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Prevalence and distribution of plant parasitic nematodes associated with sweet potato: A case study of Kirinyaga County in Kenya

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ABSTRACT

A survey of plant parasitic nematodes (PPNs) associated with sweet potato (*Ipomoea batatas*) was carried out in three agro-ecological zones of Kirinyaga County in Kenya. Samples of rhizosphere soil and sweet potato tubers were collected for PPN extraction and morphometric characterization. Seven genera were morphologically identified (*Meloidogyne*, *Pratylenchus*, *Helicotylenchulus*, *Scutellonema*, *Rotylenchulus*, *Heterodera and Aporcelaimellus*). There were differences in the shapes and sizes of the mature PPN females and the diameter ranged from 204.3 µm to 437.3 µm. *Meloidogyne* had the highest prevalence (25%) and distribution (0.161), followed by *Pratylenchus* with a prevalence and distribution of 23% and 0.151, respectively. Farmers' perceptions were captured using a semi-structured questionnaire. Overall, sweet potato farming was mainly practiced under mixed cropping (70.11%), small-scale (60.11%) and subsistence (55.17%). A higher proportion of the respondents (49.43%) sourced sweet potato vines from their own farms. The main control strategies applied for PPN were insecticides (55.59%), nematicides (11.49%) and concoctions (5.75%). Of all the respondents, 29.89% could not recognize symptoms of nematode infection. The distribution was significantly ($p < 0.05$) different among *a*gro-ecological zones, with UM3 (upper midlands) showing the highest prevalence of 31. In conclusion, the differences in shapes and sizes of the mature females extracted from PPNs reveal a high level of morphological diversity. However, morphological characterization should be integrated with molecular methods for proper identification of PPNs. Awareness-raising among farmers about the best practices for proper management of PPN is necessary.

Keywords: Agro-ecological zones, plant parasitic nematodes, prevalence, sweet potato

INTRODUCTION

Sweet potato (*Ipomoea batatas* (L.) Lam.) is a short-season tropical crop that grows on marginal and degraded soils with less agricultural input. It is among the root and tuber crops produced in Africa for food security. The crop is ranked fifth economically important food crop after rice, wheat, maize, and cassava and is widely grown and produced in African and Asian countries (Alam, *et al*., 2021). Asia is the largest producer accounting for 86.5% of the world's production, followed by Africa, which accounts for 10.6% of total production (Makini, *et al*., 2018). According to Amagloh *et al*. (2021), Nigeria, Malawi, Tanzania, Uganda, and Kenya are the top-ranked African countries in production of sweet potatoes.

Sweet potato is a potential remedial crop for small-holder farmers in Kenya because of its high productivity and low input requirements, while its usefulness for both food and feed makes it attractive in areas where land availability is declining (Claessens, *et al*., 2008). The crop is drought-tolerant and grown in medium to low altitude agro-ecological zones concentrated in drier areas (Makini, *et al*., 2018), hence an important crop for climate-smart agriculture (MoALFI, 2019). Then major producing areas are Kisii, Homa Bay, Siaya, Kericho, Busia, and Kirinyaga Counties (Echodu, *et al*., 2019). However, productivity has declined marginally and is attributed to a complex of biotic constraints, including plant-parasitic nematodes, insects amongst others (Okonya and Kroschel, 2013).

Plant parasitic nematodes are diversely distributed, with a wide host range affecting nearly all cultivated plants (Lee, *et al*., 2018; Mburu, *et al.,* 2020). The prevalence and distribution of nematodes are mainly influenced by the environment in which they grow, with a significant association to rainfall, temperature, and soil properties (Govaerts, *et al.,* 2007; Nielsen, *et al.,* 2014; Bello, *et al.,* 2020). Moreover, PPNs have the ability to spread and colonize new localities (Bebber, *et al*., 2014), and their wide host range has threatened crop production worldwide and raised concerns about understanding their strains (Riascos-Ortiz, *et al*., 2022). With the anticipated high precipitation and changes between the wet and dry seasons, the effect of rainfall on nematode abundance might become more noticeable.

