average ratio of vector transmission to planting SPVD infected materials of 5.53 in study areas (data not reported in table) (Table 4). Okonya et al. (2014) in their study of farmers' knowledge and perceptions of potato pests and their management in Uganda also reported limited knowledge among farmers. Our finding confirmed that most farmers were not knowledgeable about SPVD transmission by disease vectors as previously reported Okonya et al., 2014 and Wokorach et al., 2018 and therefore could not relate the presence of the vectors to SPVD or yield loss. Elsewhere in Democratic Republic of Congo, Munyuli et al. (2017) observed a positive relationship between population density of aphid and altitude above 1500 m. Though not the focus of this study, respondents were also knowledgeable about sweetpotato pests especially weevils (50% of the response) and butterflies (39% of the response). Other pests of minor importance included SPVD Sweet potato army worms and Millipedes (data not provided in the table).

When asked which months farmers experience SPVD in their fields, majority of the respondents said they majorly experienced SPVD during the months of January (16.3%), June (16.3%) and April (14%) (Table 4). The disease appears to prevail during first half of the year (January to June), then it diminishes starting the month of July. In all the cases, disease prevalence appeared to be high in western region during the months of January and June, central was high in June (24%) and July (20%) whereas eastern had high concentration of disease occurrence between January and May. It is clearly evident from the months reported by the farmers that SPVD occurs during the first season of the cropping seasons. This is an indication that the environmental conditions for first season is not suitable for sweet potato cultivation since it favours disease development in the host plants (Elizamar Ciriaco et al., 2013). In well studied crops like tobacco and Arabidopsis, defence responses to viral elicitors are compromised at high temperatures, allowing increased growth of these pathogens (Pandey et al., 2017; Wang et al., 2009). Whiteflies have been reported to have optimal development within temperature range of 13.9 to 33.4 °C, with a maximum finite rate of 31 population increase at 26.4 °C (Sporleder et al., 2022). These temperatures predominantly occur in Uganda. With the current climate change, rainfall patterns in Uganda have become unpredictable with more prolonged drought (Akongo, 2022), therefore farmers are more likely to experience SPVD throughout crop growth cycle. Additionally, with presence of host plants, abiotic stress conditions like drought and temperature do influence the incidence of vector-borne pathogens by altering population development and spread of vectors (Pandey et al., 2017; Wang et al., 2009).

Table 4. Knowledge of farmers on major sweet potato diseases, vectors and months of occurrence of SPVD by region of the country

	Central		Eastern		Western		Total	
	Freq.	**%age**	**Freq.**	**%age**	**Freq.**	**%age**	**Freq.**	**%age**
Sweet potato diseases								
SPVD	21	72.4	11	52.4	10	62.5	42	63.6
Alternaria blight	8	27.6	10	47.6	2	12.5	20	30.3
Unknown	0	0.0	0	0.0	4	25	4	6.1
Total	*29*	*100*	*21*	*100*	*16*	*100*	*66*	*100*
Experienced SPVD in own field								
Yes	23	69.7	24	80	20	62.5	67	70.5
No	10	30.3	6	20	12	37.5	28	29.5
Total	*33*	*100*	*30*	*100*	*32*	*100*	*95*	*100*
Knowledge of SPVD								
Yes	23	69.7	14	46.7	12	37.5	49	51.6
No	10	30.3	16	53.3	20	62.5	46	48.4
Total	*33*	*100*	*30*	*100*	*32*	*100*	*95*	*100*
Knowledge of SPVD vector								
Aphids	4	33.3	9	69.2	4	36.4	17	17.9
Whitefly	5	41.7	4	30.8	5	45.5	14	14.7
Didn't know	3	25.0	0	0.0	2	18.2	64	67.4
Total	*12*	*100*	*13*	*100*	*11*	*100*	*95*	*100*
Month of occurrence								
January	3	12.0	6	14.3	5	26.3	14	16.3
February	0	0.0	7	16.7	3	15.8	10	11.6
March	0	0.0	5	11.9	0	0.0	5	5.8
April	2	8.0	7	16.7	3	15.8	12	14.0
May	4	16.0	6	14.3	0	0.0	10	11.6
June	6	24.0	4	9.5	4	21.1	14	16.3
July	5	20.0	1	2.4	3	15.8	9	10.5
August	1	4.0	0	0.0	0	0.0	1	1.2
October	1	4.0	0	0.0	0	0.0	1	1.2
November	2	8.0	2	4.8	0	0.0	4	4.7
December	1	4.0	4	9.5	1	5.3	6	7.0
Total	*25*	*100*	*42*	*100*		*100*	*86*	*100*

