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PREVALENCE OF YAM NEMATODES IN DIVERSE SOIL COMMUNITIES, AND THEIR MORPHOMETRICS IN THE KRACHI-NCHUMURU DISTRICT OF GHANA

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ABSTRACT

Yam (*Dioscorea* spp.) is susceptible to dry rot disease, which limits its yields in farmers fields in West Africa.The objective of this study was to assess the occurrence and characteristics of the plant-parasitic nematode (*Scutellonema bradys*) on yam from the Volta Region of Ghana. A survey was conducted in KrachiI-Nchummuru District in the Volta region in Ghana, using a semi-structured questionnaire in ten communities. Majority of the farmers (62%) were unaware of nematodes and their damage caused to yam. Most interviewees (84%) mentioned the 'pona' yam variety as the most susceptible genotype to rot, especially in storage. Twelve nematode genera were identified in soils, and eight under storage conditions. Soil samples had, for relative abundance, 31.5% of nematodes as *Scutellonema bradys* and 16.8% as *Meloidogyne* spp. On the other hand, relative abundances in yam peels for *S. bradys*, *Meloidogyne* spp. and *Pratylenchus* spp. were 88.4, 6.0 and 3.3%, respectively. Body lenghts of female *S. bradys* ranged from 747.3 to 861.9 um. There was a strong positive correlation between tail length and head region diameter (r = 0.81); and stylet knob height and vulva position (r= 0.68). Agglomerative hierarchical clustering (AHC) showed 5 major groups at a dissimilarity of 90%, with sub-groups formed at dissimilarity value of 50%. In-depth survey of communities in the Krachi Nchumuru district revealed that, *Scutellonema bradys* is a threat to yam production in this region, and results in considerable dry rot disease and yield losses.

Key Words: *Dioscorea* spp., *Scutellonema bradys*

RÉSUMÉ

L'igname (*Dioscorea* spp.) est sensible à la pourriture sèche, qui limite ses rendements dans les champs des agriculteurs d'Afrique de l'Ouest. L'objectif de cette étude était d'évaluer la présence et les caractéristiques du nématode phytoparasite (*Scutellonema bradys*) sur l'igname de la région de la Volta au Ghana. Une enquête a été menée dans le district de KrachiI-Nchummuru dans la région de la

Volta au Ghana, à l'aide d'un questionnaire semi-structuré dans dix communautés. La majorité des agriculteurs (62%) n'étaient pas au courant des nématodes et de leurs dégâts causés à l'igname. La plupart des personnes interrogées (84 %) ont mentionné la variété d'igname « pona » comme le génotype le plus susceptible de pourrir, en particulier pendant le stockage. Douze genres de nématodes ont été identifiés dans les sols et huit dans des conditions de stockage. Les échantillons de sol avaient, pour l'abondance relative, 31,5 % de nématodes sous forme de *Scutellonema bradys* et 16,8 % sous forme de *Meloidogyne* spp. En revanche, les abondances relatives dans les pelures d'igname pour *S. bradys*, *Meloidogyne* spp. et *Pratylenchus* spp. étaient respectivement de 88,4, 6,0 et 3,3 %. La longueur du corps de la femelle *S. bradys* variait de 747,3 à 861,9 um. Il y avait une forte corrélation positive entre la longueur de la queue et le diamètre de la région de la tête (r = 0,81) ; et la hauteur du bouton du stylet et la position de la vulve (r = 0,68). Le regroupement hiérarchique agglomératif (AHC) a montré 5 groupes principaux à une dissimilarité de 90 %, avec des sous-groupes formés à une valeur de dissimilarité de 50 %. Une enquête approfondie des communautés du district de Krachi Nchumuru a révélé que *Scutellonema bradys* est une menace pour la production d'igname dans cette région et entraîne une pourriture sèche considérable et des pertes de rendement.

Mots Clés : *Dioscorea* spp., *Scutellonema bradys*

INTRODUCTION

Yam (*Dioscorea* spp.) plays essential roles in contributing to the dietary needs of the people (FAO World Food summit, 1996). Yam is a major tuber crop that provides food security to over 70 million people (FAO, 2012), especially in West Africa. Yam is an essential source of carbohydrates for populations in the tropical and subtropical areas (FAO, 1994; FAO, 2012).

West Africa cultivates about 80% of the world's yam (Bridge *et al.,* 2005; Coyne *et al.*, 2006; Nweke and Okoye, 2013) as a source of livelihood for farmers and consumers. The crop provides an export opportunity for international traders, especially within the West Africa countries (Asare-Bediako *et al*., 2007). Many species of yam exist, with some posessing medicinal properties (Hsu *et al.,* 2003).

Yam is the second most cultivated root and tuber crop in Ghana after cassava (*Manihot utilisima*) in terms of production and food security (Robertson and Lupien, 2008). Production levels and area for yam harvested in 2018 were 7,858,209 tonnes and 448,404 ha; respectively, with yields of 175,248 kg ha^{-1} (FAOSTAT, 2019). The Guinea savanna and forest/savanna transitional zones made up of Northern, Brong Ahafo and Ashanti regions, accounts for about 72% of the total yam produced in Ghana. Additionally, Volta region accounts for about 6% of the country's yam production (MoFA-SRID, 2013).

Despite the significance of yam production in the tropics, the crop is parasitised by numerous insect pests and pathogens, of which yam nematodes (*Scutellonema bradys*) (Steiner and LeHew, 1933; Andrassy, 1958) is of exceptional importance. The yam nematode reduces the quality of yam thus making this produce unmarkable (Cornelius, 2011). The yam nematode destroys seed yams in the field and in storage, hence damaging the quality of planting materials.

Scutellonema bradys infected yam tubers are also reported to have a weight loss of 0 to 80 % compared to the healthy tubers (Adesiyan *et al.*, 1977).