Plant parasitic nematodes are reported to lower the yield and quality of sweet potato tubers by about 12% annually (Briar, *et al*., 2016; Karuri, *et al*., 2017). Parasitic nematodes associated with sweet potato have a wide variety of species strongly impacted by the shifting trends in climate (Petralia, *et al*., 2022). A range of 41.8–88.4% yield loss for sweet potatoes is experienced by farmers depending on the level of PPNs infection (Akinsanya, *et al*., 2019). The effect of PPNs on sweet potatoes includes stunted vines, discoloured cracked roots, and reduced quality and yield of the tubers (Hunja, *et al.*, 2017). The species from the *Heterodera*, *Pratylenchus*, *Radopholus* and *Meloidogyne* have been reported to have the greatest economic impact on sweet potato farms (Jones, *et al.*, 2013; Karuri, *et al.*, 2017). There is a need for continuous surveys of PPNs associated with sweet potatoes in order to determine their distribution under different agro-ecological zones and effective management base on predominant species in time and space (Fournet, *et al.*, 2016).

Information on their prevalence and abundance is therefore important in developing management strategies to maintain them at a threshold level (Seo, *et al.,* 2018). The main objective of this study was to assess the prevalence and distribution of plant parasitic nematodes associated with sweet potatoes in Kirinyaga County to ensure proper management.

MATERIALS AND METHODS

Description of the Study Site

This study was carried out in three agro-ecological zones of Kirinyaga County (UM3, UM4, and LM3) that are suitable for sweet potato production (Table 1). Kirinyaga County is located on the borders of the southern part of Mt. Kenya and the Northern East, between longitudes E 37° 14' 11.5404" and latitudes S 0° 28' 26.7132". The County is located at an elevation of 1158.81 meters above sea level, and has a tropical wet and dry, or savannah, climate. The mean annual temperature and precipitation are 20.96 ºC and about 150 mm, respectively.

Table 1: Climatic conditions of the sampled agro-ecological zones in Kirinyaga County

Agro-ecological zone	Altitude (m)	Temperature (°C)	Rainfall (mm)
UM3	1340 – 1400	20.6-20.1	1100 – 1250
UM4	1280 – 1340	20.9-20.4	950 – 1200
LM3	1220 – 1280	21.2 - 20.9	950 -1200

Data collection

A cross-sectional survey design was conducted. This involved a household survey using a structured questionnaire to gather farmers' perceptions and a field survey to assess the prevalence and distribution of parasitic nematodes associated with sweet potato. Eighty-seven (87) household questionnaires were administered, and a total of 77 sweet potato farms were randomly sampled (15 in

UM3, 37 in UM4, and 25 in LM3). Samples of rhizosphere soil were collected using a zigzag sampling pattern. In each farm, 100 g of soil were collected from five points using a sterile soil auger, mixed together to form a composite sample (500 g), and stored at 4 ^{o}C for further analysis. Nematode extraction was done by decanting, sieving, and centrifugal flotation, according to Spaull and Braithwaite (1979). The collection of sweet potato tubers was done randomly based on signs and symptoms caused by PPNs infestation, as described by Duncan and Phillips (2009). For the root-knot nematodes, root galling was observed. Samples were collected and taken to the laboratory for further analysis. Nematodes were extracted from 500 cm^3 subsamples using a semi-automatic elutriator and centrifugal flotation according to (Viaene *et al*., 2021).

Extracted nematodes were then characterized morphologically according to Bhat *et al*. (2021). The nematodes were first killed in hot water, fixed with 5 ml of 4% formaldehyde (10% formalin), and stored at 20 °C awaiting identification. An LCD digital microscope was used for morphological identification of the nematodes at the genus level. Prevalence of PPN was determined using the formula:

$$Nematode\ prevalence = \frac{Number\ of\ nematode\ plant\ parasitic\ nematodes}{Total\ amount\ of\ soil\ assessed\ per\ farm} \text{ x } 100 \ldots\ldots\ldots\ldots\ldots (1)$$

RESULTS

Household Survey of Sweet Potato Farmers

Majority of the respondents preferred sourcing the sweet potato vines from their own farms (49.43%), followed by buying (29.89%), as shown in Table 2. They also practised subsistence farming (55.17%), with the percentage of female respondents being generally higher than that of males with regard to category of farming as shown in Table 2.

There was no significant (χ287, 100 = 3.1031, p = 0.7958) association between age and the kind of farming being practiced by sweet potato farmers (Table 3). Generally, the majority were middle-aged (36-45 years; 31.03%) and the kind of sweet potato farming being practiced was mixed cropping (70.11%), followed by rotational farming (26.44%) and a few practicing mono-cropping (3.45%) as shown in Table 3.

