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Impact of Banana Xanthomonas Wilt Epidemics on Farmers' Livelihoods in the South Western Agro-Ecological Zone of Uganda

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Abstract

Banana Xanthomonas wilt (BXW) caused by *Xanthomonas vasicola* pv., *musacearum* (XVM), had a significant impact on the stakeholders within the banana value chain, but the farmers that were highly dependent on banana for food and income were the most affected. For over two decades since Banana Xanthomonas wilt was first detected in the South Western Agro-Ecological Zone, it continues to thrive and spread within the zone, thus building-up inoculum that may result in severe epidemics if not eradicated. This in-depth socio-economic analysis of the impact of BXW on banana productivity, food security, and incomes found out that, all the common cooking and desert banana varieties grown in this zone were susceptible. The BXW epidemics of 2009-2013 caused a serious decline in banana production, which resulted in low sales, low incomes and low savings, thus increasing the level of poverty among 84.7% of the banana farmers. To cope with this deficit, farmers initiated alternative farming and non-farming resources for obtaining food and income. Families diverted most of their money to buying food, paying for labour and non-labour inputs to control the disease. Although most food crop production trends were decreasing during the BXW epidemic period, the decrease in banana production was reportedly higher among most respondents. Overall, banana field management costs significantly increased, and farmers who owned more than five acres incurred more money in controlling BXW. Because of the inadequate cooking banana productivity, consumption of the costly alternative foods increased farmers' expenses, while the resource-poor families suffered hunger due to food scarcity. Therefore, incidences of: under-nutrition among children and adults; school drop-outs for lack of fees,

clothing and other requirements; children-run away from home; late school-fees payment; abandon-relatives' support, sicknesses among children and adults due to change of diet or inadequate food and child-abandonment increased in the communities. Frequent fights and quarrels within families due to the inadequacies or increased expenditures; and reduced commitment to other community functions and saving schemes, were reported. The most common mechanisms used by respondents to deal with the negative impact of the BXW epidemics were: growing and selling short season/annual food crops; borrowing money or taking loans; working as casual labourers; growing and trading in timber, trees, sugar cane, coffee and cotton; rearing and selling of livestock and operating non-farming businesses. The diversification of food crops and income-generating activities has partly reduced farmers' over-dependence on banana, which is increasing crop production for improved food security, nutrition and income generation.

Subject Areas

Agricultural Engineering, Agricultural Science

Keywords

Banana Xanthomonas Wilt, Impact, Productivity, Food Security, Income and Livelihoods

1. Introduction

Banana Xanthomonas wilt is one disease that greatly devastated the livelihoods of farmers and other stakeholders that were highly dependent on banana for food and income in Uganda [1] [2] during the epidemic period of 2009-2013. Today, this widespread and persistent disease [3] [4], continues to threaten food and income security of banana farming communities in the South Western Agro-Ecological Zone of Uganda. A recent modeling study projected that if BXW is not controlled for 10 years, Sub-Saharan Africa would experience a 55% decline in banana production due to yield loss and acreage reduction, which would translate to an economic loss of US$ 25 billion [5].

During 2009-2013, the disease epidemics caused estimated plant and yield losses of approximately 80% - 100% in the disease hotspots of Uganda, which led to a significant decline in banana production that further had a severe negative impact on the livelihoods of the stakeholders within the banana value chain especially farming communities that were highly dependent on banana. A study carried out during 2001-2004 in central Uganda, revealed that approximately 30% - 52% yield loss due to BXW infection caused a significant reduction in the quantity of bananas harvested by the households [2], which had a negative impact on the human livelihoods. A similar study carried out in the Kagera basin of Tanzania, Rwanda and Burundi around 2012, revealed that BXW negatively impacted production leading to a decline in the number of banana bunches har-

vested per household, which resulted in substantial banana yield losses, and an economic loss of US$ 14.05 million [6]. Because of pathogen's ability to infect banana in numerous ways, this fast-spreading and destructive disease can destroy plants and fruits at any stage of development [7]. The Petsakos's models predicted that without any control, BXW can be disastrous to the local banana productivity, and production, leading to a four-time reduction in supply thus decreasing consumption and increasing food prices [8]. A simulation of Banana Xanthomonas wilt disease infection over a 10-year period without control has been predicted to cause a negative economic impact along the banana value chain from production to consumption [5].

Banana is a major crop in sub-Saharan Africa, where it plays a significant role in the wellbeing of community in terms of food security [9] [10], and approximately 75% of the Ugandan farming households grow it for food and income [11]. Because banana is essential in maintaining food security among most rural and urban residents in the SWAEZ, the BXW outbreak affected most of the households that were highly dependent on banana by causing severe food scarcity. In the Kagera regions, the decline in the number of bunches harvested for household consumption, led farmers to adopt other types of food crops, and reduce the daily per capita food intake [6].

The impact of BXW epidemics had significant negative effects on banana productivity, which led to very high economic losses to the stakeholders especially the majority of smallholder farmers in Uganda. A cost-benefit study of BXW control packages revealed that full-, low- and non-adoption of the recommended disease control technology packages resulted in household-benefit from a median net balance of US$ 35, and US$ 30 per acre per annum, respectively, while the non-adopters recorded a net loss of approximately US$ 30 per acre [12]. The Kagera region study by Nkuba *et al.*, (2017), reported that the decline in banana production led to a decline in the amount of banana sold, while the banana bunch prices increased from U$ 3.30 to US$ 4.80 before and during BXW epidemic peak period of 2007 and 2009, respectively. The widespread decline in banana production due to the BXW epidemics and the increase in prices resulted in a continuous decline in household banana consumption, which was characterized by a limited number of meals than usual and smaller amounts of food consumed by an individual [8]. Households that could not afford to buy enough banana resorted to eating available foods including tubers/roots, cereals, legumes/pulses and fruits. Because BXW-infected banana fruits were not consumable, incidences of human health problems associated with BXW-contaminated food were not reported. Before the BXW, most banana plantations had been in existence for over 30 years, and were either uprooted or rehabilitated, while new plantations were established in areas where bananas never existed. Besides expansion of banana plantations, growing of other annual and perennial crops increased in the major banana production areas [13], which increased their consumption. In addition to the direct impact of the BXW on food security and incomes, the indirect socio-economic effects and/or trade-offs of the disease on the banana growing

households and other stakeholders led to significant changes in farming and non-farming activities; natural resource management; economic activities; socio-cultural relationship and the overall welfare of stakeholders [12] [14]. The study was carried out to assess the direct and indirect impact of BXW disease and its recommended control technologies on banana productivity, food security, income and livelihoods, and derive lessons for further research, technology development and policy making.

2. Methodology

Mbarara, Isingiro, Ntungamo, Mitooma and Rubirizi are the major banana producing districts in South Western Uganda that experienced the highest banana Xanthomonas wilt disease incidences. This disease led to approximately 100% crop loss during the 2009-2013 epidemics. The criteria used to select the study sites included: 1) Ranked among the highest banana producing sub-counties; 2) Must have reported the first BXW occurrence; 3) Were currently experiencing BXW incidences; 4) BXW had been well control, and sub-county had fully recovered; 5) Banana was the major source of income; 6) Had success stories of controlling BXW. Based on the above criteria, Kichwamba, Rutoto, Mutara, Kabira, Bwongyera, Kibatsi, Rugarama, Nyakitunda, Rugaaga, Mwizi, Rugando and Rwanyamahembe were selected for this socio-economic study. A total of 384 individual household respondents or banana farmer representatives were randomly selected in the target villages using a modified version of the following Sigma (2005) 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) [15]. Data were collected from respondents (farmers), and district key informants using pre-tested interview schedules or questionnaires comprising of open-ended and closed questions through individual and focus group discussions. Bio-physical data about the disease symptoms on plants were collected through plant visual observations and pictures taken using cameras. Initial coded raw data processing was done in Microsoft Excel, and analysed using Statistical Package for Social Scientists (SPSS) Version 20, and chi-square statistics were used to examine the significance levels between categorical variables. Descriptive statistics 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

Banana farmers' sources of incomes during the disease epidemic period in SWAEZ

Although majority of the household-respondents mentioned periodic money remittances such as monthly wages, pension and donations from family members, and non-farming businesses (carpentry, fishing, brewing, transport, labour, trading, grain milling, etc.) as their major sources of income; livestock, banana, common beans and coffee (**Table 1**) were also were prioritized as other key

Table 1. Major sources of income of banana growing communities in the South Western Agro-Ecological Zone, Uganda.

Main sources of income	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Monthly wage/pension/remittances	26.4	31.0	27.6	9.5	25.6
NFB (carpentry, fishing, brewing, transport, labour, trading, grain-mills, etc.)	16.1	17.1	41.4	52.4	14.5
Livestock	13.4	15.1	31.0	35.7	12.4
Banana	12.6	14.9	0.0	0.0	11.5
Common beans	13.8	11.2	0.0	0.0	11.5
Coffee	11.5	1.6	0.0	0.0	6.5
Cassava	1.1	0.8	0.0	0.0	5.2
Sweet potatoes	2.1	1.2	0.0	0.0	3.3
Groundnuts	1.1	1.2	0.0	0.0	3.1
Irish potatoes	0.2	3.3	0.0	0.0	1.7
Maize	0.0	1.6	0.0	0.0	1.5
Tomatoes	0.2	0.2	0.0	0.0	1.7
Millet	1.1	0.4	0.0	0.0	0.0
Sorghum	0.0	0.2	0.0	0.0	0.4
Cabbage	0.0	0.0	0.0	0.0	0.4
Passion fruits	0.3	0.0	0.0	0.0	0.0
Sugar cane	0.0	0.0	0.0	0.0	0.4
Cotton	0.0	0.0	0.0	0.0	0.2
Forests	0.0	0.0	0.0	2.4	0.0
Pineapples	0.0	0.0	0.0	0.0	0.2

*NFB = non-farming business.

sources of income for farmers. Livestock was the major income generation commodity out the four agricultural options in Mbarara and Ntungamo district. Apart from coffee, cotton, forestry, sugar cane, passion fruit, cabbage and pineapple growing, which were primarily grown for income generation, most common food crops were also used as secondary income generation options during the BXW epidemic periods in various areas of SWAEZ.