Inadequate knowledge among producers, relating to management of *S. bradys* is a contributary factor to the widespread of dry-rot diseases in yam growing areas in West Africa (Jamani *et al*., 2016). Effective management of yam nematode disease therefore, relies on understanding nematode distribution in soil types and in stored yam (Kwoseh *et al.,* 2005).

The objectives of this study were to (i) assess yam farmers' knowledge and perceptions on plant-parasitic nematode occurrence and their management, (ii) identify plant-parasitic nematodes associated with yam in the Krachi Nchumuru District of Ghana and, (iii) utilise morphological characterisation of female *S. bradys* populations to locate the most useful morphometric characters in discriminating among nematode populations using agglomerative hierarchical clustering (AHC).

MATERIALS AND METHODS

Selection of sites and collection of soil and tuber samples. Ten communities were selected purposefully from yam growing areas in the research site, Krachi-Nchumuru District in the Volta region of Ghana (Table 1). The district is located at 8°18'15.7"N/0°5'24.4"W. The district is a major yam growing area in the Transitional agro-ecological zone of Ghana, with a tropical climate. Mean maximum and minimum temperatures of 30 and 25.5 °C are observed in March and August, respectively. The district experiences alternate rainy and dry seasons, with average annual rainfall of 1,300 mm. The relative humidity is high in the rainy season (85%) and low during the dry season (5%) (Ghana Statistical Service, 2014).

Survey procedure. Ten communities were selected purposefully from yam growing areas in Krachi-Nchumuru District. A semi-structured questionnaire was administered in December 2016 to obtain data concerning farmers' land-use intensity, knowledge, perception, experiences, and management of plant-parasitic nematodes on their farms. A focus group discussion was also held with yam farmers and Agricultural Extension Agents (AEAs) in the Krachi Nchumuru District to supplement the survey data. Fifty (50) yam farmers were selected randomly from the study area and questionnaires were pre-tested prior to the interviewes. Nematode infested symptomatic plants and tubers were photographed to facilitate discussions with farmers.

Data analysis. Data collected in the questionnaire were coded and subjected to descriptive statistical analysis using Statistical Package for Social Sciences (SPSS) version 20.

Collection of rhizosphere soil and yam tuber samples. Two farms each from the ten

TABLE 1. Agro-ecological zones, communities and their Global Positioning System (GPS) coordinates selected for the questionnaire survey, soil and tuber sample

	Town	Latitude	Longitude
1	Malla	8° 8.8'N	0° 1.3'W
2	Borae	8° 9.4'N	0° 2.3'W
3	Banda	8° 18.1'N	0° 5.4'W
4	Zongo Michire	8° 12.1'N	0° 7.9'W
5	Chinderi	8° 8.6'N	0° 9.1'W
6	Grubi	8° 11.5'N	0° 13.9'W
7	Korkose	8° 9.3'N	0° 10.7'W
8	Bejamse	8° 3.8'N	0° 13.5'W
9	Kaliako	8° 5.0'N	0° 9.9'W
10	Boafri	8° 3.5'N	0° 9.7'W

communities were selected and soil samples obtained from around the rhizosphere of yam plants. Soil samples were taken randomly at 0 to 15 cm. The soil auger and footwear were washed intermittently to prevent cross-contamination of soil samples and spread of nematodes from one farm to another.

GPS coordinates of the various fields were recorded with a handheld GPS device (Garmin eTrex 20, Switzerland). Tubers of yam were sampled from storage facilities across the ten communities. Three yam tubers each showing symptoms of nematode infestation were collected from two farmers in each of the ten communities, labelled and sent to the Plant Pathology Laboratory of the Department of Crop Science, University of Ghana, Legon for extraction and identification of nematodes.

Extraction and identification of nematodes. Nematodes were extracted from the soil using the sucrose centrifugation method. Sucrose solution was prepared by dissolving 454 g of sugar in distilled water and the volume made up to one litre. The soil samples were mixed and passed through coarse sieves to remove rocks and roots debris. About 200 cm^3 sub-sample was transferred into a beaker from the main soil samples. Tap water was added to twice its volume and stirred carefully and the sediments allowed to settle for three minutes before being poured through a stack of 70 µm - aperture mesh on a 36 µm - aperture mesh. Using a water bottle, nematodes (retained on the mesh) were gently washed into centrifugation tubes.

Water was added to centrifuge tubes to equalise volumes and placed in balanced pairs. This was spinned at 1700 rpm for five minutes in an MR 23i benchtop centrifuge (Jouan-Thermo Scientific, U.S.A) without using the brake; and allowed to settle for five minutes. The supernatant was aspirated to about one cm above the pellet. The tubes were filled with sucrose solution at room temperature and stirred with a spatula to break up the pellet. The sample was spinned up to 1000 rpm for one minute. The supernatant was poured through the 36 µm - aperture mesh sieve and transferred into labelled vials up to the 10 ml mark using a fine spray water bottle.

Nematode extraction from yam tubers. Nematodes were extracted from infested yam tubers using modified Baermann funnel method (Whitehead and Hemming, 1965). The tubers were peeled and cut into pieces, before 50 g of yam peels were used for nematode extraction. The yam peels were blended for five second seconds and placed into a glass funnel lined with tissue paper placed on a wire mesh. Tap water was poured gently into the funnel in which the mesh was placed until there was enough water in the funnel. The set-up was left for 48 hours and the water was poured separately into beakers and left overnight for the nematodes to settle. The supernatants were then poured through 70 µm mesh on 36 µm sieve. A spray water bottle was used to wash the nematodes into vials to a final volume of 10 mL. The examination of nematodes was done using a compound light microscope (Exacta-OptechBiostar B5P, Germany). Morphological features were used to identified nematode to both genus and species level by using techniques (Luc *et al.,*1990) and the University of Nebraska Lincoln nematode identification website (http://nematode.unl.edu/konzlistbutt.htm). The adult nematodes were used for the identification.

