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Knowledge and Perceptions on Banana Xanthomonas Wilt Control 10 Years after the Epidemics in the South Western Agro-Ecological Zone, Uganda

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Abstract

The East African highland cooking banana (*Musa* spp.) is a major food security and non-traditional income generation crop in rural and urban areas of the South Western Agro-Ecological Zone (SWAEZ) of Uganda. Being a perennial crop, the vulnerability of banana to the evolving abiotic and biotic stresses is increasing in this major production region. During the late 2000s, the SWAEZ experienced wide-spread and severe banana Xanthomonas wilt (BXW) disease epidemics, which caused 70% - 100% crop and/or yield losses. Through various partnerships, the government of Uganda applied the integrated approaches to provide the needed technical, policy, legal and financial support to rapidly eradicate the disease, strengthen the farmers' capacities to prevent further plant infections and spread of the "*Xanthomonas vasicola* pv., *musacearum* (*XVM*)" pathogen. Research has shown that the comprehensive and collective action, which focused on rapidly eliminating BXW, reduced the disease prevalence to <5%, but ten years after the eradication campaign, BXW is persistent in SWAEZ. A study carried out in five districts to assess farmers' knowledge and perception about the BXW control 10 years after the epidemics, found that the disease incidences continue to gradually rise, as efforts to control it continue to decline, which makes the zone prone to another serious epidemic if strong measures are not enforced. Given the knowledge and skills previously imparted to farmers, banana productivity and production for food and income generation have been gradually increasing; livelihoods that are highly dependent on banana have improved and crop production has been

diversified in some areas. However, because of the decline in the government's effort to continue sensitizing, monitoring and enforcing by-laws, the disease inoculum continues to build up and spread. While the majority of the household respondents agreed that the recommended disease control technology packages were very effective, they were also expensive (in terms of labour and non-labour inputs), and too difficult to be applied by the weak and vulnerable community members (females, children, elderly people, sick and other disabled community members). The farmers attributed the disease persistence in the zone to poor monitoring, ineffective use of the recommended disease management technology packages, increased disease pathogen inoculum in abandoned plantations, use of infected planting materials and unsterilized field tools. Therefore, in order to completely mitigate BXW from the SWAEZ, this study recommends that the government reinstate regular awareness creation campaigns, training, and functional BXW eradication task-forces in the banana-producing communities to ensure timely and effective disease control.

Subject Areas

Agricultural Engineering, Agricultural Science

Keywords

Banana Xanthomonas Wilt, Epidemics, IDM, Benefits, Farmers' Knowledge and Perception

1. Introduction

Banana is a widely cultivated perennial crop in the South Western Agro-Ecological Zone, which contributes approximately 68% to its annual production in Uganda [1]. Banana ranks first as the major food security and income generation crop [2], for over 10 million Ugandans including 66% of the urban population. The South Western Agro-Ecological Zone (SWAEZ) produces most of the banana exported to neighbouring countries (Kenya, Rwanda, Burundi, Eastern DRC and the Republic of South Sudan) [3], and overseas. Farmers grow over 53 different local and improved banana varieties, with the East African highland cooking types commonly known as *Matooke* [4] [5] [6], and desert types as major, while the brewing types are currently not common. *Mpologoma*, *Kibuzi*, *Mbwazirume*, *Enjagata*, *Bogoya*, *Enyeru*, *Embururu/Kabururu*, *Kababaragara (apple banana)*, *Kitika/Ntika and Kakira ka Mbogo* are the ten commonly grown varieties in the SWAEZ [7] [8].

For long, banana has been known to carry a diversity of tolerance and/or resistance genes to both biotic and abiotic stresses [9] [10], with a high level of recovery after intense destruction by wind, drought and hailstones. Since the early 20th century, banana production in Uganda has continued to decline [11], while the demand continues to raise within and outside the country [12]. The current annual banana production (~6 million metric tonnes) in Uganda is insufficient

to meet the consumption and market requirement, with an on-farm yield range of 5 - 30 t/ha, which is significantly lower than the attainable yield of 60 - 70 t/ha [9] [11] [13]. The low banana yields are attributed to a number of factors that include; continuous growing of low-yielding banana varieties by farmers due to lack of improved varieties with consumer-preferred attributes [5], low soil fertility [14], diseases (banana Xanthomonas wilt, black leaf streak/black Sigatoka and Fusarium wilt) and pests (weevils, nematodes and thrips) [15] [16], poor plant agronomic management, water deficit and high temperature [11].

In Uganda, Xanthomonas wilt is an economically important banana disease, which is very destructive causing crop and/or yield losses of approximately 80% - 100% in major production areas [17] [18]. The disease affects every stage of plant growth of all common banana varieties, and has the potential to cause an estimated loss of $360 million per annum (*i.e.*, 90% of banana contribution to the gross domestic product (GDP)) nationally. The disease, whose origin was traced to Ethiopia, was first reported in 2001 on banana in Mukono and Kayunga [18] in Central Uganda, and since then, the disease has spread to the Northern, Eastern and Western regions of the country. *Xanthomonas vasicola* pv., *musacearum* (*XVM*), the causal agent of BXW is transmitted by various means including: insects, runoff, soil erosion, field tools, animals, plant residues, mulches, infected planting materials (suckers) and organic fertilizers (banana-based compost) [19]. Studies have shown that visible symptoms are indicators of an advanced or already on-going infection [20]. This implies that plants showing symptoms are not the only ones infected in the field, but there are plants without visible symptoms already infected. The major visible BXW symptoms are: 1) withering of plant leaf lamina that initially appears as pale green, then gradually becomes scalded, 2) wilting, collapsing and drying of plants whereby leaves then wilt back on the midrib and dry up turning brown, 3) yellowish oozing of bacteria from infected banana pseudo stems or petioles, 4) uneven and premature ripening of banana fingers where a cross-section cut of a ripe finger shows yellowish flesh and dark brown placental scars [21].

During 2010-2015, a comprehensive integrated strategy comprising the following approaches was applied to eradicate BXW in the SWAEZ:

Generation of BXW control technologies and information: The National Agricultural Research Organization (NARO) in partnership with other research institutions [Makerere University, International Institute of Tropical Agriculture (IITA), International Network for the Improvement of Banana and Plantain (INIBAP), Food and Agriculture Organisation (FAO), Bioversity and Centre for Agriculture and Biosciences International (CABI)] generated disease epidemiology information and various technology options that were integrated to manage the disease [22].

Awareness creation: The Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) crop protection department in collaboration with FAO, NARO, National Agricultural Advisory Services (NAADS); District Local Government and Non-Governmental Organisations (NGOs) raised stakeholders' awareness

about the disease management through various training programmes [22] [23]. Trained extension service providers and multiple communication channels created awareness in the entire country via print and electronic media, mass media, posters, leaflets and brochures. Previous studies showed that more than 85% of the farmers were knowledgeable about BXW identification, spread and control [24].

Dissemination of BXW control technologies and information: Using the participatory development communication (PDC) approach, which centers on action plans developed by communities to address specific problems, community action plans were developed under the guidance of facilitators. In the SWAEZ, the stakeholders involved in the development and implementation of the action plans included: political, religious and cultural leaders; district and sub-county extension staff; National Agricultural Advisory Services (NAADS); NGOs; Community Based Organisations (CBOs); law-enforcement officers (Uganda police, District Internal Security Officers (DISO)); traders; processors; farmers, researchers and training institutions. This approach was deployed in all areas where the BXW disease occurred. The disease management technologies were scaled out through trained facilitators who were supported to supervise the implementation of community developed action plans. This approach was scaled out on the frontline (advancing edge of the endemic zone) and later in the endemic areas. Although this approach was more resource consuming than the top-down methods, it was very effective in setting problem-solving actions at the community level. The PDC approach resulted in the BXW prevalence reduction of up to 18% [25].

Integrated disease management: This approach combined the following methods to enable quick and effective control of BXW [2] in areas that were at risk of severe disease epidemics. 1) *Preventive methods*, included: Avoiding collection and movement of planting materials (e.g., suckers) within or across infected or non-infected banana plantations; avoiding preparation and application of compost manure using banana residues or other BXW pathogen host plants; avoiding disposing household refuse containing banana plant residues into banana plantations; resisting truck loading and/or offloading banana fruits collected from other plantations near or in farmers' compounds or plantations; avoiding movement of banana fruit-bunches across fields and homes; establishment of barriers that prevent runoff from infected and non-infected banana plantations running into other plantations; preventing animals from moving from plantation to plantation; removing the fully developed banana male flower buds immediately after flowering, using forked-sticks; sterilizing all banana field tools before and after use to kill the bacteria [26]; All banana trucks not to be allowed to move from plantation to plantation collecting banana, and avoid creating fresh wounds on banana plants that could become points of infection. 2) *Eradicative methods* included: uprooting all infected banana plants, and destroying or burying all affected plants; in cases where the entire plantations were infected, all banana plants including the non-BXW infected plants were uprooted and destroyed [27]. 3) *Quarantine methods* included: villages, where

BXW had been reported, were quarantined until the disease was eradicated; creation and enforcement of by-laws that were implemented by all stakeholders; farms where BXW was reported were not allowed to market the bananas until the disease had been controlled.

