PARASITIC NEMATODES ASSOCIATED WITH YAM (*DISCOREA ROTUNDATA*) AND MORPHOMETRIC CHARACTERIZATION OF *SCUTELLONEMA BRADYS* IN THE KRACHI NCHUMURU DISTRICT, GHANA

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF M. PHIL CROP SCIENCE DEGREE

JULY, 2017
DECLARATION

I certify that this study was conducted by me Abdullah Kwame Enchill of Crop Science Department, University of Ghana, Legon at Krachi Nchumuru District and Plant Pathology Laboratory at the University of Ghana Legon. I further testify that this thesis has never been submitted on any occasion at any University for the award of a degree and that any literature cited has been acknowledged.

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ABSTRACT

A dry rot of yam *Dioscorea rotundata* which attacks tubers in the field and in storage is currently threatening production of the crop in the Krachi Nchumuru District of the Volta Region. No detailed investigation has been conducted; therefore a study was carried out from October 2016 to May 2017 to assess the knowledge, perception and experiences of farmers in the District on the occurrence and management of the tuber dry rot disease, isolate, identify and assess plant parasitic nematode genera Krachi Nchumuru District in yam fields and stored yam tubers; determine variation within and among population of *Scutellonema bradys* using morphological and morphometric characteristics. Questionnaire were developed and administered randomly to 50 farmers in 10 communities. The questionnaires covered demographic characteristics, land use intensity, farmers’ knowledge, perception and experience concerning occurrence of nematodes in yam fields and stored yam tubers, management and economic importance of yam nematodes. Yam rhizosphere soil samples were collected from 20 farms in the district for nematode extraction using Jenkins centrifugation method. Three stored yam tubers were also collected from the same farmers for nematode extraction using Baermanns extraction method. Morphometric measurements were carried out on populations of the yam nematode *S. bradys* using compound microscope attached to a computer. The survey revealed that farmers were aware of the tuber dry rot disease, but were however, ignorant about the causes and the spread of the disease, so planting materials were not treated before use. Twelve genera belonging to seven nematode families of order Rhabdida and Dorylaimida were identified in yam rhizosphere soils and nine genera in stored yam tubers. These were *Scutellonema* spp., *Meloidogyne* spp. *Longidorus* spp., *Tylenchulus* spp., *Helicotylenchus* spp., *Ditylenchus* spp., *Heterodera* spp., *Pratylenchus* spp., *Rotylenchus* spp., *Appenlenchoides* spp., *Paratylenchus* spp., and *Bursaphelenchoides* spp. The predominant nematodes *Scutellonema*
spp., *Meloidogyne* spp. and *Pratylenchus* were present in both soil and yam tuber peels. There were low populations of other nematode genera. The most frequently detected genus was *Scutellonema bradys* (131) per 200cc of soil and (34086) in 10 gram tubers peels. Agglomerative hierarchical clustering (AHC) revealed 5 groups at a dissimilarity of 90%, however sub groups formed at dissimilarity value of 5% Significant morphology variation is present in female *S. bradys* population.
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ACKNOWLEDGEMENT

I thank almighty God for giving me life and good health for making this work possible. I sincerely thank my supervisors Dr. E.W. Cornelius and Dr. S. T. Nyaku for their encouragements suggestion and directions. My gratitude also goes to Mr Samuel Osabutey and Mr. W. Asante all of the Crop Science Department. I also thank Mr. Hanif Lutuf of Madina for his encouragement. I sincerely appreciate the warm reception and the help given to me by the staff of Department of Agriculture, Krachi Nchumuru District Assembly, especially Mr. Abusah Kplorla for his enormous help during the field work.

May Almighty God bless them all.
DEDICATION
I dedicate this work to my wife Salamatu and my lovely children.
CHAPTER ONE

1.0 INTRODUCTION

Food security exist when all people, at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO World Food summit, 1996: Halweil, 2002) also defined a nation as food secure, when a country is able to produce enough to feed its citizens awaiting the next harvesting season and readily export the surplus to other nations. One of such food security crops in West Africa is edible yam which feeds over 70 million people (FAO, 2012). It is a very diverse crop covering many species of *Discorea* (Degras 1993). It is among root and tuber crops which contribute to 31% of all food produced in the world (Paulino and Yeung, 1981). It is an important starch and protein staple for people of West Africa and many communities across other parts of Africa, Asia, South and Central America the Caribbean and the Pacific (FAO 1994; FAO 2012).

Yam is also an important socio-cultural crop which is prominent in many cultural and religious festivals of people of West Africa (Tetteh and Saakwa, 1994). Many species also have high medicinal value apart from their food value (Karnick, 1969 Degas, 1993). Yam is the second most cultivated root and tuber crop in Ghana after cassava (*Manihot utilissima*) in terms of production and food security (Robertson and Lupien, 2008). In 2013 total production of yam in Ghana was 6,638,867 metric tonnes out of which Volta Region produced 463,559 MT representing 6.98% (MOFA, SRID, 2013). Krachi Nchumuru District of the Volta Region produced about half of the region’s output.
1.1 Problem statement

