FARMERS' KNOWLEDGE, PERCEPTION AND MANAGEMENT PRACTICES OF PAPAYA RINGSPOT DISEASE IN KENYA

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Abstract

Production of papaya, an important fruit crop in Kenya is severely constrained by papaya ringspot disease (PRSD). Understanding farmers' knowledge, perceptions and practices is a prerequisite to establishing an effective disease management strategy at the community level. This study assesses the farmers' knowledge, perceptions and management practices of PRSD in Kenya. The study was conducted in five major papaya growing regions in Kenya; Coast, Western, Rift valley, Central and Eastern and a total of 103 small holder farmers randomly identified were interviewed using a semi-structured questionnaire. Chi-square (X^2) and one-way analysis of variance (ANOVA) were conducted to assess any differences between regions, gender and education levels with regards to the knowledge, perceptions and management practices of PRSD. The results show that while about four in 10 farmers (38.8 %) had the precise knowledge of PRSD, about a half of those knowledgeable of the disease (48.8 %) did not know the cause. Slightly more than fifty percent (54.8 %) of the study respondents sprayed plants showing the disease symptoms with chemical insecticides, 4.7 % removed the infected plants from the field while 40.5 % did not apply any management measure to the diseased plants. The study findings indicate awareness and knowledge about the identification and cause of the ring spot disease on papaya, as well as management practices are limited for most papaya farmers in the sampled regions. As such, this study highlight the need for capacity building of the Kenya papaya farmers on proper identification and management techniques of the disease.

Key words: *Carica papaya*; production; losses; measures; extension services

INTRODUCTION

Papaya (*Carica papaya* L.) is an important fruit crop in Kenya grown for domestic consumption, local and export markets (Asudi, 2010; Rimberia and Wamocho, 2014; HCDA, 2016). The plant produces fruits throughout the year. The fruits are rich in vitamins A and C, dietary minerals such as calcium, thiamine, iron, potassium and dietary fibers *(Aravind et al., 2013; Daagema et al.*, 2020; Krishna *et al.,* 2008). Based on the recommended daily allowance for these vitamins A and C and minerals, papaya is ranked first among 38 common fruits (Ming *et al.,* 2008). Therefore, regular consumption of the fruit can ensure a good supply of these vitamins and minerals, promoting good health in children and preventing early childhood blindness (Krishna *et al.,* 2008) in tropical and subtropical developing countries including Kenya (Oyunga *et al.,* 2016). The ripe fruit crop is also a major source of income to the resource-scarce farmers because the crop has a rapid growth rate and requires minimal

maintenance cost giving quick returns. Papaya fruit crop is also a heavy producer and adapts well to diverse soil and climatic conditions (Gonsalves, 1998; Okon *et al.,* 2017; Tennant *et al.,* 2007). Its production is however severely constrained by biotic and abiotic stressors, with viral diseases playing an important role (Asudi, 2010; Rimberia and Wamocho, 2014; HCDA, 2016).

Papaya ringspot disease (PRSD) is one of the most destructive viral diseases affecting papaya in Kenya (Ombwara *et al.,* 2014; Rimberia and Wamocho, 2014; Mumo *et al.,* 2020). The disease affects papaya plants at all stages of growth, eventually causing yield losses of up to 100 % (Tripathi *et al.*, 2008; Sharma and Tripathi, 2014). Papaya ringspot disease infected plants are easily recognized by symptoms including presence of ring spots on fruits; mosaic, mottling, vein clearing, puckering, shoe stringing, downward curling and distortion of the leaves. Additionally, PRSD infected papaya plants have stems and petioles with irregular oily or water-soaked marks (Arocha *et al.,* 2008; Tripathi *et al.,* 2008; Mumo *et al.*, 2020). Some of these PRSD symptoms unfortunately closely resemble those caused by other plant stressors, such as insect or pest damage, and soil nutrient toxicity and/or deficiency (Tripathi *et al.*, 2008; Jones, 2014; Schreinemachers *et al.*, 2015). The infected papaya fruits also have low sugar content which together with the ring spots lower their quality and hence make the fruits attract low prices in the markets (Tripathi *et al.*, 2008; Sharma and Tripathi, 2014).

A fundamental part of designing integrated disease management approaches in agriculture is knowledge and perceptions of farmers on the disease as well as its implications on management practices. The knowledge, for instance, informs on how farmers understand and appreciate a problem, and how they feel about the cause of the problem, and this information certainly influences the farm management practices they carry out (Lwin *et al.,* 2012; Schreinemachers *et al.*, 2015). Farmers in developing countries have long been using local knowledge to manage crop diseases caused by different pathogens (Asudi *et al.*, 2015; Hubert *et al.*, 2016). Modern scientific knowledge on identification and management of PRSD has also grown and disseminated through agricultural extension systems (Ventura *et al.,* 2004). Thus, for successful management of the disease, researchers can integrate the existing indigenous knowledge of the papaya farming community with scientific knowledge in the management of the disease. More importantly, use of the two folds of knowledge (indigenous and conventional science) can effectively guide in papaya PRSD management action, as well as in the national agricultural extension systems. However, the understanding on the level of farmers' knowledge, perceptions and management practices for PRSD in Kenya is limited. The objective of this study is to document farmers' knowledge, perceptions and management practices of PRSD in major papaya growing regions in Kenya. This understanding is necessary in order to guide the development of appropriate management strategies for PRSD in papaya fruit crop production.

