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Production Characteristics and Strategies for Adapting to the Impacts of Climate Change on Cassava Whiteflies and Viruses in Tanzania

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Abstract

Cassava is Africa's most important food security crop and sustains about 700 million people globally. Survey interviews of 320 farmers in three regions of Tanzania to identify their production characteristics, and interviews with 20 international whitefly/virus experts were conducted to identify adaptation strategies to lessen the impacts of cassava whiteflies and viruses due to climate change in Tanzania. Structured and pre-tested interview schedules were conducted using a multistage sampling technique. Most of the farmers (66.8%) produced cassava primarily for food, and relied mainly on their friends (43.8%) and their farms (41.9%) for cassava planting materials. Farmers significantly differed in their socio-economic and production characteristics except for gender and access to extension support ($P < 0.01$). A significant association was found between extension support, sources of planting materials, and reasons for growing cassava with both the control of cassava viruses and the control of whiteflies by the farmers. A significantly higher number of farmers controlled cassava viruses (38.1%) than cassava whiteflies (19.7%). The adaptation strategies most recommended by experts were integrating pest and disease management programs, phytosanitation, and applying novel vector management techniques. The experts also recommended capacity building through the training of stakeholders, establishing monitoring networks to get updates on cassava pests and disease statuses, incorporating pest and disease adaptation planning into the general agricultural management plans, and developing climate change-pest/disease models for accessing the local and national level impacts that can facilitate more specific adaptation planning in order to enhance the farmers' adaptive capacities.

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Introduction

Cassava is Africa's most important food security crop and sustains about 700 million people globally (FAO, 2013). Pests and diseases are the major constraints to cassava production. The most significant diseases of cassava are the two viral diseases cassava mosaic disease (CMD) and cassava brown streak disease (CBSD). The viruses causing both of these diseases are transmitted by the whitefly vector *Bemisia tabaci* (Gennadius) (Dubern, 1994; Maruthi *et al.*, 2005). The continued expansion of cassava virus pandemics driven by super-abundant populations of *B. tabaci* is considered the greatest threat to cassava production in Africa (Legg *et al.*, 2014a).

Agricultural systems in Africa are among the world's most vulnerable to the impacts of climate change (Niang *et al.*, 2014; Adhikari *et al.*, 2015). Tanzania farmers have been adopting different strategies in response to climate change impacts including diversifying crop production, diversifying to non-farm sectors of the economy, irrigation and water harvesting, applying fertilizer to boost yield, changing planting dates, growing short-season crops, growing drought-resistant crops, planting trees, rotating crops, using improved seeds and new crop varieties, and using mixed cropping systems (Mary & Majule, 2009; Balama *et al.*, 2013; Lyimo *et al.*, 2013; Komba & Muchapondwa, 2018). Research reports have demonstrated that the responses of cassava viruses and their whitefly vector to climate change will vary spatially depending on the prevailing conditions (Bellotti *et al.*, 2012; Jarvis *et al.*, 2012). Gamarra *et al*. (2016), Aregbesola (2018), and Aregbesola *et al.* (2019; 2020) suggested that climate change will lead to an increase in the population growth of *B. tabaci* for regions in East, Central, and Southern Africa. Similarly, Campo *et al.* (2011) identified the African rift valley as a hotspot for cassava pests and diseases (including *B. tabaci*, CMD, and CBSD) considering future climate scenarios. This makes it necessary to plan and implement strategies for adapting to the predicted increased burden of cassava viruses and whiteflies on cassava production caused by climate change.

Strategies for adapting to the impacts of climate change on cassava whiteflies and viruses, and measures needed to enhance the adaptive capacity of farmers to reduce the impacts of cassava whiteflies and viruses due to climate change have not been investigated and remain poorly understood. This study, therefore, aimed at filling these gaps. The objectives of the study were to: evaluate cassava farmers' production characteristics, explore potential adaptation strategies to counter the impacts of cassava whiteflies and viruses due to climate change, and identify relevant measures for enhancing the adaptive capacity of farmers on their farms, at regional or national levels, so that they can respond better to changes in crop damages caused by cassava whiteflies and the viruses that they transmit.

Materials and Methods

Description of the study sites

The study was conducted in Kigoma, Pwani, and Zanzibar regions of Tanzania. From each region, the selected districts were Kakonko, Mkuranga, and Unguja respectively. Agriculture accounts for about 29.1% of the national gross domestic product (GDP), provides 70% of the raw materials used by industries, and 30% of the export earnings of Tanzania (Chongela, 2015). The climate of Tanzania is characterized by a long dry spell from May to October, followed by a period of low rainfall. Tanzania experiences a main rainy season from March to June and a short rainy season from October to December (URT, 2012a). The Kigoma region is located in northwest Tanzania, close to Lake Tanganyika. It is covered by coordinates between 29.5°-31.5° to the East, and 3.5°-6.5° to the South. Unguja is one of the islands of Zanzibar located in the Indian Ocean, around the coordinates 39.4° South - 6.1 East°. Mkuranga is a district in the Pwani Region of Tanzania. It is to the south of Dar es Salaam, and shares its eastern and western borders with the Indian Ocean and Kisarawe District, respectively. It is bordered on the south by Rufiji District (URT, 2012b). The study sites are depicted in **Figure 1**.

