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Farmer Reported Pest and Disease Impacts on Root, Tuber, and Banana Crops and Livelihoods in Rwanda and Burundi

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Abstract: Biotic constraints cause major crop losses and, hence, food insecurity in sub-Saharan Africa. This study documented the popularity, production constraints, pests and diseases, farmers' perceptions on the severity of biotic constraints and the impact of related crop losses on household food security for the key root, tuber and banana (RTB) crops (cassava, potato, sweetpotato and banana). Farmer interviews were conducted in 2014 covering 811 households in Rwanda and Burundi. Farmers were asked to list their RTB crop production constraints, name insect pests and diseases of RTB crops, estimate crop loss due to pests and diseases, and mention if their household experienced any form of food insecurity due to pests and diseases. Cutworms and late blight in potato, banana weevils and banana *Xanthomonas* wilt in banana, cassava whitefly and cassava mosaic disease in cassava, sweetpotato weevils, and sweetpotato virus disease in sweetpotato were the most predominant pests and diseases reported. Crop losses due to pests and diseases for sweetpotato, banana, potato and cassava were estimated at 26%, 29%, 33%, and 36%, respectively, in Rwanda and 37%, 48%, 38%, and 37% in Burundi. Pests and diseases reduce the profitability of RTB crops, threaten food security, and constitute a disincentive for investment. Sustainable and affordable integrated pest management packages need to be developed.

Keywords: farmers' perceptions; crop losses; food security; potato; sweet potato; cassava; rural development, IPM

1. Introduction

Roots, tubers, and bananas (RTB) are important crops in Rwanda and Burundi as they play important role in food security and income generation. They are both staple food- and cash- crops for many households in the rural areas of both countries. In Burundi, the production of RTB crops is slightly lower than in Rwanda with an annual production of 2.24 vs. 3.26, 2.23 vs. 2.95, 0.12 vs. 2.24, and 0.84 vs. 1.08 million tonnes for bananas (*Musa* sp.), cassava (*Manihot esculenta* Crantz), potato

(*Solanum tuberosum* L.) and sweetpotato (*Ipomoea batatas* L. Lam.) in 2014, respectively [1]. Despite the substantial production of food in most homes in Rwanda and Burundi, many families are still food insecure [2,3]. There is a higher prevalence of hunger among the farming communities in Burundi than in Rwanda [4]. Average on-farm yields in Burundi for banana, cassava, potato and sweetpotato are estimated at 9.13, 8.12, 8.17 and 11.09 t/ha, respectively [1]. In Rwanda, on-farm yields for banana, cassava, potato and sweetpotato are 6.18, 17.57, 14.86 and 7.36 t/ha, respectively. The popularity of these crops for household cash income has been reported to have increased recently as a response to acute nutrition needs caused by longer droughts in 2016, fall armyworm (*Spodoptera frugiperda* (JE Smith)) outbreaks in 2016 and, the emergence of maize lethal necrosis (MLN) [5,6]. Further, several private sector investors in the processing industry are also contributing to the increased demand for roots and tubers by getting starch from cassava, confectionery from sweetpotato and beer from banana in Rwanda. RTB crops, however, are constrained by pests and diseases, low market prices, price fluctuations, soil infertility, unpredictable rains, drought, and lack of clean planting material [7–10].

While there is widespread consensus that insect pests and diseases can play an important role in causing food insecurity, there is little information about the magnitude of yield and post-harvest losses in the African Great Lakes region. Many pests and diseases of RTB crops have been reported in the East and Central African region, which can cause crop losses of up to 100% (Table 1 and references therein). As a result, food security and livelihoods of the affected households is severely compromised. A review by Oerke [11] reported global potato yield losses due to pathogens, insects and weeds between 1990 to 1998 at 9.8, 9.6 and 5.3 billion US$, respectively. Limited information is available on crop losses due to pathogens, insects and weeds in banana, cassava and sweetpotato. In addition, global warming may further accelerate pest- and disease- related losses due to more pest generations leading to increased abundance, range expansion and infestations [12,13].

This study was undertaken to get an understanding of farmer concerns related to pests and diseases in RTB crops. Currently, no literature or data on this topic is available in the two countries despite the high dependence on agriculture and farmer complaints about damage by pests and diseases. This study aimed to document: (i) the RTB crops (banana, cassava, potato, and sweetpotato) commonly grown by farmers, (ii) farmers perceptions of the constraints limiting production of RTB crops, (iii) the pests and diseases reported by farmers to be affecting production of the four RTB crops, (iv) farmers' perceptions of the severity of the existing pests/diseases, and (v) the impact of the crop losses related to pests and diseases on household food- and income-security in the region.

Proper pest and disease management can play an important role in stabilizing food production at the household level by reducing pre- and post-harvest food losses. Information on the existing pests and diseases in Rwanda and Burundi and the associated degree of damage will be very useful in guiding policy, development interventions, and research to design sustainable management strategies. Such studies are also intended to draw attention to RTB crops and attract funding that will help to control biotic causes of crop losses and hence increase household food- and nutritional security.

Table 1. Some of the most important pests and diseases limiting production of roots, tubers and bananas in the East and Central African region.

Crop	Type of Harmful Organism	Economic Importance (Yield and Economic Losses) of Pest	References
Potato	**Insects** 1. The potato tuber moth (*Phthorimaea operculella* [Zeller]) 2. Leafminer flies (*Liriomyza* spp.) 3. Aphids (*Aphis gossypii* Glover, *Aphis fabae* Scopoli, *Macrosiphum euphorbiae* Thomas, and *Myzus persicae* Sulzer)	Tubers infested with P. *operculella* often initiate tuber infestation in potato stores causing losses of tubers of up to 70%.	[14–18]
	Pathogens/diseases 1. Late blight caused by *Phytophthora infestans* (Mont.) de Bary 2. Bacterial wilt caused by *Ralstonia solanacearum* (Smith 1896) 3. Potato viruses (Potato Virus S (PVS), Potato Virus (PVY), Potato Virus X (PVX) and Potato Leaf Roll Virus (PLRV))	Yield reductions in Rwanda and Burundi can reach 75% for late blight if no control measures are taken. For bacterial wilt, reductions in yield range from 70–100%, depending on the inoculum density. Seed degeneration due to viral diseases have been reported to cause yield reduction of up to 90%.	[7,10,15,19–21]
Sweet potato	**Insects** 1. The African sweetpotato weevil (*Cylas puncticollis* Boheman and *C. brunneus* Olivier), 2. The sweetpotato butterfly (*Acraea acerata* Hew) 3. The sweetpotato whitefly *Bemisia tabaci* (Gennadius)	Root yield losses due to *C. puncticollis* alone can reach 100% during prolonged dry seasons.	[22–24]
	Pathogens/diseases 1. The sweetpotato virus disease (SPVD), 2. *Alternaria* leaf and stem blight and 3. Fungal root rots	Root yield losses due to SPVD ranges between 30–40% at on-farm.	[25,26]