3.2.2 Knowledge of SPVD Management Practices

Across all the study regions, majority of farmers (68.4%) were not using SPVD management practices as a result of limited knowledge on both disease identification and management methods (Table 5). A few (31.6%) who applied management method were limited to non-chemical control (phytosanitation, plant healthy cuttings and rouging). Nonetheless, proportion of farmers reported in our study using non-chemical method was more than 15.2% of farmers reported in Munyuli et al. (2017) who also used similar methods. Planting healthy-looking planting materials was the most common method applied by 15.8% of the farmers interviewed. Eastern region accounted for 26.7% for farmers planting healthy cuttings, central (15.2%) whereas, western region less practiced (6.3%) confirming a study by Aritua et al. (2007). Selection of clean planting materials by farmers is based on visual judgement which may be ineffective because not all healthy-looking vines are virus-free. SPVD symptoms are obvious in only susceptible varieties but more tolerant varieties may develop no or mild symptoms after infection with viruses. This negatively affects the selection of virus free planting materials visually leading to presence of infections from planting material as observed in the study. Other cultural management methods mentioned were rogueing (9.5%) of the farmers, with higher practiced reported in Eastern region (16.7%) but Central region practiced rogueing less (3%). Rogueing of symptomatic plants eliminates sources of virus inoculum for transmission, but this practice may instead spread SPVD than effective control it as those plants

can sprout again because farmers usually throw rogued plants at the side of the field. Such practice is due to lack of knowledge among farmers on the spreading mechanisms of the disease. It is therefore important that sweet potato farmers are trained on the different phytosanitation measures to enhance control of SPVD in their fields.

There were also cases of farmers who reported use of combination of strategies such as rogueing infected plants/planting healthy cuttings which accounted for 4.2% of the practices used. However, this was majorly done in Central region (9.1%) and Western to some extent (3.1%). Other control strategies less practiced were destroying diseased volunteer and host plants (1.1%) and follow good sanitation practices/phytosanitation (1.1%).

Table 5. Farmers' knowledge of SPVD management practices

	Central		Eastern		Western		Total	
	Freq.	**%age**	**Freq.**	**%age**	**Freq.**	**%age**	**Freq.**	**%age**
Management methods								
Didn't use any method	23	69.7	16	53.3	26	81.3	65	68.4
Good sanitation practices (phytosanitation)	0	0	1	3.3	0	0	1	1.1
Plant healthy cuttings	5	15.2	8	26.7	2	6.3	15	15.8
Rouging infected plants	2	6	5	16.7	3	9.4	10	10.6
Rogue infected plants/Plant healthy cutting	3	9.1	0	0	1	3.1	4	4.2
Total	*33*	*100*	*30*	*100*	*32*	*100*	*95*	*100*
Knowledge concern								
Management methods for SPVD	25	89.2	37	90.3	29	78.3	91	85.8
Causes of pests and diseases	2	7.2	3	7.3	6	16.2	11	10.2
Others	1	3.6	4	9.7	5	13.5	10	9.4
Total	*28*	*100*	*41*	*100*	*37*	*100*	*106*	*100*

Generally, knowledge gaps existed on control and management strategies for SPVD and its vectors as indicted by limited management options at farmers' disposal. The most important knowledge concern raised was about management strategies for pests and diseases generally which accounted for 85.8% of the concerns (Table 5). Specifically, they needed information and trainings on control measures such as: chemicals; crop varieties of high yield, disease resistant and drought tolerant. Information and trainings on causes of sweet potato diseases constituted 10.2% of farmers' response registered during the study. Specifically, farmers wanted to know what causes rotting of sweet potato vines; weevils in sweet potato; shrinking of tuber and fibrous; yellowing of sweet potato vines; and high prevalence of pests and diseases during dry season. Although farmers were concern about pests and diseases in sweet potato, they also had other knowledge concerns which accounted for 9.5%. Among others were benefits or outcome of this study; low yields of sweet potato even when healthy vines are planted; need for irrigation and production constraints in other crops like maize and banana crops.

3.3 Relationship Between Farmers' Coping Strategies to Control SPVD and Their Knowledge

The results of analysis through binary probit regression model are reported and interpreted as marginal effects. The results are based on priori assumptions that farmers' decision to use coping strategies to control SPVD is closely related with knowledge-based factors. Seven variables were statistically significant except an interaction between knowledge of SPVD and experience in sweet potato farming. Variables including knowledge in SPVD identification; knowledge of months of SPVD occurrence; an interaction between formal education and knowledge on months of occurrence; and an interaction between acreage under sweet potato and experience registered positive relations. The rest of the variables depicted negative relationship with response variable.

The result generated for effects of knowledge of SPVD on coping strategies to control SPVD was positive as expected. Accordingly, the likelihood of a farmer using coping strategies to control SPVD increases by 38.7% above farmers with knowledge limitation. This is driven by the fact that knowledgeable farmers are motivated to take proactive action upon suspecting a disease incidence in their fields. Similarly, a positive relationship was observed between knowledge of months of SPVD occurrence and coping strategies. According to the marginal effects, decision to use management methods improves by 40.4% for knowledgeable farmers above their counterparts. This is because farmers can predict period of disease occurrence and plan coping strategies accordingly. However, interaction effect of knowledge in SPVD and months of occurrences does not necessarily

translate into a farmer using coping strategies to control SPVD. As such, chances of a farmer using coping strategies to control SPVD reduces by 41.1% below farmers without knowledge in both SPVD and month of occurrence. Our result contradicts priori expectation that combined knowledge in SPVD and period of occurrence is a good decision-making tool and hence promotes adoption of management methods. Nonetheless, likelihood increases (24.1%) for interaction between ability to identify month of disease occurrence and higher education level of the farmer. This result confirms recommendation by (Echodu et al., 2019) that attainment of formal education increase literacy levels and increase awareness and access to information of the farmers.