Given all the efforts invested into promoting the IDM technologies for controlling BXW in the SWAEZ, uptake of these technologies apparently seems to have slowed down, hence limiting the possibility of complete disease mitigation [2] [28] [29]. The disease has become endemic and is still causing yield losses. Isingiro district, which was formally known as the major producer and supplier of banana in Uganda, experienced a famine that resulted from the BXW epidemics. Therefore, this study was carried out to: assess farmers' knowledge about BXW control; assess the current status of BXW in the SWAEZ, and identify factors favouring BXW persistence in the region; assess farmers' access, acceptance, uptake and benefits from BXW control technologies, and then set strategies or develop methodologies for systematic and effective BXW eradication from the zone.

2. Methodology

This study was carried out in five districts (Mbarara, Mitooma, Rubirizi, Ntungamo, Isingiro), which experienced severe BXW epidemics between 2009 and 2013. Two sub-counties were purposively selected to represent the major banana growing areas, that were most affected by the disease in each district. In this research study, respondents of whom the majority were banana farmers were randomly selected from four parishes and villages following the criteria described in **Table 1**. The three hundred eighty-four respondents represented the banana growing households in the current study. A sampling frame was used to select the participating households so that each category of farmers (individual or group) directly involved in BXW control research and demonstrations; technology promotion and dissemination were represented. Each category of household representatives that participated in either technology development or dissemination was purposively selected, whereas individuals who were interviewed within each category were randomly selected using the criteria. The sample size of the participating farmers was determined using the formula $(X_2NP(1-P)/C_2(N-1) + X_2P(1-P)$. Where: X_2 = Chi-square value for 1 degree of freedom (3.841); N = Population size; P = Population parameter (0.475); C = Confidence interval (0.05) [30]. Both primary qualitative and quantitative data were collected through formal interviews of household representatives using pre-tested structured questionnaires that were uniformly administered to male and female respondents. This research study was carried out to determine the level of BXW information, control technology uptake, acceptance and the farmer's perceptions about the BXW control technologies. The variables that were captured to characterize the determinants of acceptance included socio-economic data such as household size, farm and family size, educational status of the household, perception

Table 1. The socio-economic study sites in the five districts of South Western Agro-Ecological Zone (SWAEZ), Uganda.

District	Sub-County	Selection criteria for the study sites and respondents
Rubirizi	*Kichwamba* *Rutoto*	• Kichwamba was the most severely affected by BXW • Kichwamba, Katerera and Ryeru were the first to be attached by BXW • Rutoto was not severely affected by BXW • Rutoto was the highest banana producing sub-county.
Mitooma	*Kabira* *Mutara*	• First incidences were reported in Mutara sub-county • Mayanga, Rurehe and Kabira sub-county still experience BXW incidences • Kashenshero S/C, Kashenshero T/C, Mutara have recovered well • Kabira was the major banana producer, followed by Kashenshero and Mitooma.
Ntungamo	*Bwongyera* *Kabatsi*	• Bwongyera and Kibatsi were the most affected by BXW • Rugarama was the highest banana producer, and the BXW incidences were managed because farmers here highly value their banana for income.
Isingiro	*Nyakitunda* *Rugaaga*	• Nyakitunda had the first BXW attack • Rugaaga is still struggling with recovery • Rugaaga was the major banana producer, then Ngarama and Kashunga.
Mbarara	*Mwizi* *Rugando*	• Mwizi had the BXW attack, but had a success story in controlling it • Rugando still has the BXW problem • Rwanyamahembe was the major banana producer, and farmers were able to keep BXW in control.

about technology effectiveness and challenges, technology labour requirement, technology performance, technology attributes preferred by farmers, and the extent of BXW control technology application. More data about the BXW control technologies were collected in inform of case studies from key informants in the communities using checklists. Data were analyzed using Statistical Package for Social Scientists (SPSS), and chi-square statistics was used to examine the significance levels between categorical variables. Descriptive statistical analysis data outputs derived through frequencies and cross-tabulation were exported to MS-Excel and summarized in tables and figures for accurate interpretation.

3. Results

3.1. Socio-Demographic Characteristics of the Study Household Respondents

Majority of the respondents in the five districts (Mbarara, Isingiro, Mitooma, Ntungamo and Rubirizi) were males (63.8%), married (84.4%), and with primary school education level (54.7%). The higher number of male respondents that participated in this study was attributed to the fact that males are household heads who are normally expected to represent their families in such activities. Apart from respondents who had attained primary school education (**Table 2**), the study also involved participants who had attained secondary school (24.3%)

Table 2. Demographic and socio-economic characteristics of the survey respondents in Mbarara, Isingiro, Mitooma, Ntungamo and Rubirizi district in South Western Agro-Ecological Zone, Uganda.

Category	Characteristics	% Respondents (n = 384)
Sex	Male	63.8
	Female	36.2
Marital status	Married	84.4
	Single	2.7
	Widow/er	11.6
	Separated/divorce	1.35
Education level	Primary school	54.7
	Secondary school	24.3
	College/University	8.1
	None	12.9
Age (years)	10 - 20	0.3
	21 - 30	10.8
	31 - 40	22.0
	41 - 50	26.9
	51 - 60	23.1
	61 - 70	10.2
	71 - 80	5.9
	81 - 90	0.8

and college education (8.1%). Thirteen percent of the respondents had not acquired any formal education. Because the individual respondents were randomly selected within the banana growing communities, the minority households were represented by a few single, windows/ers and separated/divorced participants (Table 2), while the majority of respondents were married. The age range of most respondents engaged in banana production was 31 - 60 years, while the least number of farmers in banana production were in the age ranges of 10 - 20 and 71 - 90 years. Most households were headed by males whose primary and secondary occupations were farming (89.4%) and non-farm businesses (70.1%), respectively (Table 3). Fifteen percent of the respondents' households were headed by women while two (0.5%) were children-headed. Apart from the women- and children-headed households, the level of household decision making by husbands and wives on the different household activities did not vary widely. Besides decision making on income expenditure, which was mostly done by husbands (40.7%), other decisions on farming, marketing of produce and attendance of meetings were mostly done by husbands in agreement with wives (Table 3). Whereas most respondents indicated that they used household labour

Table 3. Household head description, occupation and sources of labour in Mbarara, Isingiro, Mitooma, Ntungamo and Rubirizi district in South Western Agro-Ecological Zone, Uganda.

Category	Characteristics	% Respondents (n = 377)
Household head	Husband	84.6
	Wife	14.9
	Children	0.5
Household head's 1˚ occupation	Farming	89.4
	Non-farm businesses	7.7
	Employed (Government/NGO)	1.9
	None	1.1
Household head's 2˚ occupation	Farming	28.2
	Non-farm businesses	70.1
	Employed (Government/NGO)	1.8
	None	0.0
Household decision making on farming activities	Husband	35.4
	Wife	24.2
	Both husband and wife	40.1
	Children	0.28
Household decision making on attending meetings	Husband	35.2
	Wife	26.6
	Both husband and wife	37.6
	Children	0.54
Household decision making on marketing produce	Husband	34.4
	Wife	26.9
	Both husband and wife	38.4
	Children	0.27
Household decision making on income expenditure	Husband	40.7
	Wife	19.4
	Both husband and wife	39.4
	Children	0.53
Household source of labour	Family	58.7
	Hired labour	10.7
	Hired plus family (50:50)	30.5
	Others	0.08

(58.7%) for the various farming activities, others combined family and hired labour (30.5%) or used hired labour (10.7%) only.

