academicJournals

Vol. 9(26), pp. 2031-2040, 26 June, 2014
DOI: 10.5897/AJAR2014.8758
Article Number: 52813E445744
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Household dynamics influencing effective eradication of Xanthomonas wilt in smallholder banana systems in Ugunja division - Kenya

Dennis Ochola[1]*, Wellington Jogo[1], Michael Odongo[2], William Tinzaara[1], Margaret Onyango[3] and Eldad Karamura[1]

[1]Bioversity International, P. O. Box 24348, Kampala, Uganda.
[2]Rural Energy and Food Security Organization (REFSO), P.O. B ox 342, Busia, Kenya.
[3]Kenya Agricultural Research Institute (KARI), P.O. Box 523-40200, Kisii, Kenya.

Received 13 April, 2014; Accepted 16 June, 2014

Declines in banana (*Musa* spp.) productivity in western Kenya since 2006 have been exacerbated by Xanthomonas wilt, caused by *Xanthomonas campestris* pv. *musacearum*. This study provided insight of household dynamics influencing efforts to eradicate the disease from Ugunja, Lunjre, Sidindi and Sigomere. Surveyed households (N = 120) were purposively selected from villages with and without banana-based farmer field schools (FFS). Results showed limited banana experience, noted by the irregularities in timing and frequency of essential agronomic practices. In addition, a rampant tendency to replant sword suckers obtained from own production or farmer-to-farmer exchange. Even though farmers were sensitized on correct diagnosis and control measures, significant disparities between awareness and actual application of control options seem to prevail over the impact of recent massive eradication campaigns. Selective deployment of elements of Avoid introduction, Break-off male bud, Cut infected plants and Clean cutting tools (ABCC) intervention strategy was evident. Dismantling the ABCC package interferes with complementarities embedded within, which ultimately leads to disease upsurge or resurgence. Repeated exposure and demonstrable efficacy of the practices to halt disease spread may have profound bearing on farmer adoption of Xanthomonas wilt control measures. Therefore, the ABCC package should be validated and fine-tuned within the local context of smallholders.

Key words: Avoid introduction, break-off male bud, cut infected plants and clean cutting tools (ABCC), banana, resurgence, western Kenya, Xanthomonas wilt.

INTRODUCTION

Bananas (*Musa* spp.) are amongst the most important crops in East and Central Africa, both as a staple food crop and a source of income for smallholder farmers (Eledu et al., 2004; Wambugu and Kiome, 2001). With an estimated total annual production of one million metric tons, banana is ranked third after avocado and mango among the horticultural crops in Kenya, where it occupies an estimated 1.7% of total arable land. A wide range of

*Correspondence author. E-mail: d.ochola@cgiar.org

different cultivars are grown on holdings not exceeding 0.4 hectares in various agro-ecological zones, stretching from sea level at the coast to around 1800 meters in the western highlands (Qaim, 1999). Despite its versatility, the banana growing regions in Kenya (Rift valley, Nyanza, Central, North-Eastern and Coast) have experienced significant productivity losses due to worsening soil nutrient depletion, pests and diseases that have contributed to continuing poverty in rural communities (Kahangi et al., 2002).

A multiplicity of pests and diseases that pose a serious threat to sustainable smallholder banana production in western Kenya include banana weevils, nematodes, Fusarium wilt, Black sigatoka and Xanthomonas wilt (Seshu-Reddy et al., 1999; Karanja et al., 2008). Amongst diseases, Xanthomonas wilt caused by *Xanthomonas campestris* pv. *musacearum* has been spreading rapidly thus presenting the greatest threat to smallholder livelihoods in western Kenya (Inzaule, 2009). The bacterial agent was first identified as an important constraint of Enset (*Ensete ventricosum*) - a close relative of banana that is native to the highlands of Ethiopia (Yirgou and Bradbury, 1968). Forty years later, the disease was reported on East African highland (AAA) banana in central Uganda in 2001 (Tushemereirwe et al., 2003). Subsequently, it rapidly spread and developed into full-blown epidemics in eastern Democratic Republic of Congo (Ndungo et al., 2006), Tanzania (Mgenzi et al., 2006), Rwanda (Reeder et al., 2007) and Burundi (Carter et al., 2010). The disease is mainly transmitted through contaminated tools, infected planting materials and insects (Eden-Green, 2004; Tinzaara et al., 2006).

Unlike in the case of other biotic constraints, host plant resistance to Xanthomonas wilt is not known in any of the cultivated bananas (Ssekiwoko et al., 2006). The extent of devastation in East and Central Africa is estimated at US$ 500 million (Mwangi et al., 2007). This is comparable to production losses caused by similar bacterial wilts, namely Blood, Moko and Bugtok that almost decimated banana production in Indonesia, Latin America and Philippines, respectively (Molina, 1999). Infections are characterized by diverse symptoms such as progressive yellowing and wilting of leaves, shriveling and blackening of male buds, premature ripening and rotting of bunches that renders fruits inedible (Tripathi et al., 2009). A cross-section of infected pseudostem, leaf petiole and flower stalk reveals pockets of thick, pale yellow or orange bacterial ooze accompanied by vascular streaking (Mwangi et al., 2007; Mbaka et al., 2009; Tripathi et al., 2010).

The outbreak of Xanthomonas wilt in western Kenya has increasingly received committed responses from public research institutions, extension agencies, religious institutions, non-governmental organizations and developmental partners. Massive awareness creation campaigns were initiated to sensitize farmers on diagnosis and prevention concurrently with the promotion of Avoid introduction, Break-off male bud, Cut infected plants and Clean cutting tools (ABCC) strategy, consisting of: i) complete uprooting of diseased mats, ii) burying of uprooted and chopped plant debris, iii) disinfection of farm tools with sodium hypochlorite or fire, and iv) timely removal of the male buds with forked stick to prevent insect-mediated spread (Karamura et al., 2006). Contrary to expectations, a growing concern has emerged among stakeholders regarding the impracticability and associated costs of the ABCC strategy (Tushemereirwe et al., 2006). The issue has grown in importance in light of recent resurgence of Xanthomonas wilt in growing areas wherein it had been previously contained. Researchers were thus tasked to review and develop a more pragmatic, less demanding but effective control strategy for Xanthomonas wilt.