Morphological observations. Morphological characterisation was performed on 10 female nematodes from each sample. Picking and manipulation of the nematodes were done using a fine eyelash mounted on a steel needle unto the centre of a clean glass slide. The nematodes were heat-killed by adding a hot (~70-75ºC) Formalin–acetic acid–alcohol (FAA) fixative on a glass slide, covered with a coverslip (Hooper *et al.,* 2005) and sealed using clear nail polish. The prepared slides were observed under a binocular compound light microscope connected to a computer with

Scope- Image-Professional Imaging software (Version 9.0) for processing and storing the images.

The Scope- Image-Professional Imaging software was used to snap digital pictures from the slides of the nematode specimen at 100x, 200x and 400x magnification. The measurements obtained included the total body length, greatest body width, stylet length, tail length and hyaline tail length. De Man's ratios a = (total body length /greatest body width) and c = (total body length /tail length) were also calculated.

Some important computations. Population density (PD) of nematodes per 200 cm^3 of soil and 50 g tuber peel samples, frequency of occurrence (FO) and relative percentage of abundance (RA%) were calculated according to Norton (1978) as follows: PD = average number of nematodes per 200 cm^3 of soil and 50 g tuber peel root samples, FO = (number of ûelds containing a particular genus or species /total number of ûelds sampled) and RA% = the number of individuals of a nematode genus or species / the total number of nematodes identiûed and counted from 200 cm^3 soil or 50 g tuber peel ×100.

Data analysis. Data from questionnaires were analysed using an SPSS version of PASW Statistics 20 (http://www.spss.com.hk/statistics). Agglomerative Hierarchical Clustering (AHC) (Ward, 1963; Everitt *et al*., 2001) was also used to generate a dendrogram to discern the various groups and sub-groups of classes within female *S. bradys* populations using Microsoft Excel XLSTAT (Version 2017, Addinsoft, Inc., Brooklyn, NY, USA).

RESULTS

Farmer perception of plant-parasitic nematodes occurrence and control. Majority of the farmers (54%) had been cultivating yam for more than 15 years; while 10% had been in yam farming between 12 - 15 years, and 26% between 6-10 years, and 10% have been in yam farming between 1-5 years.

Most of the yam farmers (40%) used their own saved seed yam, whereas 12% of the farmers got their planting materials from family members, others (18%) from the market. Twenty percent (20%) obtained yam seed from market and family members.

Majority (98%) of yam farmers cultivated 'pona' variety, other varieties cultivated on a lower scale included 'Olondo' ,'Asobayere', 'Kplinjo', 'Nyame nti' and 'Nkunuku'. The 'Pona' yam variety was intercropped with cassava (14.0%), maize (24.0%), other yam varieties (18.0%), groundnut (16%), cowpea (8.0%), soybean(4.0%) and vegetables (16%). Majority of the farmers (54%) cultivated yam for more than 15 years, 10% for 12-15 years, 26% for 6-10 years and 10% 1-5years.

The respondents indicated observing nematode infection in all types of soils. Lowland sandy soils (38%), well-drained sandy soils (10%), sandy soils (16%), sandy clay soil (18%), loamy soil (4%), and clay soil (18%). Control strategies used by farmers to combat nematode disease at the study areas were as follows: majority of farmers (50%) did not control, 20% destroyed the infested tubers, 10% used land rotation, crop rotation, and nematicides to control the disease (Table 2).

Farmer knowledge on nematode parasitism. Majority of farmers (88%) observed external cracks on tubers; while (12%) did not observed these symptoms. Most of the farmers (82%), also observed weight loss of yam tubers in storage, while the rest did not experience significant weight losses, due to nematodes infection.

Majority of the farmers (84%) observed yellow lesions below the outer skin of the tuber; while 16% did not observe the symptoms. Also, majority of farmers (84%) indicated that they observed rotting of the outer 1-2 cm layer of the tuber; however, 16% did not observe such symptoms. About 80% of

TABLE 2. Farmer perception of plant-parasitic nematodes occurrence, their control and yam characteristics in Krachi Nchumuru district of the Volta region of Ghana

Variable	Percentage of growers (%)
Source of seed yam by farmers	
Farmer saved seed	40
Family member	12
Market	18
Market and family member	20
Farmer saved seed and family	10
Farmer saved seed and market	10
Varieties of yam	
Pona	98.0
Olondo	1.0
Mpoano	1.0
Crops intercropped with yam	
Cassava	14.0
Cowpea	8.0
Soybean	4.0
Vegetables	16.0
Maize	24.0
Groundnut	16.0
Yam	18.0
Period of cultivating yam	
1-3 years	30.0
4-6 years	24.0
7-10	12.0
11-15 years	4.0
Ã15 years	30.0
Type of soil associated with nematode parasitism of yam tubers	
Lowland sandy soil	38.0
Well-drained sandy soil	10.0
Sandy clay	16.0
Sandy soil	14.0
Loamy soil	4.0
Clayey soil	18.0
Control strategies/measures	
land rotation	10.0
Crop rotation	10.0
Nematicides	10.0
Destruction of infected tubers	20.0
Use of organic fertilisers	0.0
Others	0.0
No control	50.0

farmers indicated they observed flaking of external coverings with dark brown patches, while the rest did not observe any of the symptoms. Most farmers (88%) experienced general decay of yam tubers during storage, however, 12% did not.

Postharvest losses of harvested yam. The percentage of farmers who experienced post-harvest losses from 2013 to 2016, varied based on the year of cultivation. Less than 10% of farmers experienced over 50% of losses in 2016 (Fig. 1). Over 30% of farmers had the highest losses incurred in 2014, with a range within 30 to 39%.