Data collection

A methodological triangulation technique was employed in the study (Olsen, 2004). This involved farmer interviews, direct farm observations, expert interviews, follow-up visits, and desk research. The desk research involved the compilation of secondary data through a review of literature on the impacts of climate change on agriculture, the management of cassava pests and diseases, strategies for adapting to the impacts of climate change on pests and diseases, and enhancing the adaptive capacity of farmers to minimize the impacts of climate change.

A semi-structured questionnaire was used to collect information on the socio-economic characteristics of the farmers relating to their age, years of formal education, gender, occupation besides farming, household size, etc. Additional information was also collected on the production characteristics of the farmers including their challenges, reasons for cassava production, sources of cassava planting materials, methods used to control cassava whiteflies and viruses, and use of agricultural extension support.

For the expert survey, the questionnaire intended to collect information on expert opinions on adaptation strategies to reduce the impacts of climate change on cassava virus disease pandemics in Africa and ways to enhance the adaptive capacity of farmers. Climate change adaptation strategies and measures to enhance the adaptive capacity were rated on a 4-point scale with 1 = Not recommended, 2 = Neutral, 3 = Recommended, and 4 = Strongly recommended**.** Questionnaires were pre-tested and updated based on expert advice before the actual survey.

Surveys

Sampling was based on information and expertise on cassava production at the

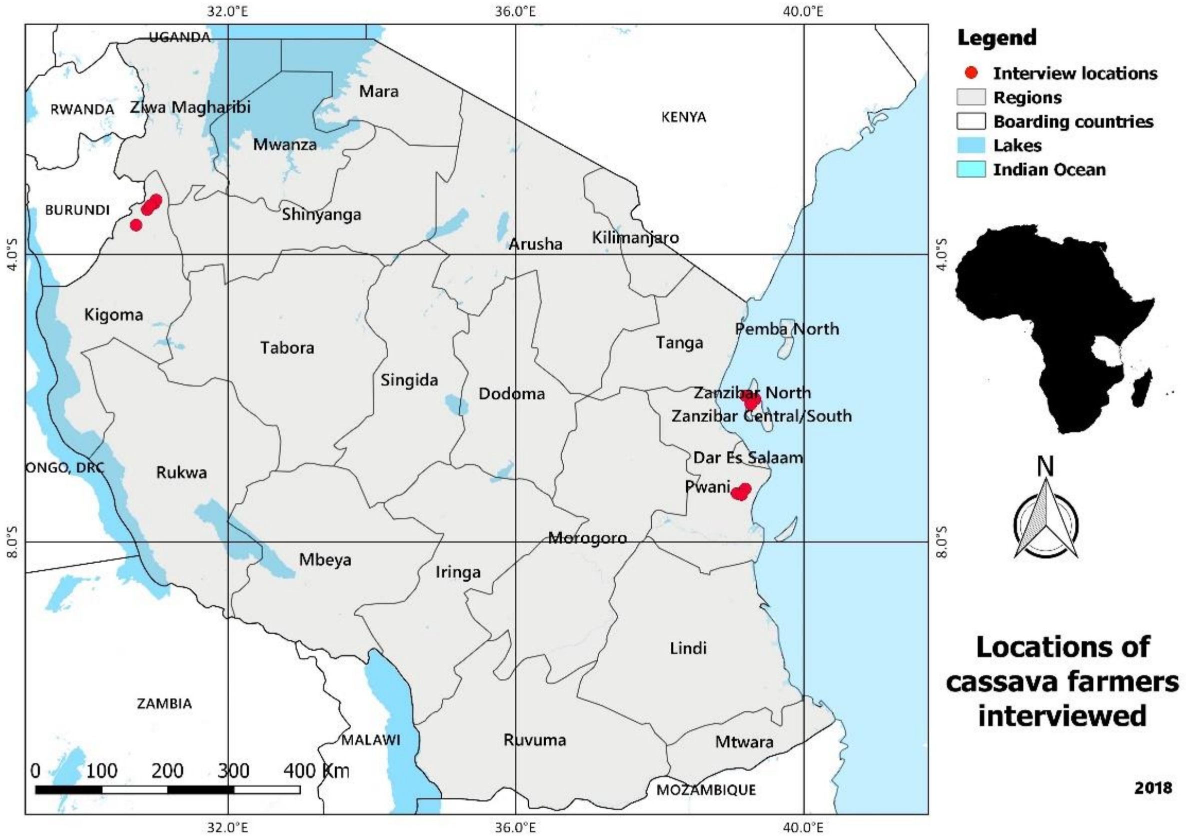

Figure 1. Locations of the farmers interviewed

International Institute of Tropical Agriculture (Tanzania); and a desk review of cassava pest problems in Tanzania (Legg & Raya, 1998; Ndyetabula *et al.*, 2016). A multi-stage sampling procedure with three phases was used in selecting respondents for the study. The first phase involved the selection of three districts from three major cassava growing regions in Tanzania. The selected cassava growing regions were Kigoma, Pwani, and Zanzibar, while the selected districts were Kakonko, Mkuranga, and Unguja located in each region, respectively. The three regions were selected because they are major cassava growing areas and represent different cassava whitefly and virus situations. Villages within each district were subsequently selected using a cluster sampling technique based on cassava production information from the agricultural extension officers in charge of each district. The last sampling stage involved a random household selection from a list maintained by the resident agricultural extension agent in each village. Overall, four villages were chosen from each district, with 25 respondents per village in Kakonko and Unguja, and 30 respondents per village in Mkuranga, making a total of 320 respondents. Out of the 320 questionnaires from the farmers' survey, 318 were suitable for data analysis.

The farmers' survey was conducted in the local language (Swahili) for easy comprehension of the questions. Questionnaires were administered through face-to-face interviews by trained researchers and extension agents. The enumerators were experienced researchers and agricultural extension officers who were very familiar with the respective study areas. Recruitment of researchers and extension officers the farmers were conversant with facilitated effective interactions with the farmers. The services of four enumerators (both men and women) were used in each study area.

Survey interviews of experts were used to investigate the transforming structures and processes that could enhance each farmers' adaptive capacity and also to identify useful adaptation strategies on the farms and at regional or national levels. First, a desk review of research on climate change adaptation, adaptive strategies of farmers to crop pests and adaptation strategies to crop pests was conducted. From the review, key aspects related to enhancing the adaptive capacity to crop pests and diseases, and possible adaptation strategies to the potential impacts of climate change on crop pests and diseases were identified. Based on the desk research, we then