3.2. Food Security, Income Generation, and Factors Affecting Banana Production

The South Western Agro-Ecological (SWAEZ) is characterized by a complex mixed cropping system, but in the current study, most respondents grew banana, common beans and coffee (Figure 1) as the major crops. Other legumes (groundnuts), root/tuber crops (cassava, solanum potato and sweet potato), cereals (maize, millet and sorghum) and vegetable (tomatoes), were grown by fewer farmers for both food security and income generation. Because of the importance of banana as the major food and income generation crop in the zone, there were respondents who had been growing bananas for 80 years. Majority of the participants had been growing banana for 11 - 30 years, while very few respondents had been growing bananas for 50 - 80 years. Of the 373 respondents, majority owned 1 - 3 banana fields with 176 (47.2%) owning one field, while 102 (27.0%) and 56 (15%) owned two and three fields, respectively. Respondents that owned 4 - 8 fields were 39 (10.5%), and one (0.3%) owned one field. Ninety-two percent of the respondents in the five districts indicated that their banana plants were affected by various abiotic and biotic problems of which the major ones were: diseases (52.3%), mainly banana Xanthomonas wilt), severe drought/dry spells (19.6%) and soil infertility (11.9%). Pests including nematodes, weevils (*Cosmopolites sordidus*), and weeds were mentioned as other biotic stresses constraining banana production. During cropping seasons, plants were occasionally destroyed by heavy wind, soil erosion and excess soil moisture resulting from high erratic rainfall (Figure 2).

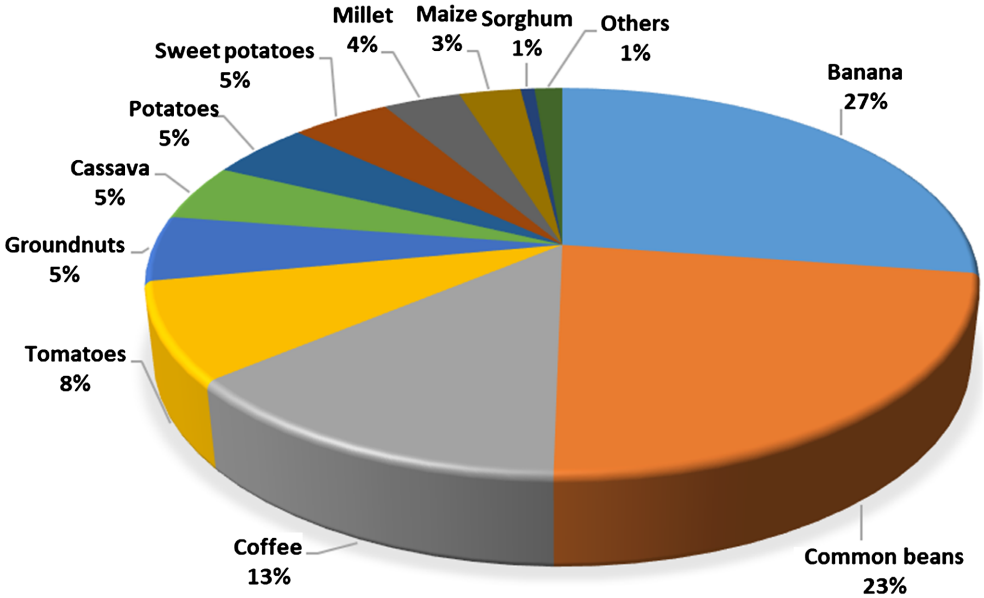

Figure 1. Farmers' common food and income generation crops grown in Mbarara, Isingiro, Mitooma, Ntungamo and Rubirizi district in South Western Agro-Ecological Zone, Uganda.

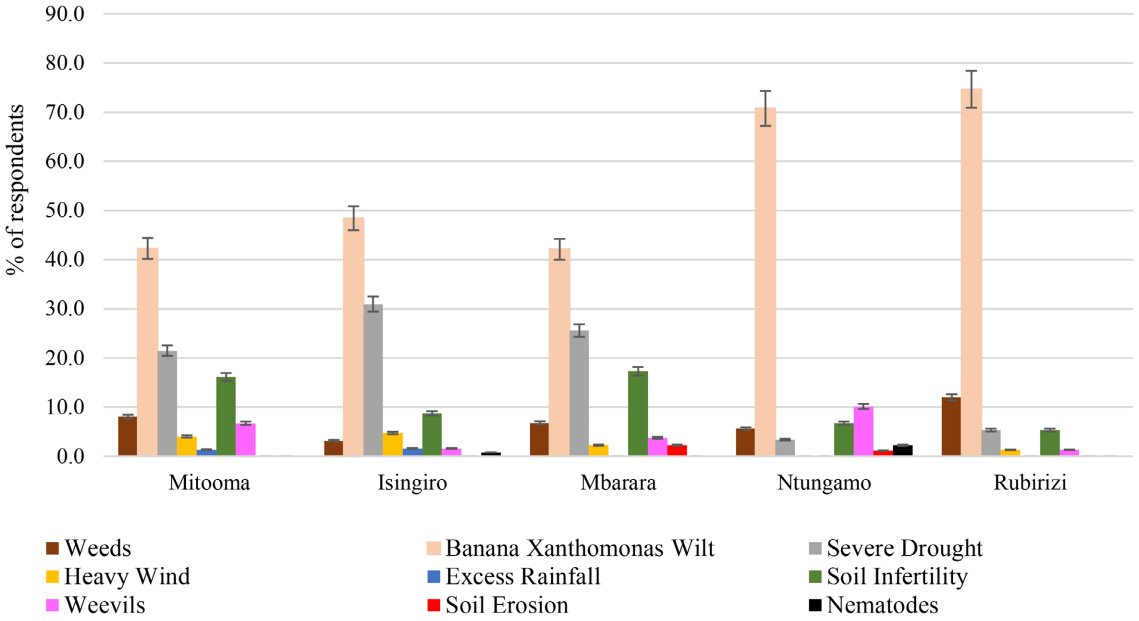

Figure 2. Abiotic and biotic stresses affecting banana (*Musa* spp.) production in Mbarara, Isingiro, Mitooma, Ntungamo and Rubirizi districts in South Western Agro-Ecological Zone, Uganda.

3.3. Farmers' Knowledge and Management of Banana Xanthomonas Wilt

Majority of the respondents in Mitooma (96%), Isingiro (100%), Mbarara (97%), Ntungamo (99%) and Rubirizi (100%) indicated that they were knowledgeable about banana Xanthomonas wilt, while the rest had no idea about the disease. However, most of these respondents (81.5%) did not know the causal agent of Xanthomonas wilt, while 7.4% knew that the disease was caused by bacteria, and 11% thought that the disease was caused by pests (e.g., bees and house flies). The banana Xanthomonas wilt pathogen infected all plant parts ranging from the above-ground pseudostem, vegetative and fruiting parts to the below-ground corms and rooting systems. Besides wilting or withering of vegetative plant parts, pre-mature fruit ripening and flowing of yellowish exudates from cut pseudostems, the respondents also mentioned withering and drying of male buds and fruit pulp discoloration as known Xanthomonas wilt disease symptoms (**Figure 3**). The level of farmers' knowledge about the disease symptoms across the five districts was generally similar, mainly because all farmers received the same sensitization, trainings and control interventions during and after the disease epidemics.

Overall, the banana production area, which covered 47.6% - 73.3% of the farmers' land holding during the BXW epidemic periods remained similar between 2010 and 2017 (**Figure 4**). However, the banana production trend declined from an average of 65 bunches to 33 bunches harvested from each respondent's field mainly due to the BXW disease. Ninety-seven percent of the respondents (n = 361) in the five districts mentioned that their banana plants had experienced BXW infection, while 98.3% affected and non-affected were controlling the disease using

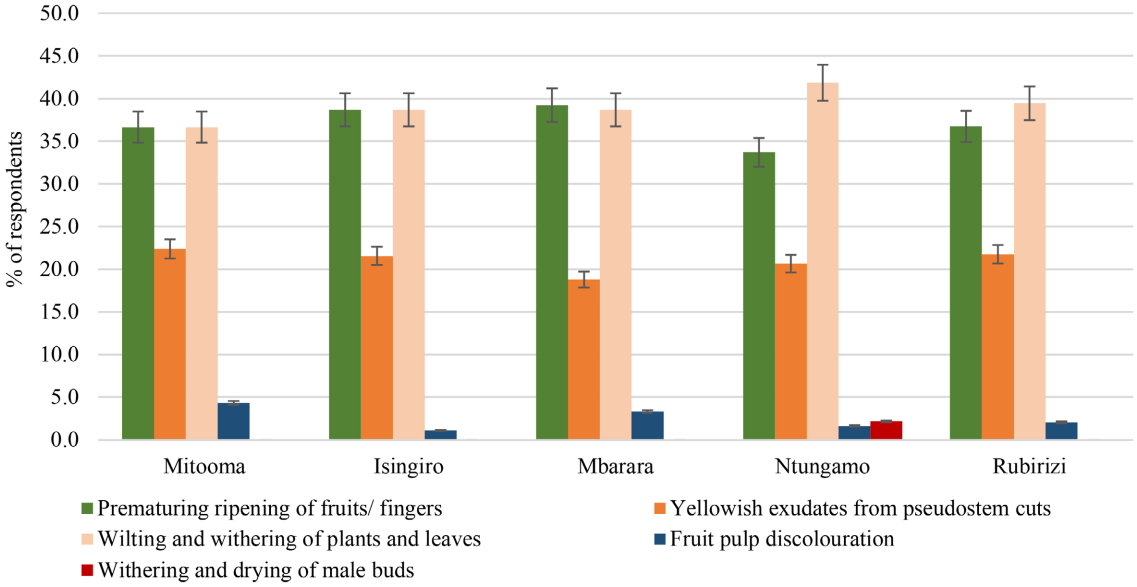

Figure 3. Banana Xanthomonas wilt symptoms observed by farmers on *Musa* spp., in Mbarara, Isingiro, Mitooma, Ntungamo and Rubirizi district in South Western Agro-Ecological Zone, Uganda.