Despite the importance of yam, it is attacked by many insect pests and pathogens of which yam nematodes *Scutellonema bradys* (Steiner and LeHew, 1933; Andrassy 1958) is of importance. The situation is a worry to farmers and traders because affected tubers become unmarketable (Cornelius, 2011). This nematode is also threat to cassava (Bridge *et al.*, 2005) and potato (Coyne *et al.*, 2006) which appear to be suitable host. Infected yam tubers mostly have a cracked or flaky surface, under which nematodes feed endo parasitically, destroying cell walls as they multiply and migrate intracellularly, forming cavities and tissue necrosis which turn from brown to black as the disease progress, these symptoms are more severe as the length of storage increases (Coyne *et al.*, 2006). *S. bradys* destruction of yam also depends on level of infection, crop genotype, and soil conditions. (Bridge *et al.*, 2005). Infested yam tubers in storage lose weight of 0 to 80% compared to healthy tubers (Adesiyan *et al.*, 1977). This nematode infestation has resulted in high post-harvest losses leading to scarcity of yam during the storage period. It also has negative impact on the livelihood of these farmers. In order to reduce these losses, an estimated amount of US$500 million was spent on general nematode control on all crops globally (Keren-Zur *et al.*, 2000). Nematodes are difficult to control pest and are considered to be the most destructive in the kingdom metazoan in tropical and subtropical countries (Simpson and Starr, 2001).

In Ghana, *Scutellonema* infestation of yam tubers is a major hindrance to yam production (Kwoseh, 2008). They cause serious damage to yam quality at the fields, in storage and markets and farmers do not use pesticides to control the nematodes. There are chemicals to treat nematodes because some crops cannot be grown economically without the use of nematicide (Hemeng, 1981; Sikora and Fernandez, 2005).
Nematicides such as 1, 3-D and Carbofuran at 5kg ai/ha was recommended for the control of root-knot nematodes in the northern savanna and transitional zones of Ghana for vegetables such as tomatoes. The limitation in the use of these nematicides on the field crops in the developing countries are due to the subsistence nature of many farmers (Luc et al., 2005), high prices of this nematicides (Freckman and Sasser, 1987) and banning from most of the world markets of the fumigants D-D, ethylene dibromide and dibromochloropropene (Luc et al., 2005). The banning of the most effective fumigant methyl bromide, due to its negative effect on the ozone layer, has serious consequences on Ghanaian farmers especially yam producers. Modifying existing agricultural practices such that nematodes populations in the soils can be reduced can be alternatives to synthetic nematicide in tropical Africa (Starr et al., 2001).

Crop rotation can decrease the nematodes population in the soil and therefore reduce number of infested yams in both storage and in the market, biological control can be a successful alternative in future (Evans et al., 1993). The environment can be manipulated to promote biological activity for the near future (Starr et al., 2001). It is, therefore important to look for other methods of control to maintain nematode infestation below economic threshold.

1.2 Justification

The inadequate knowledge about nematodes may be the reason the dry rot disease is common in yam growing areas of Ghana (Nyaku, et al, 2016). Soil nematode distribution and importance have been studied (Addoh, 1971) and nematodes have also been found associated with stored yam (Kwoseh et al., 2005). From available literature, there is no study on farmers’ perception, knowledge and management of dry rot disease of yam tubers as well as accurate identification of the causal organism using morphological features and morphometric analysis. The study was done
to identify and establish the incidence of the causal organism in yam fields and storage facilities in Krachi Nchumuru District of the Volta Region.

The objectives of the study were to

1. Assess knowledge, perception and experiences of farmers in Krachi Nchumuru District on the occurrence and management of dry rot disease of tubers of white yam.
2. Identify and assess population of nematode genera on tubers of white yam (*D. rotundata*)
3. Determine variation within and among population of *S. bradys* using morphometric analysis.
CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. Yam Production
Yam *Discorea* spp. and cassava *Manihot utilissima* are tuber and roots crops produced significantly in West Africa with annual quantities of 24.4 and 51 million tons respectively. These represent 96% and 40% of world production respectively (Korth 1993). It is major source of income for farmers and traders. Throughout the world yam is extensively used but it’s used vary from one country to the other (Degras, 1993). In West Africa yam is grown in well drained sandy loam and fertile soils. Land preparation is done either by ploughing with a tractor or using a hand hoe. Yam is planted either on a mound or a ridge using seed yam or yam setts. It is planted at a distance of 30-40cm on a ridge at 1metre apart. It could also be planted on mounds 1metre apart. In Ghana yam is planted in all the Regions of the country except Greater Accra and Upper East Regions (MOFA SRID, 2014).

2.2 Constrain to yam production
Yam production is affected by several constrains and some of these factors are unavailability and high cost of planting materials, pests and diseases, poor soil fertility, high labour cost, erratic rainfall pattern leading drought and water logging. Nematodes, insects, vertebrates and diseases are the most important impediments to yam production both in the field and storage (Osagie, 1992). Yam tuber rots are the highest losses in storage resulting from infection with micro-organisms such as nematodes, fungi, and bacteria (Knoth,1993). Some strains of pathogenic fungi can
penetrate the yam tuber directly, which is then followed by others. Other fungi pathogens penetrate through lesion, cuts, holes bored by rodents and nematodes. It is known that the pathogens infect yam tubers in the field and in the storage (Ogundana et al., 1970, 1971). Yam tubers have no protective cuticle and the corky periderm and meristematic tissues are few millimetres thick, therefore, damage to the surface requires only a slight force to breech these barriers (Osage, 1992). At harvest and during handling yam tubers may be damaged to a certain degree, the site of excision of the tuber from the aerial plant and any other injury, cuts or abrasion no matter small can provide point of entry for wound pathogen (Pasam et al., 1976). Many authors have also observed that fungi pathogens can enter into the tuber if there are pre-existing physical damage (Cornelius, 1998; Morse et al., 2000).