developed our question items, which were subjected to further review and scrutiny by experts on the subjects before the final versions of the questionnaires were prepared. The expert survey was conducted as both an e-mailed survey and a paper survey. For the expert survey, a database of publications relating to cassava virus diseases and whiteflies, and climate change plant disease and insect studies was created. From this database, a list of scientists was compiled based on publication records, and electronic copies of the survey were sent to a total of 80 scientists. Due to the relatively low response rate, the number was augmented by administering a printed copy of the survey to selected experts at the 2nd International Whitefly Symposium held in Arusha, Tanzania. In all, 20 questionnaires were processed for further analysis.

Data analysis

Responses from the questionnaires were encoded and analyzed using SPPS® (IBM® SPSS® statistics version 20. Based on the nature of the data, dichotomous variables were analyzed using the binomial exact test, while other categorical variables were analyzed using the chi-square test at $P = 0.05$. The chi-square test was also used to test the association between production characteristics and the control of both whiteflies and cassava viruses. Furthermore, the McNemar test was used to compare the proportion of farmers who controlled cassava viruses to the proportion of farmers who controlled whiteflies. Data on the adaptation strategies and building adaptive capacity were subjected to either the chi-square test or binomial test ($P = 0.05$).

Results

Production characteristics of cassava farmers

The percentage of male cassava farmers interviewed was not significantly higher than females. Cassava farmers surveyed in the three locations had a mean age of 44.7 ± 12.8 (SD) years, though farmers in Unguja tended to be older than farmers in the other locations. The majority of the farmers completed primary education, whereas a good number of respondents from Unguja completed secondary education. Occupations besides farming differed significantly across the respondents (**Table 1**). Overall, almost half of the farmers interviewed had no other occupation apart from farming. Some also engaged in petty trading. Incomes from cassava production and other activities were low. The mean off-farm income per annum for the three locations was USD 442.68 ± 1513.84, while the mean income from cassava production per annum was USD 277.10 ± 446.54. More than 80% of the farmers reported making less than USD 500 per annum from both cassava production and non-farm activities, respectively (**Table 1**).

Farmers in Mkuranga and Unguja tended to be more experienced than farmers in Kakonko. Considering all the locations, the mean number of years in cassava cultivation was 12.6 years. Land areas put into cassava cultivation were small. Over seventy-seven percent (77.4%) of the farmers grew cassava on less than 1ha (**Table 2**). On average, farmers in Kakonko put more land area into cassava cultivation, while the mean land area used for growing cassava was 0.28 ± 0.58ha. Almost all the farmers (98.0%) grew other crops. The highest percentage of farmers that controlled cassava viruses was recorded in Unguja (67.0%), while the least was recorded in Mkuranga (7.1%). Considering all the locations, 38.1% (of 318 farmers) controlled cassava viruses, while only 19.7% of the 318 farmers controlled cassava whiteflies (**Table 2**). No farmer reported controlling cassava whiteflies in Kakonko, while more farmers in Unguja (58.0%) reported controlling cassava whiteflies than Mkuranga (3.5%). The frequencies of farmers who got extension support did not significantly differ from those who did not. **Table 2** shows that more farmers in Unguja received extension support than farmers in other locations. The majority of the respondents got their planting materials from their friends and the previous seasons, and significant differences existed among the sources of planting materials (**Table 2**). Generally, the primary motivation for cassava cultivation was for food. However, farmers in Unguja and Kakonko also showed a higher inclination toward cultivating cassava for-profit compared to farmers in Mkuranga. The reasons for growing cassava differed significantly among the interviewed farmers (**Table 2**).