Consequently, a tripartite agreement was reached between Bioversity International, Kenya Agricultural Research Institute (KARI) and Rural Energy and Food Security Organization (REFSO) in 2009 to strengthen partnerships along the banana value chain to mitigate Xanthomonas wilt.

A key objective of the project was to validate and fine-tune existing disease management options and scale up their adoption by farmers and stakeholders along the banana value chain. The baseline survey conducted in Ugunja has shown significant variation between farmer awareness and application of Xanthomonas wilt control options. Not all farmers who knew the control measures were actually applying them (Jogo et al., 2011). Although the noted disparity could be used to highlight the inconsistent deployment of disease control interventions, it does not sufficiently explain the recent disease upsurge and resurgence in some parts of western Kenya. Even so, such an exposition is unsatisfactory since research was restricted to a limited sample size of 52 households (Jogo et al., 2011).

Little is known about household dynamics responsible for the marginal application of recommended control measures at farm and community-level in western Kenya and possible outcomes from recent eradication campaigns masterminded by banana-based farmer field schools (FFS) established in Ugunja, Lunjre, Sidindi and Sigomere. This paper therefore provides insight into the extent to which the FFS have contributed to the eradication of Xanthomonas wilt in the mentioned sites and likely spillover effects on households outside the study area. Findings from this study will inform stakeholders along the banana value-chain on what should be done differently in the management of Xanthomonas wilt to reduce its impacts on rural food security and incomes.

MATERIALS AND METHODS

A household survey was conducted in September 2012 in Ugunja Division, Siaya County of Kenya. Selection of the study area was based on banana steadily becoming a key income crop for

Table 1. Multistage sampling framework.

Pilot sites	Villages[#]	Households[*]	Sample (n)	Total (N)
Ugunja	FFS	HHFFSM	8	30
	Non-FFS	HHNFFSM	22	
Lunjre	FFS	HHFFSM	10	30
	Non-FFS	HHNFFSM	20	
Sidindi	FFS	HHFFSM	10	30
	Non-FFS	HHNFFSM	20	
Sigomere	FFS	HHFFSM	10	30
	Non-FFS	HHNFFSM	20	

[#] FFS – Farmer Field Schools; [*] HHFFSM – Household head FFS Member; HHNFFSM - Household head Non-FFS Member.

Table 2. Demographic characteristics of surveyed households in Ugunja Division, Siaya County, Kenya.

Characteristics	Gender		All
	Male (n = 73)	Female (n = 47)	(n = 120)
Farming as main occupation (%)	87.5	93.5	89.8
Age of interviewee (years)	54.5	52.6	53.8
Education (years)	10.0	8.2	9.3
Living in the area (years)	43.6	31.0	38.8
Banana experience (years)	6.6	10.3	8.1
Household size	7.0	5.0	6.0
Total land holding (hectares)	1.5	1.2	1.4
Total arable land (hectares)	1.1	0.9	1.0
Area under banana (hectares)	0.2	0.2	0.2

smallholder farm households, and by the fact that banana Xanthomonas wilt has increased in prevalence. Like elsewhere in western Kenya, the production system in Ugunja Division is dominated by dessert bananas including: Apple AAB, Muraru AA, Cavendish AAA and Gros Michel AAA (Onyango et al., 2008; Mbaka et al., 2009). A multistage random sampling procedure was used to select 120 farm households (Table 1). Throughout this paper, the term household will be used to refer to a group of persons who normally live and eat their meals together in the same dwelling.

In the first stage, four pilot sites of Ugunja, Lunjre, Sidindi and Sigomere were purposively selected to facilitate resampling of some households that had participated in the original baseline survey of 52 households conducted in 2010 (Jogo et al., 2011).

In the second stage, each site was subdivided into villages with banana-based FFS and those without Non-farmer field schools (Non-FFS). The non-FFS participating villages were selected to ensure that sampled households are comparable in terms of biophysical and socioeconomic characteristics.

In the third stage, households in which the head were active members of a banana-based FFS were randomly selected from the list provided by the Rural Energy and Food Security Organization (REFSO). A semi-structured questionnaire was used to collect data covering household socioeconomic characteristics; on-farm status and capacity for Xanthomonas wilt diagnosis; awareness and application of recommended cultural control options. Although male and female household heads were the targeted respondents during the face-to-face interviews, any other adult in the household familiar with banana production was interviewed in the absence of the head.

Data were analyzed with descriptive and inferential statistics. Chi-square test determined the significance of association between awareness and application of cultural control practices by smallholder banana farmers in Ugunja Division. A comparative analysis of the potential change in awareness and application of control practices was carried out against the 2010 baseline dataset (Jogo et al., 2011). All data were processed and analyzed using SPSS version 17 (IBM Corporation, New York, USA).

RESULTS

Sample household characteristics

Descriptive statistics of surveyed households are presented in Table 2. Farming was the key agricultural livelihood strategy of 89.8% of respondents, who averaged roughly 54 years of age and with about 9 years of education. Though age and years in school were higher for males compared to females, the magnitude of the difference was ($p>0.05$). Majority (58.1%) of sampled households were male headed. Housewives comprised the highest proportion (41.9%) of interviewed females.