Because most of the respondents did not record their annual incomes made from the various sources, it was not possible for them to specify the amount obtained from each commodity. The various sources of income per year were listed based on the previous year's information, and the incomes were calculated based on the number of receipts, amount of money received per receipt, produce sold per season and income per sale. Overall, the average farmer's income ranged from UGX 3000 to UGX 18,000,000 per year (Table 2). Out of the 20 commodities used for income generation, banana (31.6%), coffee (16.7%), common beans (15.1%), NFB (10.5%) and livestock (7.5%), were the most common, moreover,

Table 2. Incomes generated per year by banana farmers from the various commodity combinations in the South Western Agro-Ecological Zone, Uganda.

Sources of income	Income per year (UGX) '000
Banana, beans, cabbage, coffee, ground nuts, Irish potato, livestock, maize, millet, NFB, passion, sorghum, monthly wages	3 - 100
Banana, beans, cassava, coffee, ground nuts, Irish potato, livestock, maize, millet, NFB, sorghum, tomatoes, monthly wages	120 - 500
Banana, beans, cassava, coffee, Irish potato, livestock, maize, NFB, monthly wages	510 - 980
Banana, beans, cabbage, coffee, Irish potato, livestock, maize, NFB, pineapple, tomatoes, monthly wages	1000 -1900
Banana, beans, coffee, cotton, livestock, NFB, sorghum, tomatoes, monthly wages	2000 - 2980
Banana, beans, coffee, Irish potatoes, livestock, NFB	3000 - 3960
Banana, coffee, livestock, Forests, Irish potatoes, NFB, monthly wages	4000 - 4800
Banana, coffee, livestock, NFB, monthly wages	5000 - 5900
Banana, beans, coffee, NFB	6000 - 6900
Banana, coffee, NFB	7000 - 7960
Banana	8000 - 8900
NFB	9000 - 9700
Banana, coffee, NFB	10,000 - 18,000

*NFB = non-farming business (carpentry, fishing, brewing, transport, labour, trading, grain mills, etc.).

banana, coffee and NFB were ranked as the first income generations commodities by 122, 36 and 28 respondents, respectively. Coffee (41), common beans (36), and banana (35) also ranked highly in the second position. In the third rank, common beans (27), banana (13) and coffee (10) were retained as major income generation agricultural commodities.

Household food security crop production

During the BXW epidemic period, eleven crops including; banana (97.4%), common beans (99.2%), cassava (98.7%), groundnuts (98.7), maize (98.7%), millet (98.7%), potatoes (100%), rice (98.7%), sorghum (98.7%), sweet potato (98.7%) and yams (0.5%) were the common food security crops grown by the household-respondents in the study sites of Mbarara, Mitooma, Ntungamo, Isingiro and Rubirizi district. However, banana, which had previously been the most common food crop in the above districts before the BXW outbreak, became comparable to the crops that were earlier not as common as banana during and after the BXW epidemics. Although banana and common beans were ranked as the most important food crops (**Figure 1**), with larger areas of production, to most respondents, their production trends rapidly decreased more than the other food crops. Apart from yams, most of the food crops were used for household consumption while smaller proportions of each crop were used for sale or income generation during the BXW epidemics (**Figure 1**).

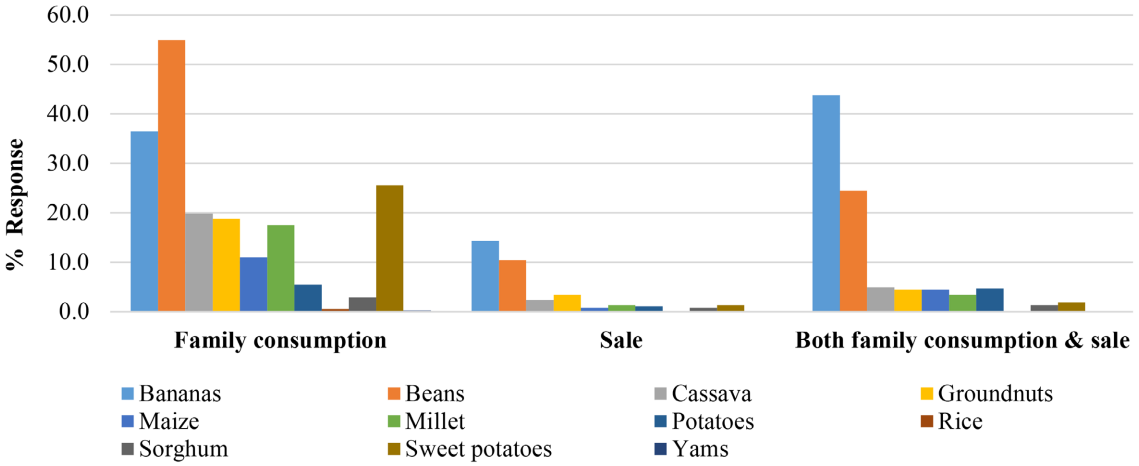

Figure 1. Common crops grown in the five districts for food security and income generation during the banana Xanthomonas wilt epidemics in the South Western Agro-Ecological Zone, Uganda.

Over twenty-six banana varieties including the East African highland cooking, brewing and desert types, were listed by the respondents in the five districts. However, 65.8% of the responses indicated that all varieties were highly susceptible to banana Xanthomonas wilt because they were all infected. Nineteen percent mentioned that their plants were moderately affected, while 15% indicated that the varieties were highly tolerant because they did not show the disease symptoms in their fields (**Table 3**). Varieties including Butende, Butoobe, Embururu and Red banana displayed moderate to high levels of tolerance to BXW in Mitooma and Isingiro district. The severe impact of the BXW disease significantly reduced banana production among most farmers indirectly resulting in low household banana consumption and sales. Besides the increase in household consumption of common beans, there was an increase in the consumptions of sweet potatoes, cassava, groundnuts and millet, which were not major food crops in the SWAEZ. Maize, rice, yam, sorghum and *Solanum* potato, which were grown by a small proportion of the respondents, were also used for both food and income generation. Banana and common beans were not only the major food security crops, but were also major income generation crops during the BXW epidemic periods.

Although most respondents indicated that during the BXW epidemics, the food security crop-production trend of bananas, beans, cassava, groundnuts, maize, sweet potatoes and millet was decreasing, the decrease in the production of banana was reportedly the highest among most respondents, followed by beans (**Figure 2**). Nevertheless, a smaller proportion of respondents reported an increase and/or constant production trends of the banana, beans, and other non-major food crops that were also utilized for income generation. The major reasons for the decreasing crop production trends were: climate change, which was characterised by severe droughts (86.5%), soil infertility (62.4%), banana Xanthomonas Wilt (41.5%), pests (0.4%) and land shortage (5.7%). On the other hand, farmers' reasons for increasing crop production trends were: application

Table 3. Banana Xanthomonas wilt tolerance in the common highland cooking, brewing and desert banana varieties in the South Western Agro-Ecological Zone, Uganda.

Banana varieties	Highly tolerant	Moderately tolerant	Highly susceptible
Butende	100.0	0.0	0.0
Butoobe	0.0	100.0	0.0
Mbazirume	5.7	14.6	79.8
Embire	19.6	19.6	60.9
Embururu	100.0	0.0	0.0
Enjagata	5.4	9.8	84.8
Enshenyi	0.0	0.0	100.0
Entaragaza	2.8	15.1	82.1
Entazinduka	33.3	0.0	66.7
Entukura	0.0	0.0	100.0
Enzirabahima	4.5	20.5	75.0
Enzirabushera	0.0	25.0	75.0
Kibuzi	4.5	12.3	83.2
Kisubi	33.3	0.0	66.7
Mporogoma	28.6	14.3	57.1
Mujuba	5.7	17.0	77.4
Mushankara	1.6	6.6	91.8
Nyeru	5.6	14.8	79.6
Rwambarara	0.0	0.0	100.0
Rwashesha	0.0	0.0	100.0
FHIA	0.0	16.7	83.3
Gonja	26.3	31.6	42.1
Kabaragara	14.6	31.7	53.7
Red banana	0.0	100.0	0.0
Bogoya	5.7	27.1	67.1
Kawanda (unknown)	0.0	16.7	83.3

of organic fertilizers (animal kraal manure), small-scale intensive farming, reduced BXW incidences, improved crop agronomic management, adoption of improved varieties, increased size of land for crop production and adequate rainfall. This study revealed that apart from banana Xanthomonas wilt, there were other factors that were responsible for the decreases in production of food crops. The proportion (6% - 21%) of the respondents whose banana production trends were either increasing or constant (**Figure 2**) were either not affected by BXW or had adopted the fully recommended integrated disease management