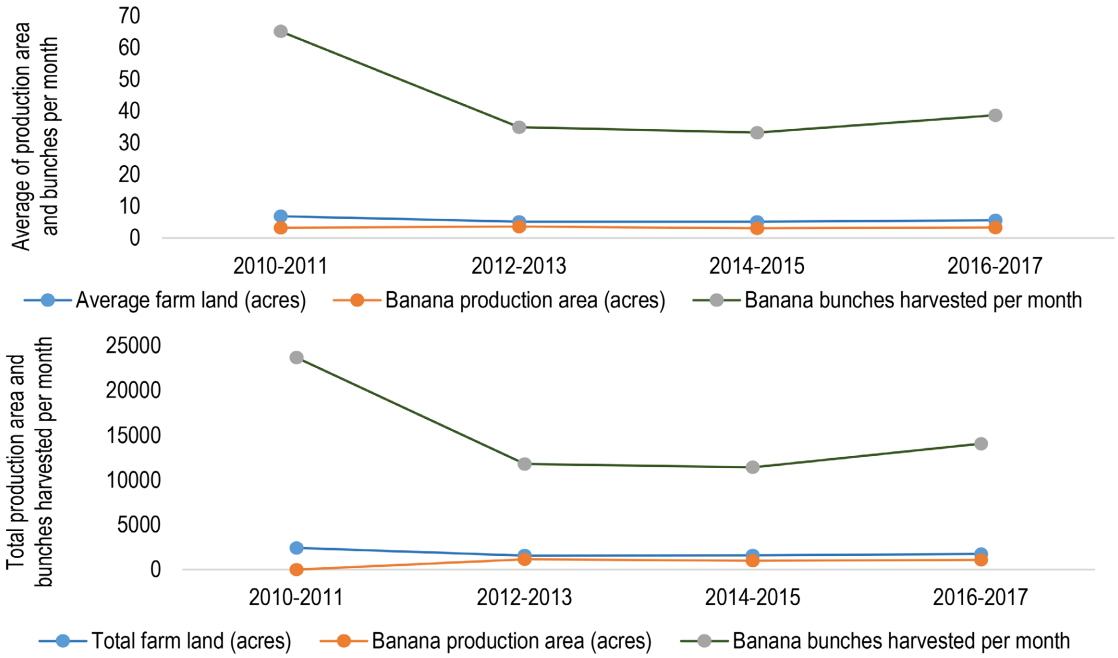

Figure 4. Farmer's land holdings, banana production areas (acres) and bunches harvested per month during the banana Xanthonomas wilt epidemics period in the South Western Agro-Ecological Zone, Uganda.

various methods across all sub-counties. At the time of the current study, all respondents in Ntungamo, Mitooma, Rubirizi and Isingiro were controlling BXW, but in Mwizi and Rugando sub-counties, which experienced the most serious epidemics in Mbarara, some farmers (15.6%) were not controlling the disease. Although various factors including unsterilized field tools (9.0%), animals (3.4%), insects (9.5%), contaminated soils (5.0%), new banana varieties (1.1%), neighbours' infected plants (7.9%), banana residues (2.1%) and wind (1.1), were

considered to be sources of the Xanthomonas wilt inoculum, 61% of the respondents had no ideas about the source of the disease inoculum. To the respondents, the common modes by which the bacterial wilt disease was spread from infected plants were pollinating insects (37.1%) and unsterilized field tools (44.5%). However, animals that fed on plant residues were also mentioned as means by which the wilt causal agent spreads among banana plants. Although 84.9% of the respondents indicated that the most favourable weather for banana bacterial wilt was the rainy/wet condition, 7% mentioned dry weather as the most favourable, while 2.7% insisted that infection occurred during both rainy and dry weather.

Because there is neither a banana variety that is immune to BXW nor a single effective control technology recommended for this disease; technology packages integrating various options were promoted and disseminated among farmers in the affected regions. The respondents mentioned 14 technologies that were used singly or in combination to control the disease in the SWAEZ. The common BXW control technologies used by most respondents were: removing male buds using a forked stick; sterilizing field tools before and after use; uprooting and chopping diseased plants; uprooting and leaving whole infected plants to dry (**Table 4**). Apart from Isingiro and Mitooma districts where each of the listed technologies was applied to some level, there are some districts where some key technologies were not mentioned and probably were not applied. Chi-square analysis between the respondents' education level and BXW control technologies applied indicated a significant association at 5% (χ^2 = 375.084, df = 85, p = 0.000), thus supporting hypothesis. The BXW control technologies were promoted jointly in the affected study districts by teams from the NARO, MAAIF, FAO, District Agriculture and extension departments. The National Agricultural and Advisory Services (27.2%) and the district agricultural extension departments (58.7%) were the major sources of BXW control technologies used by farmers. Of the various methods used by the service providers to disseminate information/knowledge and technologies among banana farmers to effectively control BXW in the epidemic areas, community + mobilization/sensitization + training (**Table 5**) were the most used approaches. House-to-house trainings, group trainings and demonstrations were also integrated into BXW control technology dissemination methods among farmers.

Although major efforts have been invested in integrated control of BXW, this study found that the disease recurrence incidences were reported by 83.1% of the respondents in each of the five districts, while 16.9% mentioned no re-occurrence. The highest level of BXW recurrence was reported in Isingiro district, which had been severely affected by the disease epidemics. The farmers attributed the re-occurrence to infected banana plants whose owners were not effectively controlling the disease (**Figure 5**), mainly because the introduced technologies/methods were; too expensive to apply, labour intensive, time consuming and required wood for making fire to continuously sterilize field tools (**Table 6**). Majority (91.4%) of the respondents indicated that the integrated technologies

Table 4. Banana Xanthomonas wilt control technologies used by the respondents (farmers) in Mbarara, Isingiro, Mitooma, Ntungamo and Rubirizi district in SWAEZ, Uganda.

BXW control technologies/practices	Percent (%) of respondents				
	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Uproot and chop diseased plants	23.8	15.0	4.1	8.9	29.6
Uproot and leave whole plant to dry	7.1	7.8	11.9	18.8	8.8
Uproot, chop and bury plant residues	2.4	14.6	14.4	4.7	1.2
Remove male buds with forked stick	27.6	26.7	26.8	29.2	25.8
Sterilize field tools before and after use	25.7	25.7	26.8	21.4	27.0
Prune dry leaves only	3.8	2.9	4.1	7.8	4.4
Cut, uproot and heap residue to dry	1.4	1.5	1.0	0.5	1.9
Cut, uproot, chop, apply ash, pepper and urine	1.0	1.0	6.2	6.8	0.0
Regular monitoring	0.0	2.9	1.0	0.0	0.0
Do not share tools with neighbours	1.9	0.5	1.0	0.0	0.0
Suspend pruning banana plants	4.3	1.0	2.6	0.0	0.6
Stake plants	0.5	0.0	0.0	0.0	0.0
Cut, chop, uproot and cover infected plants residues	0.5	0.5	0.0	2.1	0.6

Table 5. Methods used by service provides to disseminate banana Xanthomonas wilt management technology packages among farmers in the South Western Agro-Ecological Zone, Uganda.

Dissemination methods used by service providers	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Enforcing by-laws through local leaders, police	0.0	0.0	1.2	0.0	0.0
and religious programmes	0.5	1.3	1.2	0.0	0.0
Community mobilization, sensitization and trainings	86.5	36.0	49.4	71.4	55.6
Demonstration and mass media	0.0	1.3	0.0	0.0	0.0
House-to-house training and demonstrations	9.0	22.7	22.4	8.3	20.8
Mass media programmes only	1.8	21.3	1.2	2.4	6.9
Organized farmer group meetings and trainings	1.8	13.3	17.6	15.5	13.9
Training workshops	0.5	2.7	4.7	1.2	2.8
Field trainings and demonstrations	0.0	1.3	2.4	1.2	0.0

introduced by research were very effective, and 96.2% would continue applying the technologies in controlling BXW. However, 87.1% were not interested in modifying the technologies for effective utilization because of various reasons of which the high technology effectiveness was major in most districts (40%). On the other hand, 12.9% would prefer to modify the technologies for better use.