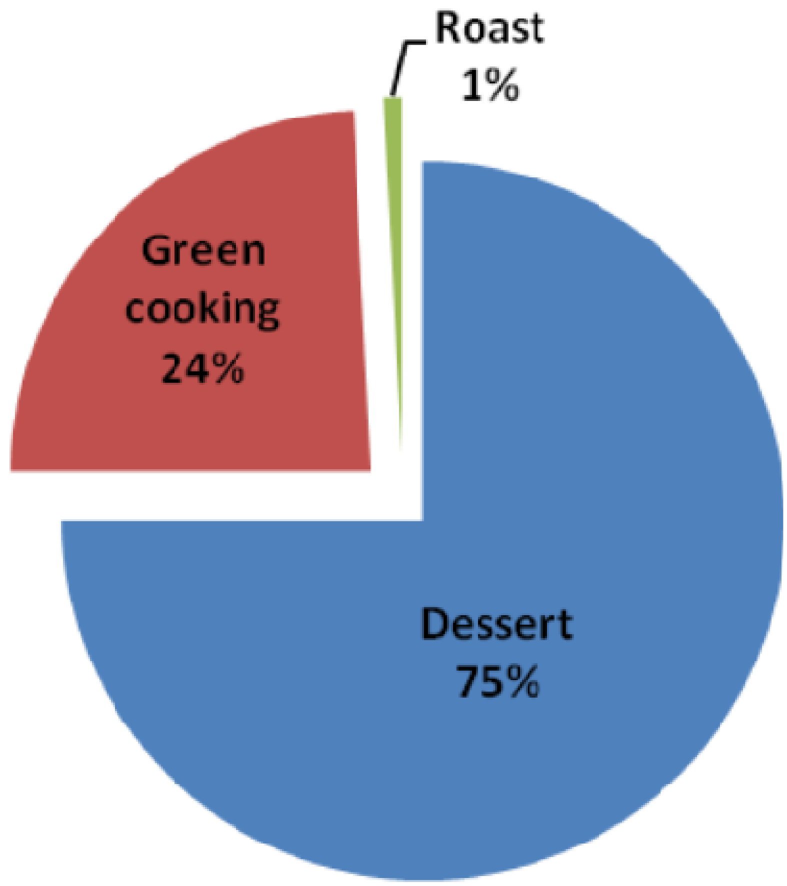

Figure 1a. Percentage of households choosing different banana cultivars.

Average household size was 6 persons, with dependents (children less than 18 years and adults older than 64 years) constituting a third of households (Table 2). Generally, high dependency ratio implies that labour endowments for banana management could be inadequate to boost household crop productivity. Nearly 75% of households had lived in the study area for approximately 39 years, although males had lived there longer (44 years) than their female counterparts (31 years) (Table 2).

A Chi-square test revealed a statistically significant ($p<0.05$) relationship between the years the households lived in the study area and experience in growing banana. However, little household banana farming experience of approximately eight years implies that banana production in the study sites is still at its infancy (Table 2). Although the difference was ($p>0.05$), men possessed relatively less banana farming experience (7 years) than women (10 years) (Table 2). As indicated by the big proportion of housewives, there is likelihood that some women in the study area had prior experience with banana farming before relocating to Ugunja upon getting married. Available arable land significantly determined how much land a household allocated for banana production. The area under banana (0.2 ha was about six times smaller than the available arable land holding (1.1 ha). Despite being grown by 95% households for food and income, banana was prioritized secondary to maize in terms of land allocation (data not shown).

Banana cultivars and agronomic practices

Dessert cultivars dominated 75% of the banana landscape in Ugunja Division (Figure 1a). Most households cultivated FHIA, Apple AAB, Muraru AA, Cavendish AAA and Gros Michel AAA types. About 24% households cultivated green cooking EAHB-AAA bananas while the remaining 1% grew Plantains (Figure 1a). Due to a lack of formal systems to regulate planting material quality for banana growers, 99.2% households had used sword suckers to establish their orchards. About 30.7% households had acquired suckers from within their existing plantations. Exchange of planting materials was also widely practiced by 56.6% households, who had acquired suckers from a neighboring plantation at one point in time. These practices inadvertently contribute to the spread of pests

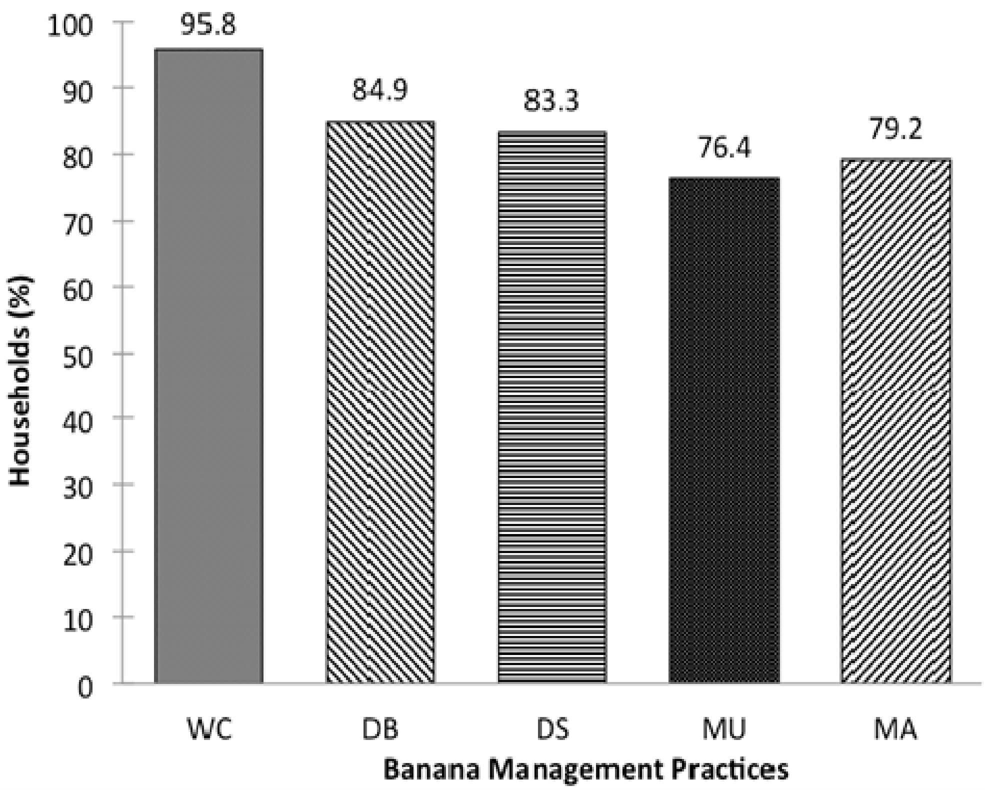

Figure 1b. Percentage of households adopting different crop- related management practices. WC – weed control; DB – debudding; DS – desuckering; MU – mulching; MA – manuring.