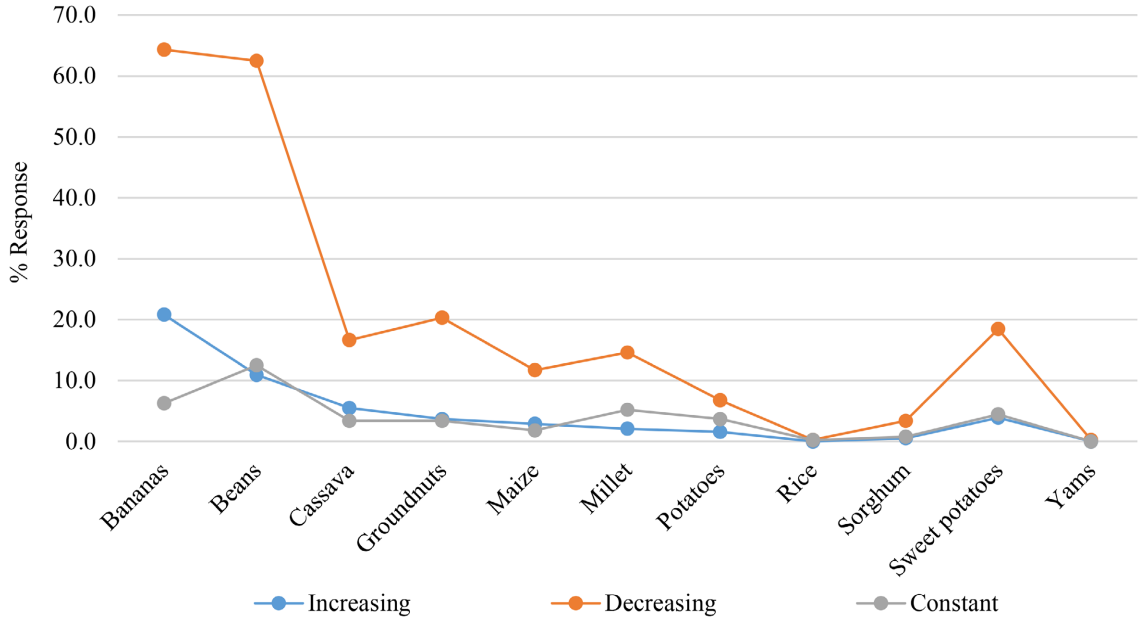

Figure 2. Household food crop production trends during the banana Xanthomonas wilt epidemics in the South Western Agro-Ecological Zone, Uganda.

(IDM) packages.

Before the BXW epidemics, farmers grew all the different banana varieties on land ranging from <1 acre to 40 acres, but majority (44%) of the current study's respondents owned ≤ 1 acre of banana fields. Respondents who owned two-acre banana plantations were 27.9%, while 3 - 5 acres were owned by 18.8%. Respondents with 6 - 9, 10 - 15 and >15 - 40 acres were 4.6%, 3.3% and 1.4% in the five districts, respectively. Depending on the size of the banana plantation, types and number of management activities, the respondents or participating farmers spend UGX ranging from 1000/ = to 1,600,000/ = per month. While the number of bunches harvested depended on the following main factors: field size, agronomic management practices, weather and variety before the BXW epidemics, most respondents harvested 1 - 10, 11 - 20, 21 - 30, 31 - 40 bunches per month, while the least number harvested > 100 - 300 bunches during the disease epidemics. The average price of each bunch of bananas also depended on size, variety, supply/produce, location and distance from market/urban centers. The most common price of banana mentioned by the respondents (26.8%) in the selected study sites was UGX 10,000 followed by UGX 5,000. Price ranges of UGX 1000 - 9000 and UGX 11,000 - 50,000 per bunch were also recorded, implying that prices fluctuated due to the demand and supply dynamics.

Banana production costs during and after the banana Xanthomonas wilt epidemics

Overall, the cost of banana field management significantly increased during the BXW epidemics in the five districts. Respondents or farmers who owned over five acres of banana fields incurred more money in carrying out the integrated disease-control cultural practices. During the BXW epidemics, farmers

spent an average of UGX 820,000 per acre, which was three-five times greater than expenditures after the epidemics (Figure 3). The BXW management technology combinations across the districts varied with farmers integrating: uprooting and chopping infected plants; uprooting infected plants and leaving whole uprooted plants to dry; uprooting, chopping and burying the diseased plants; de-budding/ removing of male buds using forked sticks; removing of dry leaves; cutting, uprooting, heaping and leaving plant tissue to dry; mulching; applying fertilizers /manure; suspending pruning; digging trenches/contour bands; hand weeding; cutting, uprooting, burying and adding ash; de-suckering; handing weeding and pruning.

The average area (3.7 acres) under banana production during 2010-2017, remained low among the respondents in the five district-study areas. Banana Xanthomonas wilt prevalence in the SWAEZ spread over a period of approximately two decades, during which banana production drastically declined especially around 2009-2012. After this phase, the number of bunches harvested gradually increased as farmers continued to apply the recommended IDM packages. As expected, the average number of bananas harvested by a household per acre during the BXW epidemic period was lower than after the epidemics in all districts. However, the average banana bunch size in all districts ranked medium (code 2), while no records of large bunch sizes were taken during and after the disease epidemics. Although Isingiro and Mbarara banana fields experienced the highest disease incidences during the peak epidemic period of 2010-2011, they showed faster recovery during 2013-2017 after intensive application of the recommended IDM packages, and yields gradually increased 2.0 - 3.4 times.

During the banana Xanthomonas wilt epidemics, banana production ranged

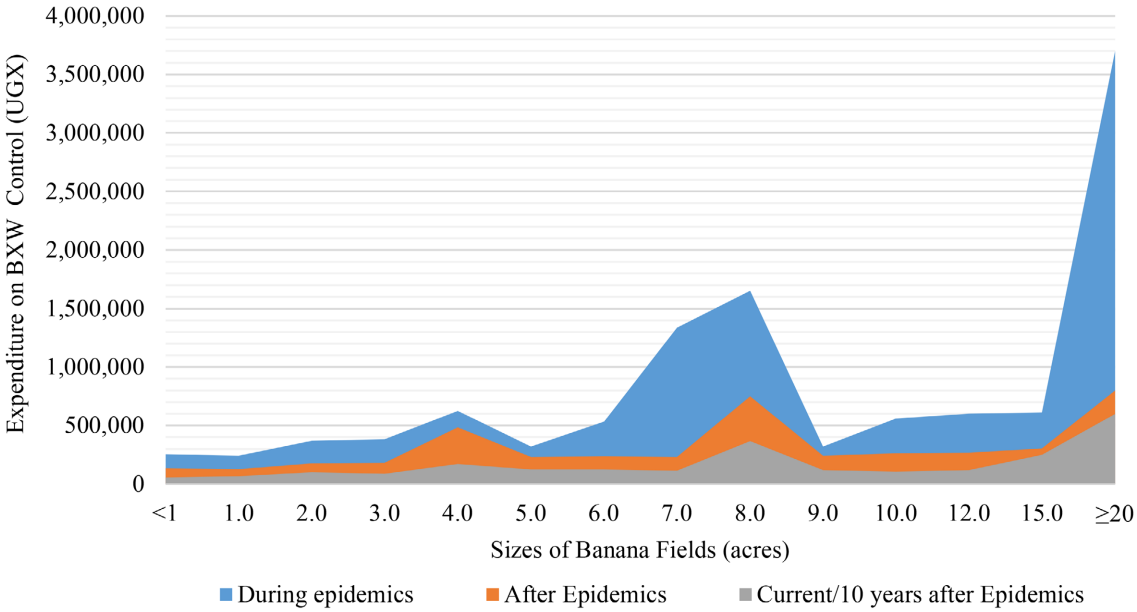

Figure 3. Banana field management costs per acre during and after the banana Xanthomonas wilt epidemics in the South Western Agro-Ecological Zone, Uganda.

from one bunch to four hundred bunches per household, however, most respondents' (41.2%) production range was 1 ≤ 10 bunches (Table 4). Although 13.8% and 11.9% harvested 11 ≤ 20 and 21 ≤ 30 bunches, respectively, 17% of the respondents did not harvest any banana under the similar epidemic periods. Sixteen percent of the participating respondents in the five study sites produced 31 - 400 bunches. Bananas harvested during the disease epidemics, were either consumed, sold, donated and lost/wasted through premature ripening in the field. Majority of the respondents (68.6%) indicated that the banana price trend during the BXW epidemics gradually increased while 19.9% insisted that the price trend decreased. 11.5% stated that the banana prices were constant. Because the overall banana production during epidemics was low, the prices of each bunch ranged from UGX 1000 (very small sizes) to UGX 40,000 (very big sizes), but most respondents (52%) sold each banana bunch at UGX 6000 - 10,000. The increasing on-farm banana selling price was due to limited supply, which resulted from low production, yet the demand remained high.

The bacterial wilt epidemics in the SWAEZ during 2010-2013 affected many households that were highly dependent on banana as the main source of food and income. Most of the respondents (58.9%, 19.7%) indicated that food (meaning

Table 4. Distribution of banana bunches harvested during the BXW epidemic period in the South Western Agro-Ecological Zone, Uganda.

Banana bunches	Produced (n = 382)	Consumed (n = 374)	Sold (n = 372)	Donated (n = 363)	Wasted (ripened, n = 361)
0	17.0	20.5	53.8	83.2	97.0
1 ≤ 10	41.2	55.0	25.4	15.3	2.3
11 ≤ 20	13.8	14.5	14.9	0.9	0.6
21 ≤ 30	11.9	4.8	6.3	0.0	0.0
31 ≤ 40	3.1	1.4	2.7	0.0	0.3
41 ≤ 50	4.7	0.8	0.5	0.6	
51 ≤ 60	2.4	1.6	0.6	0.3	
61 ≤ 70	0.3	0.3	0.0		
71 ≤ 80	0.8	0.3	0.0		
81 ≤ 90	0.8	0.0	0.5		
91 ≤ 100	1.1	0.0	1.1		
101 ≤ 150	0.8	0.5			
151 ≤ 200	0.9	0.3			
201 ≤ 250	0.3				
251 ≤ 300	0.6				
301 ≤ 350	0.0				
351 ≤ 400	0.3				

the Eastern African highland cooking banana) was inadequate due to low productivity, and this led to increased consumption of alternative foods, respectively, (Table 5), which increased family expenditures because the alternative food was purchased. Families that were resource poor experienced increased episodes of hunger/famine due inadequate food supply and reduced number of meals per day. The insufficient food consumption by families resulted in malnutrition among the vulnerable people. Families whose banana plants did not experience the BXW epidemics, did not experience food shortages.

