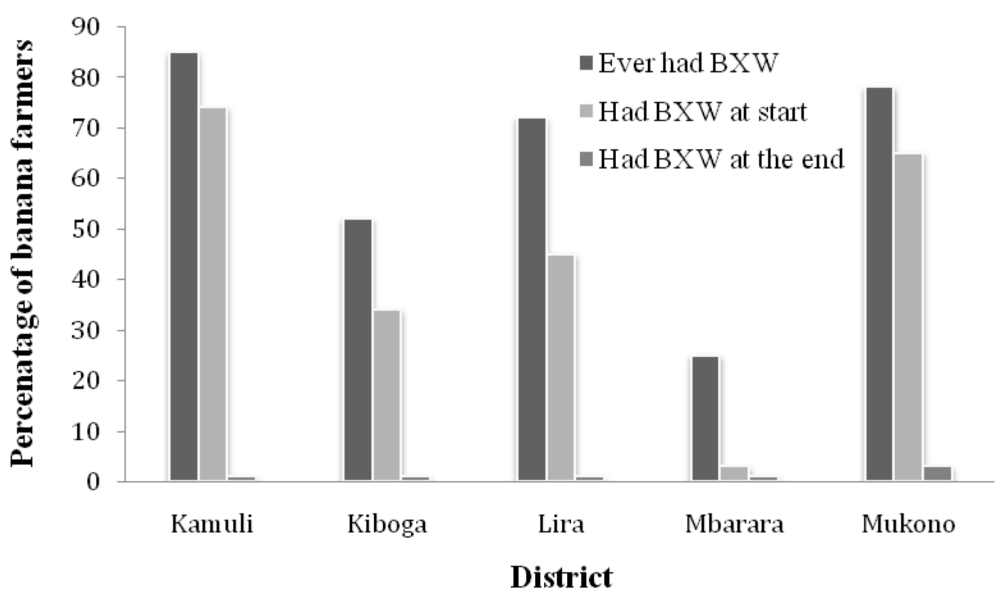

Figure 2. Level of BXW control in communities hosting farmer field schools in Uganda.

management. Research and extension agents too often use scientific terminology-laden approaches in information dissemination; they do not attempt to explain the disease life cycles to farmers, thereby underestimating the farmers contribution as key to unlocking the mystery of the disease. This problem was circumvented by involvement of various stakeholders (including the end users) in packaging information and selecting dissemination pathways (Ngambeki et al., 2006). Following the massive and aggressive awareness campaigns in Uganda, over 80% of the banana farmers knew BXW - its diagnosis, spread and means of control (Muhangi et al., 2006). Information materials developed from this process have been revised and further translated into different languages including Swahili and French used in all the 6 ECA countries (Karamura et al., 2006). The impact of using such information should be assessed to enable more appropriate modifications where necessary.

Despite the fact that most banana farmers knew how to control BXW from the awareness campaigns, only 30% utilized the knowledge to effect BXW control (Tushemereirwe et al., 2006). In order to address this problem, participatory approaches reviewed in this paper were used. The key elements of participatory approaches included getting communities together, facilitating them to formulate and implement action plans, mobilizing political and other leaders to support community efforts and ensuring their effective monitoring and evaluation were all important BXW control.

As a result, it was possible to control BXW to below 5% in important banana growing areas in Uganda for over 3 years while more than 90% of the farmers participating in FFS controlled the disease in their fields and their communities (Kubiriba et al., 2012). In future, the stakeholders in ECA who may use these participatory approaches needed to continuously evaluate their effectiveness and to make the necessary modifications to suit end user situation without compromising the key principles.

CONCLUSION

A number of management options and approaches for the control of BXW have been explored. However, no single management option can effectively control the disease. Successful control of BXW and possibly other epidemics is only possible by deploying effective technologies together with participatory approaches that effectively mobilize stakeholders for the control of the epidemic. While generation of technologies that effectively control BXW is mainly the role of researchers, other elements for successful control of BXW are roles of different stakeholders including local leaders (political and opinion leaders), extension officers (both governmental and non-governmental organizations) and farmers.

The East and Central African regional partners under the Crop Crisis Control Project (C3P), Association for strengthening Agricultural Research in Eastern and Central Africa (ASARECA) project used these approaches to control BXW in 6 countries: Uganda, Tanzania, Kenya, Rwanda, Burundi and Democratic Republic of Congo. A remarkable reduction in the incidence of BXW has been recorded in most of the pilot areas. Approaches that have registered successful disease control need to be carefully evaluated and scaled out in order to effectively control BXW in the region. This will only be possible with the support of all key stakeholders including policy makers at regional and national levels.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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