Genera of plant-parasitic nematodes associated with yam rhizosphere and yam tubers in storage. Twelve nematode genera were identified in soils within yam rhizosphere and yam tubers in storage, with seven families from the Order Rhabdida and Dorylaimida (Table 3).

Frequency of occurrence of plant-parasitic nematodes associated with yam rhizosphere. *Scutellonema bradys* was identified in all the soil samples from all the communities, with a relative abundance of 31.5% (Table 4). Frequency rating of *Meloidogyne* spp. was 75%, with relative abundance of 16.8%. *Longidorus* spp. was identified in 17 farms with a relative abundance of 12.5%. *Helicotylenchus* spp. had a frequency occurrence of 55% and was identified in 11 farms. *Longidorus* spp. was also identified in 11 farms.

Densities of nematodes of soils within yam rhizosphere of harvested yams and yams in storage. The mean population densities of nematodes from the rhizosphere showed that *S.bradys* had the greatest nematode populations (65). *Scutellonema bradys* was found in all the çommunitie's rhizosphere samples, with Bejamse soils having the highest nematode population (10). *Meloidogyne* spp. and *Pratylenchus* spp. were found in 6 of the 10 communities (60%) (Table 5). The relative abundance of nematodes in yam peels ranged from 0.1 to 88.4% for *Heterodera* spp. and *S. bradys*. *Meloidogyne* spp. and *Pratylenchus* spp. had relative abundances of 6 and 3.3%, respectively (Table 6).

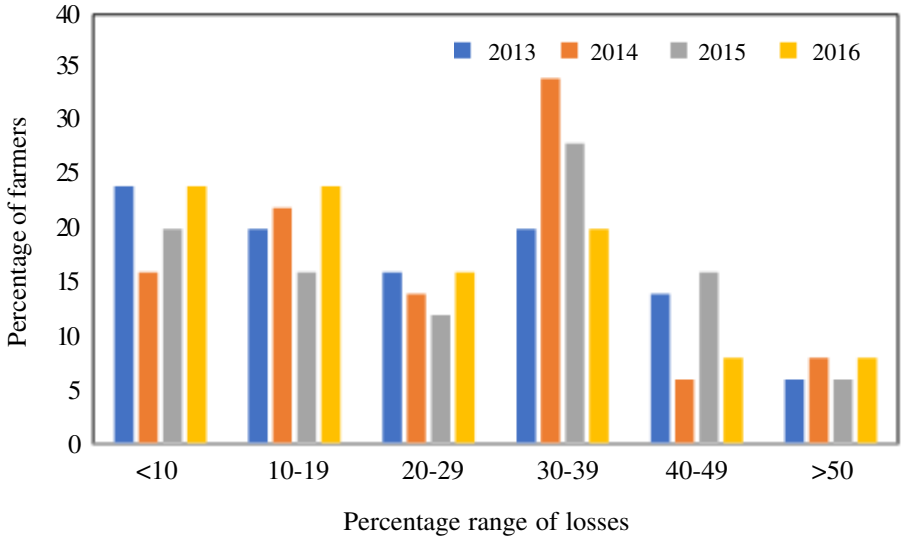

Figure 1. Percentage of farmers with yam tuber losses to dry rot disease from 2013 to 2016.

TABLE 3. Plant-parasitic nematodes extracted from the soil in yam rhizosphere in the Krachi Nchumuru district of the Volta region in Ghana

Order	Sub Order	Family	Genus
Rhabditida		Pratylenchidae	*Pratylenchus*
		Hoplolaimidae	*Helicotylenchus*
			Heterodera
			Rotylenchulus
			Scutellonema
		Aphelenchoididae	*Aphelenchoides*
		Meloidogynidae	*Meloidogyne*
		Tylenchulidae	*TylenchulusTylenchus*
			Paratylenchus
Dorylaimida	Dorylaimia	Longidoridae	*Longidurus*
		Anguinidae	*Ditylenchus*

TABLE 4. Relative abundance of nematode in soil in yam rhizosphere

Nematode genera	Frequency of occurrence	% Frequency rating*	Nematode population/ 200 cm^3 soil	Relative abundance %**
Scutellonema bradys	20	100	131	31.5
Meloidogyne spp.	15	75	70	16.8
Helicotylenchus spp.	11	55	46	11.1
Longidorus spp.	17	85	52	12.5
Ditylenchus spp.	2	10	3	0.7
Rotylenchus spp.	4	20	10	2.4
Bursaphelenchus spp.	3	15	3	0.7
Paratylenchus spp.	6	30	10	2.4
Pratylenchus spp.	5	25	19	4.6
Apelenchoides spp.	2	10	2	0.5
Heterodera spp.	9	45	18	4.0
Tylenchulus spp.	11	55	52	12.5

*n/NX100(n=frequency of individual nematode occurrence. N=sample size (20)
**In/TN (In individual genera in all samples, TN=Total Nematode population in all genera)

Mean population densities of nematodes from yam tubers in storage ranged from 16 to 15,619 for *Radopholus* spp. and *S. bradys,* respectively. The highest and lowest nematodes populations were from Kaliako (8,067) and Bejamse (69), respectively. The top three nematode species populated were *Scutellonema bradys* (15,619), *Meloidogyne* spp. (1054), and *Paratylenchus* spp. (580), respectively (Table 7).