Various types of rots have been identified on yam tubers and these are characterised as dry, watery and soft rot depending on the consistency of the rotten tissue. Some bacteria also cause rots (Centre for overseas Pest Research, 1978) and rots can infect part of the tuber or a whole tuber. Rots normally affect the tuber consistency, colour and flavour making it no longer suitable for consumption, and also reduce its market value. Dry rot disease of yam tubers is caused by nematode *Scutellonema bradys* which are migratory endo plant parasitic nematodes (Coyne et al., 2006).

### 2.3 Plant Parasitic Nematodes

Many nematode species have been found to be associated with yam and the most important is *Scutellonema bradys* which cause dry rot disease. Lesion nematode *Pratylenchus* spp. and root knot nematode *Meloidogyne* spp. have also been found to be associated with root and tubers (Bridge and Page 1984; Bridge et al., 2005). In other parts of the world (apart from West Africa
where yams are grown) *Pratylenchus caffae* is the most serious nematode of yam (Bridge *et al.*, 2005).

Nematodes are considered to be the most abundant and numerous animals on earth. They are either free-living or parasitic organisms of plants or animals and are present in almost all possible habitats including under the oceans. (Neher *et al.*, 2010) Nematodes are aquatic organisms and their movement depends on moisture. Plant parasitic nematodes are obligate parasites that complete their life cycle partially or entirely in the soil environment in association with plant roots and therefore destroy plant tissue during feeding. They feed on all parts of vascular plants but the most economically important species infect roots and tubers (Hunt *et al.*, 2005). Plant parasitic nematodes exhibit three types of parasitism, i) ecto-parasitism, ii) semi endo-parasitism and iii) endo-parasitism. Some are migratory endo-parasites which means they spend parts of their life cycle in the soil while parts are in the host organism. Others such as *Meloidogyne* spp. are sedentary endo-parasites. The endoparasitic and semi- endoparasitic nematodes induce sophisticated trophic systems of nurse cells or sincytia in their host (Hunt *et al.*, 2005). Plants whose root system are affected by nematodes show symptoms such as stunting, chlorosis (yellowing of leaves, wilting, drying due to shortage of moisture) and most importantly from an economic stand point, reduced yields. The symptoms in aerial part of the plants are due to the poor ability of the root system to deliver water and nutrients hence the chlorosis and therefore wilting. Symptoms induced by nematodes are normally confused with water and nutrients deficiencies (*Coyne*, 2006). This is because the vascular system of the plants is affected by their feeding behaviour and therefore nutrient and water translocations are impeded. In all areas where crops are grown problems associated with plant-parasitic nematodes are present; however, the most severe damages occur in the tropics or sub-tropics due to the elevated temperatures,
continuous cropping patterns, long growing seasons, large number of susceptible crops and alternative host plants which will gradually increase the nematode populations year by year (Mai, 1985). Agriculture intensification due to increase in population and pressure on land use has resulted in promoting favourable conditions for plant parasitic nematodes. (Elgawad et al., 2007).

Agrios, (2005) estimated that plant-parasitic nematodes are responsible for global agricultural losses close to $80 billion. In the West African sub-region, the severity of plant parasitic nematodes has been documented. Losses in the range of 20-94% due to nematodes have been recorded in Nigeria (Olowe, 1978; Duponnois et al., 1995). Scutellonema bradys is reported species parasitizing on yam tubers in West Africa. In Ghana, Osei et al., (2012) also observed populations of plant parasitic nematodes parasiting tomatoes of which root knot nematode (Meloidogyne incognita) is the most important species. Other nematode genera reported on yam in Ghana include Helicotylenchus spp., Paratylenchus spp., Tylenchus spp., Hoplolaimus spp. and Xiphinema spp. (Osei et al., 2012; Nyaku, et al.,2015).

2.4. Factors influencing distribution of nematodes

Population density and the distribution of plant parasitic nematodes are influenced by various factors which include biotic and abiotic sources (Wachira et al., 2009). Farming practices such as addition of organic matter and application of organic amendment in form of manure in the soil suppresses nematodes by generating toxic compounds in the soil that are harmful to the nematodes (Norton, 1979). Soil texture also influences the population density of nematodes (Norton, 1979). Soils which are loose and have high porosity, support large population of plant parasitic nematodes as a result of improved aeration and mobility of nematodes in the soil (Sultan and Ferris,1991). Plant parasitic nematodes are able to multiply in moist soils. Moisture enables mobility and infection of appropriate host by nematodes (Ferris et al.,1991) and temperature also influence
nematodes activity (Norton, 1979). Most nematodes are active between 25-30° C. So there is high density of plant parasitic nematodes along the tropical and sub-tropical regions which normal temperatures lie within the above temperatures. These factors however, do not work independently to influence nematode population but are interrelated.

The most important nematode of yam is *Scutellonema bradyi* which is the causal agent of dry rot disease of yam tuber (Coyne *et al.*, 2006). Most severe symptoms of dry rot are observed during storage (Baimey *et al.*, 2009). Decay symptoms begin with brown or black lesions beneath the outer skin where it progresses into the tuber, as nematodes feed and multiply endo parasitically, it progresses into the tuber causing the infected tissues to turn black or brown (Coyne *et al.*, 2006). The yam tuber may appear healthy while the outer cortex may crack and flake off. The severity of above symptoms increases as the length of storage increases (Coyne *et al.*, 2006; Baimey *et al.*, 2009).