and diseases because farmers cannot recognize already infested or diseased planting material. However, over 75% households demonstrated a willingness to invest in improved and disease-free tissue culture generated materials, as the sterile nature of tissue culture procedures is capable of excluding fungi, bacteria and pests from the production system. Given that bananas are propagated continuously on the same site, sustained productivity demands intensive management. Figure 1b shows the different agronomic practices deployed in banana production in Ugunja Division: weed control (95.8%), debudding (removal of male inflorescence) (84.9%), desuckering (removal of excess plants on a mat) (83.3%), manuring (animal waste and composted household refuse (79.2%), and application of dry organic mulch (grass or crop residues) (76.4%). However, 96.7% households did not use any chemicals to curb pests and diseases in their banana plantations. Debudding was carried out immediately after the last banana cluster was formed, as a strategy to curb insect vector transmission of Xanthomonas wilt. Meanwhile, desuckering was carried out in tandem with weeding, but with significant irregularities in timing and frequency. Although half of the households preferred to weed and desucker bananas twice each month, they found it rather more reasonable to implement these two practices at least twice a year.

Household diagnosis capacity and status of Xanthomonas wilt

From the farmers' perspective, initial outbreaks of Xanthomonas wilt in western Kenya begun between 2004 and 2006. Moreover, outbreaks on banana orchards in Ugunja were relatively recent that is between 2009 and 2012. Table 3a shows the heterogeneity in household recognition of Xanthomonas wilt symptoms. About 66% households knew more than three symptoms, while 27.7% households knew at least one symptom. Notably, the easiest symptoms to identify were premature bunch ripening, leaves yellowing and wilting and pulp discoloration. From the data, it also emerged that 5.9% households were completely inept at diagnosing wilt symptoms (Table 3a). Despite no significant gender-based difference in diagnostic capacity, it was evident that females (11.1%) could not adeptly identify Xanthomonas wilt compared to 2.7% males (Table 3a). About 58% households had noticed Xanthomonas wilt symptoms on their farms (Table 3b). This table is quite revealing in several ways.

Firstly, 41% households reported a reduction of disease prevalence to less than 10 mats, while only 16.9% farms had prevalence > 10 infected mats. Secondly, 42% households made claim of having

Table 3a. Household-level competences for diagnosis of Xanthomonas wilt symptoms.

Xanthomonas wilt diagnosis	Gender		
	Male	Female	All
	(N=73)	(N=45)	(N=118)
None	2.7[a]	11.1[b]	5.9[a]
At least one symptom	28.8[bc]	26.7[bc]	27.7[bc]
At least two symptoms	27.4[bc]	31.1[c]	29.4[bc]
All symptoms	41.1[cd]	31.1[c]	37.0[cd]

Values in the same column followed by same superscript letter are not significant (p ≤ 0.05).

Table 3b. Respondent projections of Xanthomonas wilt prevalence in Ugunja Division, Siaya County, Kenya.

Prevalence	Farm-level* (n=112)	Community-level** (n=113)	Village-level*** (n=114)	Averaged (n=113)
No infection	42.0[c]	0.9[a]	0.9[a]	14.6[ab]
1-10 mats	41.1[c]	31.0[bc]	22.8[b]	31.6[bc]
> 10 mats	16.9[ab]	68.1[d]	76.3[d]	53.8[cd]

*Surveyed households; **non-surveyed households in study areas; ***non-surveyed households outside study areas. Values in the same column followed by same superscript letter are not significant (p ≤ 0.05).

eradicated disease from their farms through the enforcement of control strategies like debudding with forked stick and sterilization of farm tools using sodium hypochlorite (Tables 3b and 4). Notwithstanding the downturn of disease prevalence at farm-level, data also revealed an upsurge in some communities (68.1%) and villages (76.3%) outside the study area (Table 3b). This is consistent with reports of a resurgence of Xanthomonas wilt in areas where disease prevalence had previously been reduced. Most striking from the data is that farmer action research networks along the banana value chain contributed to 14.6% eradication and 31.6% containment of disease within household farms in Ugunja Division (Table 3b).

Awareness and application of ABCC control practices

Significant variations existed in awareness of the different control options embedded within the different cultural practices (Table 4). Surveyed households acquired information from multiple sources besides the Ministry of Agriculture, namely (a) farmer-to-farmer (56.7%), (b) religious institutions (23.3%), and (c) farmer field schools (21.6%). Households were mostly aware of debudding with a forked stick (67.5%) and tool sterilization with Jik® sodium hypochlorite (61.7%). Whereas 23% households seemed to have limited awareness of potential risks associated with use of cutting tools for debudding. Further, despite its reported impracticability and drudgery implications, 55.3% households expressed awareness of the practice of completely destroying and resting the affected plantation as an essential disease control practice. It is apparent that marginal awareness of certain control options reiterates that Xanthomonas wilt outbreak in Ugunja is rather recent (that is 2009 and 2012).

In addition, on-farm application of control options also varied significantly among households. The most popular practices were debudding with a forked stick (54.2%) and tool sterilization with Jik® (49.1%). Moreover, the different alternatives of cutting down infected plants were the least applied control options: cut down and leave unheaped (2.8%), cut down and heap (9.2%), and cut down and bury mat (11.2%). Comparative analysis of 2010 and 2012 datasets indicated significant reduction in the deployment of control practices such as the cutting down only infected plants ($p<0.01$) and removal of male buds with cutting tools ($p<0.05$). In contrast, there was a significant increase ($p<0.01$) in the implementation of debudding with a forked stick and sterilization of tools using Jik® (Table 4).

In summary, these results show that increased awareness may not necessarily translate into greater application of Xanthomonas wilt control strategies, which emphasizes the subtleties of smallholder agriculture.