Morphometric characterisation of *Scutellonema bradys* from yam peels. The mean total body length of the *S. bradys*

TABLE 5. Densities of nematodes from soil 200 cm^3 in yam rhizosphere in the Krachi Nchumuru district of the Volta region in Ghana

Community	*Scutello-nema* bradys	*Meloido-gyne* spp.	*Paratyle-nchus* spp.	*Longi-dorus* spp.	*Dityle-nchus* spp.	*Rotyle-nchus* spp.	*Tylenchu-lus* spp.	*Hetero-dera* spp.	*Apend-choides* spp.	*Helico-tylenchus* spp.	*Tylen-chulums*	*Pratylen-culus* spp.	Total mean
Borae	4	4	0	2	1	0	0	0	1	5	4	1	22
Malla	3	0	2	2	1	1	2	1	2	0	1	1	16
Chinderi	8	0	1	2	0	0	0	0	0	3	0	0	14
Zongo	6	5	1	0	7	0	0	0	0	2	0	1	22
Banda	8	2	2	1	0	0	0	1	0	0	1	0	15
Kaliako	8	5	1	2	2	0	0	2	1	0	6	0	27
Kokorse	6	0	5	6	9	1	0	1	1	2	0	0	31
Bejamse	10	0	0	4	0	0	0	3	1	6	2	0	26
Grube	4	2	0	3	1	3	0	1	1	2	4	1	22
Boafri	8	5	0	4	0	0	1	1	0	2	8	0	29
Total	65	23	12	26	21	5	3	10	7	22	26	4	224

populations ranged from 747 to 861 µm (Table 8). The ratio 'a' ranged from 17.4 to 30.0 µm with a mean of 25.4 µm. The range of ratio 'c' was 82.4 -130.6 µm and the rhizosphere mean of 100.6 µm. The ratio 'c'' ranged from 0.3 to 0.5 µm.

The stylet length also ranged between 18 and 28.1 µm, with Banda having the highest mean stylet length (23.9 µm) among the nematode populations. The tail length of the *S. bradys* ranged between 5.7 and 9.3 µm. The average lip region diameter of *S. bradys* was 9.8 µm ranging from 7.3 and 11.9 µm. The diameter at the head region ranged from 11.3 to 27.8 µm. The tail diameter ranged from 15.4 and 17.6 µm in all the communities' and mean measurement was 15.6 µm. The longest tail diameter (17.6 µm) was obtained from nematodes extracted from yam peels obtained from Banda. The stylet knob width ranged from 3.1 µm and 5.9 µm.

Correlation between morphometric characters. There was a strong positive correlation between tail length and head region diameter (r = 0.81); and stylet knob height and vulva position (r= 0.68) (Table 9). Moderate positive correlations were obtained between lip region diameter and head region diameter (r= 0.46), lip region diameter and tail region diameter (r= 0.48), lip region height and scutellum length (r= 0.47), and vulva position and scutellum length (r=0.50). Most of the other variables were weakly positively or negetively correlated.

Agglomerative Hierarchical Clustering. Agglomerative hierarchical clustering (AHC) revealed five groups at a dissimilarity of 90% (Fig. 2). However, below 50% of sub-groups were formed as nematodes from different sites clustered together, irrespective of their communities. Nematodes from Groups one and two consisted only of nematodes from the Banda community, however, the other groups were made of nematodes from varying communities.

TABLE 6. Relative abundance of plant-parasitic nematodes in yam tuber peels

Nematode genera	Frequency of occurrence	% frequency rating*	Nematode population /50g peels	Relative abundance (%)
Scutellonema bradys	20	100	15,619	88.4
Meloidogyne spp.	20	100	1,054	6.0
Pratylenchus spp.	20	100	580	3.3
Heterodera spp.	2	10	19	0.1
Helicotylenchus spp.	1	5	180	1.0
Paratylenchus spp.	4	20	140	0.8
Radopholus spp.	2	10	16	0.1
Tylenculus spp.	1	5	60	0.3

*n/NX100(n=frequency of individual nematode occurrence. N=sample size (20) **In/TN (In individual genera in all samples, TN=Total Nematode population in all genera)

DISCUSSION

The spread of dry-rot disease was a result of inadequate knowledge of management strategies of nematodes in both field and storage environments. This included improper cultural practices e.g., mono-cropping systems, non-removal of an alternative host plants, and placement of yams on floors of yam barns. Nematode inoculum can survive on alternate host plants, especially those with underground food storage over long periods (Luc *et al*., 2005; Sikora and Fernandez, 2005). Abundant food sources for nematodes aids in completion of their life cycles, postively imparting their spread, through soil particles, and their movement from one location to another through adherence to farm tools and footwear (Hunt *et al.,* 2005).

The major sources of infected planting materials could be through seed yams, which may not be produced under certified protocols (Kwoseh *et al*., 2005). Farmers used their personal planting materials due high cost of seed yams (Nweke *et al.,* 1991; MiDA, 2010).

In the present study, an increase in yield loss by farmers could be associated with the parasitic nature of *S. bradys*, resulting in decrease in yam tuber quality, with estimated losses of over 75% for yams in storage (Jakata and Bridge 1990; Coyne and Affokpon, 2018). Furthermore, the absence of application of manure by farmers to yam fields in the various districts, also contributed to nematode population build up. Manure not only improves soil quality, but also drastically reduces nematode populations, through release of toxic substances in soils (Wachira *et al.*, 2009).

Nematode infestation is a serious constraint in yam production in various parts of the world (Kwoseh *et al.,* 2005; Baimey, 2006; Kumar and Singh, 2010). The percentage of increase of *Scutellonema bradys* in stored yam tuber indicated that this pest can reproduce on stored yam tubers rapidly (Kwoseh *et al.,* 2005). In this study, the predominant nematodes in both soil and yam tuber peels were *S. bradys*, *Meloidogyne* spp., and *Pratylenchus* spp. In previous studies (Adesiyan and Odihirin, 1977), *Scutellonema* spp., *Pratylenchus* spp., *Meloidogyn*e spp., *Helicotylenchus* spp., *Criconemoides* spp, and *Xiphinema* spp. were the most important nematode species identified on yam in the Mid-West State of Nigeria.