Loses from 25 to 75 % has been recorded in Nigeria where yam tubers were stored for only 16 weeks due to nematodes (Nwauzor and Fawole, 1981). The disease is a trait to yam production because the vegetative materials used (yam sett or seed yam) perpetuate the disease cycle from one season to the other which will lead to decline in yam production (Bridge, 1982; Florini, 1996). Storage losses up to 80% has also been recorded (Nwauzor, 1982)

### 2.5 The Yam Nematode *Scutellonema bradyi*

#### 2.5.1 Taxonomy and nomenclature

Yam nematode was first described in Jamaica in Rotylenchus1933 (Steiner and Hew 1933) it was classified into the genus *haplolaimus* (Steiner and Hew 1933). And later changed to *Rotylenchus*
It was again described from *Haplolaimus* to *Rotylenchus* in 1952. (Goodey, 1952) In 1971 it was reclassified as *Scutellonema*. (Andrassy, 1958; Morgan, 1971)

### Scheme of Classification

**Kingdom:** Metazoa  
**Phylum:** Nemada Cobb, 1919  
**Class:** Secernentea von Lionstow, 1905  
**Subclass:** Diplogasteria Maggenti, 1982  
**Order:** Tylenchida Thorn, 1949  
**Sub order:** Tylinchina Chitwood, 1950  
**Super family:** Tylenchoidea Orley, 1880  
**Family:** Hoplolamainae Flip’ev, 1934  
**Genus:** Scutellonema Adrassy, 1958  
**Species:** *Scutellonema bradys* (Steiner and LeHew, 1933; Andrassy 1958)  

Source (Morgan, 1971)

#### 2.5.2 Order Tylenchida

Three groups of plants parasitic nematodes (PPN) known are, *Tylenchs*, *Longidorids* and *Trichodorids* (Luc *et al.*, 1990). Most of these (PPN) belongs to the Order *Tylenchida*. Prominent among them are: *Heteroderidae, Hoplolaimidae*, (*Scutellonema* and *heterodera* belongs to this family)*Pratylenchidae, Meloidogynidae etc* (Hunt *et al.*, 2005). Members of this group are vermiform nematodes although some of the genera such as *Meloidogyne, Heterodera* and
*Globodera* the female loses vermiform and becomes obsessed and sexual dimorphism can also occur. Their body length is normally between 0.2 to 1 mm. Under certain conditions the length can be over 3 mm. Nematodes from this Order have stomatostylet, a protrusible culticular tube generally swelling posteriorly to form a basal knob. This knob may be rounded as in *Pratylenchus*. The knob could also be tulip shaped with anterior tooth-like projections as in *Hoplolaimus* (Luc, *et al*., 1990; Siddiqi, 2000). Members of the Order Tylinchida have a complete digestive system which comprise of stylet, esophagus, intestine and rectum. In identification of nematodes the type of esophagus and intestine overlap is vital. In *Scutellonema, Radopholus*, and *Hoplolaimus spp.* the esophagus overlaps intestine dorsally. In *Pratylenchus* and *Helicotylenchus* the overlap is ventral (Hunt *et al*., 2005).

Females possess a reproductive structure which comprises of vagina, uterus, oviduct and ovary. Spermatheca a specialised reproductive organ may be present. The genital system of a female may be either didelphic or monodelphic. The position of vulva is significant for identification, if the vulva position is posterior (60%-70%) in *Helicotylenchus* and median in *Radopholus* spp. The shapes of the tail tip tend to vary within members of this group of nematodes. Some are dorsally convexconoid or hemispherical as in *Helicotylenchus*, others are elongated as is the case with *Radopholus* while other are conical in shape (Hunt *et al*., 2005; Jabbari and Niknam, 2006). These features are significant in nematode identification.

### 2.5.3 Importance of Scutellonema bradys in yam cultivation

This is a major pest of yam, in yam growing areas of Senegal, Cote d’Ivoire, Ghana, Togo, Benin, Nigeria and Cameroun (what is known as yam zone in West Africa). However, this pest is not an economic pest in other parts of the world notably the Caribbean (Puerto Rico, Cuba and Jamaica)
Brazil, India and Japan (Bridge et al., 2005). Almost all edible yam cultivated in the yam zone of West Africa are susceptible to *Scutellonema bradys*. The direct damage of this nematode is of economic importance although it is difficult to determine damage associated with loss in total yield (Coyne et al., 2006). It causes reduction in quality, edible portions are reduced and thereby affecting its marketability. Bridge (1972) reported that almost 47% of all tubers on sale in markets in Nigeria are infected with *S. bradys*. In Ghana, Kwoseh et al. (2005) found that yam tubers in storage are all infected with *S. bradys* irrespective of the variety.

### 2.5.4 Biology and ecology of *Scutellonema bradys*

*Scutellonema bradys*, the yam nematode is a microscopic organism with total body length of 820µm -1040µm. It has stylet length of 16µm-29 µm (Goodey, 1952 Sher 1964 Siddique 1972) It has de Mans ratio ‘a’ (body length/ diameter at mid body) 19µm-30µm (Germani et al., 1985). It has round tail of about 6.5µm -33µm (Siddique, 1972). Amphimictic reproduction is observed in *S. brady* where eggs are produced in the soil, roots and tubers by mature female nematode (Tchabi, 2008). First molting occurs in the egg, four moltings and four juvenile stages are recorded (Kwoseh and Krampah, 2008). In Nigeria population build up to 200 nematodes per gram of soil has been recorded (Bridge, 1972) and *S. bradys* population of 7824 in 10 g of yam tuber peels has also been recorded (Nyaku et al., 2016). Sites of *S. bradys* invasion is through the root tips and can also enter tubers though the growing points. They also invade through cracks and damaged areas of roots and tubers. They feed intracellularly in yam tuber tissues which result in rupturing of cell walls and loss of its content which create tunnels and cavities in the tubers for other organisms (Bridge, 1972; Bridge, 2005; Coyne et al., 2011).
2.5.5 Life cycle of *Scutellonema bradys*