A significant association was found between extension support, sources of planting materials, and reasons for growing cassava for both the variables of controlling cassava viruses and controlling whiteflies. Furthermore, experience in cassava production, cassava farm size, non-farm income, extension support, and the use of chemicals to control whiteflies were also significantly associated with the control of cassava whiteflies, but not the control of viruses (**Table 3**).

Current cassava whitefly and virus control measures employed by the farmers

Most farmers did not control cassava whiteflies and viruses, although more farmers controlled cassava viruses than whiteflies (**Table 4**). Among the farmers who reported controlling cassava whiteflies and viruses, various approaches were reported. For control of cassava whiteflies, farmers mainly applied farm sanitation and roguing. A few farmers reported using resistant/tolerant/improved varieties to control whiteflies. The categories of whitefly control methods reported by farmers occurred with different probabilities ($P< 0.01$) (**Table 4**). For control of cassava viruses, the farmers used roguing, clean cassava planting materials, and resistant varieties. However, the proportions of farmers who applied these control methods were very low compared to the total number of respondents. Additionally, the farmers did not use chemicals to control cassava whiteflies (**Table 2**). Significant differences occurred in the cassava virus control methods reported by the farmers ($P< 0.01$) (**Table 4**). The frequencies of farmers who controlled cassava whiteflies

Table 1. Socio-economic characteristics of the cassava farmers

Variables (n)	Kakonko (100)	Mkuranga (118)	Unguja (100)	Total (318)	*P*-value
	F (%)	F (%)	F (%)	F (%)	
Gender					0.911
Male	56 (56.0)	76 (65.0)	28 (28.0)	160 (50.5)	
Female	44 (44.0)	41 (35.0)	72 (72.0)	157 (49.5)	
Age (years) [x]	40.42 ± 10.66	45.78 ± 10.49	47.97 ± 10.49	44.8 ± 12.9	< 0.001
20-30	19 (19.0)	26 (22.2)	6 (6.1)	51 (16.1)	
31-40	65 (65.0)	44(37.6)	58 (58.6)	167 (52.8)	
>40	16 (16.0)	47 (40.17)	35 (25.4)	98 (31.1)	
Level of education					< 0.001
No formal education	2 (2.0)	33 (28.0)	29 (29.0)	64 (20.1)	
Primary	88 (88.0)	76 (64.4)	28 (28.0)	192 (60.4)	
Secondary	9 (9.0)	9 (7.6)	41 (41.0)	59 (18.6)	
Tertiary	1 (1.0)	0 (0.0)	2 (2.0)	3 (0.9)	
Occupation besides farming					< 0.001
Petty trade	25 (25.0)	45 (38.5)	39 (39.4)	109 (34.5)	
Retiree	2 (2.0)	1 (0.9)	3 (3.0)	6 (1.9)	
Artisan	12 (12.0)	2 (1.7)	6 (6.1)	20 (6.3)	
Others	6 (6.0)	7 (6.0)	7 (7.1)	20 (6.3)	
Formal employment	0 (0.0)	0 (0.0)	15 (15.2)	15 (4.7)	
None	55 (55.0)	62 (53.0)	29 (29.3)	146 (46.2)	
Non-farm income/year (USD) [x]	159.46 ± 557.95	145.68 ± 289.91	1076.36 ± 2517.09	442.68 ± 1513.84	< 0.001
< 500	92 (92.0)	108 (91.5)	61 (61.0)	261 (82.1)	
500 - <2000	7 (7.0)	10 (8.5)	28 (28.0)	45 (14.1)	
> 2000	1 (1.0)	0 (0.0)	11 (11.0)	12 (3.8)	
Income from cassava/year (USD) [x]	197.26 ± 377.32	289.72 ± 331.35	342.06 ± 596.20	277.10 ± 446.54	< 0.001
< 500	95 (95.0)	103 (87.3)	83 (83.0)	281 (88.4)	
500 - <2000	3 4 (4.0)	14 (11.9)	14 (14.0)	32 (10.0)	
> 2000	1 (1.0)	1 (0.8)	3 (3.0)	5 (1.6)	

Note: n = number of respondents. P-value based on one sample chi-square test except otherwise indicated. [x] means of variables on ratio scale are presented. F represents the frequency of interviewed respondents.

Source: Field survey (2016 and 2017).