Table 1. *Cont.*

Crop	Type of Harmful Organism	Economic Importance (Yield and Economic Losses) of Pest	References
Banana and plantain	**Insects** 1. Banana weevil (Cosmopolites sordidus Germar) Banana aphid (*Pentalonia nigronervosa Coquerel)* **Nematodes** 1. *Radopholus similis* (Cobb) Thorne, 2. *Pratylenchus goodeyi* Sher and Allen, *Helicotylenchus multicinctus* (Cobb) Golden 3. *Meloidogyne* spp.	Yield losses of 30–50% in fertile soils and over 75% in poor soils. Direct feeding by large colonies of the banana aphid reduces market value due to blemishes on the fruit. The secretion of honeydew by aphid colonies provides a substrate for sooty mold fungus, which reduces banana yields and market value.	[27–34]
	Pathogens/diseases 1. *Xanthomonas* wilt of banana (BXW) caused by *Xanthomonas campestris* pv. *musacearum* 2. Fusarium wilt caused by *Fusarium oxysporum* f. sp. *Cubense* 3. Banana bunchy-top disease (BBTD), caused by the banana bunchy top virus (BBTV)	Up to 100% yield loss if control of BXW is delayed. Economic losses worth US$200–295 million/year due to BXW were estimated in Uganda. Annual production losses due to BXW valued at US$10.2 million and US$2.95 million in Tanzania and Rwanda, respectively. Reduction in fruit sales by 35% and a doubling of bunch prices due to BXW. Severe effects of BXW on ecosystem health of banana-based agro-ecosystems. Losses of up to 100% due to BBTD in Burundi and eastern DR Congo.	[35–45]
Cassava	**Insects** 1. Cassava mealybug (*Phenacoccus manihoti* Matile-Ferrero). 2. Cassava green mite (*Mononychellus tanajoa* Bondar) and 3. Cassava whitefly (*B. tabaci* (Genn.)).	No data could be accessed.	[26].
	Pathogens/diseases 1. Cassava brown streak disease (CBSD) 2. Cassava mosaic disease (CMD) 3. Cassava bacterial blight (CBB)	Africa-wide losses to CMD have been estimated at more than US$1 billion annually. Loss estimate for CBSD in East and Central Africa is greater than US$75 million per year.	[35,36]

2. Materials and Methods

2.1. Study Area

A household survey was conducted in the Ruhengeri and Rusizi watersheds of Rwanda and Burundi, respectively. The Rusizi watershed covers parts of Bujumbura Rural, Bubanza, Cibitoke, and Muramvya Provinces while the Ruhengeri watershed covers areas in Musanze, Burera, Gakenke, Ngororero, and Nyabihu Districts (Figure 1). The survey was conducted in the second half of 2014 and was implemented jointly by the International Potato Center (CIP), the International Institute of Tropical Agriculture (IITA), Bioversity International, the Rwanda Agricultural Board (RAB), and the Institute des Sciences Agronomiques du Burundi (ISABU). The survey covered 54 villages (27 in Rwanda and 27 in Burundi).

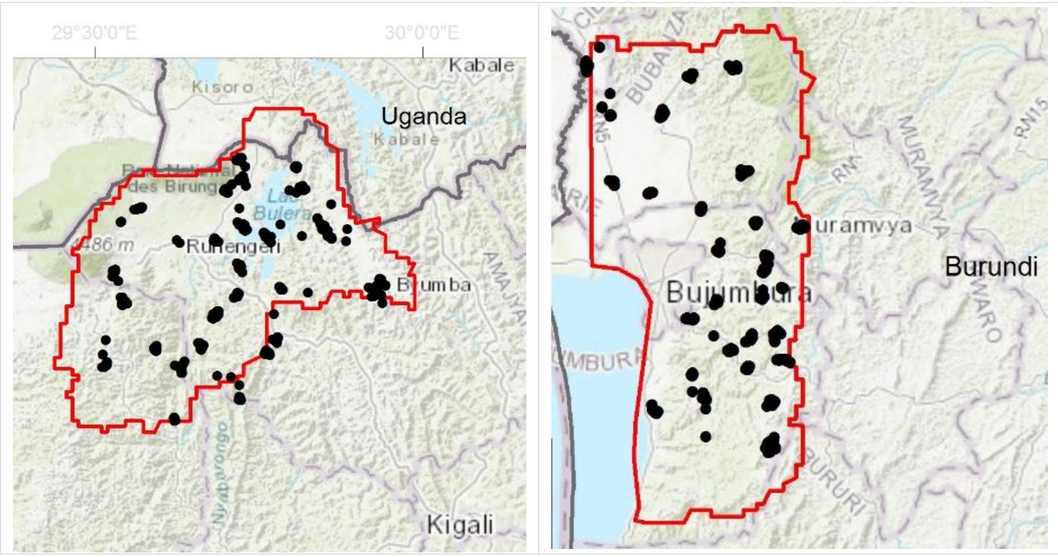

Figure 1. Map of Rwanda and Burundi showing the location of the surveyed households.

2.2. Study and Sampling Design (Study Subjects, Inclusion Criteria, and Ethical Approval)

The study design was cross-sectional and used quantitative methods for data collection. The sampling unit for respondents was a household. A household was defined as a group of family members living and eating together for at least the last three months. The primary study subjects were household heads and spouses to the household head or any adult in the household who was responsible for production of bananas, cassava, potato, or sweetpotato. Fifteen households per village were randomly selected and enumerated with the help of local community leaders. In cases where insufficient farming households were present, a neighboring or nearest farming community was selected. Only one adult was interviewed from each household using a structured questionnaire specifically designed for this study. In cases where both the husband and wife were present at home, the person who makes most of the decisions on RTB crops was interviewed. In total, 810 households (405 in Rusizi and 405 in Ruhengeri) were sampled in the two watersheds. For large populations with unknown variability, representative sample sizes at a 95% confidence level were calculated using the formula of Glenn [37] as a minimum of 384 farmers for each watershed (Equation (1)):

$$n_0 = \frac{Z^2 \mathrm{pq}}{e^2} = \frac{(1.96^2)(0.5)(0.5)}{0.05^2} = 384 \text{ farmers} \tag{1}$$

where n_0 is the sample size, Z^2 is the abscissa of the normal curve that cuts off an area α at the tails ($1 - \alpha$ equals the desired confidence level, 95%), e is the desired level of precision, p is the estimated proportion of an attribute that is present in the population, and q is $1 - \mathrm{p}$.