The low banana production resulted in low sales, low income and poverty. Overall, most household incomes and savings were reduced, which increased the level of poverty (84.7%) as indicated in Table 6. Families diverted their money to buying food, paying for labour and non-labour inputs for controlling bacterial wilt. Households that were financially dependent on banana also experienced a severe reduction in their incomes, which negatively affected all their business

Table 5. Impact of the BXW epidemics on household (HH) food availability in the South Western Agro-Ecological Zone, Uganda.

Effect of BXW on HH food availability	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Food was available, farmer was not affected	2.6	9.8	10.8	6.7	3.8
Inadequate food (banana) availability	59.1	53.3	58.1	59.6	65.4
Increased consumption of alternative foods	21.7	16.3	18.3	24.0	16.7
Increased expenditure on buying food	7.9	0.0	3.2	1.0	1.3
Increased hunger, famine and malnutrition	2.6	3.3	0.0	1.9	2.6
Low crop (banana) production	3.5	15.2	9.7	6.7	10.3
Number of meals reduced to 1 - 2 per day	2.6	2.2	0.0	0.0	0.0

Table 6. Impact of the BXW epidemics on household income in the South Western Agro-Ecological Zone, Uganda.

Effect of BXW on HH income	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Could not access loans	0.0	1.3	0.0	0.0	0.0
Conflicts/lack of family respect for men for not providing enough support	1.2	0.0	0.0	0.0	0.0
Expenditure on buying other food stuffs increased	2.4	1.3	1.3	1.0	0.0
Generated income from selling other crops and livestock	7.2	2.5	3.8	7.3	5.9
Resorted to loan loans and borrowing to support families	0.0	2.5	3.8	9.4	0.0
Income was diverted to buy food instead of other items	0.0	0.0	1.3	0.0	0.0
Increased expenditure on materials and labour to fight BXW	2.4	0.0	1.3	1.0	0.0
Low income resulted in no savings and poverty	84.3	91.3	83.3	79.2	86.8
No income to buy basic needs and pay school fees	0.0	0.0	2.6	0.0	0.0
Resorted to own a retail shop	0.0	0.0	0.0	0.0	1.5
Worked as labourers to earn money and sort for donations	2.4	1.3	2.6	2.1	5.9

and livelihood transactions that required money. In order to cope with the financial crises, households resorted to other sources of money such as: providing labour services, seeking donations from well-wishers, trading, taking loans, selling crops and animals. In situation where there was no money to provide the family requirements such as food, school fees and other basic items, conflicts and domestic violent increased. Frequent fights and quarrels within families due to inadequacies or increased expenditure; reduced farmer's commitment to other community functions and saving schemes; inadequate incomes for providing basic family requirements become common, but also the BXW epidemic effects indirectly resulted in increased farmer's commitment to fighting the disease, collective action and cooperation within families and among communities in controlling the disease (Table 7). This situation also attracted external support from which men and women acquired knowledge and information through the sensitization and training workshops, and some people acquired alternative jobs. In a worse situation, men and children fled their homes in search of food, money, employment, and also to hide from being arrested for not controlling the disease. Children dropped out of school, and some families sold their land to cope with the negative impact of the BXW epidemics.

The BXW epidemics indirectly affected the children's welfare and family livelihoods, because the low banana production resulted in food and money scarcity. Therefore, incidences of malnutrition among children and adults due to inadequate

Table 7. Impact of the BXW epidemics on household gender and socio-relationships in the South Western Agro-Ecological Zone, Uganda.

Effect of BXW on HH gender and socio-relationships	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Families worked hard, increased expenditure and most husbands got involved in BXW control	6.5	16.7	4.7	0.0	10.3
In fear of being arrested, many men ran away from families, while children ran away in search of food	2.2	5.6	2.3	0.0	0.0
Frequent fights and quarrels within families due to inadequacies	23.9	13.9	16.3	44.0	31.0
Husbands acquired other jobs for income generation	4.3	0.0	0.0	0.0	3.4
Increased commitment, collective action and cooperation within families and communities in BXW control	8.7	5.6	25.6	40.0	6.9
Increased community sensitization meetings and trainings improved unity and knowledge	0.0	0.0	0.0	8.0	10.3
Some families sold their land	2.2	0.0	0.0	0.0	0.0
Limited availability of food to families and increased resource use in looking for food elsewhere	17.4	2.8	11.6	0.0	6.9
No income to provide basic family requirements	26.1	13.9	11.6	8.0	17.2
Reduced commitment to other community functions and saving schemes	8.7	36.1	25.6	0.0	13.8
School dropout due to lack of school fees and young children leaving home to look for jobs	0.0	5.6	2.3	0.0	0.0

food; school drops for lack of fees, clothing and other requirements; children-run away from home; late school-fees payment; abandoned-relative support, sicknesses among children and adults due change in diet and inadequate food and children abandoning increased in the communities (Table 8). Because of the epidemics, some families moved to stay with relatives who had enough food, while husbands moved away from their homes to search for employment elsewhere.

The most common mechanisms used by the household respondents to cope with the BXW epidemics were: growing and selling short season food crops; borrowing money or loans to support families and working as labourers. In Ntungamo and Mitooma district, farmers engaged in growing and trading in timber, trees, sugar cane, coffee and cotton; rearing and selling of livestock as indicated in Table 9. In Mitooma, Isingiro and Mbarara the respondents also engaged in non-farming business to generate income in order to cope with the BXW epidemics' negative effects. The respondents in Isingiro and Mbarara used salaries, savings, family remittances and donations to cope with the negative impacts of the disease epidemics. Other coping mechanisms included selling assets such as land, buying food, planting new banana gardens, paying school-fees

Table 8. Impact of the BXW epidemics on children welfare and family livelihoods in the South Western Agro-Ecological Zone, Uganda.

Effect of BXW on children welfare and family livelihoods	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Acquired loan to support family	0.0	0.0	1.4	0.0	1.4
Alternative food (maize meal, potatoes, yams, rice, cassava and millet) consumed	3.6	6.1	2.9	1.2	4.3
Children stopped going to school or home, increasing the number of run-away children	4.8	4.9	8.7	0.0	4.3
Increased dependence on husband's salaries	1.2	0.0	0.0	0.0	0.0
Increased family conflicts and husbands leaving families	2.4	1.2	1.4	0.0	0.0
Increased malnourishment among children and adults due to limited food	22.6	37.8	33.3	35.8	26.1
Increased school dropout due to lack of fees, clothing and other basic requirements	13.1	11.0	18.8	42.0	20.3
Increased sicknesses due to insufficient food and changes in diet	3.6	1.2	0.0	1.2	1.4
increased well-fare financial support	1.2	0.0	0.0	0.0	0.0
Lack of income at household to provide basic family requirements	28.6	13.4	15.9	16.0	24.6
limited school fees, late payment, increased school dropout	14.3	17.1	15.9	3.7	15.9
Stopped supporting dependents outside	0.0	1.2	0.0	0.0	0.0
They went visiting most of the time	0.0	1.2	0.0	0.0	0.0
Farmers were not affected and no change in diet	1.2	1.2	1.4	0.0	1.4
Not able to buy more land	0.0	1.2	0.0	0.0	0.0
Worked extra hard to control BXW and established new plantations	3.6	2.4	0.0	0.0	0.0

Table 9. Households' coping mechanisms during the BXW epidemics in the South Western Agro-Ecological Zone, Uganda.

Coping mechanisms during the BXW epidemics	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Used a lot of effort and applied the IDM technologies to effectively control	3.3	6.7	5.5	2.0	2.7
Avoid unnecessary expenditure and persisted through difficulties	3.3	3.3	1.6	1.4	0.9
Borrowed money and acquired loans to support families	13.9	12.5	17.2	16.9	16.2
Engaged in non-farming business to generate income	6.6	6.7	6.3	1.4	2.7
Growing and trading in timber, trees, sugar cane, coffee and cotton	9.0	1.7	3.9	6.8	8.1
Growing and selling of other short season food crops	36.1	41.7	40.6	41.2	39.6
Paid children's school fees in installment or late	0.0	1.7	0.8	0.0	0.0
Rearing and selling of livestock to get money	8.2	4.2	2.3	14.9	9.0
Reducing amount of meals/food, and no food for school children to pack	2.5	0.8	0.0	2.0	0.9
Resorted to planting new banana gardens	0.8	0.8	1.6	0.0	0.0
Sales from the little harvested banana were used to buy more food	0.0	0.0	1.6	0.0	0.0
Sold land to buy food for the families	0.0	0.0	0.8	0.0	0.0
Stocking and trading of grain and flour of maize, rice and cassava	4.1	2.5	1.6	0.0	0.0
Used salaries, savings, family remittances and donations	2.5	11.7	9.4	4.7	3.6
Worked as labourers for wage payments	9.8	5.8	7.0	8.8	16.2

installments, using all the IDM technologies to control BXW, stopping unnecessary spending, stocking and trading in dry produce.