About 30% of the respondents could not recognise symptoms of nematode infestation. Out of these, 22.99% were females and 6.9% were males (Table 4). However, the majority acquired disease knowledge from their farms (33.33%) while about 35% had no knowledge at all. Farmers who acquired disease knowledge from friends ranged from 3.45% in males to 11.49% in females. Farmers who acquired disease knowledge from school ranged from 3.45% in females to 8.05% in males. Very few acquired knowledge from training (5.75%) as shown in Table 4.

There was no significant (χ287, 100 = 0.8784 p = 0.8306) association between the scale of sweet potato farming and the methods used in controlling nematode pests on the farms. The respondents used various intervention methods in management of nematode pests both in small- and large-scale farming (Fig. 1). In total, those who used insecticides with nematicidal effect were 55.59%, followed by nematicides (11.49%) and concoctions (5.75%).

Table 2: Sources of Sweet potato vines and the category of Sweet potato farming

Gender	Source of sweet potato vines			Category of sweet potato farming	
	Own vines	From friends	Buying	Subsistence	Commercial
Male	20 (22.99)	2 (0.00)	12 (13.79)	19 (21.84)	15 (17.24)
Female	23 (26.44)	16 (18.39)	14 (16.09)	29 (33.33)	24 (27.59)
Total	43 (49.43)	18 (20.69)	26 (29.89)	48 (55.17)	14 (44.83)

Table 3: Kind of farming practised based on the age of the farmer in Kirinyaga County

Age	Kind of farming practiced			
	Mono crop farming	Mixed	Rotational	Total
20-35	1 (1.15)	17 (19.54)	4 (4.60)	22 (25.29)
36 - 45	1 (1.15)	20 (22.99)	6 (6.90)	27 (31.03)
46-60	1 (1.15)	15 (17.24)	7 (8.05)	23 (26.44)
Over 60	0 (0.00)	9 (10.34)	6 (6.90)	15 (17.24)
Total	3 (3.45)	61 (70.11)	23 (26.44)	87 (100.00)

Table 4: Knowledge of the Nematode Infestation Symptoms and the Source of Knowledge

Gender	Knowledge Symptoms		Source of Knowledge				
	Yes	No	Training	School	Friends	Farming	None
Male	28 (32.18)	6 (6.90)	2 (2.30)	7 (8.05)	3 (3.45)	13 (14.94)	9 (10.34)
Female	33 (37.93)	20 (22.99)	3 (3.45)	3 (3.45)	10 (11.49)	16 (18.39)	21 (24.14)
Total	61 (70.11)	26 (29.89)	5 (5.75)	10 (11.49)	13 (14.94)	26 (33.33)	30 (34.48)