To ensure validity and clarity of the content in the questionnaire, pre-testing was done prior to formal data collection. Interviews were conducted in the local language (Kinyarwanda in Rwanda and Kirundi in Burundi) by trained enumerators, who were local experts in the field of crop protection supervised by the first author. Quantitative data were collected on several major themes which included: household demographics, production constraints, identification of major pests and diseases of RTB crops (farmers were shown photographs of pests and diseases and crop and tuber damage) and pest and disease control methods, food insecurity (see questionnaire at https://www.mdpi.com/1660-4601/16/3/400/s1). Verbal informed consent to participate in the study was sought from farmers after the objectives and methods had been explained. If a farmer accepted, he/she was then interviewed.

2.3. Data Analysis

Statistics (frequencies, percentages, and means) were used to generate summaries and tables at country level using SAS software V.9.2 for Windows [38]. Chi-square and one-way analysis of variance (ANOVA) were carried out to determine if there were any differences between countries. The significance level was set at $p \leq 0.05$ and means were separated using the LSD test. For the ease of comparison, a weighted average index, was calculated on basis of perceived scores for importance by multiplying the proportion of households by the score for importance, summing them up and dividing by number of levels. The average weighted index varied from 0.0 (for not a problem) to 1.0 (for most important constraint). The detailed scores for each constraint used to calculate the weighted average indices presented in Tables 3 and 4 are shown in Supplementary Tables S3a,b and S4.

3. Results

3.1. Characteristics of the Sampled Population

Household heads in both Rwanda and Burundi were mainly men (Table 2). Mean household size was higher (about six persons) in Burundi than in Rwanda (about five persons). The years of formal education didn't significantly vary between the two countries for men, but women in Rwanda were on average more educated than in Burundi. Farming was the main source of income of the sampled population for both men and women in both countries. Annual income from both on-farm and off-farm activities were significantly higher for men than women in both countries.

Table 2. Demographic and socio-economic characteristics of farmers interviewed in Rwanda and Burundi.

Farm and Household Characteristics	Rwanda (n = 406)	Burundi (n = 405)
Female headed households (%)	15.7	20.5
Household size by age (mean ± SE)		
Number of children below 5 years	0.69 ± 0.04 b	1.3 ± 0.05 a
Number of children 6–17 years	2.02 ± 0.08 a	2.23 ± 0.08 a
Number of men 18–65 years	1.29 ± 0.04 b	1.47 ± 0.06 a
Number of women 18–65 years	1.23 ± 0.04 b	1.44 ± 0.05 a
Number of elderly men (>65 years)	0.05 ± 0.01 a	0.04 ± 0.01 a
Number of elderly women (>65 years)	0.04 ± 0.01 a	0.03 ± 0.01 a
Total household size (mean ± SE)	5.33 ± 0.10 b	6.24 ± 0.13 a
Years of formal education for men	5.37 ± 0.18 a	5.73 ± 0.19 a
Years of formal education for women	5.15 ± 0.18 a	3.83 ± 0.17 b
Age of men (household heads)	42.22 ± 0.71 b	46.32 ± 0.70 a
Age of women (spouses)	39.18 ± 0.65 a	39.82 ± 0.69 a

Table 2. *Cont.*

Farm and Household Characteristics	Rwanda (n = 406)	Burundi (n = 405)
Main occupation for women (% responses)		
Farming (crop and livestock husbandry)	94.6	97.3
Salaried employment	2.7	1.7
Retail business (shops)	0.3	0.5
Casual labor	0	0.3
Handicraft	0	1.7
Other		
Main occupation for men (% responses)		
Farming (crop and livestock husbandry)	91.4	82.2
Salaried employment	4.4	9.1
Retail business (shops)	1.2	3.2
Casual labor	0.5	2.5
Handicraft	0.5	1.7
Other		
Mean annual income (mean ± SE) in US$ *		
Farm income for men	331.59 ± 13.93 a	229.77 ± 11.56 b
Off-farm income for men	335.65 ± 23.96 a	246 11 ± 19.06 b
Farm income for women	224.70 ± 22.75 a	208.29 ±17.01 a
Off-farm income for women	172.24 ± 35.17 a	133.76 ± 25.74 a

Mean values with the same letter in a row between are not significantly different at $p \leq 0.05$. n = number of respondents. * 1 US$ = 682.33 RWF = 1522.45 BIF.

3.2. Importance of RTB Crops

The four RTB crops were of great economic importance (food, nutrition and income security) in the study sites (Ruhengeri and Rusizi watersheds). All surveyed farmers grew at least one of the four RTB crops. In Rwanda, most farmers grew potato only (27.6%) followed by nearly equal numbers of farmers growing combinations of potato and sweetpotato (19.7%) and banana, cassava, and sweetpotato (19.5%) (Figure 2). In Burundi, most households had a combination of banana, cassava and sweetpotato (47.4%) followed by cassava and sweetpotato in 16.3% of the households, and a combination of potato and sweetpotato (11.4% of the households).

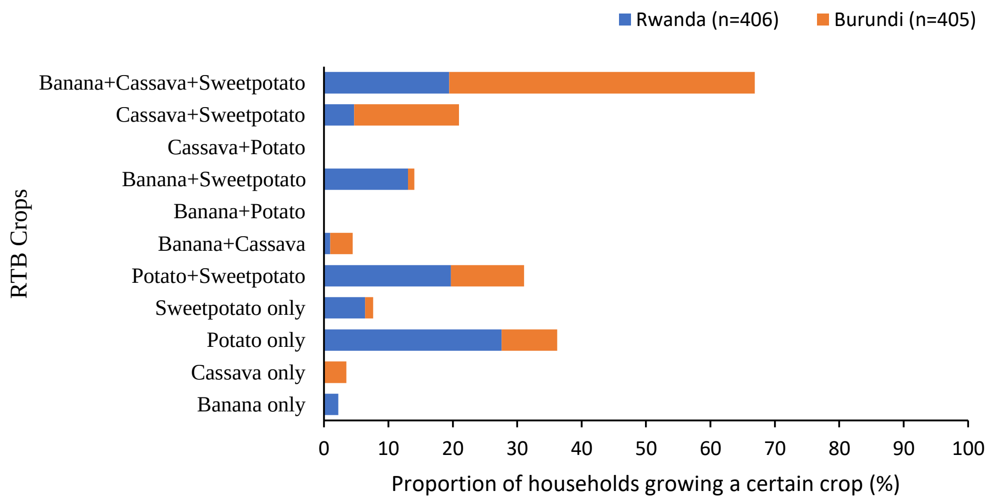

Figure 2. Number of households growing a single RTB crop or combinations of RTB crops.

3.3. Contribution of RTB Crops to Food and Income Security

More than 50% of the households in Burundi grew the four RTB crops primarily for food, with cassava and sweetpotato being grown by nearly 80% of the households (Figure 3). In Rwanda, a similar trend was observed, with sweetpotato leading other RTB crops in being grown primarily for food by nearly 60% of the households, followed by cassava (47%). In Rwanda, banana and potato were mainly grown as cash crops. This trend further emphasizes the importance of RTB crops as food, nutrition, and income security crops in both countries.