Factors influencing the application of the ABCC intervention strategy

Several factors were identified to influence farm-level application of the different Xanthomonas wilt control strategies (Figure 2). About 73% households emphasized

Table 4. Comparative analysis of farmer awareness and application of Xanthomonas wilt cultural control practices.

Cultural practices	Control options	Awareness (%)		χ^2	Application (%)		χ^2
		2010	2012		2010	2012	
Destruction of infected plants	Destroy all infected plants and rest field	45	55.3	ns	39	26.3	ns
	Cut down only infected plants	57	31.9	*	41	11.9	**
	Cut down and bury whole mat	6	26.1	**	2	11.2	**
	Cut down infected plants and heap	10	23.5	*	6	9.3	ns
	Cut down infected plants and leave unheaped	6	10.8	ns	4	2.8	ns
Removal of male inflorescence (debudding)	Forked stick	12	67.5	**	8	54.2	**
	Cutting tools	45	31.3	ns	39	23.3	*
Sterilization of farm tools	Sodium hypochlorite (Jik®)	4	61.7	**	4	49.1	**
	Fire	-	56.5	-	-	36.4	-
Use of disease-free free planting materials	Tissue culture plants	-	40.4	-	-	18.2	-

In the χ^2 column: ns – not significant ($p > 0.05$); * significant ($p \leq 0.05$); ** significant ($p \leq 0.01$).

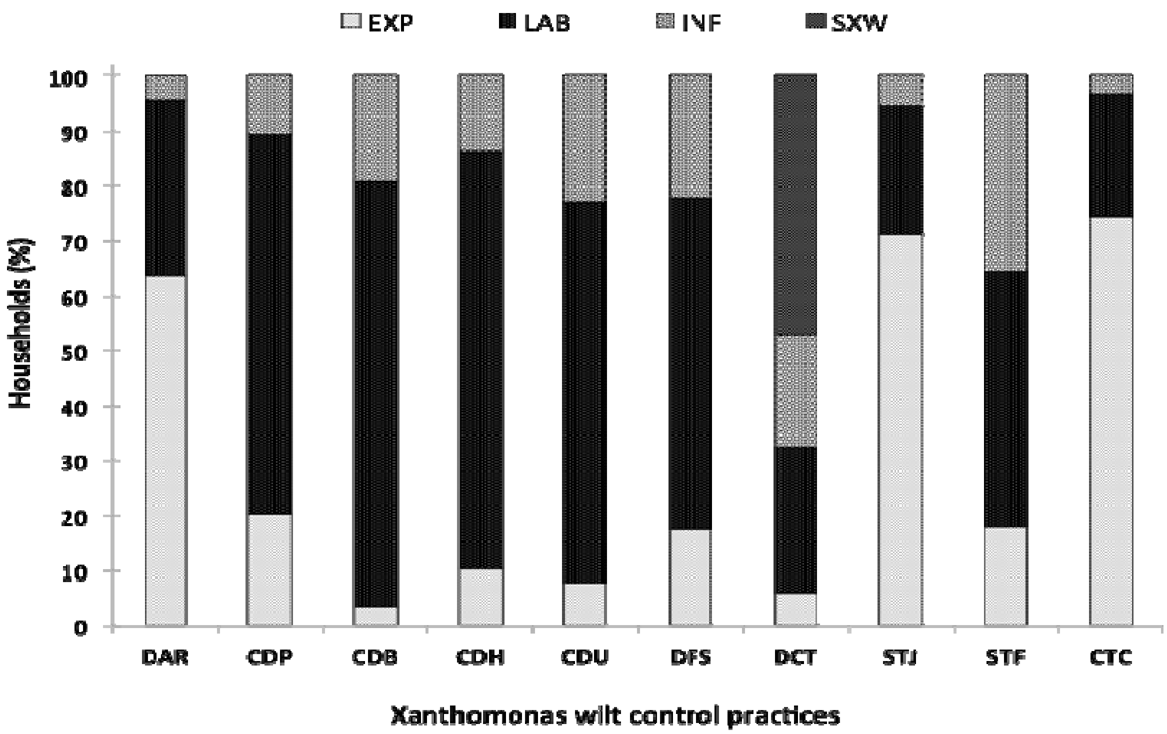

Figure 2. Factors influencing application of the different Xanthomonas wilt control practices. **Strategies:** DAR – destruction of all infected plants; CDP – cut down only infected plants; CDB – cut down and bury whole mats; CDH – cut down and heap on ground; CDU – cut down and leave unheaped on ground; DFS – debudding with forked stick; DCT – debudding with cutting tools; STJ – sterilize tools with jik®; STF – sterilize tools with fire; CTC – disease-free tissue culture. **Factors:** INF – ineffective; LAB – labour intensive; EXP – expensive to implement; SXW – spreads Xanthomonas wilt.

high labour demand as a major limitation to the different options of destroying infected plants. In addition to its drudgery implications, 63.6% households perceived the destruction of all infected mats and resting the affected plantation was expensive and impractical to implement, particularly in the context of limited arable land (Figure 2). Notwithstanding, debudding with a forked stick being the most deployed in the study area, 60.4% households perceived it to be an arduous and time-consuming task. This explains why in Table 3, some households (23.3%) opted to debud using cutting tools amidst the risks of spreading Xanthomonas wilt disease. Given that farm tools are amongst the primary mechanisms of Xanthomonas wilt transmission, sterilization with Jik® or fire is paramount especially for operations that involve wounding such as desuckering, detrashing and harvesting of green leaves for domestic use. Apparently, 71.1% households identified the high cost of Jik® as a key constraint to effective sterilization of farm tools (Figure 2). Moreover, heat sterilization of tools with fire amongst households was reportedly curtailed by its laborious nature during farm operations (46.4%). Likewise, persistent replanting of sword suckers by 74.1% households was attributed to poor access and high cost of tissue cultured bananas. Figure 2 also revealed that misconceptions regarding the efficacy of control practices to some extent limit household deployment of the destruction of diseased plants (14.3%), sterilization of farm tools (20.7%) and removal of male inflorescences (21.4%).