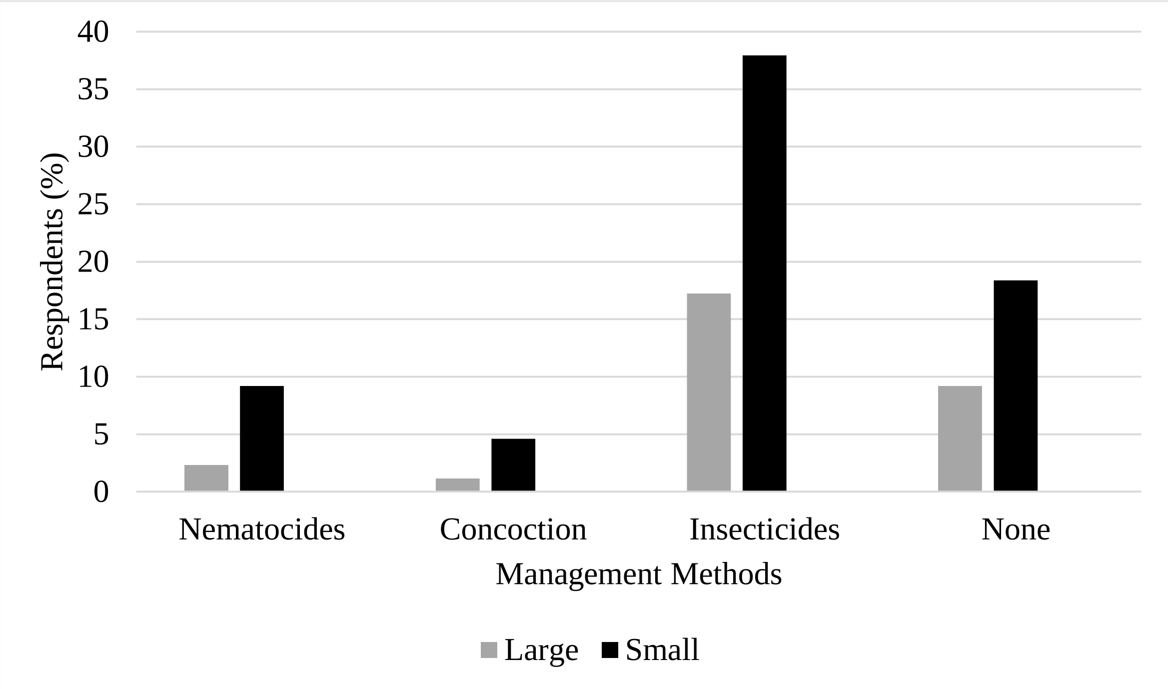

Figure 1: Association between categories of farming and methods used in managing nematodes in Kirinyaga County, Kenya

Distribution of plant parasitic nematodes in sweet potato farms of Kirinyaga County

Seven different genera of PPNs were identified. These were *Meloidogyne, Pratylenchus, Helicotylenchulus, Scutellonema, Rotylenchulus (Reniformis), Heterodera* and *Aporcelaimellus* (Table 5). *Meloidogyne* had the highest prevalence (25%) and distribution (0.161) followed by *Pratylenchus* with a prevalence and distribution of 23% and 0.151, respectively, while *Aporcelaimellus* had the lowest prevalence of 8% (Table 5). The distribution was significantly ($p < 0.05$) different among agro-ecological zones, with UM3 showing the highest prevalence of 31%.

Characterization of Plant Parasitic Nematodes Associated with Sweet potato in Kirinyaga County

There were differences in the shapes and sizes of the extracted mature females of PPNs (Fig. 2). The diameter ranged from 204.3 µm to 437.3 µm. The different developmental stages of PPNs (eggs within mature females, mature females without eggs, second-stage juveniles (J2) and third-stage juveniles [J3]) were also observed (Fig. 3). The formation of galls on sweet potato tubers was also identified (Fig. 4).

Table 5: Prevalence and distribution of plant parasitic nematodes associated with Sweet Potato in Kirinyaga County

Nematode genera	Prevalence (%)	Distribution (*Pi*)
Helicotylenchus Steiner	12	0.081
Heterodera Schmidt	10	0.067
Meloidogyne Göldi	25	0.161
Pratylenchus Filipjev	23	0.151
Aporcelaimellus Heyns	8	0.050
Rotylenchulus Linford and Oliveira	12	0.081
Scutellonema Andrássy	10	0.068
Total	100	