Table 2. Production characteristics of the cassava farmers

Variables (n)	Kakonko (100)	Mkuranga (118)	Unguja (100)	Total (318)	*P*-value
	F (%)	F (%)	F (%)	F (%)	
Experience in cassava production (years) X	6.68 ± 6.60	13.97 ± 9.83	17.02 ± 10.70	12.57 ± 10.1	< 0.001
1 - < 5	53 (53.0)	21 (19.8)	10 (10.1)	84 (27.5)	
5 - < 15	32 (32.0)	34 (32.1.8)	31 (31.3)	97 (31.8)	
>15	15 (15.0)	51(48.1)	58 (58.6)	124 (40.7)	
Cassava farm size (ha) X	0.91 ± 0.68	0.77 ± 0.33	0.72 ± 0.50	0.80 ± 0.52	< 0.001
< 1	64 (64.0)	95 (81.2)	84 (86.6)	243 (77.4)	
1 - <4	35 (35.0)	22 (18.8)	13 (13.4)	70 (22.3)	
> 4	1 (1.0)	0 (0.0)	0 (0.0)	1 (0.3)	
Grow other crops (%)					< 0.001a
Yes	100.0 (100)	114 (96.6)	97 (98.0)	311 (98.1)	
No	0 (0.0)	4 (3.4)	2 (2.0)	6 (1.9)	
Control whiteflies (%)					< 0.001a
Yes	0 (0.0)	4 (3.5)	58 (58.0)	62 (19.7)	
No	100.0 (100)	111 (96.5)	42 (42.0)	253 (80.3)	
Control cassava viruses (%)					< 0.001a
Yes	44 (44.0)	8 (7.1)	67 (67.0)	119 (38.1)	
No	56 (56.0)	104 (92.9)	33 (33.0)	193 (61.9)	
Got extension support (%)					0.160a
Yes	38 (38.8)	22 (18.6)	85 (85.0)	145 (45.9)	
No	60 (61.2)	96 (81.4)	15 (15.0)	171 (54.1)	
Used chemicals to control whiteflies (%)					< 0.001a
Yes	0 (0.0)	1 (0.8)	1 (1.0)	2 (0.6)	
No	100.0 (100)	117 (99.2)	99 (99.0)	316 (99.4)	
Sources of planting materials#					< 0.001
Friends	60 (56.6)	49 (41.9)	53 (36.1)	162 (43.8)	
Previous own crop	42 (39.6)	65 (55.6)	48 (32.7)	155 (41.9)	
Extension service	0 (0.0)	0 (0.0)	7 (4.8)	7 (1.9)	
Research institute	4 (3.8)	0 (0.0)	38 (25.9)	42 (11.4)	
Market	0 (0.0)	3 (2.6)	1 (0.7)	4 (1.1)	
Motivation for growing cassava#					< 0.001
Food	52 (47.7)	77 (85.6)	88 (71.0)	217 (67.2)	
Profit	57 (52.3)	13 (14.4)	34 (27.4)	104 (32.2)	
Leisure	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	
Interest	0 (0.0)	0 (0.0)	2 (1.6)	2 (0.6)	
No choice	0(0.0)	2 (2.2)	0 (0.0)	2 (0.6)	

Notes: n= number of respondents.P-value based on one sample chi-square test except otherwise indicated. a – P-values based on one sample binomial test. X means of variables on a ratio scale are presented. # multiple responses possible. F represents the frequency of interviewed respondents. Source: Field survey (2016 and 2017).

Table 3. Association between production characteristics and control of cassava viruses and whiteflies

Production Characteristics	Cassava viruses			Cassava whiteflies		
	Chi-Square	d.f	*P*-value	Chi-Square	d.f	*P*-value
Experience in cassava production (years)	30.121	31	0.511	54.957	31	0.005
Size of cassava farm (ha)	30.717	18	0.031	34.722	18	0.010
Income from cassava production (USD)	80.535	85	0.617	77.918	85	0.694
Non-farm income (USD)	48.863	41	0.186	95.987	41	< 0.001
Produce other crops apart from cassava (%)	2.089	1	0.148	0.713	1	0.399
Received extension advice (%)	84.473	1	<0.001	40.903	1	< 0.001
Use chemicals to control whiteflies (%)	0.120	1	0.729	8.213	1	0.004
Sources of planting materials	47.174	8	<0.001	76.482	8	< 0.001
Reasons for growing cassava	41.194	3	<0.001	36.981	3	< 0.001

Note: n= 318, P-value based on chi-square test.
Source: Field survey (2016 and 2017).

Table 4. Whitefly and virus control methods reported by the farmers

Whitefly control practices	F (%)	Virus control practices	F (%)
Farm sanitation including weeding	23 (7.3)	Early planting	1 (0.3)
Improved varieties	3 (0.9)	Planting clean seeds	24 (7.5)
Resistant varieties	3 (0.9)	Improved varieties	3 (0.9)
Tolerant varieties	2 (0.6)	Resistant varieties	16 (5.0)
Roguing	11 (3.5)	Roguing	46 (14.5)
Using ash	1 (0.3)	Using ash	1 (0.3)
No response	5 (1.6)	Weeding	1 (0.3)
No control	270 (84.9)	No response	8 (2.5)
		No control	218 (68.6)
P-value	<0.001	*P*-value	< 0.001

Note: n= 318, P-value based on one sample chi-square test. F represents the frequency of interviewed respondents.