DISCUSSION

This study set out with the aim of providing insights into household dynamics that influence the deployment of strategies for effective control and eradication of Xanthomonas wilt from western Kenya. Amongst the key finding from the survey was the structure of banana production, characterized by small-scale growers who allocated a meager 0.2 ha to bananas. The banana landscape in Ugunja was dominated by dessert cultivars, the predominant types being Apple AAB, Muraru AA, Cavendish AAA and Gros Michel AAA. Since dessert bananas are mainly grown for local consumption, they are an important source of income in Kenya (Onyango et al., 2008).

From our data, it was apparent that irregularities in timing and frequency of essential agronomic practices was indicative of growers' limited experience and investment in banana management. To a great extent, households still prioritize maize over banana since the former has been a major component of livelihood strategies of rural people in western Kenya (Overfield et al., 2001).

Like in most smallholder banana systems in East Africa, there was a rampant tendency for households in Ugunja to replant sword suckers. This seems to suggest that the informal seed system was a reliable source of low-cost planting material for resource-poor farmers (Njuguna et al., 2010; Kabunga et al., 2011). In case of banana, the system operates mainly through retention of own production or farmer-to-farmer exchange within or outside the community. This explains why removal of excess suckers was among the important crop management practices. Despite the merits of the informal seed sector in the eyes of smallholders, replanting of suckers has inadvertent consequences, particularly in the spread of pests and diseases. Generally, most smallholders are unable to recognize infested or diseased planting materials or fully understand the life cycles and transfer mechanisms of pests and diseases (Kikulwe et al., 2007). Apparently, even when tissue culture banana production is being popularized in Kenya, the current study shows that farmers in Ugunja are yet to adopt the technology. This is consistent with earlier studies in Kenya, which established that the potential of tissue culture technology is yet to be fully exploited (Njuguna et al., 2010; Kabunga et al., 2011). Recent research has attributed the noted marginal adoption to inaccessibility and high cost price of tissue culture plants (Kikulwe et al., 2011; Kabunga et al., 2012). An explanation being that about 46% Kenyan's live on less than 1 US$ a day, moreover a tissue culture plantlet costs about 0.3 US$ more. Furthermore, the scope for private sector entry in the banana seed sector is limited by low profit margins and government regulations in the seed sector (Lynam, 2011). Even so, the availability of affordable clean and healthy tissue culture is crucial for establishment of new orchards and sustained management of pests and diseases in a complex smallholder system.

Xanthomonas wilt is a serious and intractable crop protection constraint to smallholder banana production particularly in western Kenya, where outbreaks were first detected in 2006. Sustainable management of Xanthomonas wilt has to a great extent been elusive, due to the poor understanding of the dynamics of its spread and control among stakeholders along the banana value chain (Tinzaara et al., 2013).

This study shows that majority of households had competence to identify at least one symptom, in contrast to 5.9% households ineptitude to recognize any symptoms. Though the government seems to have a comparative advantage in the provision of extension services, banana growers in Ugunja obtained information on Xanthomonas wilt from multiple sources. Moreover, multiple sources of information raise the risks of farmers receiving conflicting messages (Jogo et al., 2011). Notwithstanding, farmer-to-farmer knowledge exchange is perceived as the most cost effective, accessible and reliable. The strength of farmer-to-farmer collaborations in Kenya is hinged on the dynamism inherent in the operation of 'Harambee' that encourages people to work together towards achieving a common goal (Wambugu and Kiome, 2001). Considering that farmer-to-farmer knowledge sharing alone may not provide scientifically proven solutions, alternative approaches of information delivery such as banana-based FFS are important as backstopping mechanisms to maximize the potential for experimental learning and scaling up of new technologies (Hakiza et al., 2004). Notably, the FFS approach does not rely on highly trained external advisors but on farmers' own discovery and reflection.

At face value, this study demonstrates the success of massive awareness creation campaigns to sensitize famers about correct diagnosis, spread and control of Xanthomonas wilt. As indicated in the results, about 40% households have experienced a farm-level downturn in disease prevalence through measures like debudding with forked stick and disinfection of farm tools with sodium hypochlorite. Conversely, just as advances in disease eradication seem to be made within the study area, an upsurge is apparent in communities and villages outside the study area. Significant disparities between awareness and application of different control options are examples of issues that have had profound impact on disease eradication. For instance, although debudding with a forked stick eliminates opportunities of spread by insect vectors, not all those who know its benefits were actually deploying the practice on-farm, but rather opted to debud with cutting tools. Similar trends were observed in previous research on farmer awareness (Jogo et al., 2011; Ochola et al., 2013).

Many strong driving forces seem to exert pressure on the deployment of control measures within the four-pronged ABCC intervention strategy, consisting of: i) complete uprooting of diseased mats, ii) burying of uprooted and chopped plant debris, iii) disinfection of farm tools with sodium hypochlorite or fire, and iv) timely removal of the male buds with forked stick to prevent insect-mediated spread (Karamura et al., 2006).

In this study, failure to adopt the whole ABCC package was also an outcome of interactions between socioeconomic, behavioral and technological aspects of smallholder farming (Bagamba et al., 2006; Mbaka et al., 2008). Contrary to expectations, no significant gender-based differences in disease awareness were observed between women and men. There is a twofold explanation for this: primarily, it depicts an improved context in which research and extension services reach rural women with gender sensitive technologies and secondarily, it represents women's distinct food security interests as custodians of important agricultural enterprises. Interestingly, this justifies why banana is termed a women's crop in Kenya (Wambugu and Kiome, 2001).