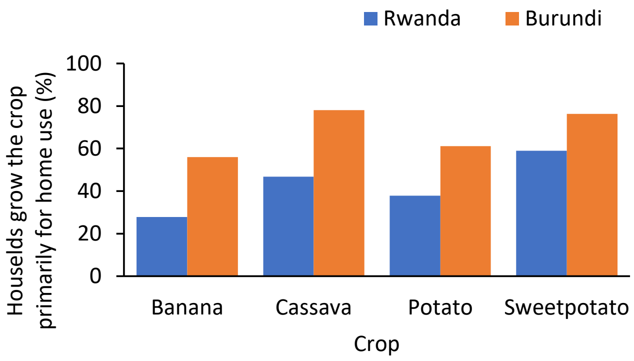

Figure 3. RTB crops primarily grown for home consumption (food). Number of responses for banana, cassava, potato, and sweetpotato were 201, 141, 251, 305 in Rwanda and 261, 319, 144, 371 in Burundi, respectively.

3.4. Production Constraints of RTB Crops

In Rwanda, the top four most important constraints identified by farmers for potato (in order of decreasing importance) were diseases, high costs of planting material, high cost of fungicides, and insect pests (Table 3). For sweetpotato, farmers ranked poor-quality planting material as most important followed by high cost of transport. Both insect pests and diseases were ranked similarly at position three by most of the farmers. Among farmers of banana, poor-quality planting material was reported as the most important constraint to production, followed by drought. Low market prices and high cost of planting material were in third and fourth place, respectively. The majority of farmers of cassava ranked poor-quality planting materials, drought or unpredictable rains, and low market prices as the first, second, and third most important production constraints responsible for crop losses. In Burundi, the production constraints ranked to be most important by the majority of potato farmers were diseases, high cost of planting material, high cost of fungicides, and insect pests (Table 3). For sweetpotato, most of the farmers ranked both insect pests and diseases to be the most important constraint limiting production, followed by the poor-quality planting material. Poor planting material and drought were the number one- and two- main factor limiting production of banana. Among cassava farmers, the constraints ranked as most important by majority of the farmers were diseases followed by poor-quality planting material.

Table 3. Farmer reported production constraints of RTB crops in Rwanda and Burundi (weighted average index).

Constraint/Crop	Potato		Sweetpotato		Banana		Cassava	
	Rwanda (n = 216)	Burundi (n = 115)	Rwanda (n = 281)	Burundi (n = 343)	Rwanda (n = 169)	Burundi (n = 238)	Rwanda (n = 111)	Burundi (n = 305)
Diseases	0.87	0.92	0.65	0.73	0.45	0.4	0.55	0.69
Drought (unpredictable rainfall)	0.61	0.63	0.56	0.46	0.61	0.52	0.62	0.49
Exploitation by vendors	0.37	0.23	0.28	0.25	0.28	0.25	0.28	0.25
Floods/mud slides/soil erosion	0.61	0.51	0.4	0.42	0.32	0.32	0.39	0.35

Table 3. *Cont.*

Constraint/Crop	Potato		Sweetpotato		Banana		Cassava	
	Rwanda (n = 216)	Burundi (n = 115)	Rwanda (n = 281)	Burundi (n = 343)	Rwanda (n = 169)	Burundi (n = 238)	Rwanda (n = 111)	Burundi (n = 305)
High cost of fertilizers	0.26	0.23	0.26	0.24	0.25	0.23	0.28	0.25
High cost of fungicides	0.79	0.63	0.49	0.42	-	-	-	-
High cost of insecticides	0.73	0.38	0.4	0.32	-	-	0.38	0.37
High cost of planting material	0.81	0.26	0.6	0.28	0.5	0.31	0.49	0.27
High cost of transport	0.57	0.49	0.66	0.36	0.49	0.32	0.53	0.35
High cost of weed control	0.32	0.25	0.3	0.25	0.32	0.25	0.28	0.25
Insect pests	0.78	0.67	0.65	0.73	0.34	0.32	0.29	0.29
Invertebrate pests (millipedes, nematodes)	0.43	0.31	0.54	0.47	0.36	0.37	0.45	0.47
Low market prices	0.74	0.28	0.56	0.24	0.52	0.24	0.58	0.23
Low soil fertility	0.68	0.3	0.39	0.26	0.38	0.29	0.4	0.26
Poor-quality planting material	0.66	0.62	0.84	0.67	0.69	0.63	0.7	0.64
Short shelf life (perishability)	0.43	0.4	0.35	0.32	0.38	0.29	0.4	0.31
Weeds	0.39	0.31	0.31	0.28	0.35	0.3	0.33	0.3

The weighted average index was calculated on basis of perceived scores for importance and it varied from 0.0 (for not a problem) to 1.0 (for most important constraint). n = number of respondents.

3.5. Pests and Diseases Affecting RTB Crops

Banana weevils (*Cosmopolites sordidus* Germar) were mentioned by most farmers (44% and 49% of the respondents in Rwanda and Burundi, respectively) affecting banana followed by nematodes (8% and 19% of the respondents in Rwanda and Burundi) (Table 4). In importance, however, farmers in Rwanda on average ranked banana nematodes to be more important than banana weevils. The reverse was true in Burundi with banana weevils being ranked as most important.

Among the cassava pests, most farmers (17% and 74% of the respondents in Rwanda and Burundi, respectively) (Table 4) mentioned the cassava whitefly *Bemisia tabaci* (Gennadius, 1889) as a major constraint followed by the cassava mealybug *Phenacoccus manihoti* Matile-Ferrero (9% and 47% of the respondents in Rwanda and Burundi, respectively). Aphids and the cassava whitefly were ranked as the most devastating pests in Rwanda and Burundi, respectively. The cassava mealybug was both the second most prevalent and important cassava pest in Burundi. In Rwanda, although the cassava whitefly was most prevalent, it was ranked as second most important pest. Only 4% and 23% of the respondents in Rwanda and Burundi mentioned the presence of cassava green mite *Mononychellus tanajoa* Bondar, respectively. In importance, the cassava green mite was ranked fourth in both Rwanda and Burundi.

In potato, cutworms (*Agrotis* spp.) were perceived to be the most prevalent insect pests in Rwanda and Burundi (58% and 56% of the respondents, respectively), followed by potato aphids (39% and 34% of the respondent in Rwanda and Burundi, respectively) (Table 4). In Rwanda, three insect pests (the potato tuber moth *Phthorimaea operculella* [Zeller], the cutworm, and aphids) were ranked equally as the top most severe pests. In Burundi, both the cutworm and whitefly were ranked number one most important insect pests followed by aphids. Cutworm infestations start early in the season (1–4 weeks after sprouting) and cut down the tender plants. The damage is highly visible to the farmers just as the cutworm larvae.