Table 5. Comparison of farmers who controlled cassava whiteflies and viruses across all locations

Variables	Kakonko	Mkuranga	Unguja	Total	*P*-value
	F (%)	F (%)	F (%)	F (%)	
Control whiteflies (%)	0 (0.0)	4 (3.5)	58 (58.0)	62 (19.7)	< 0.001
Control cassava viruses (%)	44 (44.0)	8 (7.1)	67 (67.0)	119 (38.1)	

*Note: P-value based on the McNemar test * significant at P = 0.05. F represents the frequency of interviewed respondents. Source: Field survey (2016 and 2017).*

differed significantly from the farmers who did not control cassava whiteflies (*P*< 0.01) (**Table 5**).

A qualitative evaluation of the socio-economic and production characteristics of the farmers showed that some of the problems recorded in the study areas could influence their adaption to the impacts of climate change on cassava whiteflies and viruses.

Description of experts

The majority (95.0%) of the cassava pest and disease experts surveyed were male, and their most common disciplines were entomology and plant virology (30.0%). Furthermore, they had an

Table 6. Distribution of the cassava pest and disease experts by selected professional characteristics

Variables	Frequency	Percentages	Mean
Sex			
Male	19	95.0	
Female	1	5.0	
Specialization			
Entomology	7	35.0	
Plant breeding	2	10.0	
Plant molecular biology	1	5.0	
Plant virology	6	30.0	
Vector entomology	4	20.0	
Years of experience as an expert			
Below 10	5	25.0	
11-20	8	40.0	19.1 ± 9.4
Above 20	7	35.0	
Scientific meetings on cassava and climate change attended			
Below 5	18	90.0	
6-10	2	10.0	3.3 ± 2.5
Membership of professional bodies			
Below 5	17	85.0	
6-10	3	15.0	2.4 ± 1.9

Note: n = 20. Source: Field survey (2016 and 2017)

average of 19.1 ± 9.4 years of experience as experts in their various fields (**Table 6**).

Adaptive strategies and enhancing the adaptive capacity to reduce the impacts of cassava whiteflies and viruses due to climate change

The results showed that integrating pest and disease management programs ranked the highest as a proposed adaptive strategy to control cassava pests and diseases, followed by phytosanitation and applying novel vector management techniques, while increasing off-farm income was ranked lowest (**Table 7**).

Experts were unanimous in their recommendation of capacity building through training of stakeholders, establishing monitoring networks, and incorporating pest and disease adaptation planning into agricultural management plans, as a majority of them strongly recommended these approaches for building the adaptive capacity of farmers to decreasing the potential impacts of cassava pests and diseases due to climate change (**Table 8**).

Discussion

Production characteristics

Our results suggested that the farmers have diversified cropping systems that could make them resilient to the impacts of cassava whiteflies and viruses due to climate change, which support previous reports from Tanzania and other African countries (Oleke *et al.*, 2011; Makate *et al.*, 2016; Kissoly *et al.*, 2018). Access to agricultural extension services was relatively low in two (Mkuranga and Kakonko) of the three study locations. This agrees with the reports for Dodoma and Unguja (Tanzania) by Anderson (2017) and URT (2012a), respectively. Increasing access of African farmers to agricultural information through mobile phone services is likely to augment the work of extension in the years ahead, and the use of mobile phones for the exchange of agricultural

Table 7. Distribution of experts by adaptation strategies to cassava whitefly and viruses

Adaptation strategies	NR F (%)	Neutral F (%)	R F (%)	SR F (%)	Mean	*P*–value
Integrating pest and disease management programs	0 (0.0)	0 (0.0)	7 (35.0)	13 (65.0)	3.65	0.263‡
Phytosanitation	1 (5.0)	2 (10.0)	6 (30.0)	11 (55.0)	3.35	0.006
Controlling whiteflies and viruses with resistant varieties	1 (5.0)	0 (0.0)	10 (50.0)	9 (45.0)	3.35	0.026
Controlling whiteflies with biocontrol	0 (0.0)	1 (5.0)	11 (55.0)	8 (40.0)	3.35	0.019
Diversifying crop production	0 (0.0)	3 (15.0)	9 (45.0)	8 (40.0)	3.25	0.212
Applying novel vector management techniques	1 (5.0)	3 (15.0)	11 (55.0)	5 (25.0)	3.00	0.011
Adjusting planting dates	2 (10.0)	5 (25.0)	13 (65.0)	0 (0.0)	2.55	0.008
Controlling whiteflies with chemicals	9 (45.0)	6 (30.0)	5 (25.0)	0 (0.0)	1.80	0.522
Shifting from cassava to other crops	13 (65.0)	6 (30.0)	1 (5.0)	0 (0.0)	1.40	0.004

Note: n = 20. NR – Not Recommended, R – Recommended, SR – Strongly Recommended. ‡P-value based on one sample binomial test, all other P-values are based on one sample chi-square test. F represents the frequency of interviewed respondents.
Source: Field survey (2016 and 2017).