MATERIALS AND METHODS

Study Areas

The study was carried in smallholder papaya farmers in 22 selected counties across five main producing regions in Kenya – namely, Coastal, Eastern, Central, Rift Valley and Western (Figure 1). These regions were chosen because of the relatively high numbers of farmers growing papaya and also the presence of many PRSD reported incidences (Asudi, 2010; Ombwara *et al.,* 2014). In the coastal region, the counties incorporated in the research included Kilifi, Kwale and Taita Taveta counties. In the Eastern region, the

counties involved were Makueni, Machakos, Embu, Tharaka Nithi, Meru and Kitui. In central region, the areas included Kiambu, Murang'a, and Kirinyaga. In the Rift valley region, the counties included Nakuru, Baringo, and Elgeyo Marakwet. In western region sites were in Migori, Homa Bay, Kisumu, Siaya, Busia, Bungoma and Vihiga (Figure. 1)

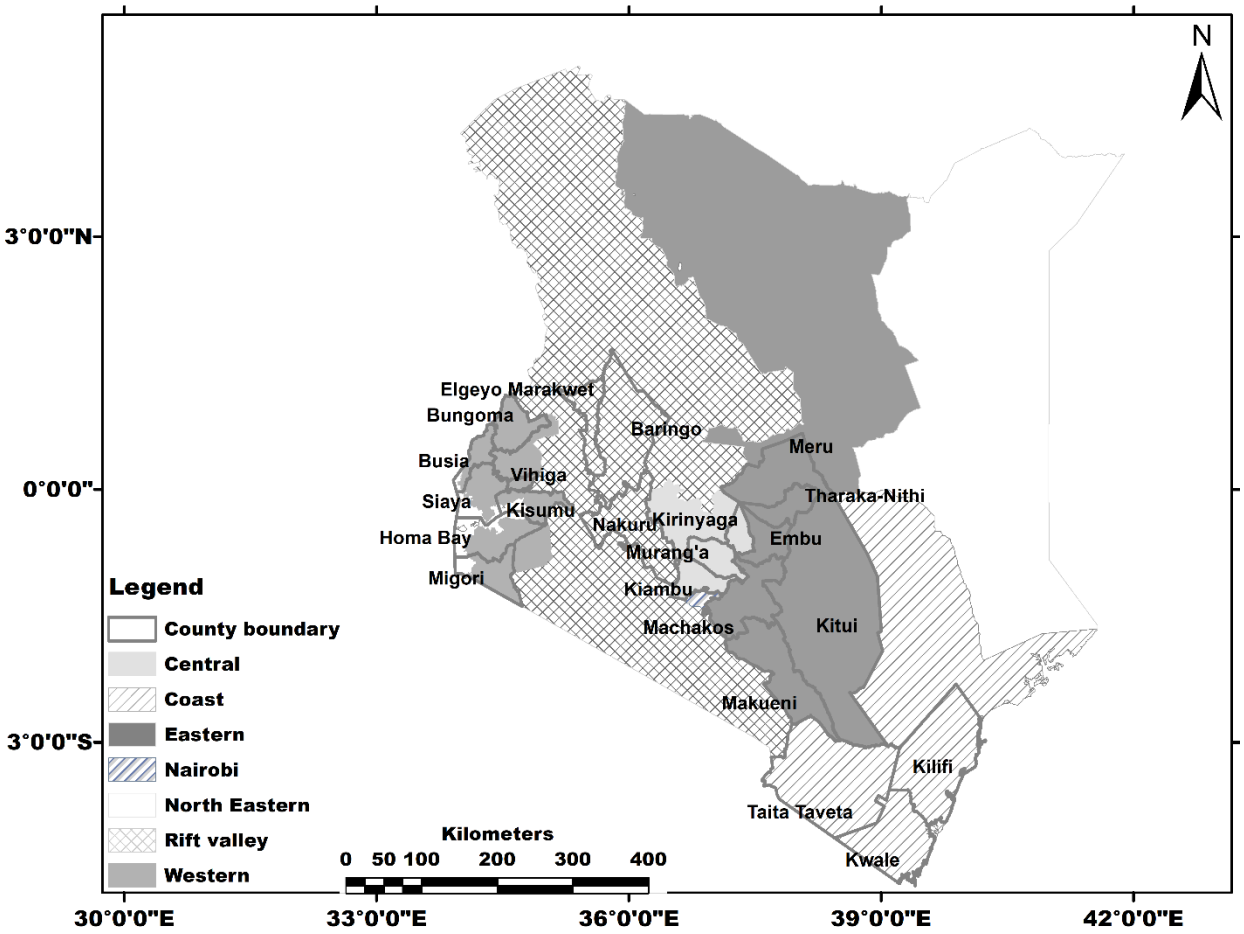

Figure 1. Location of selected regions and counties surveyed for knowledge, perceptions and management practices of PRSD