Apart from the respondents in Rubirizi district, 43.1% experienced food shortages in all the other four districts still after the BXW epidemics, while 56.9% did not experience food shortages. The most common types of food consumed in the five districts during the time of scarcity were maize meal (posho) and cassava mainly because they were cheap. In Ntungamo, sweet potatoes and *Solanum* potatoes were common alternatives, but in Mitooma and Isingiro district where multiple crops (Table 10) were grown, the farmers had many alternative types of food to consume. Farmers consumed alternative foods because they were cheap, acquired from their own plantation and bananas were too costly. During the period of food scarcity period, most respondents mostly worked as labourer for other people to generate income (28.9%); borrowed money to buy food (22.8%); sold livestock (18.5%) and used child-support to work (10.3%), while others sold livestock, household items, and borrowed food; worked for building and construction companies and carpentries. Before and during the BXW epidemics most respondents' families usually had two meals per day, but during the epidemics the number of households having one meal per day increased while the proportion of households having three meals decreased in Isingiro, Mbarara, Rubirizi and Ntungamo district. Interestingly, the number of respondents having two and three meals in Rubirizi and Mitooma district were

Table 10. Food consumed in time of shortage in the South Western Agro-Ecological Zone, Uganda.

Type of food consumed	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Banana	1.1	1.0	1.3	3.0	1.8
Common beans	5.6	10.1	12.8	0.0	7.3
Maize meal (posho)	26.7	36.3	39.8	57.5	39.5
Cassava	11.1	15.2	20.5	15.2	19.3
Irish potatoes	1.1	2.0	6.4	0.0	1.8
Millet	7.8	6.1	3.8	0.0	2.8
Sweet potatoes	8.9	5.1	7.7	12.1	5.5
Vegetables (onions, tomatoes, pumpkin, greens)	0.0	3.0	1.3	0.0	4.6
Yams	4.4	4.0	1.3	0.0	1.8
Ground nuts	0.0	1.0	0.0	0.0	1.8
Sorghum	0.0	1.0	0.0	0.0	0.0
Maize meal (posho)/cassava/yam/sweet potatoes/millet/beans	10.0	11.1	2.6	0.0	10.1
Solanum potatoes	5.6	4.0	2.6	12.1	1.8
Cassava/beans/millet/sweet potato/yam	14.4	0.0	0.0	0.0	0.0
Millet/yams/maize/beans	3.3	0.0	0.0	0.0	0.0
Fish	0.0	0.0	0.0	0.0	0.9
Rice	0.0	0.0	0.0	0.0	0.9

not different, probably because banana was not the only major food crop before and during the BXW epidemics. The proportion of farmers that was consuming four meals per day did not vary before and during the epidemics. The types of foods consumed by respondents before, during and after the BXW epidemics were similar (Figure 4), but interestingly common beans, cooking banana and maize meals were the most common across the three eras. Cassava, sweet potatoes, groundnuts, milk and millet comprised the second set of foods consumed by farmers. Meat, chicken, eggs, fish, ghee, garden peas, rice, yams, yoghurt and apple banana were consumed by the lowest proportion of respondents.

Socio-economic changes due to the BXW control

Although there have been several benefits (Table 11) resulting from the integrated BXW control interventions in the SWAEZ, the most significant benefits among banana farming communities included: increased banana-based food consumption; improved household incomes and increased savings generated from banana sales; BXW was managed/eradicated and increased knowledge, skills and technologies for BXW control. Interestingly, the benefits directly linked to banana production and productivity were not listed as major probably because they directly benefited the plants and not farmers. Such benefits included: recovery of formally destroyed plantations, increased banana yield, and

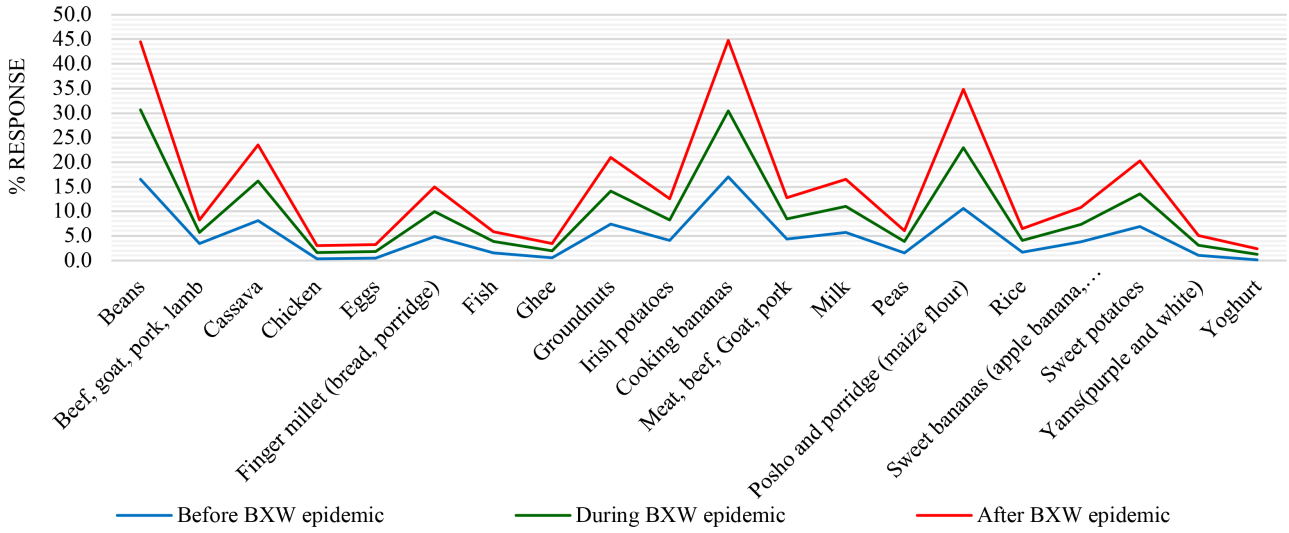

Figure 4. Categories of foods consumed by the respondents' households before, during and after the banana Xanthomonas wilt epidemics in the South Western Agro-Ecological Zone, Uganda.

Table 11. Benefits that resulted from the BXW control in the South Western Agro-Ecological Zone, Uganda.

Benefits from BXW control	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Able to invest in other business	0.8	0.0	0.0	0.0	0.0
Acquired/increased knowledge, skills and technologies for BXW control	1.6	19.1	12.8	20.0	12.9
BXW was managed/eradicated	7.3	13.6	18.4	18.5	24.3
Community meetings promoted and enhanced group savings	0.0	0.0	0.7	0.0	0.0
Good human health from good feeding	0.8	0.0	0.7	0.0	0.0
Growth and introduction of other crops for food and income	0.8	4.5	4.3	0.8	5.7
Improve soil fertility by burying plant residues	0.0	0.9	0.7	0.0	0.0
Increased acreage under banana growing and with new plantations	0.8	1.8	2.1	0.8	0.0
Increasing banana yield and production	7.3	2.7	3.5	6.9	4.3
Increasing household income and savings from banana sales	30.6	20.9	19.1	16.2	15.7
Increased banana food consumption	39.5	27.3	27.7	32.3	27.1
No borrowing from banks for fees	0.0	0.0	0.0	0.0	1.4
Formally destroyed plantations recovered and gradually increased yields	8.1	8.2	3.5	0.8	5.7
Reduced expenditure on buying other foods	0.0	0.9	0.0	0.0	0.0
Social cohesion, hard work, interactions and knowledge	2.4	0.0	5.7	3.8	2.9
Increased use of own tools to avoid the spread	0.0	0.0	0.7	0.0	0.0

increased acreage under banana growing.

Besides the benefits, the comprehensive BXW control campaign also resulted in changes to individual respondents in the banana farming communities (Table 12), and of these the major ones were: availability of enough banana food; increased incomes generated from banana sales; increased well-managed banana

Table 12. Socio-economic changes that resulted from BXW control among banana growing farmers in the South Western Agro-Ecological Zone, Uganda.

Individual respondents' changes in due to the benefits	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Acquired knowledge/skill to effectively control BXW	3.8	18.4	12.1	12.4	13.5
Adopted other crops for food and income	3.8	1.0	2.1	2.2	0.0
Farmers become harder working	1.0	0.0	0.7	0.0	0.0
Had enough banana food, no more borrowing money/buying food	36.2	36.7	34.8	28.5	33.8
Increased soil fertility	0.0	1.0	0.0	0.0	0.0
Improved family nutrition, health, children's school fees were fully paid	1.9	0.0	0.7	0.0	0.0
Increased incomes generated from banana sales used for domestic purposes	37.1	33.7	30.5	31.4	36.5
Increased collective action, interaction and unity among farmers	1.9	3.1	6.4	1.5	0.0
Increased savings, purchased new assets: (land, goats, cows, vehicle, motorcycle)	4.8	2.0	0.7	0.0	0.0
Increased well managed banana acreage, yield and production	6.7	2.0	11.3	24.1	14.9
Reduced banana plantation size	1.0	0.0	0.0	0.0	0.0
Reduced expenditure	1.9	2.0	0.0	0.0	1.4
Reduced stealing of people's crops like coffee and bananas	0.0	0.0	0.7	0.0	0.0

plantations; increased yield and production and improved knowledge/skills to effectively control BXW. Although not considered major, the following socio-economic changes resulted from the benefits of BXW control: reduced financial expenditure; increased savings; increased purchase of new assets by farmers; increased collective action, improved socio-interaction and improved unity among farmers; improved family nutrition and health, and children went back to school with fees fully paid. The respondents observed several changes in the communities but the major ones were: increased food availability in homes; increased incomes; improved knowledge to fight/control the BXW; increased number of fully recovered banana plantations and increased banana production.