A study conducted in Ghana identified the top three nematodes with high relative abundances from yam peels as *Pratylenchus* spp. (32.4%), *Scutellonema bradys* (18.2%), and *Meloidogyne* spp. (21.3%) (Jamani *et al.,* 2016). However, in the present study, the top

TABLE 7. Densities of nematodes from yam tubers in storage in Krachi Nchumuru district of the Volta region in Ghana

Community	*Scutello-nema bradys*	*Meloido gyne* spp.	*Pratyle-nchus* spp.	*Rado-pholus* spp.	*Hetero-dera* spp.	*Helicoty-lenchus* spp.	*Tylenchu-lus* spp.	*Paratyle-nculus* spp.	Total mean
Borae	390	10	5	10	6	20	0	0	441
Malla	1620	14	25	0	0	0	0	0	1719
Chinderi	2633	450	230	0	13	100	0	0	3426
Zongo Michire	109	96	39	0	0	0	0	0	274
Banda	430	105	46	6	0	40	0	0	627
Kaliako	7767	96	44	0	0	0	60	100	8067
Kokorse	150	63	80	0	0	20	0	0	313
Bejamse	20	0	49	0	0	0	0	0	69
Grube	500	200	52	0	0	0	0	20	772
Boafri	2000	20	10	0	0	0	0	20	2050
Total	15619	1054	580	16	19	180	60	140	17758

TABLE 8. Morphometrics of *Scutellonema bradys* females from Krachi Nchumuru district of the Volta region in Ghana

Location	Chinderi	Bemjamse	Grubi	Boafri	Zongo Micheri
Body length	794.0±40(624.6-965)	774.0±24.8(624.6-996.1)	861.9±96.4(624.6-932.3)	754.4±11.0(624.6-932.3)	752.4±13.0(624.6-886.54)
A	25.2±14.9(10.3-24.3)	24.8±8.6(20.1-24.3)	25.8±8.6(28.0-28.5)	25.8±11.0(24.3-28.0)	25.7±13.0(24.3-28.0)
C	106.4±0.0(82.4-122.1)	98.7±0.2(86.0-110.3)	100.0±0.1(100.7-130.6)	99.1±0.0(100.7-130.6)	98.8±0.0(100.7-110.3)
C’	0.5±0.1(0.3-0.5)	0.5±0.(0.4-0.5)	0.5±0.1(0.4-0.5)	0.5±0.7(0.4-0.5)	0.5±0.1(0.4-0.5)
S	1.6±0.2(1.3-1.8)	1.4±4(1.4-1.5)	1.4±0.1(1.4-1.7)	1.4±0.1(1.4-1.7)	1.4±0.8(1.4-1.7)
Stylet length	24.4±1.4(20.7-26.4)	22.7±0.3(19.1-25.4)	22.6±0.5(19.1-25.4)	22.6±0.5(19.1-25.4)	22.6±0.5(19.1-25.4)
Diameter at mid body	32.0±1.9(25.7-77.2)	31.2±1.1(25.7-44.2)	29.2±0.9(25.7-33.2)	29.2±0.9(25.7-33.2)	29.2±0.9(25.7-33.2)
Tail length	7.6±0.0(3.6-9.7)	7.8±0.2(5.7-9.3)	7.5±0.1(5.7-9.3)	7.6± 0.0(5.7-9.3)	7.6±0.0(5.7-9.3)
Lip region diameter	9.9±0.3(7.3-11.9)	9.9±0.4(7.4-11.9)	9.8±0.4(7.4-11.8)	9.8± 0.4(7.4-11.8)	9.8±0.4(7.4-11.8)
Diameter at head region	15.3±1.6(11.3-19.6)	15.9±1.1(13.3-18.8)	16.2±0.7(11.5-17.8)	16.2±0.7(11.5-17.8)	16.2±0.7(11.5-17.8)
Diameter at tail region	14.3±1.8(13.2-17.6)	15.2±0.9(13.2-17.6)	15.3±0.8(13.3-17.6)	15.4±0.7(13.3-17.6)	15.3±0.8(13.3-17.6)
Stylet knob height	3.8±0.1(3.3-4.5)	4.1±0.2(3.3-4.5)	3.8±0.1(3.3-4.5)	3.8±0.1(3.3-4.5)	4.4±0.4(3.3-4.5)
Stylet knob width	4.5±0.4(3.1-5.9)	5.1±0.2(3.8-5.9)	4.9±0.0(3.8-5.8)	4.9±0.0(3.8-5.9)	4.8±0.1(3.8-5.9)
Lip region height	4.5±0.2(3.0-6.0)	4.8±0.1(3.4-6.0)	4.6±0.1(3.4-6.0)	4.6±0.1(3.4-6.0)	5.5±0.8(3.4-6.0)
Position of vulva to interior	366.8±11.1(304.35-456.8)	409.2±31.3(313.6-498.9)	362.3±15.6(317.6-412.5)	362.3±15.6(3.8-5.8)	362.3±15.6(3.8-5.8)
Scutellum height	6.2±0.2(3.3-9.6)	6.7±0.3(5.4-8.9)	64±0.1(5.4-8.9)	6.4±0.1(5.4-8.9)	5.5±0.9(5.4-8.9)
Scutellum width	4.8±1.4(3.3-6.5)	3.6±0.3(2.0-4.9)	3.3±0.1(2.0-4.9)	3.3±0.1(2.0-4.9)	3.3±0.1(2.0-4.9)

TABLE 8. Contd.