Data Collection

Surveyed sites were mapped using global positioning system (GPS; Magellan GPS 315, San Dimas, CA). Sites altitudes ranged from; 11 to 1116 m above sea level (m a.s.l.) in the Coast, 784 to 1568 m a.s.l. in the Eastern, 1020 to 1914 m a.s.l. in the Rift Valley, 1160 to 1523 m a.s.l. in the Western, and 877 to 1576 m a.s.l. in the Central region.

Papaya farmers in the counties within these regions were randomly selected for the study. A total of 103 farmers were interviewed, with 28 from Central, 14 from Coast, 37 from Eastern, 8 from Rift Valley and 16 from Western region. When farmers resided within the same county, only those spaced at a minimum distance of 5 km were interviewed. Data for the study were collected using a semi-structured questionnaire administered through face-to-face interviews. The questionnaire was pre-tested on five farmers prior to conducting the study.

The data collected included farmer demographic characteristics, papaya production, farmers' knowledge, perceptions and management practices of the PRSD. Farmers' knowledge was assessed by asking if they were aware of PRSD and its occurrences in their farms. Because farmers' fields were always nearby a distance of less than 1 km from the homestead, it was possible to verify the farmers' responses with field observations. The responses to the knowledge questionswere recorded in a series of binary responses (1 for yes and 0 for no) following Khan *et al.,* (2014) and Asudi *et al.,* (2015).

Data enumerators used an A4 sized photographs of a papaya plant with leaves, stems, petioles and fruits infected by PRSD to asses farmers' knowledge of the disease (Figure 2). The photos had no text to ensure the identification was based on visual cues by correlating the symptoms in fields with those in pictures. When needed, the disease symptoms were described to the farmers. The perception on the disease problem and the rate of disease spread was captured as a categorical variable using a 4-point Likert scale rating (Khan *et al.*, 2014; Asudi *et al.*, 2015). For this, farmers were asked to rate the disease problem on a scale of 0 to 3, where 0 = no problem, 1 = moderate problem, 2 = severe problem and 3 = very severe problem. The rate of disease spread for the past one year was scored on a scale of 0 to 3 where 0 = no spread, 1 = slow spread, 2 = fast spread and 3 = very fast spread. Interviewed farmers were also asked to name the papaya cultivars grown, purposes for which papaya was cultivated, source of planting materials, cropping system, seasonal prevalence of PRSD on their papaya crops and the control measures they practiced.

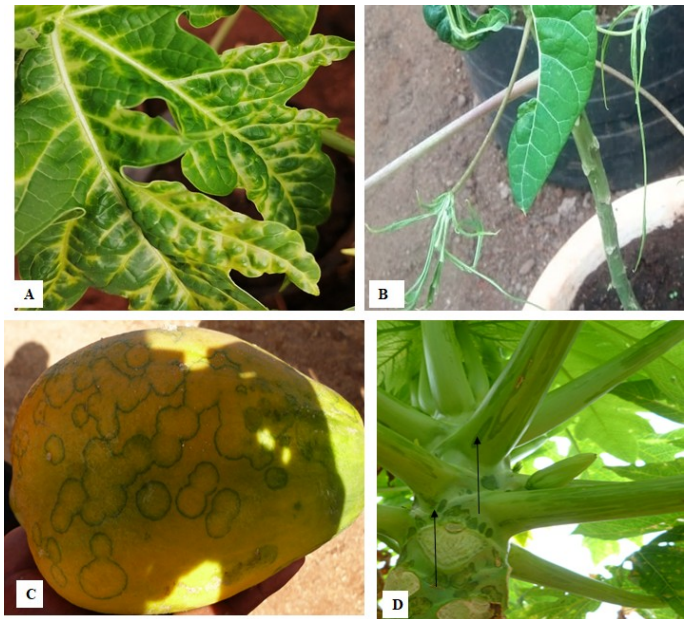

Figure 2: Papaya pictures showing PRSD infections used for evaluating farmers knowledge and awareness; (A): Leaf distortion, puckering, mosaic and vein clearing; (B): Shoe stringing; (C): Ringspots on fruit and (D):Water or oil-soaked marks on stem and petioles (shown with arrows)

Data Analysis

Data collected were cleaned and analysed descriptively by frequencies and percentages in the Statistical Package for Social Sciences (SPSS, ver. 20; SPSS Inc. Chicago, USA). To determine variations among regions with regards to the knowledge and perceptions of the disease and management practices, non-parametric Chi-Square (χ^2) tests were used in cases where data were categorical, while one-way analysis of variance (ANOVA) was used for quantitative continuous variables for instance age of the respondents. Statistical significance was determined at $\alpha = 0.05$.