Apart from the benefits, the banana farmers experienced challenges associated with BXW control technologies (Table 13), of which the most serious constraints were: severe yield reduction that resulted from complete destruction of affected plants; very high expenditure on labour used in the rigorous BXW control activities; insufficient field tools, equipment and disinfectants, and disease persistence due to ineffective management. Social conflicts, political interference, arrest of non-compliant farmers, payment of penalties, running away of men and children from homes, loss of field tools due to fire sterilization and health problems (backache and chest pain) were also key challenges associated with BXW control technologies.

In order to manage the challenges experienced in implementing the BXW control technologies, the respondents, combined hard work, commitment, persistence of task forces, hiring labour and seeking government support to control BXW; planting other crops for food and income; borrowing money and acquir-

ing loans from financial institutions; consumption of alternative foods; use of alternative methods to sterilize equipment and buying of more field tools and provision of casual labour services elsewhere (Table 14). Apart from the

Table 13. Constraints experienced by farmers from integrated BXW control technology used in the South Western Agro-Ecological Zone, Uganda.

Challenges experienced with BXW technologies	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Chopping increased fruit flies	1.0	0.0	0.0	0.0	0.0
Expensive, labour intensive and difficult for elderly people	28.2	32.0	35.4	9.4	24.1
Health problems like backache and chest pain developed	1.9	2.1	0.0	0.0	0.0
Insufficient tools, jik and other effective equipment	5.8	7.2	2.5	1.2	7.6
Limited time to carry out other business and attend social functions	2.9	2.1	1.3	2.4	0.0
Loss and weakening of tools due to fire sterilization	4.9	1.0	3.8	0.0	0.0
People paying fines were arrested for not controlling and some men ran away	1.9	3.1	5.1	0.0	1.3
Persistence of the disease due to poor management	8.7	6.2	6.3	2.4	0.0
Political interferences by enforcing laws	0.0	2.1	0.0	0.0	0.0
Significant yield reduction resulted due to completed destruction of plants	43.7	43.3	44.3	84.7	64.6
Social conflicts increased within and among families	1.0	1.0	1.3	0.0	2.5

Table 14. Measures used to cope with the challenges associated with the integrated BXW control technology application in the South Western Agro-Ecological Zone.

How farmers handled the constraints	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Borrowed money from other people and loans	4.5	19.4	10.9	34.3	6.3
Combine hard work, commitment, persistence of task forces, hired labour and government support with farmer groups to control BXW	48.5	43.1	47.3	25.7	41.7
Cut the whole plantation, replanted bananas and did gap filling	1.5	1.4	0.0	0.0	0.0
Employed someone to ride the farmers' commercial motor cycle	1.5	0.0	0.0	0.0	0.0
Families consumed alternative foods or bought food	7.6	11.1	5.5	22.9	27.1
Got specific tools to work in the plantations	1.5	1.4	3.6	0.0	0.0
Got treated when needed, left the work and reduced the workload	0.0	2.8	1.8	0.0	0.0
Did nothing and left the community	1.5	0.0	0.0	0.0	0.0
Paid the fines/penalties	0.0	1.4	1.8	0.0	0.0
Decided to abandon banana farming	0.0	1.4	0.0	0.0	0.0
Planted other crops for food and income generation	22.7	12.5	16.4	11.4	6.3
Reported husbands for not working or husbands left families	0.0	2.8	1.8	0.0	0.0
Used fire, jik and other methods to sterilize equipment or bought more tools	6.1	1.4	10.9	5.7	2.1
Used less time to get involved in social functions	0.0	0.0	0.0	0.0	2.1
Working as a labourer for money	1.5	1.4	0.0	0.0	12.5
Women would regularly monitor banana fields with their husbands	3.0	0.0	0.0	0.0	2.1

BXW control coping measures, some affected women sort legal support to deal with non-complaint husbands; farmers invested more times in controlling the disease; got employment in commercial transport businesses and got treated in case of health problems. Apart from banana production, most (58%) respondents got involved in growing other crops (listed in Table 1 and Table 10) for food and income generations, while 27% were engaged in carrying out non-farming businesses (Figure 5). Livestock (diary and small animal) farming, employment for salary and tree growing were also alternative activities in which banana farmers were also engaged.

The study revealed that most banana farmers (85.5%) abandoned certain activities in preference of BXW control, mainly because of lack of enough time (87.3%) since most of it was spent in controlling BXW. Lack of income, low profits, low crop yield and preservation of the available produce for food and cash needs emergencies were the other reasons why the farmers abandoned some activities or sold their business enterprises, and relocated from towns to villages to fight the BXW. Although, there were no clear positive effects of the adopted BXW control technologies on the other non-banana farming activities including; building, trading/retail shops, hair dressing salons, tailoring, restaurant/hotel operation, church leadership, government jobs and livestock farming, the negative effects included: reduced time to carry out other activities; incomes/savings from the other businesses were diverted to controlling the banana disease; growing of beans in banana fields was stopped; employees delayed to go to work; other activities were scaled-down and the health of the farmers was exhausted. Because of the intensive BXW control activities, 85.5% (n = 324) of respondents failed to carry out other activities including: community savings, employees delaying going to work, growing other food/cash crops, businesses, animal farming and tree growing. Respondents were not able to continue carrying out the above activities because; some of the businesses were sold-off, and the owner relocated to their villages to concentrate on controlling BXW, lacked time

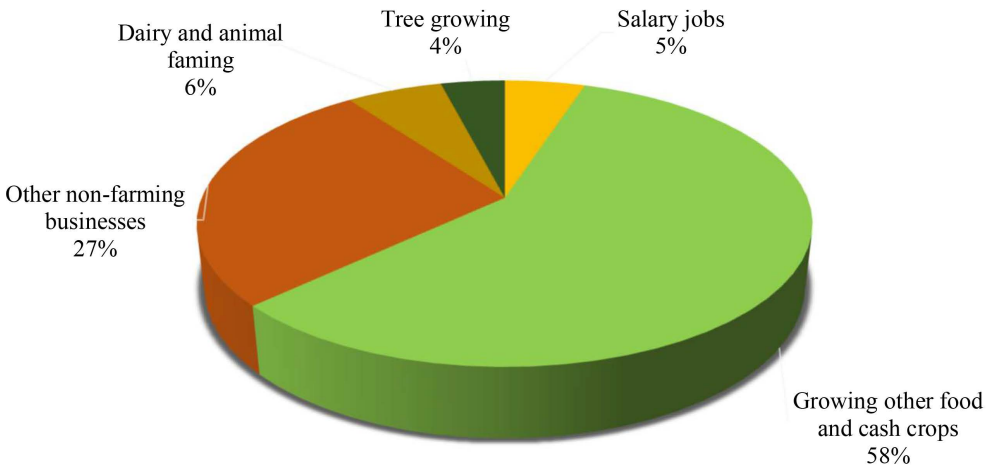

Figure 5. Additional economic activities carried out by participating respondents/banana farmers in the South Western Agro-Ecological Zone.

and money to carry out activities. The abandoned activities including other businesses or jobs; growing of food and cash crops; livestock rearing; community saving; employment work and tree growing formally generated an income range of UGX 4000 - 3,600,000 per month (Figure 6) before the BXW epidemics.

Factors favouring the current persistence of BXW in the South Western Agro-Ecological Zone

Overall, 83.3% (n = 366) of the survey respondents observed and destroyed BXW infected plants in their fields, while 16.7% did not experience any disease recurrence after implementing IDM technologies in the five districts. Although most respondents destroyed one to three infected plants per month in each the district, cases of destroying ≥ 10 plants occurred. The respondents (90.4%) that observed BXW infected banana plants in their villages mentioned; limited sensitization about the disease, absence of by-laws enforcement and no/poor use of BXW control technologies (Table 15), as the major factors favouring the diseases persistence. However, poor supervision of hired labourers that were not properly sterilizing field tools; grazing livestock in the banana plantations; sharing of farm tools; lack of tools to use in controlling the BXW, and failure of authorities to communicate and ensure proper training of farmers in application of the recommended BXW technology packages were the factors contributing to the disease persistence in the zone. Furthermore, some farmers feared that the BXW technologies disseminated were not 100% effective while other farmers indicated that the frequent high rainfall was the major factor favouring the fast rate of disease spread (Table 15). To mitigate BXW disease from the districts, 77% of the respondents suggested the following approaches as major (Table 16): 1) Increased sensitization and awareness creation among banana farmers, 2) Bye-law enforcement, 3) Continuous monitoring or implementation of the recommended BXW control technology packages. Use of resistant varieties and

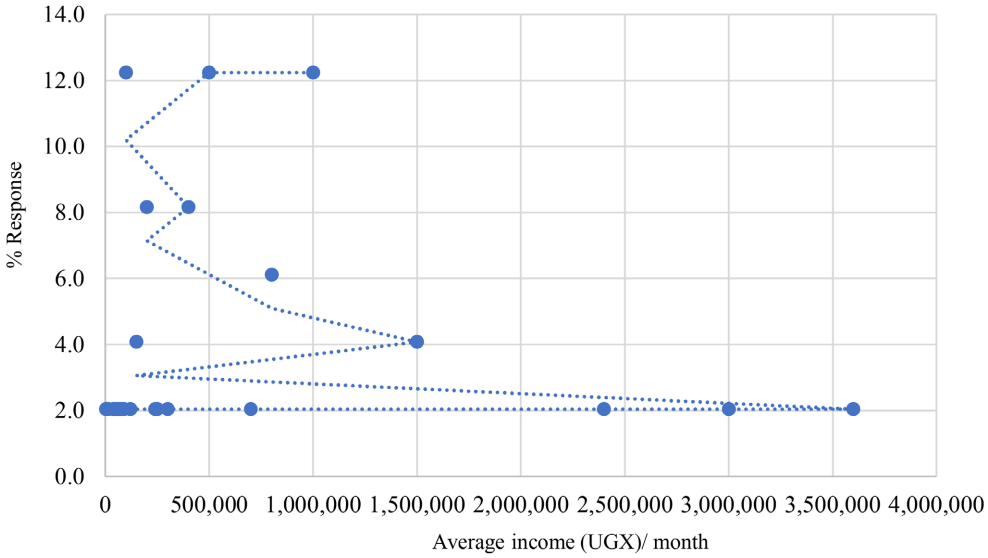

Figure 6. Average income formally generated from the abandoned economic activities in preference of banana Xanthomonas wilt control in the South Western Agro-Ecological Zone.