Table 8. Distribution of respondents by measures to enhance adaptive capacity

Measures to enhance adaptive capacity	NR F (%)	Neutral F (%)	R F (%)	SR F (%)	Mean	*P*-value
Capacity building through training of stakeholders from farms to the regional levels	0 (0.0)	0 (0.0)	6 (30.0)	14 (70.0)	3.70	0.115‡
Establish monitoring networks (through coordinated national and international surveillance and monitoring programs to get updates on new developments)	0 (0.0)	0 (0.0)	8 (40.0)	12 (60.0)	3.60	0.503‡
Incorporating pest and disease adaptation planning into the general agricultural management plans at both national and regional levels	0 (0.0)	0 (0.0)	8 (40.0)	12 (60.0)	3.60	0.503‡
Development of climate change-pest/disease models for accessing local and national level impact that can facilitate more specific adaptation planning	0 (0.0)	1 (5.0)	12 (60.0)	7 (35.0)	3.30	0.011
Assess adaptation needs (including technological needs) through stakeholder (farmers, research community, and governments)	1 (5)	2 (10.0)	10 (50.0)	7 (35.0)	3.20	0.157
Enforcing quarantine and regulations	1 (5.0)	2 (10.0)	10 (50.0)	7 (35.0)	3.15	0.013
Improve access to credit and insurance (to make improved and clean planting material affordable)	2 (10.0)	3 (15.0)	12 (60.0)	3 (15.0)	2.80	0.004

Notes: n = 20. NR – Not Recommended, R – Recommended, SR – Strongly Recommended. ‡P-value based on one sample binomial test, all other P-values are based on one sample chi-square test. F represents the frequency of interviewed respondents. Source: Field survey (2016 and 2017).

information is increasing in Africa (Krone *et al.*, 2014; Asa & Uwem, 2017). Osei *et al.* (2009) and Houngue *et al*. (2018) observed that the primary sources of planting materials used for cassava cultivation by smallholder farmers were neighbors and their own farms, which agrees with our report from Tanzania. Oyekanmi & Okeleye (2007) also reported food and economic benefits as the major reasons for cassava production in Nigeria.

An important finding about cassava pest and disease management among the interviewed farmers was that the majority of them controlled neither cassava whiteflies nor viruses. Consistent with these findings, a recent report from the Republic of Benin suggested that farmers do not control CMD even when CMD is observed in their fields (Houngue *et al.,* 2018). This might be related to the small-scale and low input cropping systems employed for cassava production in most cassava-growing areas in sub-Saharan Africa (SSA). For the control of cassava viruses, the planting of clean stem cuttings and the use of resistant varieties are among the best control options (Legg & Fauquet, 2004; Legg *et al.*, 2015), and our study indicated that many farmers that control cassava viruses depend on these methods.

This study also showed that several factors are associated with whether a farmer controls cassava whiteflies and viruses, which agree with findings from other crop production systems (Omolehin *et al.*, 2007; Uwagboe *et al.*, 2012). Among these factors, access to extension services, the reasons for cassava production, and the sources of planting materials were significantly associated with the control of both whiteflies and viruses. This suggests that they are important factors that could explain whether a farmer controls cassava whiteflies and viruses, and should be given attention in cassava whitefly and virus management programs.

Adaptation strategies

From this study, the important among relevant climate change adaptation strategies were integrating cassava pest and disease management programs, the use of resistant varieties, phytosanitation, the use of novel whitefly management techniques, biological control of whiteflies, and diversifying crop production. Similarly, these strategies were also recommended for climate change adaptation by Howden *et al.* (2007) (integrated pest management (IPM), resistant varieties, phytosanitation and quarantine, and diversifying crop production), Jones (2009) (IPM), Ceballos *et al.* (2011) (IPM, the use of resistant varieties, and biological control), Juroszek & von Tiedemann (2011) (IPM, disease-resistant varieties, phytosanitation and quarantine, and diversifying crop production), Ghini *et al.* (2012) (disease-resistant varieties and the introduction of new control methods), Fahim *et al.* (2013) (IPM, disease and pest-resistant varieties, and the introduction of biological control organism), Kroschel *et al.* (2014) (IPM, disease and pest-resistant varieties, phytosanitation and quarantine, the introduction of biological control organisms, and the introduction of new control methods) and Salaudeen *et al.* (2016) (IPM, virus-resistant varieties, and biological controls of the virus vectors).

Interestingly, a majority of these strategies have been deployed for the management of cassava pests in Africa (Neuenschwander *et al.*, 2003; Legg & Fauquet, 2004; Anderson & Morales, 2005; Legg *et al.*, 2006; IITA, 2012; Omongo *et al.*, 2012; Fahim *et al.*, 2013; Kroschel *et al.*, 2014; Salaudeen *et al.*, 2016; Legg *et al.*, 2017; Legg *et al.*, 2015, 2017; IITA, 2017). To maximize the opportunities for climate change adaptation, all barriers associated with the accessibility, availability, and adoption of these methods have to be addressed. This will involve increasing access to virus-free planting materials, increasing the use of virus and whitefly-resistant cassava planting materials, encouraging phytosanitation, and the use of available commercial whitefly biocontrol agents (which appear to be the most feasible strategies at the farm level). In the past, farmers have been supported in the deployment of IPM for the management of cassava pests (Neuenschwander *et al.*, 2003; Anderson & Morales, 2005; Legg *et al.*, 2017). Additionally, regional or national initiatives on augmentative biological control and IPM programs for the control of cassava pests have been implemented (Anderson & Morales, 2005). Encouraging these initiatives for climate change adaptation will be a further step in sustaining cassava production in the future.