*Scutellonema* is a thread nematode found in the soils. It is a migratory endo-parasitic nematode present in the soils where yam is cultivated. They are bisexual, that is they exist as a separate male and female. When reproduction occurs the ovum from the female is fertilized by the sperm of the male. Infective stages of *S. bradys* are from J2, J3 and J4. First moulting occurs in the egg and there are four juvenile stages before adult. The juvenile nematodes invade young developing yam tubers, roots and also through cracks and damage parts of the tuber (Bridge 1972; Coyne *et al*., 2011). This nematode is mostly confined to the peridermal and subdermal and parenchyma tissues in the outer 1 to 2 cm of the yam tuber. *S. bradys* continues to feed and reproduce within the yam tuber tissues even after harvesting. The yam nematode feeds by sucking out cell contents of the plant with their stylet and move ahead leaving lesions behind. They create wounds by their feeding action and secondary infection can occur by bacterial and fungi which normally result in soft rot. They are able to move into the soil in search of new tuber or root. The nematode grow and moult from J2 three times to become adult male or female. If there are unfavourable weather conditions during drought the nematode become quiescence until moisture increases and it resume growth (Coyne *et al*., 2011).

2.5.6 Symptoms and diagnosis

The major disease caused by *S. bradys* is called the dry rot of yam tuber (Coyne *et al*., 2005) It occurs in the outer two to three centimetre of the tuber which has been infected with *S. bradys*. In this disease, the initial stage after infection is light yellow lesions below the skin of the yam tuber without showing any external symptoms initially (Baimy, 2006; Humphrey, 2014). As the disease progresses, the external parts of the tuber flakes off exposing patches of dark brown dry tissues.
The disease affects 1 to 2 cm of the tuber but this can go deeper and the tuber will turn into yellow colouration. There has not been reported case of any foliar symptoms of \textit{S. bradys} infected soil (Bridge, 1994).

2.5.7 Host range of \textit{Scutellonema bradys}

\textit{S. bradys} has number of alternative hosts which make them to survive in soils in the absence of yam. The nematode can survive in any soil in the yam growing soils across West Africa (Coyne \textit{et al.}, 2006). It has also been reported that in the Carribean islands of Jamaica, Puerto Rico and Costa Rica it has wide host range so it survives without yam. In South America, it has been reported in Brasil (Bridge \textit{et al.}, 2005; Humphrey \textit{et al.}, 2010). All edible \textit{Dioscorea} are affected while crops such okra, yam bean, pigeon pea, kenaf, sorghum, sesame, cassava and tomato are also affected (Kwoseh and Krampah, 2008).

2.5.8 Morphological identification

In the Kingdom metazoan the phylum nematoda is one of the most abundant group on earth in terms of species richness. Nematodes constitute about 90\% of all multicellular organisms. In marine ecosystem alone about one hundred million species which have not been described, only 26,646 species have been described from all habitats (Lamshead, 1993; Hugot \textit{et al.}, 2001). In identification of \textit{Scutellonema bradys} scanning electron microscope is used for accuracy. (Nguyen, 2010). Although light microscope has been used for morphological characters but the light microscope has its limitations (Coomans, 2000). It is very difficult to separate the genus \textit{Scutellonema} because the 46 species have overlapping morphological characters at species level (Sidiqi, 2000; Van de Berg \textit{et al.}, 2003). To identify species accurately, various dichotomous
keys have designed and used. These include: Filipov (1936); Chitwood (1951); Andrassy (1976); Fortuner (1986) and Sidiqqi (2000).

Some of morphological characters used to separate *Scutellonema* species are:

- Total body length
- Specimen width
- Position of vulva to anterior
- DEGO
- Diameter at anus
- Vledian bulb valve length
- Median bulb valve
- Scutellum with
- Scutellum height
- Lip region height
- Lip region diameter
- Lip annule shape
- Pharynx length
- Diameter at head region
- Diameter at mid body
- Diameter at tail region
- Tail length
- Stylet length
- The de man’s ratios (a, b, c, c’, s)

2.5.9 Morphometric identification

*Scutellonema* has large and raised lateral lips whereas sub median lips are narrow and flat or knoblike which obsect by constriction, lip region is knob like and obsect by conscription with labial disc and 6 to 8 striations. The organ for locomotion and copulation is the tail and the tail tip is bluntly concoid, the tail is shorter or equal to the body width. Tail is rounded with striation terminus. The annules are about 1.6 µm near the middle. Vulva is traverse slit with circular thicken toward ends (Nyaku *et al.*, 2016).

The males have large bursa, crenate enclosing tail and the specules slightly cephalated which is ventrally arcuate which have large distal fingures, telamon is prominent and is about 10µm long, terminal portion of the tail is about 11-16 µm long (Sidiqqi, 2000; Van de Berg *et al.*, 2003).