For sweetpotato, farmers in Rwanda reported that the sweetpotato weevil (*Cylas* spp.) was the most prevalent insect pest of sweetpotato (65% of the respondents), followed by the sweetpotato butterfly *Acraea acerata* Hew (54% of the respondents) (Table 4). In Burundi, more farmers (62% of the respondents) reported a higher prevalence of the sweetpotato butterfly in the previous cropping season compared to the sweetpotato weevil (54% of the respondents). More than half of the respondents ranked the sweetpotato butterfly as the most damaging insect pest of sweetpotato. In the second place (in terms of importance) came the sweetpotato weevil in Rwanda and the sweetpotato armyworm in Burundi.

Banana *Xanthomonas* wilt (BXW) was the most prevalent disease in Rwanda and Burundi (59% and 73% of the respondents, respectively) (Table 4). BXW was also ranked as the most important disease of banana in Rwanda and Burundi. In importance, *Fusarium* wilt and Banana bunchy top disease were ranked second in Rwanda and Burundi, respectively.

Cassava mosaic disease (CMD) was the most frequently reported disease of cassava (72% and 88% of the respondents in Rwanda and Burundi, respectively) (Table 4). The second most prevalent disease was Cassava brown streak disease (CBSD) (15% and 57% of the respondents in Rwanda and Burundi, respectively). CMD was also ranked to be the most severe disease both in Rwanda and Burundi. Cassava bacterial blight and CBSD were ranked as the second most important diseases of cassava in Rwanda and Burundi, respectively.

Potato late blight caused by *Phytophthora infestans* (Mont.) de Bary was the most prevalent reported disease (58% and 72% of the respondents in Rwanda and Burundi, respectively) (Table 4). However, bacterial wilt caused by *Ralstonia solanacearum* (Smith 1896) was ranked as the most important potato disease in the two countries. Late blight ranked as the second most important disease in both countries.

Sweetpotato virus disease (SPVD) was the most commonly reported disease in Rwanda and Burundi. Root rots and *Alternaria* leaf and stem blight were ranked to be the most important diseases of sweetpotato in Rwanda and Burundi. In both Rwanda and Burundi, SPVD was ranked as second most important disease. *Alternaria* leaf and stem blight was also reported.

Table 4. Perceived level of importance of major pests and diseases in potato, sweetpotato, banana and cassava in Rwanda and Burundi (2014 survey; n = 810).

	Rwanda		Burundi	
Pests and Diseases	**Households (%) ***	**Perceived Level of Importance (Weighted Average Index)**	**Households (%) ***	**Perceived Level of Importance (Weighted Average Index)**
Banana pests				
Banana weevil (*Cosmopolites sordidus*)	44 (168)	0.59	49 (261)	0.56
Banana nematodes	8 (168)	0.64	19 (246)	0.45
Others	6 (168)	0.43	0 (234)	-
Cassava pests				
Whiteflies (*Bemisia tabaci*)	17 (110)	0.82	74 (316)	0.85
Green mites (*Mononychellus tanajoa)*	4 (110)	0.67	23 (309)	0.36
Mealybugs (*Phenacoccus manihoti)*	9 (109)	0.66	47 (311)	0.78
Aphids	6 (109)	0.89	7 (302)	0.62
Others	30 (109)	0.51	1 (303)	-
Potato pests				
Leafminer fly (*Liriomyza huidobrensis*)	28 (215)	0.55	17 (110)	0.38
Aphid (*Myzus persicae*)	49 (215)	0.69	34 (116)	0.46
Potato tuber moth (*Phthorimaea operculella*)	43 (215)	0.69	31(110)	0.45
Cutworm (*Agrotis* spp.)	58 (215)	0.69	56 (134)	0.57
Whitefly (*Bemisia tabaci*)	23 (215)	0.67	30 (117)	0.57
Ants (*Dorylis orantalis*)	11 (215)	0.43	29 (128)	0.43
Others	29 (215)	0.74	0 (110)	-

Table 4. *Cont.*

Pests and Diseases	Rwanda		Burundi	
	Households (%) *	Perceived Level of Importance (Weighted Average Index)	Households (%) *	Perceived Level of Importance (Weighted Average Index)
Sweetpotato pests				
Sweetpotato weevils (*Cylas* spp.)	65 (280)	0.70	54 (348)	0.57
Sweetpotato butterfly (*Acraea acerata*)	54 (280)	0.80	62 (356)	0.79
Sweetpotato Armyworm (*Spodoptera* spp.)	20 (280)	0.59	57 (348)	0.73
Sweetpotato hornworm (*Agrius convolvuli*)	24 (280)	0.56	44 (351)	0.47
Sweetpotato whitefly (*Bemisia tabaci)*	6 (280)	0.62	26 (347)	0.50
Sweetpotato clearwing (*Synanthedon* spp.)	1 (280)	0.67	1 (342)	0.33
Others	1 (280)	0.50	0 (342)	-
Banana diseases				
Banana *Xanthomonas* wilt (BXW)	59 (191)	0.94	73 (267)	0.93
Fusarium wilt	25 (181)	0.87	46 (251)	0.82
Banana bunchy top disease (BBTD)	5 (172)	0.58	63 (256)	0.87
Black sigatoka	8 (173)	0.76	12 (241)	0.66
Others	10 (175)	0.91	1 (234)	0.50
Cassava diseases				
Cassava mosaic disease (CMD)	72 (134)	0.95	88 (319)	0.91
Cassava brown streak virus disease (CBSD)	15 (114)	0.70	57 (313)	0.86
Cassava bacterial blight (CBB)	11 (116)	0.82	27 (310)	0.81
Others	1 (111)	0.67	20 (306)	0.81
Potato diseases				
Bacterial wilt	6 (230)	0.89	11 (125)	0.90
Late blight	58 (237)	0.87	72 (123)	0.85
Early blight	14 (224)	0.79	24 (115)	0.74
Viral diseases	21 (221)	0.85	9 (111)	0.73
Fusarium dry rot	11 (220)	0.76	23 (116)	0.78
Others	1 (216)	0.67	2 (110)	0.67
Sweetpotato diseases				
Sweetpotato virus disease (SPVD)	33 (288)	0.75	42 (352)	0.80
Alternaria leaf and stem blight	24 (286)	0.76	33 (348)	0.76
Root rots	12 (165)	0.76	77 (35)	0.86
Others	3 (281)	0.76	<1 (343)	1.00

The weighted average index was calculated on basis of perceived scores for importance and it varied from 0.0 (for not a problem) to 1.0 (for most important constraint). * the number in parentheses is the sample size, n. Some percentages may be adding to more than 100% due to rounding off.