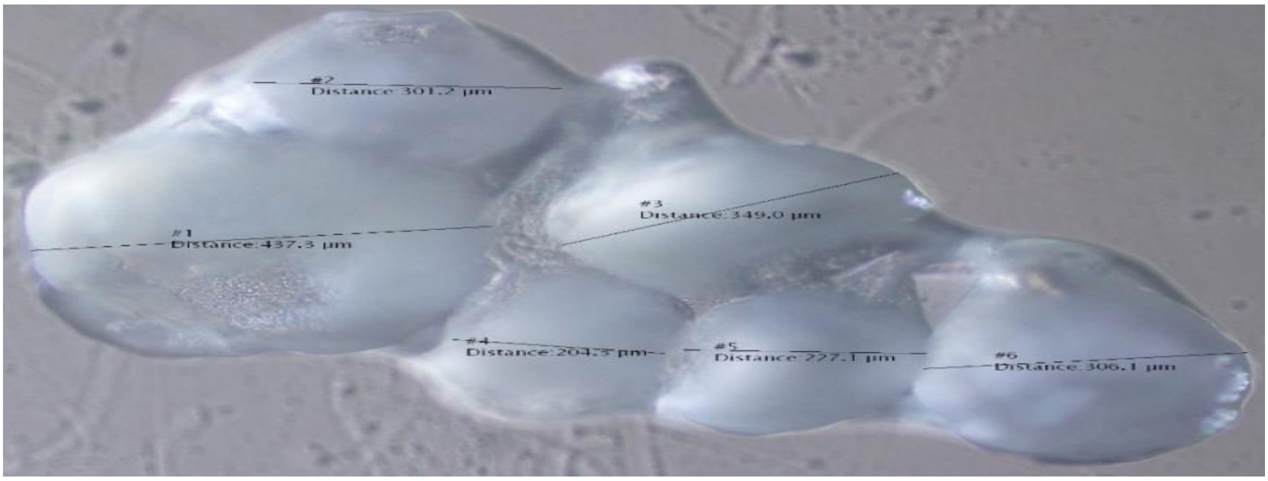

Figure 2: Diameter size of sampled mature females of plant parasitic nematodes associated with sweet potatoes in Kirinyaga County

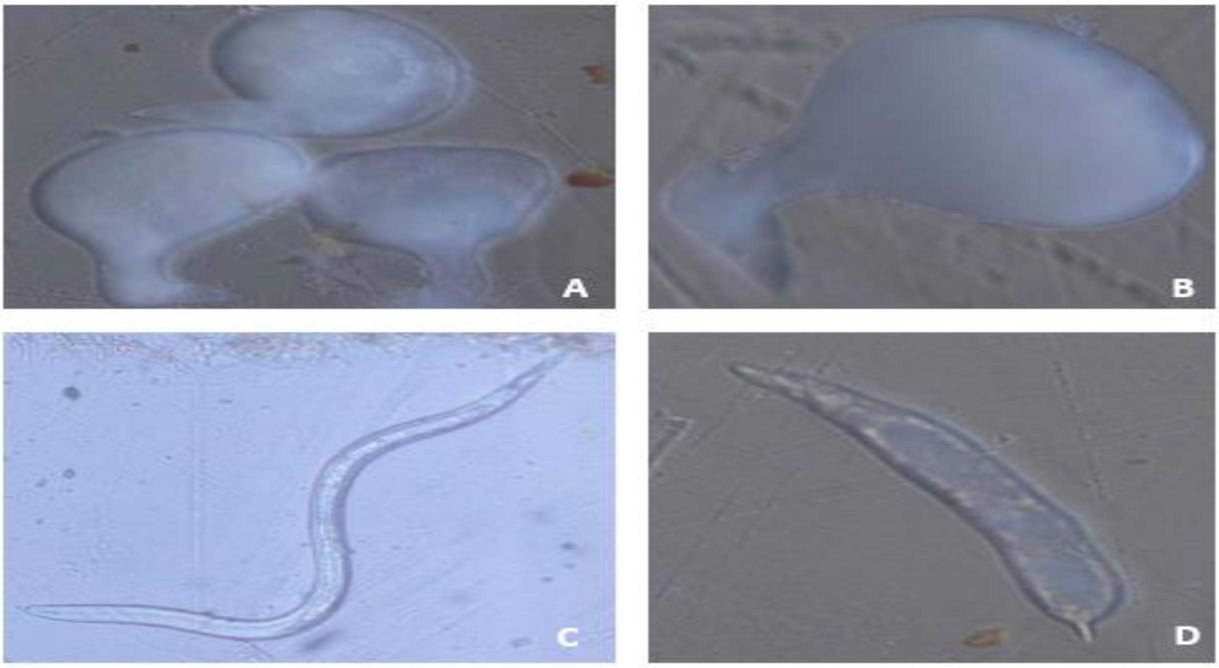

Figure 3: Developmental stages of plant parasitic nematodes (*Meloidogyne* species) as observed under the microscope (A-eggs within mature females; B-mature female without eggs; C-second-stage juveniles (J2) and D-third-stage juveniles [J3])