RESULTS

Socio-economic Profile of Sampled Population

Of the total 103 farmers interviewed, slightly over half of the respondents were male (58.3 %). Respondents' age bracket was between 20

to above 60 years, and majority (41.7 %) of them are between 41 to 50 years. Half of the respondents (50 %) had attained secondary school education (i.e., 12 years of basic education). The purpose for papaya production differed significantly across regions (χ^2 = 23.90, df = 12, $P < 0.05$; Table 1).

Table 1. Socio-economic characteristics of the respondents interviewed in five regions of Kenya for the perceptions and knowledge of papaya ringspot disease in papaya

Variable	Region					Mean	Significance	
	Central	Coast	Eastern	Rift Valley	Western		χ^2	*F*-test
Number of farms surveyed	28	14	37	8	16	103		
Gender of the respondents (%)								
Male	62.2	42.9	60.7	62.5	56.2	58.3	1.75^{ns}	
Female	37.8	57.1	39.3	37.5	43.8	41.7		
Age								
Age (years)	43.8	43.9	43.3	38.0	43.1	43.1		0.71^{ns}
Education levels (%)								
Below primary	–	–	3.6	14.3	18.8	4.9	18.5^{ns}	
Primary	27.0	28.6	28.6	14.3	50.0	30.4		
Secondary	54.1	64.3	53.6	42.9	25.0	50.0		
Tertiary	18.9	7.1	14.3	28.6	6.2	14.7		
Utilization of papaya (%)								
Subsistence	5.4	28.6	28.6	12.5	56.2	23.3	23.90^{*}	
Subsistence and market	70.3	50.0	57.1	20.0	37.5	56.3		
Market	21.6	21.4	14.3	50.0	6.2	19.4		
Research	2.7	–	–	17.5	–	–		
Proportions of papaya fruits sold (%)								
0 –25 %	20.6	33.3	40.0	14.3	14.3	26.2	26.45^{**}	
26 –50 %	29.4	8.3	25.0	28.6	85.7	30.0		
51 –75 %	35.3	25.0	10.0	–	–	21.2		
>75 %	14.7	33.3	25.0	57.1	–	22.5		
Proportion of farm under papaya cultivation								
0 –2 %	35.1	57.1	57.1	37.5	81.2	51.5	26.95^{**}	
3 –4 %	43.2	14.3	14.3	12.5	18.8	25.2		
5 –8 %	13.5	7.1	10.7	–	–	8.7		
>8 %	8.1	21.4	17.9	50.0	–	14.6		

Statistically significant (Chi-square analysis and *F*-test) at *p < 0.05, **p < 0.01; ^{ns}, not significant; -, no reported case.

Most of the farmers interviewed (56.3 %) produced papaya for use at home but also sold the surplus (i.e. used for subsistence and market). Central, Coast and Eastern regions had 70.3 %, 50 % and 57.1 % of the households producing papaya for home consumption and selling the surplus, respectively, while in the Rift Valley region, 50 % produced papaya fruits for market. In the Western region, 56.2 % of the respondents planted papaya for home consumption (Table 1). The proportions of papaya fruits sold by the respondents also varied significantly across regions (χ^2 = 26.45, df = 12, $P < 0.01$; Table 1), with only 30 % of the farmers selling between 26 and 50 % of their produce.

However, the overall proportion of farms under papaya cultivation was very low with 51.5 % of the respondents putting less than 2 % of their total land under papaya cultivation.

Cropping System and Papaya Cultivars Grown by Farmers

Papaya cropping system varied significantly across the five regions (χ^2 = 12.6; df = 4; P < 0.05), with majority of the respondents (87.3%) intercropping the crop with other crops (Table 2). In Central, Coast and Eastern regions, at least 9 in 10 farmers (91.9 %, 92.9 %, and 92.9 % respectively) intercropped papaya with other crops. The proportion of farmers who intercropped papaya in Western was much lower (80%) and lowest in Rift valley (50%). Maize, banana, mango, cowpea, sweet potato, coffee, pigeon pea, cassava, citrus, passion fruit, vegetable crops and cucurbits, were cited by the respondents as the common intercrops in papaya plants.

A majority of the respondents (74 %) did not known names of papaya cultivars on their farms (Table 2). 'Solo sunrise' (16.3%), 'SP' (7.7%) and 'Mountain' (6.7) were the most known cultivars grown by the respondents, with the respondents from central region reporting the highest number of these cultivars (Table 2). The survey also recorded recently imported papaya cultivars 'Malaysian 5', 'Red royale', Vega F1 and 'Sinta F1', which were only recorded for the Central region respondents. All the papaya grown by Western region respondents did not know the cultivars they planted (Table 2). About 76.9% of the respondents responded they save seed from healthy-looking ripened fruits from their farms, while 9.6% source seeds from the nearest neighbouring farms or from National Research Institutes such as Kenya Agricultural Livestock and Research Organizations (KARLO). Nine farms (about 3.8 % of the respondents) in Central region reported buying imported from commercial seed companies, and the remaining 1 % of the respondents from Central bought papaya fruits from markets and extracted the seeds or alternatively bought seedlings from local tree nurseries (Table 2).