3.6. *Perceived Levels of Crop Losses Due to Insect Pests and Diseases*

Perceptions of crop losses due to pests and diseases were on average ranked between 26–37% for sweetpotato in Rwanda and Burundi, respectively (Figure 4). Farmers of banana and sweetpotato in Burundi reported significantly higher crop losses due to pests and diseases (48% for banana and 37% for sweetpotato) than in Rwanda (29% for banana and 26% for sweetpotato). No significant differences were observed in perceived crop losses among cassava (36% in Rwanda and 37% in Burundi) and potato farmers (33% in Rwanda and 38% in Burundi).

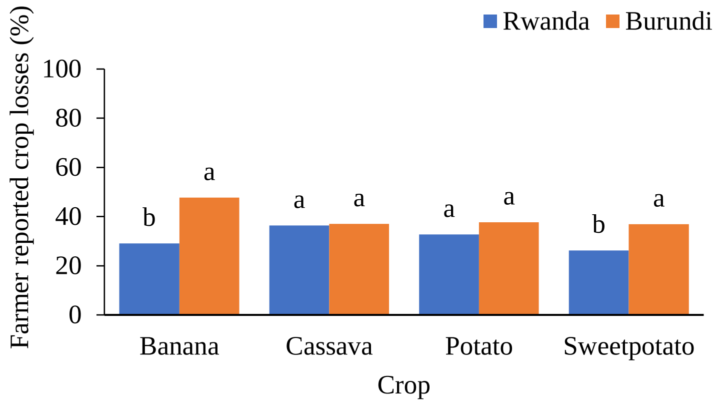

Figure 4. Perceived crop losses (%) due to insect pests and diseases in the 2014 cropping season estimated by farmers. Number of responses for banana, cassava, potato, and sweetpotato were 154, 204, 104, 258 in Rwanda and 208, 94, 260, 279 in Burundi, respectively.

3.7. Contribution of Pests and Diseases to Food Insecurity

Perceived crop losses due to pests and diseases caused varying levels of food insecurity and risk of vulnerability to food insecurity in both countries but mainly in Burundi where 80% of the households reported not getting enough food to feed their families throughout the year. In Rwanda, this was reported by 39% of households. Additionally, almost 90% of households in Burundi blamed pests and diseases for high food prices (Figure 5).

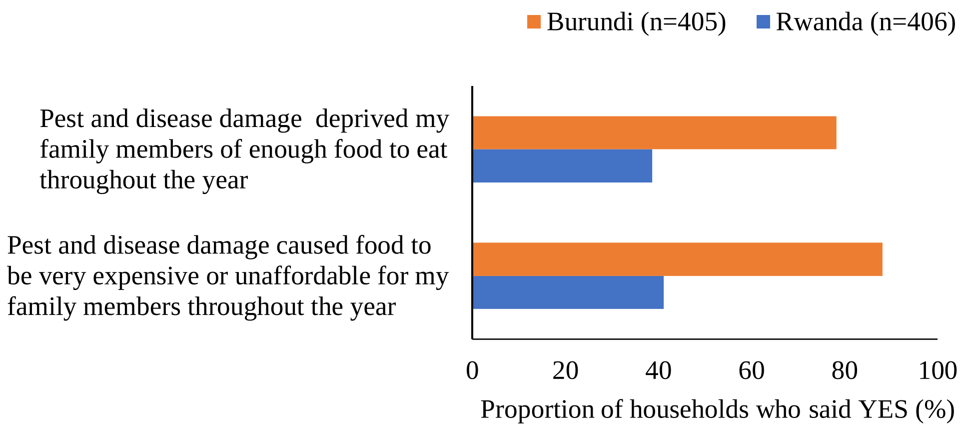

Figure 5. Pest and disease parameters in RTB crops contributing to household food insecurity.

In Rwanda, a significant proportion of households reported to have reduced their potato consumption due to either rotting, staleness or damage by pests and diseases. (Figure 6). Post-harvest losses for sweetpotato, cassava, and banana were 66%, 62%, and 55%, respectively, in Rwanda. In Burundi, the highest number of households who reportedly disposed-off banana, potato, sweetpotato and cassava damaged by pests and diseases were 69%, 29%, 28%, and 22%, respectively (Figure 7). The·other factor that is closely related to severe food insecurity is when farmers could not replant a crop in the subsequent season following serious damage by pests and diseases, reported by 16%, 15%, 12%, and 9% of the banana, cassava, potato, and sweetpotato farmers in Rwanda, respectively (Figure 6).

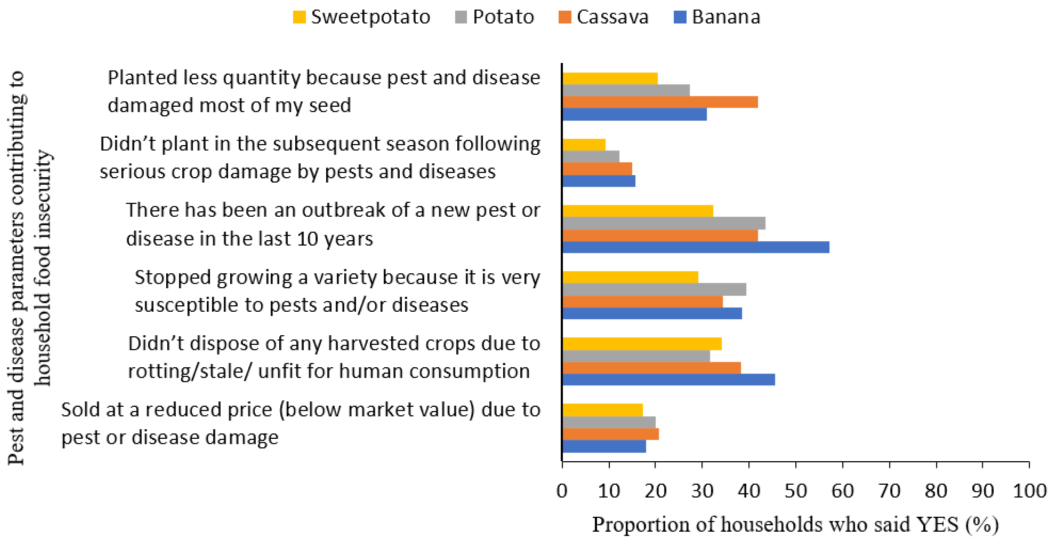

Figure 6. Pest and disease parameters in RTB crops contributing to household food insecurity in Rwanda.