Evidence reveals that ABCC was adapted from previous experiences with Bugtok and Moko in Asia and Latin America, respectively (Karamura et al., 2006; Molina, 1999). It is likely that during the rapid outbreaks in western Kenya, ABCC practices were disseminated to stakeholders without being validated in the local context of smallholders. Subsequently, many farmers in the study area have embarked on selective deployment of elements of the disseminated ABCC package, unfortunately some of which they do not know how to apply properly (Jogo et al., 2011). For example, due to associated drudgery implications, farmers are not always inclined to destroy an entire banana mat especially when only one symptomatic sucker appears (Mwangi and Nakato, 2007). Studies reveal that some famers do not understand the rationale behind the different control options or what motivates research and extension practitioners to discourage certain practices (Jogo et al., 2011). Meanwhile, others have a misconstrued perception about the effectiveness of certain practices, which has a direct effect on their adoption decisions (Ochola et al., 2013; Jogo et al., 2013). A scenario also arises whereby some farmers expect immediate results from the deployment of recommended control measures, so whenever this is delayed they become discouraged and abandon some disease management practices (Tinzaara et al., 2013).

It is increasingly difficult to ignore that when deployed in a collaborative manner by smallholders; the practices were proven in Uganda to be an effective strategy of reducing inoculum sources and eliminating further spread in infested fields (Tushemereirwe et al., 2004; Blomme et al., 2005). This implies that when farmers dismantle the control package, they also interfere with potential complementarities embedded within the ABCC package, which may lead to disease upsurge or resurgence as noted in communities outside the study area. Repeated exposure and demonstrable efficacy of the practices to halt disease spread may have profound bearing on farmer adoption of Xanthomonas wilt control measures. This necessitates for the fine-tuning of ABCC practices within the context of smallholders and closely monitoring of the extent of adoption among smallholders.

Conflict of Interests

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

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the farmers in Ugunja Division, Kenya for their participation in this study. Funding for this research was by the McKnight Foundation Project Grant #09-500.

REFERENCES

Bagamba F, Kikulwe E, Tushemereirwe WK, Ngambeki D, Muhangi J, Kagezi GH, Ragama PE, Eden-Green S (2006). Awareness of banana bacterial wilt control in Uganda: 1. Farmers' perspective. Afr. Crop Sci. J. 14:157–164.

Blomme G, Mukasa H, Ssekiwoko F, Eden-Green S (2005). On-farm assessments of banana bacterial wilt control options. [editors?] African Crop Science Society Conference Proceedings, Entebbe, Uganda, 5-9 December 2005. pp. 317-320.

Carter BA, Reeder R, Mgenzi SR, Kinyua M, Mbaka JN, Doyle K, Nakato V, Mwangi M, Beed F, Aritua V, Lewis Ivey ML, Miller SL, Smith JJ (2010). Identification of *Xanthomonas vasicola* (formerly *X. campestris* pv. musacearum) causative organism of banana Xanthomonas wilt, in Tanzania, Kenya and Burundi. Plant Pathol. 59(2):403. http://dx.doi.org/10.1111/j.1365-3059.2009.02124.x

Eden-Green SJ (2004). How can the advance of banana Xanthomonas wilt be halted, Infomusa 13:38-41.

Eledu CA, Karamura EB, Tushemereirwe WK (2004). Agroecological distribution of banana systems in the Great Lakes Region. Afr. Crop Sci. J. 12(1):33-42. http://dx.doi.org/10.4314/acsj.v12i1.27660

Hakiza JJ, Odogola W, Mugisha J, Semana AR, Nalukwago J, Okoth J, Ekwamu A (2004). Challenges and prospects of disseminating technologies through farmer field schools: lessons learnt based on experiences from Uganda. Uganda J. Agric. Sci. 9:196-175.

Inzaule SSS (2009). Xanthomonas wilt management in Kenya In: Karamura E, Tinzaara W (eds): Management of banana Xanthomonas wilt in East and Central Africa. Proceedings of the workshop on review of the strategy for the management of banana Xanthomonas wilt. pp. 23-27.

Jogo W, Karamura E, Kubiriba J, Tinzaara W, Rietveld A, Onyango M, Odongo M (2011). Farmers' awareness and application of banana Xanthomonas wilt control options: the case of Uganda and Kenya. J. Develop. Agric. Econ. 11(3):561-571.

Jogo W, Karamura E, Tinzaara W, Kubiriba J, Rietveld A. (2013). Determinants of farm-level adoption of cultural practices for banana Xanthomonas wilt control in Uganda. J. Agric. Sci. 5(7):70-81.

Kabunga NS, Dubois T, Qaim M (2012). Yield effects of tissue culture bananas in Kenya: Accounting for selection bias and the role of complementary inputs. J. Agric. Econ. 63:444–464. http://dx.doi.org/10.1111/j.1477-9552.2012.00337.x

Kabunga NS, Dubois T, Qaim M (2011). Information asymmetries and technology adoption: The case of tissue culture bananas in Kenya. Discussion Georg- August-Universität Göttingen P. 74.

Kahangi EM, Muthee AM, Chege BK (2002). Constraints and sustainable solutions for adoption of TC banana technology and marketing. Acta Hortic. 638:441-447.

Karamura EB, Osiru M, Blomme G, Lusty C, Picq C (2006). Developing a regional strategy to address the outbreak of banana Xanthomonas wilt in East and Central Africa: Proceedings of the Banana Xanthomonas wilt regional preparedness and strategy development workshop held in Kampala, Uganda - 14–18 February 2005. International Network for the Improvement of Banana and Plantain, Montpellier, France.

Karanja L, Wangai A, Harper G, Pathak RS (2008). Molecular identification of banana streak virus isolates in Kenya. J. Phytopathol. 156:678–686. http://dx.doi.org/10.1111/j.1439-0434.2008.01415.x

Kikulwe EM, Nowakunda K, Byabachwezi MSR, Nkuba JM, Namaganda J, Talengera D, Katungi E, Tushemereirwe WK (2007). Development and dissemination of improved banana cultivars and management practices in Uganda and Tanzania. In: Smale M and Tushemereirwe WK (eds) An economic assessment of banana genetic improvement and innovation in the Lake Victoria region of Uganda and Tanzania. Research report ch. 4, International Food Policy Research Institute, Washington, D.C. P. 155.

Kikulwe EM, Wesseler J, Falck-Zepeda J (2011). Attitudes, perceptions, and trust. Insights from a consumer survey regarding genetically modified banana in Uganda. Appetite 57(2):401-413. http://dx.doi.org/10.1016/j.appet.2011.06.001 PMid:21704665.