3.4. Banana Xanthomonas Wilt Disease Control Technology Accessibility and Utilization

The respondents in Mitooma, Isingiro, Mbarara, Ntungamo and Rubirizi used various inputs in controlling BXW in the fields, but out of the 15 items, the most

common were hand hoes/forked hoes, pangas, forked sticks, pruning knives, fire, spades and axes (Table 6). Apart from the forked sticks, which were

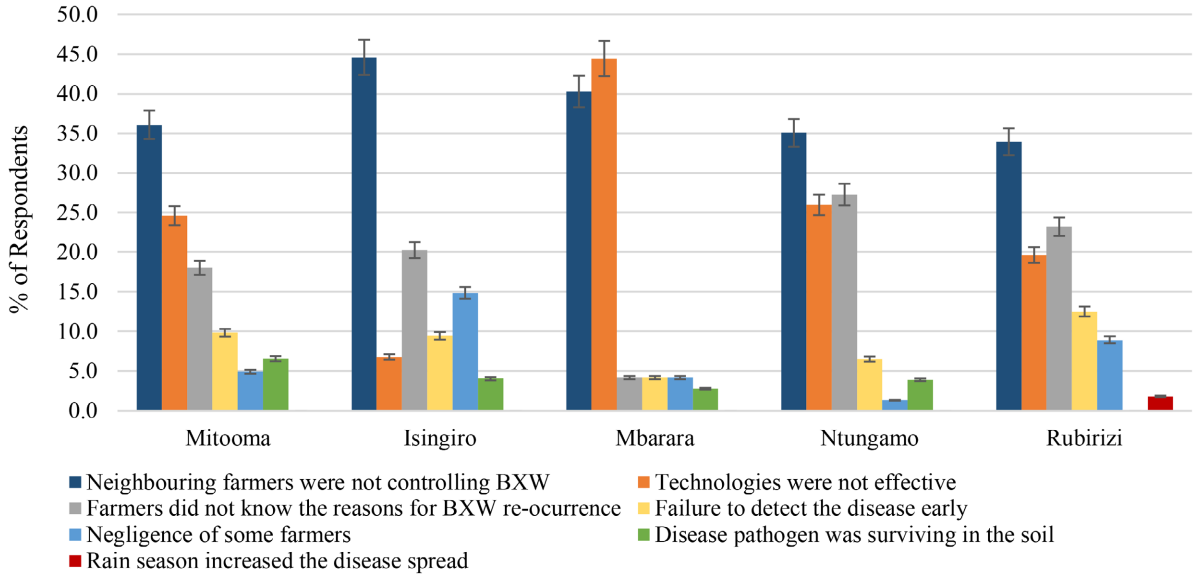

Figure 5. Reasons why banana Xanthomonas wilt persisted in Mbarara, Isingiro, Mitooma, Ntungamo and Rubirizi district in South Western Agro-Ecological Zone, Uganda.

Table 6. Inputs used in banana Xanthomonas wilt control using the integrated management technologies in Mbarara, Isingiro, Mitooma, Ntungamo and Rubirizi district in SWAEZ, Uganda.

Inputs	% of Respondents				
	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Hand hoes/forked hoe	34.9	40.4	31.4	32.2	37.8
Panga	33.5	33.5	29.7	31.8	32.7
Forked stick	15.1	3.7	11.9	16.3	9.7
Pruning knife	3.8	3.2	8.1	8.4	2.0
Fire	3.8	1.8	4.2	7.1	6.1
Spade	0.9	7.3	4.7	0.0	3.6
Axe	3.3	4.6	5.9	1.7	4.1
Mattock	0.0	3.7	2.5	0.0	1.5
Disinfectant (Jik)	2.8	1.4	0.8	0.8	0.5
Wood ash	0.0	0.5	0.8	0.8	0.0
hand knife	0.9	0.0	0.0	0.0	1.0
Sickle	0.0	0.0	0.0	0.4	0.5
Wheel barrow	0.5	0.0	0.0	0.0	0.5
Rake	0.5	0.0	0.0	0.0	0.0
Spear	0.0	0.0	0.0	0.4	0.0

collected from forests (7.9%) and old coffee fields (0.2), most of the inputs were obtained from agro-input shops (90.1%), hardware shops (0.2%) and local retail markets (0.8%). Although majority (82.4% - 91.1%) of the respondents indicated that the BXW management technologies were easily accessed and applied by most farmers, 8.9% - 25.8% of respondents in the various districts were not accessing or applying the technologies mainly because they had never been trained or had inadequate training (37.8%), were lazy and/or negligent (35.1%) and some had abandoned the banana plantations (10.8%). Nevertheless, some respondents lacked adequate money to invest in fighting the diseases (5.4%), the elderly were unable to apply the labour-intensive BXW technologies (2.7%), some farmers failed to access the appropriate BXW control tools (5.4%), and the rest considered the technologies to be ineffective (2.7%) (**Figure 6**).

On average 42.3% had trained other banana farmers, while 57.7% of the respondents in the five districts and 10 sub-counties had not been able to train other banana farmers in BXW control using the integrated technologies. The respondents that had not trained banana farmers in Mitooma, Isingiro and Rubirizi, indicated that there was no need for training because all banana farmers in the communities had been trained (60.2%), and 18.4% had limited time because they were engaged in other businesses or employments. Out of the 126 respondents that trained other farmers, 69%, 20.6%, 1.6%, 3.2%, 1.6%, 0.8%, 3.6% trained 1 - 5, 6 - 10, 11 - 15, 16 - 20, 21 - 25, 26 - 30 and >30 individuals, respectively, through mass mobilization, sensitization and training in villages (51.0%); demonstrations (33.5%); verbal interactions with individual farmers (9.7%); field days (5.2%) and mass media (0.6%). Most (64.7%) of the males and

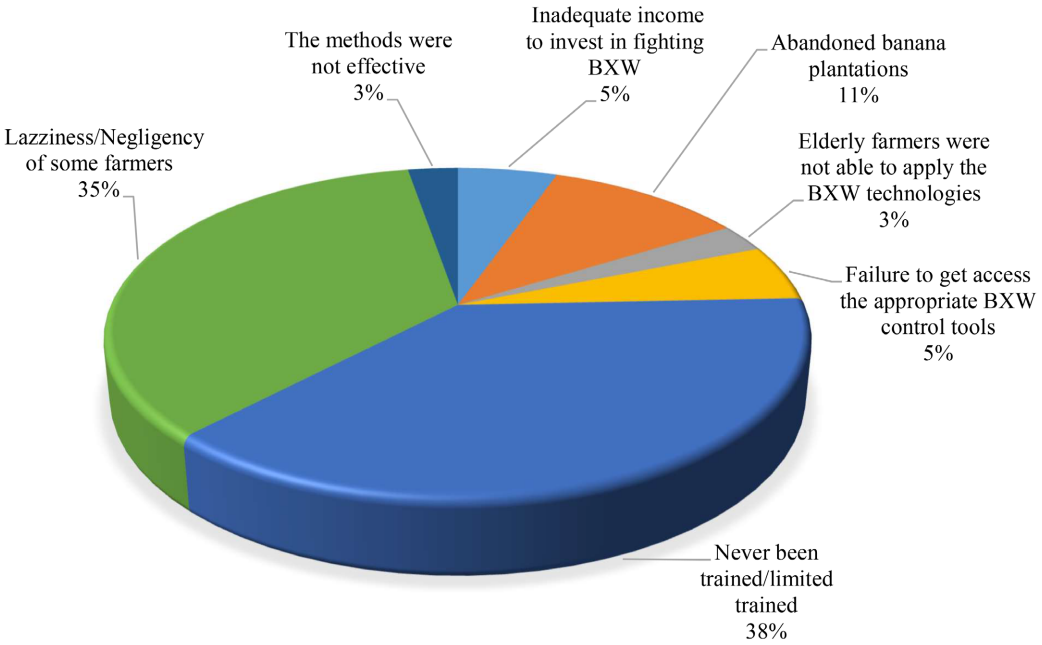

Figure 6. Reasons why banana farmers were not accessing and/or applying the recommended banana Xanthomonas wilt (BXW) management technology packages in study areas of Mitooma, Isingiro, Mbarara, Ntungamo and Rubirizi district, Uganda.

females trained by the individual respondents lived within a distance of 0 - 1 Km, but the number decreased with increasing distance whereby trained farmers living at further distances of 2 - 3, 4 - 5, 6 - 7 and >8 kilometers (Km) were 13.4%, 6.7%, 0.8% and 0.0%, respectively. Community sensitization (16%), demonstrations (50%) and individual farmer training (34%) were the common methods used in capacity building of farmers. Demonstrations had the highest score as the most effective method used for technology dissemination mainly because they were practical, and farmers learned and understood the technology application practices (Table 7). Group trainings and mass sensitization were also accepted as the second effective methods because many people were sensitized and trained at the same time. Other methods including, door-to-door, individual and community trainings enabled farmers to understand, interact and try them in the field; were effective because many people accepted the information,

Table 7. Advantages and disadvantages of methods used by respondents to disseminate banana Xanthomonas wilt (BXW) management technologies to other banana growers in South Western Agro-Ecological Zone, Uganda.