Knowledge and Awareness of Papaya Ringspot Disease in Selected Regions of Kenya

Awareness of PRSD among respondents differed significantly across the surveyed regions (χ^2 = 17.49; df = 4; P < 0.01; Table 3).About thirty nine percent (38.8 %) of the respondents correctly recognized infected plants indicating awareness of the disease. In Central, Eastern, Coast and Rift valley regions, 59.7 %, 39.3 %, 35.7 %, and 25 %, respectively were aware of the disease. The respondents from the western region, surprisingly, did not correctly recognize the disease symptoms (Table 3). Majority of the of respondents (95.5%) were aware of PRSD presence on their farms although this did not differ significantly across the surveyed regions (χ^2 = 2.79; df = 4; P > 0.05; Table 3).

Table 2. Cropping system, papaya cultivars grown by farmers and source of planting materials

Variable	Region					Mean	
	Central N = 28	Coast N = 14	Eastern N = 37	Rift Valley N = 8	Western N = 16	N = 103	χ^2
Papaya cropping system							
Intercrop	91.9	92.9	92.9	50	80	87.3	12.60*
Monocrop	8.1	7.1	7.1	50	20	12.7	
Papaya cultivars grown by farmers (%)							
Not sure of the name	51.4	85.7	92.9	50.0	100	74.0	26.93***
Solo sunrise	27.0	7.1	7.1	50	–	16.3	15.64**
Mountain	8.1	14.3	3.6	–	–	6.7	17.42**
SP	18.9	7.1	–	–	–	7.7	10.99ns
Malaysia	2.7	–	–	–	–	1.0	1.83ns
Sinta F1	2.7	–	–	–	–	1.0	1.83ns
Red Royale	5.4	–	–	–	–	1.9	3.69ns
Vega F1	2.7	–	–	–	–	1.0	1.83ns
Source of planting materials (%)							
Use of farmer's own seed	59.5	92.9	82.1	75.0	93.8	76.9	11.66*
From neighbours	10.8	7.1	10.7	1.5	6.2	9.6	0.59ns
Bought (market)	2.7	–	–	–	–	1.0	1.83ns
Imported seeds	10.8	–	–	–	–	3.8	7.53ns
KALRO	16.2	–	7.1	25.0	–	9.6	7.53ns

Statistically significant (Chi-square analysis) at *p < 0.05, **p < 0.01 or ***p < 0.001; ns – not significant. 'N' is the number of farmers surveyed, (-): no reported case.

KALRO: Kenya Agricultural and Livestock Research Organizations

Spread of PRSD differed significantly across regions (χ^2 = 13.06; df = 6; P < 0.05; Table 3), with 85 %, 40 %, 57.1 % and 50 % of the respondents from Central, Coast, Eastern and Rift valley regions, in the respective order, recognized PRSD was spreading fast on their farms. Half of respondents (50 %) regarded PRSD as moderate constraint to papaya production, but also a good proportion (40.5 %) regarded it as a serious problem. Fifty seven percent (57.1 %) of the respondents perceived symptoms of PRSD on papaya crops to be more prevalent during the dry season, while 26.2 % of the respondents not aware when the symptoms were prevalent. In Central, Rift valley and Eastern regions, 71.4 %, 100 %, and 42.9 % of the respondents respectively, perceived the disease to be prevalent in dry season, and 60 % of the Coast region respondents not aware when the PRSD symptoms were most prevalent (Table 3).

Table 3. Respondent's awareness and perception of papaya ringspot disease in selected regions of Kenya

Variable	Region Central N = 28	Coast N = 14	Eastern N = 37	Rift Valley N = 8	Western N = 16	Mean N = 103	χ^2
Farmers' awareness of the papaya ringspot disease (%)							
Yes (%)	59.5	35.7	39.3	25.0	–	38.8	17.49**
Farmers awareness of presence of papaya ringspot disease on their farms							
Yes (%)	95.5	83.3	100	100	–	95.5	2.79ns
Is the disease spreading on the farm (%)							
Yes	100	100	92.9	100		97.6	2.05ns
The rate of spread of the PRSD disease on the farmers' fields (%)							
Slow	–	40.0	42.9	50.0	–	22	13.06*
Fast	85.0	40.0	57.1	50.0	–	68.3	
Very fast	15.0	20.0	–	–	–	9.8	
Problem of PRSD in the surveyed farms (%)							
No problem	–	–	–	–	–	–	2.15ns
Low	4.8	20.0	14.3	–	–	9.5	
Moderate	57.1	40.0	42.9	50.0	–	50.0	
High	38.1	40.0	42.9	50.0	–	40.5	
When is the disease more prevalent (%)							
During dry season	71.4	20.0	42.9	100.0	–	57.1	7.23ns
During cold season	–	–	–	–	–	–	–
During long rains	9.5	–	–	–	–	4.8	2.1ns
During short rains	–	20.0	7.1	–	–	4.8	3.89ns
Always	9.5	–	7.1	–	–	7.1	0.72ns
Not aware	9.5	60.0	42.9	–	–	26.2	8.70*

*Statistically significant (Chi-square analysis) at *p < 0.05 or **p < 0.01; ns – not significant. 'N' is the number of farmers surveyed, (-): no reported case.