Lynam J (2011). Plant breeding in sub-Saharan Africa in an era of donor dependence. Instit. Develop. Stud. Bull. 42:36–47.

Mbaka JN, Nakato VG, Auma J, Odero B (2009). Status of banana Xanthomonas wilt in western Kenya and factors enhancing its spread. African Crop Science Society. African Crop Science Confer. Proceed. 9:673-676.

Mgenzi SRB, Muchunguzi D, Mutagwaba T, Mkondo F, Mohamed R (2006). An Outbreak of Banana Bacterial Wilt in Muleba District, Kagera region, Tanzania. Disease Report. Maruku Agriculture Research and Development Institute, Kagera.

Molina AB (1999). Fruit rot disease for cooking banana in South East Asia. Infomusa 8:29-30.

Mwangi M, Muthoni S, Nakato V (2007). Evaluation of disinfectants and agrochemicals for their potential in management of Xanthomonas wilt of banana. Poster presented in the ISHS ProMusa Symposium, Greenway Woods Resort, White River, South Africa, September 10-14 2007.

Mwangi M, Nakato V (2007). Key factors responsible for the banana Xanthomonas wilt pandemic on banana in East and Central Africa. In: Recent advances in banana crop protection for sustainable production and improved livelihoods. ISHS ProMusa Symposium. Acta Hortic. 828:395–404.

Ndungo V, Eden-Green S, Blomme G, Crozier J, Smith JJ (2006). Presence of banana Xanthomonas wilt (Xanthomonas campestris pv. musacearum) in the Democratic Republic of Congo (DRC). Plant Pathol. 55:294.http://dx.doi.org/10.1111/j.1365-3059.2005.01258.x

Njuguna M, Wambugu F, Acharya S, Mackey M (2010). Socio-economic impact of tissue culture banana (Musa spp.) in Kenya through the whole value chain approach. Acta Hortic. 879:77–86.

Ochola D, Jogo W, Ocimati W, Rietveld A, Tinzaara W, Karamura D, Karamura E (2013). Farmers' awareness and perceived benefits of agro-ecological intensification practices in banana systems in Uganda. Afr. J. Biotechnol. 12(29):4603-4613.

Onyango M, Haymer D, Keeley S, Manshardt R (2008). Analysis of genetic diversity and relationships in east African 'Apple Banana' (AAB genome) and 'Muraru' (AA genome) dessert bananas using microsatellite markers. In: Dubois et al. (eds) Proceedings of the International Conference on Banana and Plantains in Africa. Acta Hortic. 879:623-636.

Overfield D, Murithi FM, Muthamia JN, Ouma JO, Birungi KF, Maina JM, Kibata GN, Musembi FJ, Nyanyu G, Kamidi M, Mose LO, Odendo M, Ndungu J, Kamau G, Kikafunda J, Terry PJ (2001). Analysis of the constraints to adoption of herbicides by smallholder maize growers in Kenya and Uganda. British Crop Protect. Council 1:907-912.

Qaim M (1999). Assessing the impact of banana biotechnology in Kenya. ISAAA Briefs No. 10-1999. ISAAA in collaboration with Zentrum fur Entwicklungsforschung Centre for Development Research Universitat Bonn. P. 38.

Reeder RH, Muhinyuza JB, Opolot O, Aritua, V, Crozier J, Smith J (2007). Presence of banana bacterial wilt (Xanthomonas campestris pv. musacearum) in Rwanda. Plant Pathol. 56:1038. http://dx.doi.org/10.1111/j.1365-3059.2007.01640.x

Seshu Reddy KV, Ngode L, Ssenyonga JW, Wabule M, Onyango M, Adede TO, Ngoze S (1999). Management of pests and diseases of banana in Kenya: a status report. In: Frison E, Gold CS, Karamura EB, Sikora RA (eds.), Proceeding of a Workshop on IPM Banana held in Nelspruit, South Africa. INIBAP, Montpellier. pp. 215–223

Tinzaara W, Karamura EB, Blomme G, Jogo W, Ocimati W, Rietveld A, Kubiriba J, Opio F (2013). Why sustainable management of Xanthomonas wilt of banana in east and central Africa has been elusive. Acta Hortic. 986:157-164.

Tinzaara W, Gold CS, Ssekiwoko F, Tushemereirwe W, Bandyopadhyay R, Abera A, Eden-Green SJ (2006). The possible role of insects in the transmission of banana Xanthomonas wilt. Afr. Crop Sci. J. 14:105-110.

Tripathi L, Mwaka H, Tripathi JN, Tushemereirwe WK (2010). Expression of sweet pepper Hrap gene in banana enhances resistance to *Xanthomonas campestris* pv. musacearum. Molecular Plant Pathol. 11:721-731.PMid:21029318.

Tripathi L, Mwangi M, Abele S, Aritua V, Tushemereirwe WK, Bandyopadhyay R (2009). Xanthomonas wilt: a threat to banana production in East and Central Africa. Plant Dis. 93:422-451. http://dx.doi.org/10.1094/PDIS-93-5-0440

Tushemereirwe W, Kangire A, Ssekiwoko F, Offord LC, Crozier J, Boa E, Rutherford M, Smith JJ (2004). First report of *Xanthomonas campestris* pv. musacearum on banana in Uganda. Plant Pathol. 53:802. http://dx.doi.org/10.1111/j.1365-3059.2004.01090.x

Tushemereirwe W, Kangire A, Smith J, Ssekiwoko F, Nakyanzi M, Kataama D, Musiitwa C, Karyeija R (2003). An outbreak of bacterial wilt on banana in Uganda. InfoMusa 12:6-8.

Wambugu F, Kiome R (2001). The Benefits of Biotechnology for Small-Scale Banana Farmers in Kenya. ISAAA Briefs P. 22. ISAAA: Ithaca, NY. PMid:11421948.

Yirgou D, Bradbury JF (1968). Bacterial wilt of Enset (*Ensete ventricosum*) incited by *Xanthomonas campestris* pv. musacearum. Phytopathology 58:111–112.