Indicators of moderate food insecurity caused by pests and diseases include factors that compromise food quality and quantity. In our case, pests and diseases caused farmers to not only sell their pest-infested or diseased crops at a reduced price (below market value) but also reduced the amount of food available for intake. Households that sold at below market prices varied from 17% in sweetpotato to 21% for cassava in Rwanda and from 19% in cassava to 25% in potato in Burundi (Figures 6 and 7). Cassava brown streak virus was the main cause for the decline in the quality of cassava, while bacterial wilt was the main cause of post-harvest losses in potato.

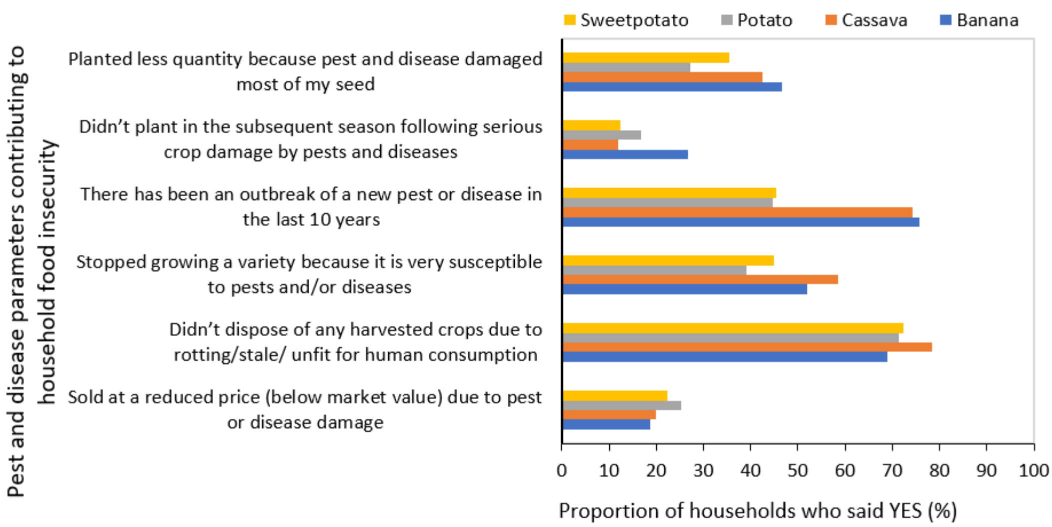

Figure 7. Pest and disease parameters in RTB crops contributing to household food insecurity in Burundi.

The proportions of farmers who had stopped growing a variety of banana, cassava, potato, and sweetpotato because of the high susceptibility to damage by of pests and diseases were 39%, 34%, 39%, and 29% in Rwanda, respectively, and 52%, 59%, 39%, and 45% in Burundi (Figures 6 and 7). The proportion of farmers who abandoned highly susceptible varieties or crops was highest in banana (variety Gisubi/Pisang Awak), probably due to Xanthomonas wilt disease of banana (58%), followed by cassava (52%) (Figure 7). There is a high possibility that households that stopped cultivating a certain crop or variety due to very high susceptibility to pests and diseases could experience some form of marginal food insecurity (worry about running out of food or having a limited selection of food).

Pests and diseases not only increase the risk of—and contribute to—food insecurity, but improper use and handling of pesticides also exposes farmers to health risks due to pesticide poisoning hence reducing the quality of life. Of the four RTB crops, pesticide use was mainly in potato, where 25% and 29% of the farmers in Rwanda and Burundi experienced negative health effects due to pesticide use, respectively [39].

4. Discussion

Agriculture contributes to 32% and >40% of the national gross domestic product (GDP) for Rwanda and Burundi, respectively [40], employs nearly 90% of the rural population of about 9.2 million in Rwanda and 8.9 million in Burundi who depend on it for their livelihoods [3]. The socio-demographics of our sampled population did not differ significantly from national averages. For instance, farming was the main source of income of the sampled population for both men and women across both countries. As elsewhere in Africa, the norm in Rwanda and Burundi is that men are the household heads and women only make decisions when either the man lives in another location, is away, or deceased. The number of female-headed households reported in our study (16%) was lower than the national average of 27%. Mean household size was higher (about six persons) in Burundi than in Rwanda (about five persons). The survey by the World Food Program of the United Nations (WFP) in 2015 [3] also reported the mean household size for Rwanda to be five, as reported in the current study. The years of formal education did not vary significantly between the two countries for men but women in Rwanda were on average more educated than their Burundian counterparts.

A high proportion of farmers who were surveyed in Rwanda grew mainly potato because the surveyed area in Rwanda is in a mid to high-altitude zone above 1500 masl [41]. In Burundi, however, most farmers grew a combination of banana, cassava and sweetpotato because of the low to mid-altitude (800–1800 masl) in the surveyed provinces. Although our study did not capture all the crops grown on the farm by each household, recent survey findings by the National Statistics Institute of Rwanda reported that root and tuber crops continue to be the most commonly grown crops in the country [42]. Results of a national agriculture survey 2008 by NIRS reported that the proportion of households in Rwanda growing banana, cassava, potato and sweetpotato were 26.4%, 49.2%, 42%, and 75%, respectively [42]. No similar information is available for Burundi. The significance of the four RTB crops under study in the livelihoods of smallholder farmers as food security crops in both Rwanda and Burundi cannot be over emphasized.

The current study documented various production constraints faced by farmers of RTB crops. Biotic constraints were some of the most important constraints and these are also responsible for the poor-quality planting material due to seed degeneration. The formal seed sector for RTB crops in SSA is still in its infancy with no certified seed commercially available in Rwanda and Burundi for any of the four crops. The bulkiness of roots and tubers, poor roads and the steep terrain of the two countries could have contributed to the high transport costs reported by farmers in the current study. Recent changes in the amount, onset and cessation of rainfall events, and prolonged dry seasons could be a result of climatic change in this region [43].

The findings of the current household survey suggest the need to effectively communicate proven cultural methods for insect pest and disease management to farmers to reduce the level of infestation and infections and related crop losses. These include strategies such as: single diseased stem removal for BXW; selection of healthy planting material for cassava mosaic disease and SPVD; crop rotation for potato bacterial wilt; and early harvesting for sweetpotato weevil [44,45]. Methods such as the use of pest and disease-free planting material have been shown to increase yields in bananas [46]. Positive selection for disease-free potato plants or plants with high (growth) vigor have shown to increase yields up to 34% [47]. Strategies focusing on resistant varieties have been reported for controlling CMD in Uganda [48], as elsewhere in SSA [49] but the use of healthy planting material has been advocated as the most easily applied control measure for CBSD [50,51]. Control measures for the management of pests and diseases in this region are varied and they include limiting the movement and use of infected planting materials, the use of pest/disease tolerant/resistant varieties such as "Cruza-148 (CIP 720118)" that is tolerant to potato late blight and bacterial wilt [52–55], as well as the routine monitoring/surveillance of the pest and disease distribution, incidence, and severity in farmers' fields by all stakeholders.