Knowledge on the Causes of Papaya Ringspot Disease and Management Practices

The results show that about a half of the respondents, (48.8 %) did not know the cause PRSD to papaya plants (Table 4). The other half speculated different causes of the diseases including insect attack (18.6 %), bacteria (2.4 %), fungi (4.8 %), virus (11.9 %) and change in weather (13.5 %). These responses, however, did not vary significantly across the regions (χ^2 = 0.67 df = 5, P>0.05; Table 4). About 73.2 % of the respondents were not aware of when newly grown papaya plants get infected by PRSD, with 22.5 % observing PRSD symptoms three months after planting, while 2.4 % observing the symptoms two and more than three months after planting. However, respondents' observations when newly planted papaya plants become infected by PRSD did not differ significantly across the surveyed regions (χ^2 = 5.27, df =4; P > 0.05; Table 4). As a disease management measure majority of the respondents (54.8 %) sprayed infected plants with chemicals, and a good percentage (40.5 %) applied no measure, while 4.8 % removed the infected plants to manage the disease (Table 4). In Central, Coast, Eastern and Rift valley, 54.5 %, 20 %, 61.5 % and 100 % of the respondents respectively, all used chemical insecticides as a disease management measure. On the other hand, 40.9 % respondents in Central, 80 % in Coast and 30.8 % in Eastern did not apply any control measures, while 4.5 % in Central and 7.7 % in Eastern regions removed and destroyed PRSD infected papaya plants (Table 4).

Table 4: Respondents knowledge on the cause of PRSD and management measures

Variable	Region					Mean N = 103	χ^2
	Central N = 28	Coast N = 14	Eastern N = 37	Rift Valley N = 8	Western N = 16		
Causes of the papaya ringspot disease on their farms (%)							
Virus (yes %)	10	–	13.3	50.0	–	11.9	3.54^{ns}
Fungus (Yes %)	10	–	–	–	–	4.8	2.31^{ns}
Insects (Yes %)	19.0	20.0	20.0	–	–	18.6	0.49^{ns}
Bacteria (Yes %)	–	20	–	–	–	2.4	7.38^{ns}
Weather (yes %)	20	–	13.3	–	–	13.5	1.71^{ns}
Don't know	42.9	60	53.3	50.0	–	48.8	0.67^{ns}
Time newly grown plants get affected (%)							
One month	–	–	–	–	–	–	–
Two months	5.0	–	–	–	–	2.4	1.08^{ns}
Three months	35.0	–	7.1	50.0	–	22.5	5.71^{ns}
More than 3 months	–	–	7.1	–	–	2.4	1.98^{ns}
Not aware	60.0	100	85.7	50.0	–	73.2	5.27^{ns}
Control measures for the disease							
Roguing	4.5	–	7.7	–	–	4.8	5.57^{ns}
Spraying with chemicals	54.5	20.0	61.5	100	–	54.8	
Do not control	40.9	80.0	30.8	–	–	40.5	

Statistically significant (Chi-square analysis) at *p < 0.05, **p < 0.01 or ***p < 0.001; ns – not significant. 'N' is the number of farmers surveyed, (-): no reported case.

DISCUSSION

In order to implement successful integrated papaya ringspot disease management program, adequate knowledge on how farmers perceive the problem, their attitude and practices to papaya crop protection are required. A survey was, thus, conducted in the five major papaya producing regions of Kenya to unravel farmers' knowledge, perceptions and management practices of PRSD in the country. The study has shown that farmers' PRSD knowledge is minimal (with only 38.3 % of the respondents able to identify the disease), implying the knowledge bottleneck likely constitutes a major obstacle to PRSD management in papaya farming in Kenya. Other studies with a focus on farmers' crop disease knowledge have found correlation on farmers' knowledge and perceptions on crop pests and diseases management. Lwin, *et al.,* (2012), for example, reported farmer's lack of knowledge on pests and diseases affecting tomatoes farming in the Inlay Lake region of South East Asia. Similarly, Khan and Damalas, (2015), cited farmers' knowledge bottleneck negatively affecting farming of cotton by small acreage holding farmers in Pakistan.