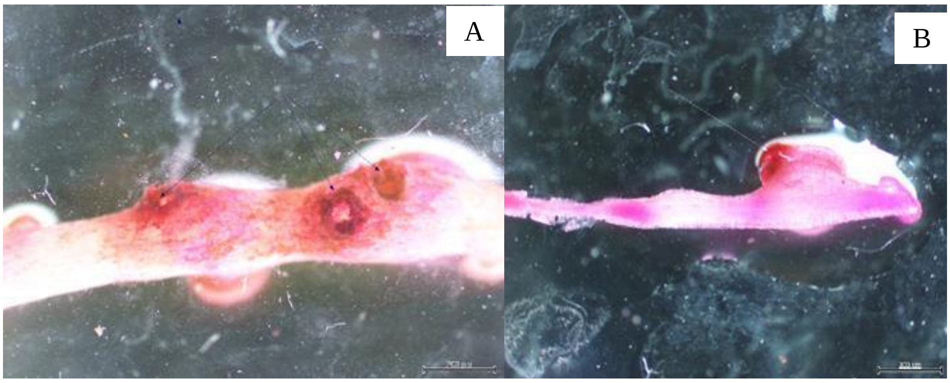

Figure 4: Microscopy observation of galls (root knots) in sweet potato tubers where A shows high severity with more galls on the tuber as compared to B.

DISCUSSION

In this study, female farmers of sweet potato in Kirinyaga County were more numerous than male farmers. In the East African and sub-Saharan Africa regions, sweet potatoes are considered mainly a "female crop" (Orinda, 2013; Egwuonwu and Ozor, 2020) because most of the production is done by female farmers for tubers, which are mainly used as food and fodder for livestock (Kivuva, *et al*., 2014). At the household level, women generally play the dominant role in the production and utilization of sweet potatoes, while men are typically more involved in the transportation and sales transactions of marketed sweet potatoes (Hall, *et al*., 1998; Adetonah, *et al*., 2015). However, due to the women's heavy workload, sometimes important operations such as weeding are not carried out on time, which leads to reduced yields (Makini, *et al*., 2018).

Intercropping sweet potato is a common practice in the semi-arid areas of Kenya (Weerarathne, *et al*., 2017). This may be attributed to the scarcity of agricultural land and the fact that the crop is primarily grown as a subsistence crop. Many African countries intercrop sweet potatoes with cassava, maize, sorghum, and a variety of other crops (Nedunchezhiyan, *et al*., 2012). The crop is also grown on border fields as well as an alleycrop in agro-forestry (Mbayaki and Karuku, 2021). Intercropping of tuber crops is regarded as a non-chemical weed management technique that achieves high productivity (Weerarathne, *et al*., 2017). For instance, Mbayaki and Karuku (2021) reported that intercropping sweet potato varieties with common beans was biologically efficient, although it significantly reduced sweet potato yields of some varieties while mono-cropping yielded a significantly higher yield. Monocropping therefore is the main practice for commercial farming in Kenya (Echodu, *et al*., 2019) although continuous monocropping results in yield decline (Hartemink, *et al*., 2000).

The main source of sweet potato vines for planting is from previous plantings in the respective farmers' farms (Wokorach, *et al*., 2018; Echodu, *et al*., 2019). This may be attributed to timely availability and affordability (Degrande, *et al*., 2013). The source of planting material may be from formal sources associated with improved cultivars, tissue culture plantlets, and low levels of diversity, or from informal seed sources mostly associated with traditional cultivars, suckers, and high levels of diversity (Kilwinger, *et al*., 2020). Informal seed systems are the dominant sources of planting material for vegetative propagated crops such as sweet potatoes and provide farmers with planting material of cultivars adapted to their agro-ecological conditions (Andrade-Piedra, *et al*., 2016). Although a high proportion of farmers are usually aware of the importance of clean seed, only a few actually resort to use of certified seed (Wang'ombe and van Dijk, 2013). Sustainable interventions should therefore be identified to increase the number of seed multiplication gardens to generate enough certified seeds to meet the demand gap (Sugri, *et al*., 2017).

A larger percentage of farmers could only tell of a few symptoms, whereas the rest had no idea of a nematode infestation. Rural farmers are able to successfully detect sweet potato plant disease through observation informed by their farming experiences (Adam, *et al*., 2015). They can holistically classify diseases, but are unable to distinguish between different types of diseases. A variety of symptoms on leaves (leaf yellowing, wilting and curling) are usually identified by farmers, but a few are able to distinguish whether these symptoms are related to viral, bacterial, or fungal diseases (Echodu *et al*., 2019). This recommends plant clinics that would aid in the diagnosis of plant diseases and the training of farmers.