Method used	Advantages	% Response	Disadvantages	% Response
Demonstrations	A lot of knowledge/information/techniques of controlling BXW were shared by different resource persons	9.9	Lack of fuel for sterilizing field tools	1.8
	Farmers did not find an problem in moving from one place to place while disseminating IDM technologies	2.8	Limited tools for everybody to participate, and some farmers lacked the tools	5.4
	Through this practical approach, farmer learnt and understood proper technology application techniques	26.7	Some people do not want their gardens used	1.8
	Increased crop production for food and income	1.4	Some people were not training	12.5
	Effective, and feedback from the farmers on-spot	1.4	Some people were careless, lazy and reluctant	5.4
	Learnt how tools are sterilized	1.4	Not much monetary benefit	1.8
	Were proper dissemination of technologies	1.4	Time consuming and labour intensive	30.3
Community trainings	Easy to understand, interact and demonstrate in the field	7.0	No hands on practical	19.6
Door to door trainings	Effective (many people accepted the information, adopted and BXW reduced)	9.9	-	
Door to door, and individual trainings	Not costly and people were trained at their homes where they observed and learnt	9.9	-	
Group trainings and mass sensitization	Many people were sensitized and trained at the same time	25.5	Not all people benefited because some never applied/adopted the technologies	8.9
	Trainers had opportunities to meet people of various status	2.8	There were arguments and negativity during the dissemination, thus not all ideas were taken and applied.	12.5

adopted and BXW reduced; and were not costly, and people were trained at their homes where they observed and learn. However, lack of fuel, tools for everybody to participate, monetary benefit, technology application being time and labour intensive made some of the technology dissemination methods ineffective. Mass sensitization did not only lack hands-on practice, but involved participants who were argumentative and negative during the dissemination activities, thus undermining its effectiveness in building farmer's capacity in BXW control.

Ten years after the BXW epidemics, and the collective control intervention in the SWAEZ, 82% of the respondents indicated that they had not received any additional technical support from the various service providers, yet the disease was persistent in some areas. Eighteen percent received additional technical support in various BXW control practices including uproot and chop diseased plants (17.5%); uproot and leave whole plants to dry (9.3%); uproot, chop and burry (10.3%); remove male buds (30.0%); sterilize tools (23.7%); prune dry leaves only (6.2%); cut, uproot, heap and leave to dry (1%); regular monitoring (1%) and suspend pruning (1%). Fifty-one percent ranked the additional technical support received as very useful, while the rest ranked it as useful (40.6%), fair (1.5%) and not useful (6.3%). Most respondents emphasized that the additional technical support received, provided them with more advice and knowledge about effective BXW control; increased their ability to apply and adopt the integrated technologies, which led to effective disease control; motivated the lazy farmers to continue controlling the disease; reminded the negligent neighbours on the negative consequence of BXW epidemics; and farmers acquired training in proper banana plant agronomic management practices apart from controlling banana Xanthomonas wilt.

3.5. Banana Farmers' Perceptions on the Recommended Banana Xanthomonas Wilt Control Technologies

All respondents in the study sites had varying positive and negative perceptions about the BXW control technologies, but majority (60.2%) were convinced that the technologies were very effective against the disease. Nineteen percent of the respondents indicated that the technologies were applied by men without difficulty, 7.6% found that the technologies were labour intensive, difficult and time consuming, whereas 7.6% insisted that the recommended technologies were not effective. Although most males (85.5%) and females (88.2%) believed that the technologies were effective (**Table 8**, **Table 9**), respondents in Ntungamo were convinced that if well applied, the technologies could effectively eradicate BXW from their banana plantations. Both males and females agreed that application of the recommended technology packages was labour intensive, tedious, difficult and time consuming. Females indicated that most activities involved were manual and best applied by males because most activities including digging up pits, uprooting, cutting, chopping and burying infected plants were difficult for females (**Table 9**). Although some males and females mentioned that the technologies were not effective, interestingly, 20% and 25% of males and females, respectively,

Table 8. Perceptions of male farmers about the recommended banana Xanthomonas wilt management (BXW) technology packages in the South Western Agro-Ecological Zone (SWAEZ), Uganda

Mens' perceptions about the BXW control technologies	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Technologies were effective	31.0	59.0	62.7	85.5	54.0
Technologies were easily applied by men	31.0	14.8	32.2	0.0	20.0
Labour intensive, difficult and time consuming	14.3	16.4	5.1	1.8	2.0
Technologies were not effective	9.5	3.3	0.0	7.3	20.0
Were still trying the technologies	0.0	0.0	0.0	1.8	4.0
Technologies were expensive	2.4	0.0	0.0	0.0	0.0
Men were controlling but the disease was persistent	2.4	0.0	0.0	0.0	0.0
Men were able to bury the affected plant residues	0.0	1.6	0.0	0.0	0.0
More intensive and continuous effort was needed to be able to control BXW	2.4	3.2	0.0	0.0	0.0
Vf Most men were ignorant about BXW	2.4	0.0	0.0	0.0	0.0
Farmers were not interested	2.4	0.0	0.0	0.0	0.0
Sterilizing tools made them wear out quickly	2.4	0.0	0.0	1.8	0.0
Technical teams and the government were expected to provide chemicals to eradicate BXW	0.0	1.6	0.0	0.0	0.0
Men were required to work on the bananas themselves for the technologies to be effective	0.0	0.0	0.0	1.8	0.0

Table 9. Perceptions of female farmers about the recommended banana Xanthomonas wilt management (BXW) technology packages in the South Western Agro-Ecological Zone (SWAEZ), Uganda.

Women's perceptions about the BXW control technologies	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Technologies were effective especially when used regularly	62.1	46.7	56.3	88.2	43.8
Some activities (digging up pits, uprooting, cutting, chopping and burying infected plants) were too difficult for women	15.9	11.1	12.5	0.0	9.4
Technology packages could be carried out by women	9.1	13.3	14.6	0.0	9.4
Labour intensive, tedious and time consuming	6.8	13.3	6.3	3.9	3.1
Technologies were not effective	0.0	6.7	0.0	5.9	25.0
BXW was persistent	0.0	2.2	2.1	2.0	0.0
Technologies needed strong people like men	2.3	2.2	2.1	0.0	0.0
Control to be done by both men and women	0.0	0.0	4.2	0.0	0.0
If all farmers used the technologies the disease incidence would be decreased and/or mitigated	2.3	0.0	0.0	0.0	0.0
With support from government, the disease would be eradicated	0.0	0.0	0.0	0.0	3.1
More sensitization of the community helped to reduce the rate of disease spread	0.0	0.0	2.1	0.0	0.0
Sterilizing tools made them wear out quickly	2.3	0.0	0.0	0.0	0.0

Continued

Women would cut and leave infected plants on the ground due to a lack of labour	0.0	2.2	0.0	0.0	3.1
Women just cut down infected plants for men to burry	0.0	2.2	0.0	0.0	0.0
Women were not interested/concerned about the technologies	2.3	0.0	0.0	0.0	3.1

in Rubirizi district insisted that the BXW technologies were not effective, and probably this was the main reason why the disease was persistent in this area. Many males and females in Mitooma were not interested in controlling, ignorant about BXW, and insisted that sterilizing field tools made them wear out quickly. Although the technologies could be carried out by women, some women did not manage to fully apply them as recommended, which slowed the eradication process and created room for the disease pathogen to continue spreading. Both males and females believed that in order to completely eradicate BXW, they needed to collectively, continuously and regularly apply the recommended IDM technology packages. Additionally, the farmers emphasized that the government needed to continue sensitizing and encouraging the men in farming households to physically and fully get involved in controlling the disease.