The study results showed that the majority of respondents relatively knowledgeable of PRSD (especially those from Central, Eastern, Coast and Rift valley regions) had attained higher education (secondary school education level). Furthermore, the respondents in addition to producing papaya for subsistence, they also farmed the crop for selling. These result further suggesting that it is likely that there is a link between farmers' level of education and the general knowledge of PRSD in papaya farming in Kenya. In fact, we noted during our survey that farmers from these regions tended to have a greater interest in the quality and quantity of the papaya they

produced, suggesting, in addition to their higher attained education, the need to produce quality pawpaw fruits to compete for market motivated them to notice obvious changes on their papaya plants that are likely to lower quality and quantity, and subsequently their potential income. The motivation is in fact likely to push the farmers to seek information on the problem, including identification of the symptoms of disease. Knowledge has been found to be directly related with education level (Adam *et al.,* 2015).

In Western region where the majority respondents had only attained primary education and produced papaya for subsistence purposes, possibly contributed to their ignorance on the PRSD despite being on their farms. In fact, we recorded a number of Central and Rift valley regions respondents who obtained their planting materials from research institutes, further suggesting presence of the institutes in those regions most likely provided the farmers with information on production as well as various challenges and their management including diseases such as PRSD, which further boosted their knowledge on crops pests and diseases.

The study showed the majority of the respondents (95.5 %) knowledgeable and aware of PRSD acknowledged presence of the disease in their farms. In fact, these respondents are able to narrate the disease general causative agents, its spread rate and severity seasons in their farms, and more importantly its effects on papaya production. These results demonstrate how important farmers' crop disease knowledge is and could motivate the potential disease management practice to adopt. Indeed, farmers' crop disease experience has been shown to positively impact on the practiced management for Napier grass stunt disease in western Kenya (Khan *et al.*, 2014). The result of a good proportion of the respondents (26.2 %) not aware when PRSD symptoms are more prevalent as well the cause of PRSD is however worrying. Technically, this result implies that the lack of knowledge of the disease is likely a major hindrance to management of PRSD by Kenya papaya farmers. Lack of knowledge of the causative agents of agricultural diseases has been reported to hinder production of legumes and vegetable crops in Asia (Schreinemachers *et al.*, 2015) and also on Napier grass in East Africa (Asudi *et al.*, 2015).

This study results show that though, majority of the respondents (54.8 %) managed the disease by spraying of chemical insecticides, yet a good proportion (40.5 %) did not apply any measure. Spraying of chemical insecticides is one of the integrated management approaches of managing the PRSD because it decreases the aphids population and distribution, reducing the level of damage they cause (Ventura *et al.,* 2004; Kalleshwaraswamy and Kumar, 2008). However, the use of chemical insecticides as management practice could be less successful in the absence of an understanding of the role of aphids or other vectors in the spread of the virus causing papaya ringspot disease (Kalleshwaraswamy and Kumar, 2008). Furthermore, insects control can be effective if practiced before symptoms of the disease appear, which requires farmers knowledge about the epidemiology of disease (Schreinemachers *et al.*, 2015). We however got a good proportion of the respondents (26.2 %) not aware when PRSD symptoms are more prevalent as well the cause of PRSD, hence this urging a robust PRSD sensitization for use of chemical insecticides to manage PRSD for Kenya papaya production. Roguing of infected plants, which is also another effective integrated management practice of PRSD (Ventura *et al.,* 2004), was only reported in Central and Eastern regions, suggesting the

practice is minimally used by Kenya papaya farmers.

This study concludes that majority of the farmers have low knowledge about the identification and cause of the ring spot disease on papaya; which is a major bottleneck to realization of optimal papaya production for the country. In terms of management, most farmers use chemicals to control the disease while others do not apply any management measures. As such, there is an urgent need to include farm-level training to increase farmers' awareness and knowledge about PRSD, identification, and good management practices, which will in return boost the country's papaya fruit production.

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REFERENCES

Aravind G, Bhowmik D, Duraivel S, Harish G. 2013. Journal of Medicinal Plants Studies Traditional and Medicinal Uses of Carica papaya. Journal of Medicinal Plants Studies Year Journal of Medicinal Plants Studies, **1(1**), 7–15.

Arocha Y, Vigheri N, Nkoy-Florent B, Bakwanamaha K, Bolomphety B, Kasongo M, Betts P, Monger WA, Harju V, Mumford RA, Jones P. 2007. First report of the identification of Moroccan watermelon mosaic virus in papaya in Democratic Republic of Congo. Plant Pathol **57**:387.

Adam RI, Sindi K, Badstue L. 2015. Farmers' knowledge, perceptions and management of diseases affecting sweet potatoes in the Lake Victoria Zone region, Tanzania. *Crop Protection* **72**:97-107.

Asudi GO. 2010. Collection, Morphological and Molecular Characterization of Papaya. MSc Thesis, Jomo Kenyatta University of Agriculture and Technology, Nairobi Kenya.

Asudi GO, van den Berg J, Midega CAO, Pittchar J, Pickett JA, Khan ZR. 2015. Napier grass stunt disease in East Africa: Farmers' perspectives on disease management. Crop Protection **71**:116–124.

Daagema AA, Orafa PN, Igbua FZ. 2020. Nutritional Potentials and Uses of Pawpaw (Carica papaya): A Review. European Journal of Nutrition & Food Safety, **12(3**): 52–66.