2.6 Nematode disease management

2.6.1 Phytosanitary measures

The first method that could be employed in nematode management in yam against *Scutellonema spp.* is the use of clean and healthy planting material that is the use of uninfected yam setts. Healthy planting materials can be obtained through tissue culture. Also at harvest all infected materials should be separated from the lot and discarded. (Dropkin, 1980; Speijer *et al.*,2000). Some varieties of yam can be propagated by vines. This can be done to produce yam setts which are nematode free for planting but not tubers. (Coursey, 1967; IITA,2005). Minisets’ technology can also be used to produce nematode free planting materials devoid of nematodes (IITA, 2007)
2.6.2 Agronomic practices on the field

Fallowing a field for about 24 months can reduce nematodes population in the soil (Adesiyan, 1976). Increased in the consumption of yam has led to increase in yam cultivation, therefore high land use intensity so it is becoming impossible for land fallow in the yam growing areas for about 24 months (Kwoseh and Krampah, 2008). Where it is practicable crop rotation with poor host such as groundnut and maize could be rotated. The use of antagonistic and trap crops is also used to reduce nematode population in the soil.

Including mucuna, alfafa and pueraria in the rotation also reduce nematode especially *Scutellonema bradys* population density in the soil (Tchabi, 2008). Super phosphate fertilizers are also reported to have reduced nematodes population in the soil (Garrido et al., 2008; Osei et al., 2011). Traditionally wood ash is used to treat yam setts before planting and this is reported to decrease nematode population in the soil. (Adesiyan and Adeniji, 1976; Diby, 2004). Removal of alternative host plants after harvest, especially those with underground food storage can decrease nematodes population in the soil (Luc et al., 2005 Sikora and Fernandez, 2005)

2.6.3 Biological control

The use of microorganisms to control nematodes will be a way and alternatives to the use of nematicides due environmental problems and also harmful of nematicides to non-target organisms (Viaenne et al., 2003). Research has proven that some fungi such as *Pachonia chlamydosporium* and *Pacellomyces lilacinus* are nematophagus (Gaspard et al., 1990).
2.6.4 Nematicides

Nematicides such as carbofuran and organophosphates can be used successfully against nematodes on yam but these chemicals are very toxic to non-target organisms including the user and also not biodegradable and therefore persistent in the environment. As a result, its use has been restricted in some countries. However, its application at 100kg/ hectare can result in optimal yield and reduction in nematode population in the soil (Adegbite and Abgage, 2006).

2.6.5 Physical control

Dipping yam setts in hot water at a temperature of 50-55°C for 45 minutes will ensure nematode free setts without destroying the yam setts (IITA, 2005). However, farmers are reluctant to practice this method due to the bulky nature of yam setts and the volumes of yam tubers to be treated will be a problem. Another challenge is how to control and maintain the temperature of the hot water. Nematode population and the depth of infestation on the yam tuber also affect this method.

2.6.6 Resistance of yam tubers to S. bradys

Resistance of yam tubers to nematodes, S. bradys is yet to be reported in the cultivated yam (IITA, 2004). There may be resistance varieties in the wild yam but due to complex nature of yam botany there have not been any breeding programme to breed the resistance line (Coursey, 1967). Breeding of resistance varieties could be the most economical way of producing yam commercially (Brandson, 2001). Some varieties of Diascorea cayennensis and Diascorea dumentorum have shown some resistance to S. bradys (Bridge, 1982 and Kwoseh, 2000).
2.6.7 Integrated pest management

Several methods of controlling yam nematodes, *S. bradys* could be used in an integrated method. Using phytosanitary measures such as hot water treatment, the use of wood ash, application of phosphoric fertilizers, crop rotation and land fallowing produced successful results against the yam nematode *S. bradys* at IITA field trials in Ibadan Nigeria (IITA, 2005).
CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Survey to assess farmers, knowledge, perception and experiences concerning occurrence and management of nematodes

A field survey was conducted in December, 2016 to obtain baseline data concerning farmers’ land use intensity, knowledge, perception, experiences, and management of plant-parasitic nematodes on their farms. Initial focal group discussion was held with Agricultural Extension Agents (AEAs) in the Krachi Nchumuru District (plate 2). Ten communities where yam is grown were selected. The communities are Bora, Malla, Chinderi, Banda, Zongo Micheri, Kaliako Boafiri, Kokorse Bejamse and Grubi. A total of fifty (50) yam farmers with varying farm sizes ranging from one (1) acre to twenty (20) or more acres were randomly selected from the study area. Pre-tested semi-structured questionnaires were administered to participating farmers by reading to them and also showing them pictures. Data collected in the questionnaire were coded and subjected to descriptive statistical analysis using Statistical Package for Social Sciences (SPSS) version 20.

3.2 Soil Sampling

Two farms each from the Ten (10) communities were sampled around yam tuber rhizosphere. Sampling of soils were undertaken in October 2016 as this period coincides with maturity of yam in the district. The soil samples were taken when the soil was not too wet or too dry as both extreme conditions make it difficult to collect and prepare samples for analysis (Shurtleff and Averre, 2000).

The soil samples from 10 communities were taken using soil augur from the depths of approximately 0-30 cm. The soil samples were taking around yam tubers in two farms per community. (Z) form was used in taking the samples in each farm. GPS coordinates were recorded in each farm. The soil augur and footwear were cleaned after sampling each farm to avoid cross contamination of soil samples and spread of nematodes.
between farms. The location of farm was logged into the field notebook with the sample number and GPS coordinate of the farm recorded (Table 1).
Table 1: Global positioning systems (GSP) coordinates of the communities where the study was conducted