Location	Borae	Kaliako	Korkorse	Banda	Malla
Body length	754.4±11.0(624.6-886.5)	767.2±1.8(624.6-932.3)	747.3±18.1(624.6-952.6)	756.5±6.8(624.6-932.3)	786.5± 21.1(624.6-955.8)
A	25.8±11.0(24.3-28.0)	26.3±1.8(24.3-30.0)	24.8±18.1(12.1-24.3)	23.0±6.8(17.1-24.3)	27.0±21.1(23.7-28.0)
C	99.1±0.0(99.7-110.3)	101.0±0.0(106.5-110.3)	99.8±0.1(100.7-110.3)	100.7±0.1(102.9-110.3)	101.5±0.1(102.9-100.3)
c'	0.7±0.7(0.4-0.5)	0.5±0.7(0.4-0.5)	0.5±0.6(0.4-0.5)	0.3±7.5(0.3-0.4)	0.5±0.5(0.4-0.5)
S	1.5±0.0(1.4-1.6.)	1.4±0.0(1.3-1.7)	1.4±0.1(1.5-1.7)	1.5±0.1(1.4-1.6)	1.4±0.0(1.5-1.6)
Stylet length	22.6± 0.5(19.1-25.4)	22.9±0.1(19.1-25.4)	22.9±0.1(19.1-26.4)	23.9± 0.9(19.7-26.0)	23.1±0.1(18.1-28.1)
Diameter at mid body	29.2±0.9(25.7-33.2)	29.1±1.0(25.7-33.2)	30.2±0.0(25.7-77.2)	32.9±2.8(25.33.4)	29.2±1.0(26.2-33.2)
Tail length	7.6±0.0(5.7-9.3)	7.6±0.0(5.7-9.3)	7.5± 0.1(5.7-9.3)	7.5±0.1(5.7-9.3)	7.8±0.1(5.7-9.3)
Lip region diameter	9.8±0.4(7.4-11.8)	9.9± 0.3(7.4-11.8)	9.8± 0.4(7.4-11.8)	10±3.4(7.4-11.8)	9.8±0.4(7.4-11.8)
Diameter at head region	16.2±0.7(11.5-17.8)	16.4±0.6(11.5-17.6)	16.3±0.6(11.5-17.8)	24.1±7.1(11.5-27.8)	16.7± 0.2(11.5-17.8)
Diameter at tail region	15.4±0.7(13.2-17.6)	15.4±0.7(13.2-17.6)	15.5±0.6(13.2-17.6)	17±0.9(15.3-17.3)	15.7± 0.5(13.2-17.6)
Stylet knob height	3.8±0.1(3.3-4.5)	3.9±0.0(3.3-4.5)	3.8± 0.1(3.3-4.5)	3.8±0.7(3.3-4.5)	3.8±0.1(3.3-4.5)
Stylet knob width	4.9±0.0(3.8-5.9)	4.9±0.0(3.8-5.9)	4.8±0.1(3.8-5.9)	5.2±0.3(3.8-6.0)	5.1±0.2(3.8-8.0)
Lip region height	4.6±0.1(3.4-6.0)	4.7±0.0(3.4-6.0)	4.6±0.1(3.4-6.0)	5.1±0.4(3.4-6.0)	4.7±0.0(3.4-6.0)
Position of vulva to interior	362.3±15.6(304.5-412.5)	366.8±11.1(304.-456.8)	362.9±15.0(304.6-412.5)	461.0±83.1(304.6-456.8)	363.0±14.9(304.6-412.5)
Scutellum height	6.4±0.1(5.4-7.7)	6.5±0.1(5.4-7.7)	6.3±0.1(5.4-7.7)	6.4±0.1(5.4-7.7)	6.8±0.3(5.4-8.9)
Scutellum width	2.3±0.1(2.3-4.2)	3.3±0.1(2.3-4.2)	3.2±0.2(2.3-4.2)	4.0±0.6(2.3-4.2)	3.2±0.2(2.3-4.2)

Measurement (µm) and ratios are in the form of mean ± standard deviation (range)a = body length/diameter at mid body, c = body length/tail length, c' = tail length/diameter at tail region, s = stylet length/diameter at head region

TABLE 9. Correlation matrix (Pearson) (n) for *S. bradys* female morphometric variables

Variables	Body length	Stylet length	Diameter at mid-region	Tail length	Lip region diameter	Head region diameter	Tail region	Stylet knob diameter	Stylet knob	Lip region height	Vulva position width	Scutellum height height	Scutellum length
Body length	**1**												
Stylet length	0.059	**1**											
Diameter at mid region	-0.096	-0.102	**1**										
Tail length	0.278	-0.336	0.291	**1**									
Lip region diameter	-0.031	0.075	0.179	0.23	**1**								
Head region diameter	-0.002	0.019	0.192	0.112	**0.455**	**1**							
Tail region diameter	-0.032	-0.101	0.123	0.155	**0.482**	**0.812**	**1**						
Stylet knob height	0.206	0.31	0.099	-0.145	0.192	0.19	0.275	**1**					
Stylet knob width	0.14	0.109	-0.156	-0.241	-0.01	0.111	0.12	0.266	**1**				
Lip region height	0.031	-0.041	0.113	0.203	0.238	0.242	0.174	0.113	-0.227	**1**			
Vulva position	0.358	0.125	0.192	0.136	0.227	0.29	0.304	**0.681**	0.377	0.223	**1**		
Scutellum height	0.088	-0.05	0.291	0.195	0.075	0.118	-0.181	-0.039	-0.017	0.238	0.081	**1**	
Scutellum length	0.134	0.088	0.218	0.142	0.291	0.141	0.122	0.376	0.16	**0.472**	**0.502**	0.278	**1**