Table 6. Relationship between farmers' knowledge and coping strategies to control SPVD

Variable	dy/dx	Std.Error	z	P > z	[95% C.I.]		Coef.
$\beta_1 idenD_i$	0.3869	0.1052	3.68	0.000	0.1807	0.5931	1.5351
$\beta_2 idenM_i$	0.4044	0.0874	4.63	0.000	0.2331	0.5757	1.5385
$\beta_3 Exp_i$	-0.0152	0.0055	-2.79	0.005	-0.0259	-0.0045	-0.0581
$\beta_4 Acre_i$	-0.0863	0.0277	-3.11	0.002	-0.1406	-0.0320	-0.3295
$\beta_5 idenMEduc_i$	0.2408	0.0890	2.71	0.007	0.0663	0.4153	0.9199
$\beta_6 idenDM_i$	-0.4110	0.1309	-3.14	0.002	-0.6675	-0.1545	-1.5698
$\beta_7 AcreExp_i$	0.0058	0.0016	3.68	0.000	0.0027	0.0089	0.0223
$\beta_8 idenExp_i$	-0.0076	0.0060	-1.26	0.207	-0.0195	0.0042	-0.0291

Experience in sweet potato farming exhibited negative relationship with using coping strategies to control SPVD. A reduction in probability of a farmer using management practices by 1.5% was observed. This scenario was unexpected but the outcome could be a result of absence of SPVD in fields owned by more experienced farmers since they are more observant and tend to apply good crop agronomy and plant protection strategies. Ideally, experience assumes a range of knowledge that allows farmers to use good production practices for high returns and sustainable production. Similarly, interaction of experience and SPVD identification portrayed a negative effect on SPVD coping strategies. In contrast, positive association was observed when experience was interacted with large production acreage and as such, likelihood of using coping strategies increases by 1%. According to Kivuva et al. (2014), farmer's knowledge acquired over time highly influences agricultural practices which in turn directly or indirectly reduces SPVD incidence.

Independently, a reduction (8.6%) in probability of using coping strategies was observed for farmers with large production acreage. This outcome undermined the priori expectation that larger farmers would try to minimize losses by employing management options but declination to use management method could also be due to cost implications on large fields. Generally, negative effects when knowledge parameters are interacted (experience, knowledge in disease identification and months of SPVD occurrences) could be linked to the fact that coping strategies are less applied because SPVD does not cause direct physical damage to crops.

4. Conclusion and Recommendations

This study used a cross-country survey to understand the socioeconomic characteristics of sweet potato farmers, assess farmers' knowledge about SPVD, SPVD vectors and their management methods, and examine the relationship between farmers' practices of coping strategies for control of SPVD and knowledge. Farmer socio-economic characteristics revealed capacity to achieve high production of sweet potato courtesy of good access to land, experience and formal education. Our study also revealed potential contribution of the crop towards eradication of food and nutrition insecurity since majority of farmers involved are female with large households.

It was also observed that farmers have limited knowledge of SPVD, its vectors and control methods and as a result, use of SPVD control options are limited hence constraining production and undermine socioeconomic growth and development in the industry. Our study corroborated with findings from previous studies that limited knowledge has implications on farmers' practices and capability to manage the disease. Limited use of SPVD management options ultimately contributes to increased occurrence of SPVD incidence in the country since there is no deliberate effort by farmers to control SPVD. Nonetheless our findings confirmed that knowledge of SPVD and months of occurrence, formal education and large production combined with experience can castigate use of SPVD management practices.

Given the overwhelming evident of women and youth engagements, prevalence of SPVD and apparent knowledge gaps among the sweet potato farmers in Uganda, this paper recommends pro women and youth support to

enhance their contribution to sweet potato farming for food and nutrition security and income. Increased awareness and training of farmers to improve their knowledge scope in SPVD characteristics and management. Breeding for virus resistant varieties and breeding for resistance to whiteflies and aphids that are SPVD vectors for effective control of the disease.

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Authors Contributions

Joanne Adero: Conceptualization, conducted survey, data analysis and wrote original manuscript; Bernard Yada, Craig Yencho and M. A. Otema:Cconceptualization and funding; G. O. Akongo: Data nalysis and wrote original manuscript. Mercy Kitavi and Denis K. Byarugaba: Conceptualization and supervision. All authors read, reviewed and approved the manuscript.

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Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed Consent

Obtained.

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The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data Sharing Statement

No additional data are available.