<table>
<thead>
<tr>
<th>S/N</th>
<th>Town</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Malla</td>
<td>8° 8.8'N</td>
<td>0° 1.3'W</td>
</tr>
<tr>
<td>2</td>
<td>Boraе</td>
<td>8° 9.4'N</td>
<td>0° 2.3'W</td>
</tr>
<tr>
<td>3</td>
<td>Banda</td>
<td>8° 18.1'N</td>
<td>0° 5.4'W</td>
</tr>
<tr>
<td>4</td>
<td>Zongo Michire</td>
<td>8° 12.1'N</td>
<td>0° 7.9'W</td>
</tr>
<tr>
<td>5</td>
<td>Chinderi</td>
<td>8° 8.6'N</td>
<td>0° 9.1'W</td>
</tr>
<tr>
<td>6</td>
<td>Grubi</td>
<td>8° 11.5'N</td>
<td>0° 13.9'W</td>
</tr>
<tr>
<td>7</td>
<td>Korkose</td>
<td>8° 9.3'N</td>
<td>0° 10.7'W</td>
</tr>
<tr>
<td>8</td>
<td>Bejamse</td>
<td>8° 3.8'N</td>
<td>0° 13.5'W</td>
</tr>
<tr>
<td>9</td>
<td>Kaliako</td>
<td>8° 5.0'N</td>
<td>0° 9.9'W</td>
</tr>
</tbody>
</table>
The soil samples from each farm was thoroughly mixed for nematode extraction. The soil samples were placed in polythene bags and put in an envelope and the date, location written using a permanent ink pen and record immediately logged.

3.3 Nematodes extraction from the soil

Nematodes were extracted from the soil using sucrose centrifugation method (Freckman, 1997). 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. From each soil sample 200 cubic centimetre (cm³) subsample of soil was collected into a beaker and weighed. Tap water was added to twice its volume and stirred carefully and allowed to settle for three minutes. It was poured through a stack of 90 µm - aperture mesh on a 36 µm - aperture mesh. Using a water bottle, nematodes (retained on the mesh) were gently washed into centrifugation tubes for centrifugation.

Water was added to centrifuge tubes to equalize volumes and placed in balanced pairs. It was spunned at 1700 rpm for five minutes without using the brake and allowed to settle for five minutes. Supernatant was aspirated to about one (1) 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 spunned 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 10mL mark using a fine spray water bottle.

3.4 Sampling of Yam tubers in storage

This sampling was done on yam in storage in February 2017. This was the period harvested yam were in storage. Three yam tubers each showing symptoms of *S. bradys* were collected from 20
farmers, labelled and send to the Plant Pathology Laboratory of Crop Science Department University of Ghana, Legon for extraction and identification of nematodes.

3.5 Extraction of nematodes from yam tubers

Nematodes were extracted from infested yam tubers using modified Baermann funnel method (Hooper, 1990). The tubers were peeled using kitchen peeler and cut into (0.3cm x 0.5cm) 10g sub sample was used for nematode extraction. The 10g was blended for five second seconds and put 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 90µm mesh on 36µ sieve. A spray water bottle was used to wash the nematodes into falcon tubes to a final volume of 10 mL. Nematode populations were assessed in a counting dish using microscope and mean nematode density calculated per unit peel (outer corter) of each yam tuber. Each nematode water suspension was separately topped with tap water to 300 ml for standardization and each suspension was homogenized by blowing air through with a rubber straw.
3.6 Quantitative analysis of nematodes

Nematode suspension was concentrated to 10 mL in a glass vial. This was shaken gently and poured into an open 50 mm plastic counting dish. Nematode densities were assessed in a counting dish using microscope and mean nematode density calculated per unit peel (outer cortex) of each yam tuber. This counting dish was already prepared by scratching grids (2 mm×2 mm) on the inner side of the base of a plastic petri dish with a needle to act as a guide when counting and examined under the compound light microscope (Exacta - Optech Biostar B5P) at 100x magnification. A hand tally counter was used for counting nematodes and counting was repeated three times and the mean nematodes numbers in a sample suspension determined. The nematodes enumerated were expressed as number of nematodes in 200 cc of dry soil and 50g of yam tubers.

3.7 Handling and processing of nematodes

Nematode suspension was shaken and small batches of about 2 mL nematodes were sucked using a syringe and transferred to a counting dish. The selected nematodes for identification were mounted on a drop of water on a microscopic slide and placed on a hot plate at 60°C (Hooper,
1990) until nematode suddenly straightened out. Extracted nematodes were examined directly under a compound light microscope.

To allow for further identification and long-term storage, nematodes were fixed. The Fixative, FAA (4% Formalin with 1% glycerol) was heated to about 70°C and an excess (2-3 mL) was quickly added to the specimens to fix and kill the nematodes in one process (Seinhorst, 1966). Nematodes were then cleared with glycerol (Hooper, 1990) before being mounted on a slide and viewed under a compound light microscope. Fixed specimens were then stored for further identification.

3.7.1 Nematode identification

Nematodes were identified to the genera level based on their morphological features as described by (Siddiqi 1989; Luc, et al., 1990) and the University of Nebraska Lincoln nematode identification website(http://nematode.unl.edu/konzlistbutt.htm). Identification was mainly based on adult nematodes.

3.8 Morphological characterization of Scutellonema spp.

3.8.1 Morphological observations and morphometries.

Ten males from each sample were used for the morphological characterization. Nematode specimen was kept in distilled water at room temperature in falcon tubes for 24 to 48 hours prior to characterization. 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 (∼70-75°C) FAA fixative on the glass slide, covered with a cover slip (Hooper et al., 2005) and sealed using clear nail polish.
The prepared slides were marked on the cover slip for easier location while viewing under the compound light microscope. A permanent marker was used to label all slides with the sample number, specimen and the date of preparation.

The prepared slides were viewed 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 and measurements undertaken.