Majority of the respondents (75%, n=360) indicated that all banana farmers in the study sites were applying the recommended BXW control technologies, 13.9% indicated that all farmers were not controlling and 11.1% mentioned that some were controlling while others were not. Across the five districts, most respondents indicated that the main reasons for not applying BXW control technologies were: carelessness, laziness, and negligence; lack of knowledge and information about the technologies; the high cost of the technology application and other reasons indicated in Table 10. Respondents in Isingiro, Ntungamo and Rubirizi, insisted that some farmers were not controlling because the technologies were not effective and some lost hope thus abandoning their infected banana fields. Nevertheless, over 95% of the respondents believed that farmers would continue applying the recommended technologies in management of BXW, while 4.7% insisted that farmers would not continue using the technologies.

The study found that the male and female banana farmers had differences in their BXW control practices, with males applying the most effective labour-intensive technologies while females utilized the less labour demanding technologies (Table 11). In the households that were cooperative, the females' duties were, monitoring and identifying infected plants while the males carried out the labour-intensive disease control activities. Because most women were normally engaged in numerous household activities, they never had enough time to identify and effectively control the disease, while men had sufficient time to carry out effective BXW control. Therefore, most single-headed women usually hired labour, while men carried out the work themselves.

A part from acquiring knowledge to control BXW and other good agronomic practices that were used to establish well-managed banana fields, which are

Table 10. Banana farmers' reasons for not controlling banana Xanthomonas wilt (BXW) using recommended technology packages in the South Western Agro-Ecological Zone (SWAEZ), Uganda.

Reasons for not controlling BXW	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Carelessness, laziness, negligence	41.7	47.6	37.5	29.6	29.2
Lacked knowledge/skill and information about the technologies	8.3	28.6	12.5	29.6	37.5
Technologies were too expensive and labour intensive	16.7	9.5	18.8	0.0	4.2
Farmers were aged, widows and disabled unable to apply the technologies	8.3	9.5	6.3	14.8	0.0
Some farmers lost hope and abandoned the banana plantation	8.3	0.0	6.3	0.0	16.7
Technologies were not effective	0.0	4.8	0.0	11.1	12.5
Some plantations were left in the hands of casual labourers	8.3	0.0	0.0	3.7	0.0
Farmers were engaged in other activities	0.0	0.0	6.3	7.4	0.0
Law enforcement was absent	4.2	0.0	0.0	3.7	0.0
Farmers owned many scattered and distant plantations	0.0	0.0	12.5	0.0	0.0
Farmers were overwhelmed by the disease due to high incidences	4.2	0.0	0.0	0.0	0.0

Table 11. Differences in banana Xanthomonas wilt (BXW) management technology application between men and women in the South Western Agro-Ecological Zone (SWAEZ), Uganda.

Differences in technology application by men and women farmers	% Response
Men used the labour-intensive methods while women used less labourious methods	68.8
Women tried hard and did most BXW control activities compared to men	11.7
Women normally used hired labour while men did the work themselves	6.5
Women used technologies that were easy to apply compared to men who used both light and heavy technologies	3.9
Women were involved in other activities, and did not have enough time, while men had enough time to effectively manage the banana plantations	2.6
Instead of using wood ash, some women used urine, which men did use	1.3
Women only monitored and identified the infected plants whereas men controlled	1.3
Men invested more labour and money; thus, their plantations were better managed	1.3
Women delayed to respond and destroy the infected plants, while men were quick and effective	1.3
Women had many responsibilities, which hindered them from Doing close monitoring	1.3

currently disease-free and highly productive, the farmers have become more hard-working and are growing other crops (sweet potatoes and cassava) to ensure food security. Most respondents indicated that; the recovery of their plants from BXW, and an increase in banana production for food and income, were the most important benefits achieved from controlling the disease using the recommended technology packages (Table 12). The second major benefit was increased incomes generated from increased banana sales from the communities. This benefit was very important because farmers were able to pay for children's education (school fees) and the most needed social services (e.g., health). Illegal

actions such as theft, domestic violence and other crimes were eliminated from the communities. Increased community cohesion, collective action and money saving schemes were developed to improve household incomes and livelihoods. However, some respondents indicated that because of the disease persistence or re-occurrence in several villages, most banana plantations were destroyed, abandoned and rendered unproductive. Even after the high efforts put into controlling BXW, the existing banana plantation continued to diminish and yield poorly. This vulnerable state of banana fields became a serious threat to food security among families that were highly dependent on banana. Therefore, these respondents concluded that the technologies were not effective and did not benefit them.

Overall, to completely eradicate BXW, several suggestions (Table 13) were

Table 12. Community benefits experienced after effective banana Xanthomonas wilt management (BXW) using the recommended technology packages in the South Western Agro-Ecological Zone (SWAEZ), Uganda.

Benefits of using the recommended BXW control technology packages	% Response
Banana plantations recovered, yield and production for food and income increased	54.1
Increased farmers' sales and income from banana for school fees and other service (health)	28.4
Increased knowledge to fight BXW	6.9
Reduced BXW incidences and spread within and across plantations	6.7
Reduced famine, theft of banana and crime rate in communities	1.0
When BXW was controlled, people had time to do other production and business activities	1.0
More well managed banana plantations were established	0.8
Production of diverse crops like cassava and sweet potatoes increased	0.1
Increased community cohesion, collective action and money saving schemes	0.4
Increase in household incomes led to improved quality of life and family stability	0.3
People became more hard working	0.1
Because all farmers cooperated in controlling BXW, arrests of non-compliant individual by task forces were stopped	0.1

Table 13. Suggestions for complete eradication of banana Xanthomonas (BXW) in the South Western Agro-Ecological Zone (SWAEZ) of Uganda.

Suggestion for effective eradication of BXW	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Continuous sensitization	34.5	38.9	43.7	56.5	45.2
Continuous by-law enforcement	21.2	25.7	18.5	17.6	25.0
Introduction chemical-based control	10.9	13.2	20.7	15.7	17.7
Regular monitoring and technology application	15.8	11.8	9.6	6.5	3.2
Involvement of more technical workers to train all farmers	12.1	6.3	2.2	0.0	7.3
Breeding and promoting resistant varieties	2.4	4.2	3.0	3.7	1.6
Nothing because the disease had been fully controlled	3.0	0.0	2.2	0.0	0.0

made by the respondents across the five districts, but the strongly supported interventions included: continuous farmer-sensitization/awareness creation (42.8%); continuous by-law enforcement (21.7%) and introduction of chemical control (15.4%). Nevertheless, regular monitoring and application of the recommended technology packages were also considered key in Mitooma, Isingiro and Mbarara. The need to train all banana farmers in Mitooma was emphasized, implying that probably most farmers had not been trained. Breeding for resistance and involvement of all extension workers in the dissemination of the IDM packages to all banana farmers were mentioned as alternative interventions for BXW eradication.

4. Discussion

Banana Xanthomonas wilt caused by *Xanthomonas vasicola* pv., *musacearum* (*XVM*), was first detected in Uganda during early 2001 [31], and reached the peak of its epidemics around 2010-2013 in the South Western Agro-Ecological Zone (SWAEZ). Over ten years after the comprehensive and widespread integrated BXW control operations, which applied various strategies including the participatory development communication approach (PDC: reduced BXW prevalence from 88% to 18%); community action (decreased BXW prevalence to 68%); farmer field school (FFS: reduced the disease prevalence to 43%) [25] [32], and learning and experimentation approaches for farmers (LEAFF) application, which led to BXW prevalence reduction from 57% to 30% that was subsequently followed by 82% eradication [33], today BXW is not only endemic, but various banana growing areas are experiencing progressive increase in the disease prevalence [34].

The current study found that most male and female respondents representing male-headed, female-headed and children-headed households with varying levels of education had an age range of 31 - 60 years, which is the most active and productive human life phase. Indeed, most of these respondents (89.4%) whose primary occupation was farming had been growing the East African highland cooking and/or desert banana types as the major food security and income generation crops for 11 - 30 years on approximately 1 - 3 acres of land. With the continuous human population increase in Uganda, the size of arable land for agricultural production is not only reducing but also its productivity is declining. Due to land shortage among the majority of smallholder farmers in the SWAEZ, banana field that would be expected to thrive for 80 - 100 years, now survive for 5 - 10 years [35], due to several factors of which increase in crop diversification within the banana fields is key.

As previously reported, abiotic (declining soil fertility, low soil moisture, extreme weather conditions) and biotic (diseases and insect pests) stresses were specified as the major banana production problems [36] [37]. Under the current climate change conditions, disease (banana Xanthomonas wilt, Fusarium wilt, thrip-rust, black leaf streak or black Sigatoka and Muko virus) epidemics have

become rampant, with banana Xanthomonas wilt being the most endemic and destructive in the SWAEZ. Elsewhere, studies show that BXW is still the most devastating disease in major banana growing regions of Eastern and Central Africa [29], and in the current study areas, BXW led to a decline in the average household banana harvests from 65 to 33 bunches per month.