Table 15. Factors favouring BXW persistence in the banana plantations in the five districts of the South Western Agro-Ecological Zone.

Factors favouring BXW persistence	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
No enough sensitization about the disease	22.6	27.9	12.4	11.9	29.6
No strong by-laws	22.6	22.1	13.3	11.9	27.8
Abandoned the BXW control technologies	29.6	30.9	41.0	33.9	27.0
Farmers who use casual labourers, never sterilize the tools	8.7	2.2	3.8	2.8	0.9
Farmers graze/browse livestock in the banana plantation	0.9	2.9	2.9	0.0	1.7
Sharing of farm tools	3.5	2.9	15.2	7.3	1.7
Lack of tools to use in controlling the banana wilt	2.6	1.5	1.9	0.0	1.7
Failure by authority to communicate with the sensitization and mobilization about BXW control technologies	3.5	2.2	3.8	0.0	7.8
The methods were not 100% effective	1.7	1.5	0.0	8.3	0.0
Over spreads during the rainy season	0.0	0.7	0.0	0.9	0.0
The disease was soil borne	0.0	0.0	0.0	0.9	0.0
Did not know	4.3	5.1	5.7	22.0	1.7

Table 16. BXW eradication strategies suggested by the respondents in the South Western Agro-Ecological Zone.

BXM mitigation strategies	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
There should be adequate sensitization about the disease	35.0	36.4	31.3	33.6	40.2
By-laws should be enforced	24.3	27.2	26.7	18.6	29.5
Continuous monitoring or implementation of BXW technologies	16.4	17.9	26.0	15.9	4.1
Government should provide chemicals	10.0	12.6	8.4	11.5	17.2
Infected banana plantations to be cut down completely, and new ones established	7.9	1.3	0.0	0.0	5.7
Cooperating with other farmers to fight the disease	1.4	1.3	6.9	1.8	1.6
Getting new technologies that can completely eliminate BXW	0.7	2.6	0.0	16.8	0.0
Introduce resistant varieties	0.7	0.7	0.0	0.9	0.8
Didn't know	3.6	0.0	0.8	0.9	0.8

chemicals, development of effective technologies other than the ones already introduced, and complete destruction of infected banana plantations, were the other options suggested by respondents.

Effects of BXW-control technologies on the environment

BXW control technologies including: cutting down infected plantations and replanting new ones; cutting, chopping and burning the infected plants; establishing soil and water conservation structures and insect pest/disease control by cultural and chemical spraying were adapted to coffee, common beans, cassava and pineapple crop management by an average of 8.4% respondents, while

91.6% did not. The BXW control practices were adapted to other crops to conserve water and control erosion; ensure proper light circulation and plant growth; improve soil fertility; prevent diseases from spreading among plants and control pests. Nevertheless, 10.4% of the respondents indicated that the BXW control technologies had positive effects on environment/ecosystem (soil, air, water, plants, animals and other vegetation); whereas 89.6% indicated that the technologies negatively affected the surrounding environment. Addition of nutrients to the soil and yield increase were the specific positive effects mentioned, while the negative effects included: overworking because the technologies were too labour intensive and tiresome, which led to human health problems (chest pain), and fear that the disease would spread to the clean plants. The challenges of overworking and tiredness were overcome by taking time to rest and hiring labour, while human health problems associated with the technologies, were managed by avoiding body accidents caused by the technology tools and chemicals, and seeking medication.

Farmers used various approaches to be able to control BXW successfully, but the most common method across all the selected districts was effective application of the recommended multiple technology packages. Because this approach required a lot of resources, several farmers invested more time, money and labour (Table 17), to be able to eradicate the disease from their fields. The need to protect the banana plants, which is the major source of food and income, families and communities worked together through collective action approaches in fighting the disease. The study found that the disease was persisting in some areas mainly because the farmers were: not willing to control, were lazy, negligent and fade-up because of the disease persistence; whereas others lacked enough skills and knowledge about effective technology application (Table 18). Other reasons why farmers were not successfully controlling the disease included:

Table 17. Approaches used by banana farmers to continue using the integrated BXW control technologies successfully in the South Western Agro-Ecological Zone.

Approaches used to control BXW successfully	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Effective application of the integrated technologies	51.0	34.8	47.3	54.3	33.9
Use appropriate tools and implements	6.3	4.3	7.7	0.0	3.6
Availing enough money for labour to apply the technologies	15.6	10.9	11.0	19.1	25.0
Motivated by plantations recovering and yielding an increase	5.2	1.1	2.2	6.4	3.6
Co-operation and collective action within families/communities	3.1	12.0	8.8	14.9	7.1
Continued sensitization, commitment, vigilance in collective action	3.1	9.8	5.5	0.0	1.8
Committed effort, time and energy to eradicate the disease	7.3	9.8	3.3	0.0	10.7
Increased knowledge/skills and hard work	3.1	4.3	1.1	2.1	3.6
Need to protect the banana plantation because of its economic importance	5.2	10.9	12.1	3.2	8.9
Strict laws of arresting farmers who did not apply the technologies	0.0	2.2	1.1	0.0	1.8

Table 18. Reason why some farmers have not been able to apply the BXW control technologies in the South Western Agro-Ecological Zone.

Reasons why farmers have not been able to successfully control BXW	Mitooma	Isingiro	Mbarara	Ntungamo	Rubirizi
Farmers are fading up because of the persistence of BXW	0.0	0.9	0.0	2.1	0.0
Farmers do not carry out regular monitoring	1.1	0.9	0.9	1.0	2.5
Focusing on the trading and other farming activities	3.3	0.0	0.0	1.0	1.3
Lack of enough skills and knowledge about technologies	18.5	19.6	17.3	32.0	24.1
Lack of money to invest BXW and also buy enough tools	4.3	5.4	0.9	0.0	2.5
Late application of BXW control technologies	1.1	0.0	0.0	0.0	0.0
Most farmers stay far away from their field plantations	3.3	10.7	6.4	1.0	6.3
Reduced BXW control campaigns, sensitization and training	0.0	0.9	1.8	0.0	0.0
Reduced by-law enforcement by local leader/government	1.1	0.9	2.7	0.0	2.5
Some Farmers are weak, very old and lack enough labour	12.0	8.0	9.1	18.6	3.8
The methods are not 100% effective	3.3	2.7	4.5	4.1	1.3
Technologies are expensive and too labour intensive/tedious	5.4	0.0	0.9	2.1	1.3
Unwilling, Laziness, negligence of farmers	46.7	50.0	55.5	38.1	54.4

not carrying out regular monitoring; focusing on the trading and other farming activities; lack of money to invest in BXW control; late application of the technologies; staying far away from their plantations; absence of BXW control awareness creation, sensitization and training; limited by-law enforcement by local leaders and government; some farmers were weak, very old and lacked enough labour; technologies were not 100% effective; technologies were expensive and too labour intensive/tedious.

This study found that the respondents acquired various capacities to carry out the BXW management activities, but the abilities to demand technical support about BXW technologies from government or other institutions/organizations (29.7%); invest in the use of the BXW control technologies for improved and sustainable banana production (21.6%) and continuous application of the technologies with sufficient knowledge and skills without external support (24.3%) ranked highly. The ability to initiate, lead and start training other farmers and/or groups in the villages/communities to completely mitigate the BXW problem using the recommended technologies (13.5%), and modify the technologies to suit their use in farmers' situation without reducing their effectiveness (10.8%) were the lowest ranked abilities of farmers. The highest-ranking abilities of respondents were derived from the fact that the farmers had acquired sufficient knowledge/skills (59.7%), which was a result of good training and high trainees' commitment or interest. Some respondents indicated that they were able to invest and continue controlling the disease using the recommended technologies effectively with or without BXW infections in order to sustain high banana produc-

tivity for food security and income generation. The reasons given for the low-ranking abilities of the respondents were due to lack of resources (time, money, knowledge) to invest; need for more training, technologies not being effective in controlling BXW, farmers needing alternatives; technologies were difficult to modify; there was need of technical support; potential farmer-to-farmer trainers doubted that they would not be listened to, or their support/leadership would not be paid attention to; and finally, some respondents were unable to carry out the activities because of old age, sickness or other health ailments.

4. Discussion

The severe Banana Xanthomonas wilt epidemics, which occurred in the South Western Agro-Ecological Zone of Uganda during 2009-2013 resulted in 80% - 100% plant loss in the major disease hotspots, and led to decline in banana productivity and production [5] [16]. All banana value chain stakeholders in this zone were directly and/or indirectly impacted by BXW, but the most affected stakeholders were the majority of smallholder farmers who were highly dependent on banana production for food, income and other livelihood requirements. Because of its ability to remain productive all year around, with the peak harvest periods of June-August and September-November, banana can continuously provide the required amounts of human food (70%) and cash (30%) under all prevailing conditions thus ensuring food security and relatively constant income generation from banana [17]. The socio-economic negative impact caused by the unpredicted outbreak of the 2009-2013-BXW epidemics in the SWAEZ has lingered around for over two decades leading farmers to adopt/adapt alternative farming and non-farming activities to obtain food and generate incomes. However, given the increasing regional demand for banana, Uganda needs to develop and/or adopt production technologies that ensure banana's resilience to abiotic and biotic stresses [18], which are progressively evolving due to climate change [19]. The diversification of food crops and income generating activities, has partially reduced farmers' over-dependence on one commodity (banana), which is increasing crop production for improved food security, nutrition and income.