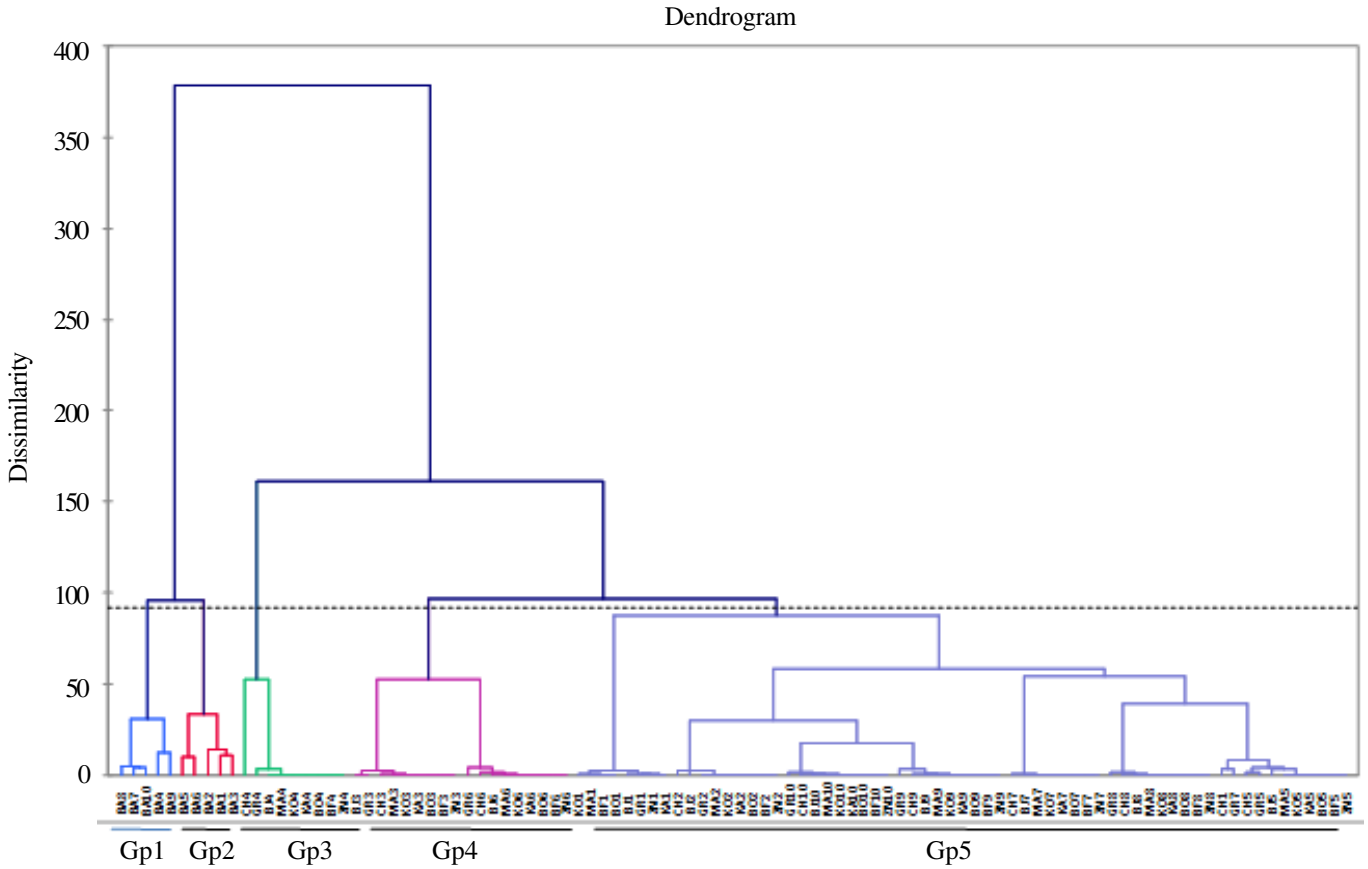

Figure 2. Agglomerative Hierarchical Clustering (AHC) of nematodes from ten communities in Krachi Nchumuru district of the Volta region in Ghana.

MA = Malla, BO = Borae, CH = Chinderi, ZN = Zongo Macheri, BA = Banda, KO = Kokorse, BJ = Bejamse, KA = Kaliako, BF = Boafri, and GR= Grubi; 0-10 = Number of *Scutellonema bradys* (female) morphometrically characterized from each community. Colour codings: Light blue-Group 1 (Gp1), Red-Group 2 (Gp2), Green-Group 3(Gp3), Purple-Group 4, and Deep Blue-Group 5(GP5)

three nematodes from yam peels were *Scutellonem*a *bradys* (88.4%), *Meloidogyne* spp. (6.0%), and *Pratylenchus* spp. (3.3%).

A comparison of the morphometric measurements in our study with others described in literature shows slight differences. Inthe present study, body lengths ranged from 624.6 - 996.1 µm, although, in a study by Jamani *et al*. (2016), body lengths ranged from 624.6 - 858.5 µm.

In our study, although AHC showed groups and sub-groups, nematodes from different communities clustered in each of these groups, because of overlaps in morphometrics among the populations. *Scutellonema brachyurus* populations from the United States (type A), South Africa (type B), and Taiwan (Type B) distinctly clustered from each other through factor analysis (Van Den Berg *et al*., 2013). The lack of distinct grouping for female *S. bradys* population in the current study could be due to the absence of similarities among the morphometrics within the populations studied.

CONCLUSION

Lack of knowledge among most farmers on nematodes and their management was responsible for most of the losses of yam both in the field and storage in the Volta region in Ghana. Twelve and eight nematode genera were identified in soils, and from yams in storage environments, respectively. The top three nematode species in storage were *Scutellonema bradys* (15,619), *Meloidogyne* spp. (1054), and *Paratylenchus* spp. (580), respectively. Correlations among the female morphometric characters existed with a strong positive correlation between tail length and head region diameter (r = 0.81). Agglomerative hierarchical clustering (AHC) showed five groups with a dissimilarity of 90%. Significant morphological variation exists within female *S. bradys* populations, because of sub-group formations among the nematode populations. Agglomerative hierarchical clustering (AHC) was therefore a useful tool for discrimination of *S. bradys* populations. Our study should be considered a prelude to extensive molecular analysis of the 18S and ITS1 rRNA regions in the *S. bradys* genome, will further be based on the morphometric groupings generated after AHC was performed. This will enable identification of potential signatures for variation in *S. bradys* groups.

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