Pests and diseases affecting RTB crops. Although information is available on some of the common pests and diseases that occur in these two countries, the severity of each pest or disease as perceived by farmers has not been documented. The severity scores given to each pest and disease by farmers should however be interpreted with care, as a low score does not necessarily mean that the constraint has very little importance. Additionally, pests and diseases which are not microscopic, new in the area, or those that cause highly visible crop damage tend to be more easily emphasized by farmers. This could be seen specifically for banana, which was wiped out in some areas of Rwanda and Burundi due to BXW but was ranked in the current study (2014 survey) to be of little importance in both countries. In areas where BXW is still a problem, the use of the single diseased stem removal method should be promoted to reduce associated crop losses. CBSD has been reported from both Rwanda [56] and Burundi [57], but here as elsewhere, the disease is more prevalent and damaging at lower altitudes [58,59] than at higher elevations. The farmer responses provide a clear confirmation of this point, as CBSD was noted as an important constraint by more Burundian than Rwandese farmers. In potato, pests and disease that mainly affect young plants (for instance cutworms and fusarium wilt) or those that affect seed potato during storage (potato tuber moth) were ranked to be very important compared to those that affect leaves such as the leafminer fly. The sweetpotato butterfly was ranked to be more important than the sweetpotato weevil in both countries probably because the larvae completely defoliate young sweetpotato fields causing an alarm unlike cryptic sweetpotato weevil which feeds mainly on the underground roots. Although weeds are generally known to be very important in production of RTB crops, farmers in the two countries perceived them to be of marginal importance as compared to pests and diseases. This is possibly because farmers tend to not see weeds in the same way as pests or diseases by not considering the hard work invested during weeding. Further, there is seldom anything farmers can do against an outbreak of pests and diseases and, therefore, they are of a more serious concern than weeds.

Perceived crop losses due to pests and diseases. To understand the perceptions of farmers about the magnitude of crop losses caused by pests and diseases, individual interviews are sometimes used especially if crop damage is visible [60–62]. Even with effective control measures, crop losses due to pests have been estimated worldwide to range from 7.9–15.1% for wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), maize (*Zea mays* L.), potato, soybean (*Glycine max* (L.) Merr.) and cotton (*Gossypium hirsutum* (L.) [11]. The magnitude of estimated crop losses due to pests and diseases in the current study seems to be quite realistic and in accordance with scientifically investigated and reported losses (Table 1 and references therein). Yield losses in cassava in experimental plots due to CMD alone vary from 35–72% in East and Central Africa [35]. The relatively high crop losses reported by farmers of RTB crops in the current study could be explained because very little is done to actively control pests and diseases in this region.

It is worth pointing out that the recall method used in the current study during data collection is not without flaws since it relies on how good a person's memory is. This, coupled with practices such as piece-meal harvesting, absence of farm records on actual crop yields, low education, and the fact that farmers have never had a pest- and disease-free (healthy) crop to allow them to compare yields with a disease- or pest-affected crop makes it very difficult to estimate crop losses. However, even for an experienced scientist or practitioner it is difficult to estimate the loss that a pest or disease may have caused as the loss is a combination of different biotic and abiotic factors.

Parameters for pests and diseases in RTB crops contributing to food insecurity of farm households. To increase food and nutritional security in Rwanda and Burundi, there is a need to reduce preand post-harvest losses. The relatively high proportion of households reporting that pests and diseases contributed to some form of food insecurity, especially in Burundi, is probably due to the fact that crop losses caused by pest and disease damage increase the vulnerability to consumption shortfalls. The difference in altitude of the surveyed areas in Rwanda and Burundi could explain why more farmers reported higher crop losses due to pests and diseases in Burundi than in Rwanda. The higher temperatures at low altitudes areas are contributing towards a more favorable environment for pests and diseases to multiply. For instance, surveys conducted during 2016 and 2018 in potato revealed a higher infestation with aphids in Burundi (40–66%) compared to Rwanda (<29%) [63]. This is a strong indicator that climate change and specifically global warming will further aggravate the food security of these two East/Central African countries due to a higher pest abundance [13].

The current study has demonstrated that pests and diseases are a key factor driving food insecurity in Rwanda and Burundi, and that this is likely to be exacerbated by the anticipated effects of climate change. In addition to pests and diseases, other factors which still contribute to food insecurity include years of displacement due to civil war, the prolonged dry seasons of 2014 and 2015, unpredictable rainfall, high levels of poverty, low soil fertility and high unemployment [2,3,64]. Other short-term measures to tackle food insecurity, as well as hidden hunger, especially in a war-affected country like Burundi could involve food stamps or school feeding programs based on nutrient-rich RTB staples such as orange-fleshed sweetpotato or yellow cassava.

5. Conclusions

The study highlighted the importance of pests and diseases of RTB crops, such as potato late blight, cutworms, BXW, banana weevils, cassava mosaic disease, cassava whitefly, sweetpotato virus disease and sweetpotato butterfly, and their devastating effects on the livelihoods of many resource-constrained subsistence farmers.

Among the pest and disease control methods practiced by farmers of RTB crops in the two countries, we didn't see a very active management of pests and diseases similar to crops, such as maize, wheat, rice, soybean or cotton in East and Central Africa probably because the crops under study are all primarily food crops.

A package of interventions is needed to control the impacts of these biotic constraints, and thereby strengthen the food security of these communities. Such interventions would combine the supply of healthy planting material of pest/disease resistant varieties with appropriate cultural control measures. Although affordable and effective control measures are already available for diseases such as BXW, CMD, and late blight of potato, more research still remains to be done in Rwanda and Burundi to develop and adapt comprehensive integrated pest and disease management packages that can tackle all of the major pests and diseases affecting the RTB crops. Understanding farmer perceptions of pest and disease constraints is an important first step towards achieving this goal.

Follow-up studies in farmers' fields and on-farm experiments to collect and measure actual crop losses by pests and diseases is recommended to overcome perception bias by individual farmers.

Supplementary Materials: The following are available (Questionnaire at https://www.mdpi.com/1660-4601/16/3/400/s1, Table 3a,b and Table S4 with raw data of the perceived level of importance used to calculate the weighted average index at http://www.mdpi.com/2071-1050/11/6/1592/s1).

Author Contributions: J.S.O. conceived and designed the study, developed the questionnaire, supervised data collection, analyzed the data, and wrote the manuscript. W.O. wrote the manuscript; A.N. translated the questionnaire into Kinyarwanda and supervised data collection; D.K. translated the questionnaire into French and collected data; N.N. Collected data; G.B. conceived the study and wrote the manuscript; J.P.L. conceived the study and wrote the manuscript; J.K. conceived and designed the study, wrote the manuscript, supervised and approved all stages of the study. All authors read, reviewed, and approved the final manuscript before submission.

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