Gonsalves D. 1998. Control of papaya ringspot virus in papaya : A Case Study. Annual Review of Phytopathology, **36(1):** 415–437.

HCDA 2016. Horticulture Validated report, Nairobi, Kenya. Nairobi, Kenya. Available at: www.agricultureauthority.go.ke/.../Horticulture-Validated-Report-2014-Final-copy.pd.

Hubert J, Ashura L, Eugénie H, Herman JFL. 2016. Farmers' Knowledge and Perceptions of Rice yellow mottle virus in Selected Rice Growing Areas in Tanzania. International Journal of Science and Research, **5(2):** 549–559.

Jones RAC. 2014. Plant virus ecology and epidemiology: historical perspectives, recent progress and future prospects. Annals of Applied Biology **164(3):** 320–347.

Kalleshwaraswamy CM, Kumar N K K. 2008. Transmission Efficiency of Papaya ringspot virus by Three Aphid Species. Phytopathology, **98(5):**541–546.

Khan M, Damalas C A. 2015. Farmers' knowledge about common pests and pesticide safety in conventional cotton production in Pakistan. Crop Protection. **77**:45–51.

Khan ZR, Midega CAO, Nyang'au IM, Murage A, Pittchar J, Agutu LO, Amudavi DM, Pickett J A. 2014. Farmers' knowledge and perceptions of the stunting disease of Napier grass in Western Kenya. Plant Pathology **63**:1426–1435.

Krishna KL, Paridhavi M, Patel J A. 2008. Review on nutritional, medicinal and pharmacological properties of papaya (Carica papaya linn.). Indian Journal of Natural Products and Resources, **7(4):** 364–373.

Lwin OOM, Yabe M, Khai HV. 2012. Farmers' Perception, knowledge and pesticide usage practices: A case study of tomato production in inlay lake. Journal of the Faculty of Agriculture, Kyushu University **57**:327–331.

Ming R, Hou S, Feng Y, Yu Q, Dionne-laporte A, Saw J H, … Mitchell-olds, T. 2008. The draft genome of the transgenic tropical fruit tree papaya (Carica papaya Linnaeus). Nature, **452:** 991–996.

Mumo NN, Mamati GE, Ateka EM, Rimberia FK, Asudi GO, Boykin LM, Machuka EM, Njuguna Joyce N, Pelle R, Stomeo F. 2020. Metagenomic Analysis of Plant Viruses Associated With Papaya Ringspot Disease in Carica papaya L . in Kenya. Frontiers in Microbiology **11**:205.

Okon WI, Ogri AI, Igile GO, Atangwho I J. 2017. Nutritional quality of raw and processed unripe Carica papaya fruit pulp and its contribution to dietary diversity and food security in some peasant communities in Nigeria. International Journal of Biological and Chemical Sciences, **11(3):** 1000.

Ombwara FK, Asudi GO, Rimberia FK, Ateka EM, Wamocho LS. 2014. The Distribution and Prevalence of Papaya Ring Spot Virus (PRSV) in Kenyan Papaya. Acta Horticulturae **1022**:119–124.

Oyunga MA, Grant FKE, Omondi DO, Ouedraogo H, Levin C, Low JW. 2016. Prevalence and predictors of Vitamin a deficiency among infants in Western Kenya using a cross-Sectional analysis. African Journal of Food, Agriculture and Nutritional Development **16**:10765–10785.

Rimberia FK, Wamocho LS. 2014. Papaya industry in Kenya: Production, consumption and outlook. Acta Horticulturae **1022**:181–188.

Schreinemachers P, Balasubramaniam S, Boopathi NM, Ha CV, Kenyon L, Praneetvatakul S, Sirijinda A, Le NT, Srinivasan R, Wu M-H. 2015. Farmers' perceptions and management of plant viruses in vegetables and legumes in tropical and subtropical Asia. Crop Protection **75**:115–123.

Sharma SK, Tripathi S. 2014. Papaya ringspot virus-P. Overcoming limitations of resistance breeding in Carica papaya L., pp 177–194. In: R.K. Gaur, Pradeep Sharma, Thomas Hohn (Eds).Plant Virus-Host Interaction: Molecular Approaches and Viral Evolution. Elsevier Science, 2013.

Tennant PF, Fermin GA, Roye ME. 2007. Viruses Infecting Papaya (Carica papaya L.): Etiology, Pathogenesis, and Molecular Biology. Plant Viruses, **1(2):** 178–188.

Tripathi S, Suzuki JY, Ferreira SA, Gonsalves D. 2008. Papaya ringspot virus-P: Characteristics, pathogenicity, sequence variability and control. Molecular Plant Pathology **9**:269–280.

Ventura JA, Costa H, Tatagiba J da S. 2004. Papaya Diseases and Integrated Control, pp 201–268. In: Naqvi SAM. (ed) Diseases of Fruits and Vegetables: Volume II. Kluwer Academic Publishers, Dordrecht.