Measures to enhance adaptive capacity

Considering the limited control of cassava whiteflies and the viruses they transmit, as shown in the study, more efforts and resources must be committed to enhancing the adaptive capacity of the farmers to decrease the possible impacts of cassava whiteflies and viruses due to climate change. Capacity building through the training of stakeholders, incorporating pest and disease adaptation planning into general agricultural management plans, establishing monitoring networks, and assessing adaptation needs through stakeholders emerged as the principal measures that can be deployed to enhance the adaptive capacity of smallholder farmers to lessen the impacts of cassava whiteflies and the viruses they vector due to climate change. These results are consistent with the findings and recommendations of other researchers (Smit *et al.*, 2001; Brooks & Adger, 2005; Howden *et al.*, 2007; Lobell *et al.*, 2008; Ingram, 2014; Kalaris *et al.*, 2014; Legg *et al.*, 2014b; Abdul-Razak & Kruse, 2017; Osumanu *et al.*, 2017; Macfadyen *et al.*, 2018).

For instance, Abdul-Razak & Kruse (2017) and Osumanu *et al.* (2017) from Ghana, emphasized the importance of training farmers and stakeholders in enhancing their adaptive capacities. Legg *et al.* (2014b) and Ingram (2014) suggested that training stakeholders will significantly contribute to reducing pest pressures and enhance the adaptive capacity of the farmers to limit the impacts of climate change. In highlighting the importance of pest surveillance and monitoring inenhancing climate change adaptation, Macfadyen *et al.* (2018) suggested that surveillance can guide the deployment and timing of pest control and also contribute to climate change adaption, while Kroshel *et al.* (2014) recommended establishing pest surveillance and regional networks on pest risks due to climate change. Monitoring cassava whiteflies and viruses is necessary for tracking changes at the regional and national levels, as well as estimating the success of regional pest management initiatives implemented to adapt to climate change. Surveillance programs can also facilitate the early detection and eradication of cassava viruses or *B. tabaci* species if they move into territories in which they were previously absent. Furthermore, Kalaris *et al.* (2014) argued that surveillance data may provide the basis for evaluating cost-benefit and management decisions. As shown in our findings, Macfadyen *et al.* (2018), Ingram (2014), Kroschel *et al.* (2012), and Kroschel *et al.* (2014) emphasized the importance of developing the capacity for pest risk forecasting in adapting to the impacts of climate change on crop pests and diseases.

Similar to our findings, Smit *et al.* (2001), Howden *et al.* (2007), Lobell *et al.* (2008), and Kroschel *et al.* (2014) also recommended building adaptive capacity through the incorporation of climate change adaptations (and in this case pest risk management due to climate change) into country climate resilience and the sustainable development plans. Smit *et al.* (2001) and Brooks & Adger (2005) suggested that the assessment and prioritization of local adaptation needs and the provision of feedback to higher levels of government will enhance the adaptive capacity at the local scale.

Conclusions

In this study, we identified the production characteristics of smallholder cassava farmers and related it to adaptations to decrease the impacts of cassava whiteflies and viruses due to climate change. We then used expert judgments to identify adaptation strategies that might be deployed, measures to enhance the adaptive capacity of the farmers to lessen the impacts of cassava whiteflies and the viruses they transmit due to climate change. Based on the study, we concluded that the respondents were low-income, small-scale farmers operating low-input but diversified cropping systems with limited deployment of control measures against cassava whiteflies and viruses. Food and economic security were their primary reasons for cassava production. In addition, several aspects of the farmers' production characteristics make them vulnerable to the impacts of cassava whiteflies and viruses due to climate change. Increased usage, modification, or intensification of existing cassava whitefly and virus management options, and deploying new methods when necessary will be important for adapting to the impacts of climate change on cassava whiteflies and viruses. Enhancing the adaptive capacity of the cassava farmers to the impacts of climate change on cassava whiteflies and viruses will require improving access to and the use of information, resources, technologies; engaging stakeholders, and putting up needed institutional and governmental support. The necessary strategies and technologies are already in place in Tanzania and other agro-ecologies across Africa. The challenge will be encouraging improved adoption of these strategies, tackling identified bottlenecks, and providing the needed resources, and institutional and governmental support. The results of this study will help farmers, governments, and institutional stakeholders in climate change adaptation planning and developing robust cassava pest management programs that will be useful for the management of the pests under current and future climate change scenarios. We recommend an appropriate level of commitment and investment geared at increasing access to resources (resistant planting materials, virus-free planting materials, biological control products, and extension services) and information as this will be a key to a more sustainable and food secure future.

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