During the BXW epidemic period, 97% of the respondents that were affected, and other banana farmers, were similarly sensitized, trained and facilitated to control the disease [33]. In agreement with Jogo *et al.* [24], the respondents in the SWAEZ (96% - 100%) had varying levels of knowledge about the BXW, causal agent, symptoms, sources of infection, plant parts infected, mode of disease spread, favourable weather conditions and control methods. Although most of the respondents (81.5%) could not remember the actual causal agent and source of the BXW (61.0%), they knew the disease symptoms on the various infected plant parts, and the influence of weather conditions on the disease prevalence. The respondents who did not have any idea about the various disease diagnosis, identification, monitoring and control practices represented a small proportion of the community members whose infected banana plants became sources of BXW inoculum capable of causing epidemics. Apart from the respondents in Ntungamo, Mitooma, Isingiro and Rubirizi district where all respondents were controlling the disease using various combinations of the 14 recommended technologies [38], 15.6% in Mbarara were not controlling. Because the majority of the banana growers were not using the BXW technology combinations as recommended by research [28] [39], incidences of the disease have continued to be reported in many areas [32] [40]. 83% of the respondents in the SWAEZ that reported incidences of BXW recurrence, continue to associate it with ineffective disease control by neighbours due to the high costs (labour and non-labour) involved [19] [38]. Apart from the 16.9% of the respondents that did not experience BXW recurrence, 91.4% reported that the integrated disease management technologies disseminated through the joint taskforces were very effective, and would be continuously used by 96.2% to eradicate the disease.

Technologies disseminated for BXW control were intentionally selected, integrated as preventive (regular monitoring of banana plantations, disease-free planting materials, sterile field tools, runoff/soil erosion prevention and male bud removal using forked sticks) plus eradicative (uproot and destroy infected plants, sterilize tool, prune dry plant tissue, proper weed control, stop intercropping and sterilize field tools) recommendations to be applied as full packages by farmers to protect non-infected and to treat the infected banana plantations [24] [41] [42]. Through widespread awareness creation and hands-on-trainings that were jointly carried out during the disease epidemic periods by taskforces comprising MAAIF, NAADS, research, NGOs, religious congregations, law enforcement departments, local leaders and policy makers, various approaches were integrated for effective and efficient disease eradication [23]. These approaches were scaled out through village, parish, sub-county, district and na-

tional level taskforces ensuring that all banana farmers and stakeholders involved in the banana value chain were alerted, informed and trained to effectively control BXW. Farmer-to-farmer knowledge sharing, monitoring and awareness creation were encouraged for collective disease eradication. In the absence of BXW immune-resistant varieties and chemical control, more than 14 preventive and eradicative cultural practices [39], were easily applied using various labour and non-labour inputs locally available and accessible to the majority of the respondents (82% - 91%). However, the 9% - 26% of banana growers or respondents in the study districts were neither accessing nor applying the BXW control technologies because they were not trained or had limited knowledge; were lazy/negligent; had abandoned their infected banana fields; lacked adequate resources for using to control the disease and considered the technologies ineffective. Such categories of banana farmers were considered partly responsible for the BXW resurgence in the zone, and elsewhere, the above factors have been pointed out as hindrances to complete disease eradication [28] [42].

The initial assumption that farmer-to-farmer technology dissemination, monitoring and support would enable the complete eradication of BXW especially in communities that were not reached through the mass awareness creation, trainings and IDM technology demonstrations; has not been successful mainly because of the decline in external support and monitoring by government [41]. Nevertheless, efforts of the 126 respondents to disseminate the recommended BXW control technologies through awareness creation, trainings and demonstrations; reached 1 - 30 individuals per trainer in the five districts just after the comprehensive BXW control by government partnerships. Ten years of government absence from regular provision of the required technical, legal and logistical support at the community level has led to the gradual phasing-out of the collective/joint farmers' and task-forces' integrated BXW control activities. Today, majority of the banana farming rural communities are well informed about effective BXW prevention and eradication practices, but the increasing laxity of both farmers and government is conducive for the pathogen inoculum to gradually build up levels of causing epidemics. Studies have shown that the partial or low level of IDM technology adoption by farmers may be a sign of decline in both public and private investments in BXW management, which can gradually develop into severe disease resurgence [28].

Although majority of the male and female respondents believed that the integrated BXW control technologies were very effective, and capable of completely eradicating the disease out of their villages, especially when collectively (as husbands and wives, males and females, families and households and entire communities), regularly, continuously applied; their high labour demand which converts into high money demand affected both male and female banana growers [43]. Unlike the male farmers that could physically apply the control technologies with ease, in the absence of a male in a household, the female depended more on hired male labour, which was very scarce and expensive. Most of the recommended BXW control activities (digging pits, uprooting, cutting, chop-

ping and burying infected plants) were too labour intensive, tedious and difficult for females and children to carry out in large or multiple banana fields. In order to cope with proper technology application for effective BXW control, some households adopted new working methods of having the women/wives do the less labour demanding activities like routine field monitoring and identification of infected plants, while the males/husbands carried out the manual control activities. On the other hand, the farmers that considered the technologies non-effective and too labour intensive, and stopped controlling the disease especially in Mitooma and Rubirizi districts did not only experience severe banana losses, but also the disease became endemic in those areas. However, some respondents indicated that because of the disease persistence or re-occurrence in some villages, most banana plantations were destroyed, abandoned and rendered unproductive. Even after the high efforts put into controlling BXW, the existing banana plantation continued to diminish and yield poorly, which is a serious threat to food security among families that are highly dependent on banana [23] [36].

Apart from acquiring knowledge to control BXW, and other good agronomic practices, which were used to establish well-managed banana plantations that are currently disease-free and highly productive, most farmers became more hard-working and started growing other crops (sweet potatoes and cassava) to ensure food security [1]. Most respondents indicated that; the recovery of their plantations from BXW and the increase in banana production for food and income was the most important benefit achieved from controlling the disease using the recommended technologies. The second major benefit was increased incomes generated from increased banana sales from the communities, and this attribute was very important because farmers were able to pay for children's education (school fees) and social services (e.g., health). Illegal actions such as stealing, domestic violence and other crimes were got rid-off in the communities. Increased community cohesion, collective action and money-saving schemes were developed to increase household incomes and improve the farmers' livelihoods. Finally, in order to completely eradicate BXW, the respondents across the five districts suggested continuous farmer-sensitization; continuous by-law enforcement and chemical control. Nevertheless, regular monitoring and application of the integrated technology combinations were also key in Mitooma, Isingiro and Mbarara. The need for continuous training of all banana farmers [41] [44] in Mitooma was emphasized, implying that probably most farmers had not been well trained. The low adoption and adaption of the effective BXW control technologies by stakeholders in East and Central Africa has been attributed to inadequate awareness, sensitization and limited knowledge [2] [28]. Breeding for resistance, and active involvement of all extension workers were mentioned as alternative intervention for BXW eradication in the SWAEZ.

5. Conclusion

Ten years after the widespread, the banana Xanthomonas wilt eradication campaign in the SWAEZ, the disease is still in existence, and is gradually spreading

across fields and villages. The 80% - 100% disease prevalence reduction in the SWAEZ, which resulted from the widespread and comprehensive integrated BXW control approach led to the re-establishment and/or recovery of banana fields in most affected areas. The current study learned that respondents/ farmers mastered the application of the various disease control technologies, but because of their costly labour and non-labour demands, they were not regularly applied as recommended especially by smallholder farmers, and vulnerable community members including females, the elderly, and other weak community members. Therefore, 10 years after the epidemics, the disease incidence continues to rise in various areas, as efforts to control it continue to decline, which makes the zone prone to another serious epidemic if strong measures are not enforced. The majority of the respondents agreed that the recommended disease control technology packages were very effective, and the knowledge plus skills imparted to farmers led to an increase in banana production for household food security and income generation, which has led to improved livelihood of highly banana-dependent families. Because of the decline in the government's effort to continue sensitizing, monitoring and enforcing by-laws, the disease inoculum continues to build up and spread. The disease persistence in the zone was attributed to poor monitoring of the disease, ineffective use of the technologies, increased disease pathogen inoculum in abandoned plantations, infected planting materials, and un-sterilized field tools. Therefore, in order to completely mitigate BXW from the SWAEZ, this study recommends that the government reinstate regular awareness creation campaigns, training, and functional BXW eradication task forces in the communities to ensure timely and effective control of BXW by applying the full IDM packages.

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Conflicts of Interest

The authors declare no conflicts of interest.

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