The most common method of managing nematode pests associated with sweet potatoes was the use of insecticides due to their large spectrum of target pests (Oka, 2020). Bashaasha, *et al.*, (1995) also noted that only a few farmers adopted other management interventions in sweet potato farming in Uganda. The use of insecticides with nematicidal effect has shown a progressive reduction of PPN populations due to their broad-spectrum mode of action formulated with some nematicidal ingredients (Schellhorn, *et al*., 2015); hence, farmers heavily depend on them (Sharifzadeh, *et al*., 2018). However, this has reduced the efficacy and enhanced the resistance of some PPNs. The use of insecticides could be attributed to a lack of knowledge on nematode pests associated with sweet potatoes (Osunlola and Fawole, 2015) and insufficient knowledge of pesticides. A few farmers in this study used nematicides. Some nematicides such as the soil-applied organophosphates have been developed for the control of nematode pests in crops (Oka, 2020). However, a time interval must be observed between the last application of the pesticide and the harvesting of edible crops. In different countries, different ranges of nematicides are still authorized for use, but the list is becoming more and more restricted because of the negative environmental impact of the chemicals (Roberts, 2003). Furthermore, none of the nematicides can eradicate nematodes from the soil because individuals can usually survive in deeper levels where they can escape chemical diffusion; re-infestation of the plants will inevitably occur after a few months or years.

Some of the nematode genera such as *Meloidogyne*, *Pratylenchus*, *Radopholus* and *Rotylenchulus* that were identified in this study are among those ranked in the top 10 as PPNs and among the most important destructive species of root-knot nematodes on sweet potato (Adomako, *et al.*, 2020). Jacobsen (2009) recorded species belonging to seven PPN genera across crops that included *Meloidogyne* spp., *Helicotylenchus* spp., and *Scutellonema* spp. However, many studies on PPNs usually focus on *Meloidogyne,* which represents one of the most polyphagous genera of PPNs (Elling, 2013), with over 123 species with a global distribution (Moens and Perry, 2009; Piedra-Buena, *et al.*, 2011; Maleita, *et al.*, 2022). Another genus, *Pratylenchus*, commonly known as lesion nematode (Crow, 2012), is a well-documented pest of sweet potatoes with a yield reduction of up to 30% in susceptible sweet potato cultivars, hence a major target for the development of pest resistance in sweet potato breeding programs (Mizukubo *et al*., 1997). The major challenge is that *Pratylenchus* is a migratory endoparasites and can endure a wide range of environmental conditions (Agrios, 2005). *Radopholus,* on the other hand, attacks agronomic and horticultural crops and many weeds, and is reported to reproduce on more than 250 plant species (O'Bannon, 1977). According to Wang *et al*. (2007), it is one of the main quarantine pests in some counties, and the risk of its invasion is becoming more and more serious with regard to the international trade intensifying day by day.

There were differences in the shapes and sizes of the extracted mature PPN females. Majority of females are usually pear-shaped, have different developmental stages and varied sizes (Tanveer, *et al*., 2015; Berg, *et al*., 2017). The most commonly used morphological traits to identify PPN species include the size and shape of the nematodes' bodies during the adult stage, the intersection of the pharyngeal glands with the intestine, the lack or existence of the stylet, the size of the tail, the position of the head, and the number of ovaries in females (Lambert and Bekal, 2002; Handoo, *et al.*, 2008). However, a thorough morphological investigation, isozyme or host plant analysis, or DNA analysis is required to classify PPNs at the species level. Among the three agro-ecological zones studied, the upper midlands (UM3) had the highest prevalence of plant parasitic nematodes compared to the other two agro-ecological zones. This is supported by Maundu *et al*. (2014) in coffee production, where the upper midland areas were highly infected with PPNs. The variation in agro-ecological zones could be attributed to farming practices, microclimate and soil properties (Mwangi, *et al*., 2014; Namu, *et al*., 2018; Mondal, *et al*., 2023).

CONCLUSIONS

The main source of sweet potato vines was from the respondents' own farms, and this may have contributed to the spread of PPNs from infected plants. Only a few farmers were able to identify symptoms and used insecticides to manage them, an indication that PPN infestations are confused with other pests and diseases. The differences in shapes and sizes of the mature females extracted from PPNs reveal a high level of diversity. Awareness-raising among farmers about the best practices for PPN control and management is therefore necessary.

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