During the severe BXW epidemics, the livelihoods of most farmers depended on periodic-cash remittances and non-farming businesses, but banana was not only the most common, but maintained the highest rank out of the various income generation options. Although most respondents indicated that all banana varieties grown in the zone were susceptible to BXW, some farmers reported a level of moderate to high disease tolerance in several varieties in Mitooma and Isingiro district. However, numerous studies have shown an absence of resistance genes in all East African Highland Cooking bananas [13] [20] [25], thus implying that disease absence or low infections on certain varieties was probably a result of escape and/or limited inoculum.

Over years there has been a general decline in crop productivity and production in Uganda, but the decline in banana due to 2009-2013-BXW epidemics in

the SWAEZ was significantly higher compared to the other common crops grown for food and income generation. Besides climate change associated stresses and soil fertility depletion [26]; BXW caused a significant decrease in banana production as indicated by 41.5% of the respondents. Moreover, climate change associated stresses have been found to accelerate BXW infections on physiologically stressed plants [27]. In addition to the abiotic and other biotic stresses, reduction of the acreage under banana plantations by the majority small holder farmers was partly due to the negative impact of BXW on banana production. Regardless of the banana acreage, the cost of plantation management, mostly varied with the BXW control technology package applied, and the average cost of integrated disease management was UGX 820,000 per acre. The high marketable-fruit yields depended on the combination of field size, agronomic practices, variety/cultivar and weather before the BXW epidemics, but yields drastically declined during and after the disease epidemics. Gradually, yield increases were reported later after the epidemics with Isingiro and Mbarara district showing 2.0 and 3.4 times yield increase, respectively. During the BXW epidemics, 68.2% of the respondents harvested zero or 1 ≤ 10 bunches of bananas, while 31 - 400 bunches were harvested by 16%. The overall decline in banana production during the BXW epidemics resulted in banana scarcity, which made the selling prices of the available marketable bunches increase to an average of UGX 40,000 for very big sizes. The recent research prediction, shows that a zero control BXW, is likely to cause a 16% domestic price increase on banana over a baseline BXW-free scenario, and this loss may cause an economic loss of over USD 25 billion [5].

The decline in banana production resulted in food scarcity among the majority banana growing households in the rural areas of the SWAEZ, and this caused many families to use their other resources (labour and non-labour assets) to generate money for buying food [15]. Taking or borrowing loans from fellow community members and local saving schemes, became a means used by farmers to acquire money for providing the basic family livelihood requirements that included food, children's scholastic materials, medical services, shelter, and others. Because of food inadequacies, many families changed from having the usual three-meal feeding system to a one or two-meal-feeding system [28]. However, families that did not have alternative sources of food and other livelihood necessities, experienced severe food scarcity, which resulted in hunger and malnutrition, especially among children and women, which agreed with the food security deterioration among areas where banana is the staple food crop [5]. Because the banana plantation is the man's important asset for providing food and money to support the family, it is usually the man's responsibility to manage it well to sustain its high productivity [29]. Development of severe BXW epidemics in the zone crashed the men's ability to support their families at any given time, which made them vulnerable to stress associated with the labour intensive IDM packages used and pressure resulting from family food and money

demands. Thus, frequent conflict, fights, quarrels, domestic violence, men and children running away from home and criminal cases including thefts also increased in the communities as indicators of severe food and money scarcity in the rural banana dependent households.

In order to cope with the negative impact of the BXW epidemics on the socio-economic and livelihoods of the affected majority households, the banana stakeholders, adopted a comprehensive integrated approach, which was used to continuously mobilize and sensitize all stakeholders in the banana value chain (producers, traders, transporters, processors and consumers); build capacity (knowledge/skills, IDM technology packages, inputs and others), demonstrate and implement the control activities through various approaches of collective action, enforcement of policies/bye-laws and monitoring and evaluation. Studies have shown that the medium and long-term effects of the above approaches resulted in widespread control of BXW, leading to increase in banana production by USD 187, and an increase in banana income by more than USD 90 per acre per annum [30]. Consistent adoption and adaption of the recommended BXW control packages acquired through training significantly suppressed disease incidences, leading to improved productivity and household incomes [13]. In the SWAEZ, because of the comprehensive BXW control campaign, individual banana farmers experienced the following major changes: improved availability of enough banana food; increased incomes generated from banana sales; increased well-managed banana plantations; increased yield and production and improved knowledge/skills to effectively eradicate BXW. Although not considered major, the following socio-economic changes also resulted from the benefits of BXW control: reduced financial expenditure; increased savings; increased purchase of new assets by farmers; increased collective action, improved socio-interaction and improved unity among farmers; improved family nutrition and health, and children went back to school with fees fully paid.

Unfortunately, farmers also experienced short and medium-term negative effects resulting from the implementation processes of BXW-control technology packages. Severe yield reduction that resulted from the complete destruction of disease-affected plants; very high expenditure on labour used in the rigorous BXW control activities; insufficient field tools, equipment and disinfectants; disease persistence due to ineffective management; social conflicts, political interference, arrest of non-compliant farmers, payment of penalties, running away of men and children from homes; loss of field tools due to fire sterilization and increased human health problems (backache and chest pain) were keys challenges associated with BXW control technologies. The BXW-control technology implementation had the following negative effects on their non-banana farming activities: reduced time to carry out other activities; incomes/savings from the other businesses were diverted to controlling BXW; growing of beans in banana fields was stopped; employees delayed to go to work; other activities were scaled-down; farmers' energies were exhausted, and some farmers failed to carry

out other activities (community savings, growing other food/cash crops, businesses, animal farming and tree growing).

A small proportion (10.4%) of the respondents in this study indicated that the BXW technology packages that were promoted had positive effects on the environment (soil, air, water, animals and vegetation) and/or ecosystems, while the majority (89.6%) emphasized the negative effects on human health and high cost of technology application. However, the good technologies that were applicable to other crops were adapted to coffee, common beans, cassava and pineapple to conserve soil moisture; control erosion; ensure proper light circulation and plant growth; improve soil fertility; prevent diseases from spreading among plants and control pests.

Given the comprehensive efforts used to eradicate the severe BXW epidemics that infected numerous banana fields in the SWAEZ during 2009-2013, the disease has persisted in the zone. Over 80% of the current study respondents have continued to experience BXW recurrences in their plantations, and cases of 1 - 10 infected plants per month were recorded in the banana growing communities/villages. Ninety percent of the respondents attributed the disease's recurrences or persistence to limited farmer sensitization about BXW; absence of by-laws enforcement and no/poor use of BXW control technologies. However, poor supervision of hired labourers at work; improper sterilization of field tools; grazing livestock in the banana plantations; sharing of farm tools; lack of appropriate BXW control tools and failure of authorities to communicate and ensure proper training of farmers in the application of the recommended BXW technology packages were the factors also contributing to the disease persistence in the zone. Because of the high rate at which the BXW pathogen aggressively infected bananas many farmers gave up and their plantations became sources of inoculum, while others were not success in controlling the disease because they did not carry out regular monitoring; focused on their other economic and farming activities; lacked money to invest BXW control; applied the technologies late; stayed far away from their plantations; lacked the required knowledge and skills; limited by-law enforcement by local leaders and government; some farmers were weak, very old and lacked enough labour; technologies were not 100% effective; technologies were expensive and too labour intensive/tedious.

5. Conclusion

In conclusion, to be able to control BXW successfully across all the selected districts, farmers highly invested in the application of the recommended multiple BXW control technology packages. Because this approach required a lot of resources, several farmers invested more time, money, and labour to be able to eradicate the disease from their fields. The need to protect banana plants, which are the main source of food and income, led families and communities in some areas to work together through collective action approaches to fight the disease. Overall,

throughout the whole process of eradicating BXW from the SWAEZ, farmers acquired various capacities to carry out the BXW management activities, to demand technical support from the government or other institutions/organizations, invest in the use of the BXW control technologies for improved and sustainable banana production, continuous application of the technologies with sufficient knowledge and skills without external support [31]. The above highly ranked abilities of respondents were derived from the fact that the farmers had acquired sufficient knowledge/skills, which was a result of good training and high trainees' commitment or interest. Some respondents indicated that they were able to invest and continue controlling the disease using the recommended technologies effectively with or without BXW infections in order to sustain high banana productivity for food security and income generation. However, the ability to initiate, lead, and start training other farmers and/or groups in the villages/communities to completely mitigate the BXW problem using the recommended technologies and modify the technologies to suit their use in farmers' situations without reducing their effectiveness ranked lowest because: of lack of the required resources (time, money, labour, knowledge) to invest; need of more training; the negative perception that the technologies were not effective; lack of effective technologies; lack of technical support; the potential farmer-to-farmer trainers doubted that they would not be listened to, or their support/leadership would not be paid attention to; and finally, some respondents were unable to carry out the activities because of old age, sickness or other health ailments. Therefore, in order to completely eradicate BXW from the SWAEZ, the following recommendations were made by the study respondents: 1) Increase mobilization and sensitization of banana farmers about the disease, 2) Reinstate bye-law enforcement, 3) Continue monitoring or implementation of the recommended BXW control technology packages, 4) Develop effective technologies (resistant varieties and chemicals) other than the ones already introduced, and 5) Completely destroy infected banana plantations.

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Conflicts of Interest

The authors declare no conflicts of interest.

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