The measurements obtained included the total body length, greatest body width, stylet length, tail length and the hyaline tail length. De Man’s ratios $a = \frac{\text{total body length}}{\text{greatest body width}}$ and $c = \frac{\text{total body length}}{\text{tail length}}$ were calculated.

All measurements were recorded and for each locality, the data was summarized by calculating the averages, range and standard deviation. The morphological observations and measurements were compared with the species descriptions given in the literature of Chitwood (1949), Eisenback (1985b), Hewlett and Tarjan (1983), Jepson (1983, 1987), Whitehead (1968) and Sing (2009).

3.9 Data Analysis

SPSS PASW of Statistics Windows Version 20 was used to analyse the questionnaires administered. Agglomerative Hierarchical Clustering (AHC) (Ward, 1963; Everitt et al., 2001), was also used in generating a dendrogram to reveal the various groups and sub-groups of classes.
within female *S. bradys* populations in Microsoft Excel XLSTAT (Version 2017, Addinsoft, Inc., Brooklyn, NY, USA 3.7
CHAPTER FOUR

4.0 RESULTS

4.1 Farmers’ knowledge, perceptions, and experiences concerning occurrences and management of dry rot disease of yam tubers in Krachi Nchumuru District of the Volta Region of Ghana

4.1.1 Background of Yam (Dioecorea rotundata) Farmers in the study area

4.1.1.1 Age and sex of Respondent

Majority of yam farmers in the study area were males (98%) while the rest were females (2%) (Table 2).

Table 2. Sex of the respondents

<table>
<thead>
<tr>
<th>sex</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEMALE</td>
<td>1</td>
<td>2.0</td>
</tr>
<tr>
<td>MALE</td>
<td>49</td>
<td>98.0</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Most of the farmers were within the age ranges 21-30 years (30%) and 41-50 years. Those aged 31-40 years were 24 % while the rest (16%) were 50 years Figure 2.
4.1.1.2 Educational Background of the Respondents

The survey revealed that majority (42%) of the yam farmers had been to either middle school or Junior High School. The rest had been to primary school (14%), Senior High School (10%) and tertiary institutions (10%), has no formal education (34%) (Figure 3).
4.1.2. Period in yam farming

Majority of the farmers (54%) had been cultivating yam for more than 15 years. The rest had been in yam farming for 12 - 15 years (10%), 6 – 10 years (26%) and have been in yam farming between 1-5 years (10%) (Figure 4).

![Figure 4. Period in yam farming](http://ugspace.ug.edu.gh)

4.1.3 Source of seed yam used by farmers

In 2016 majority of farmers (40%) used their own seed yam. The rest obtained their planting materials from family members (12%), the market (18%) or other source including own farm (30%) (Figure 5).
Figure 5. Source of planting materials for yam farmers

4.1.4 Farmers farm size in the year 2016

Majority of the farmers (62%) were small scale farmers with farm holdings less than 1 acre. The rest has farm size between 1 and 2 acres (12%) or 3 to 4 acres (26%) (Figure 6).
4.1.5. Varieties of yam planted

The survey reveal that majority of yam farmers (98%) planted ‘Pona’ variety of white yam in addition to other varieties. Varieties planted among others are ‘Pona’, ‘Olondo’, ‘Asobayere’, ‘Kplinjo’, ‘Nyame nti’, ‘Nkunuku’ etc (Figure 7).
4.1.6 Land use intensity of yam farmers in the Krachi Nchumuru District

Most of the farmers (30%) had farmed in their land for 1-3 years. Another 30% had cultivated on the same piece of land for more than 15 years. Yam farmers who had cultivated on the same piece of land for the period between 4-6 years were 24%. Those who had cultivated between 7-10 years were 12%. The rest of (4%) had cultivated on the same piece of land for 11-15 years (Figure 8).
Figure 8. Duration of continuous cultivation of yam on same piece of land by farmers

4.1.7. Crops used in intercrop with yam

Maize, yam, groundnut, cassava and vegetables such as okra, pepper and tomatoes were major crops cultivated alongside yam on the land at the percentages of 18, 24, 20 and 14 and respectively. Soybean was also prominent among the intercrops. However, all the farmers were into mixed cropping of the above crops. (Table 3)

Table 3: Crops used in intercropping with yam

<table>
<thead>
<tr>
<th>Responses</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yam</td>
<td>9</td>
<td>18.0</td>
</tr>
<tr>
<td>Cassava</td>
<td>7</td>
<td>14.0</td>
</tr>
<tr>
<td>Cowpea</td>
<td>4</td>
<td>8.0</td>
</tr>
<tr>
<td>Maize</td>
<td>12</td>
<td>24.0</td>
</tr>
<tr>
<td>Soybean</td>
<td>2</td>
<td>4.0</td>
</tr>
<tr>
<td>Groundnut</td>
<td>8</td>
<td>16.0</td>
</tr>
<tr>
<td>Vegetables</td>
<td>8</td>
<td>16.0</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>
4.1.8 Land Rotation

Majority of the farmers (54%) had rotated their land for 1-2 years, while the rest 3-5 years 38% and more than 5 years 8% (Figure 9).

![Figure 9 Duration of bush fallowing by yam farmers in the Krachi Nchumuru District](http://ugspace.ug.edu.gh)

4.1.9. Land Fallowing

Majority of the farmer (66%) had fallowed their land while 34 % were into continuous cropping of yam without fallowing but rotating with other crops such as groundnut and maize (Table 4).

<table>
<thead>
<tr>
<th>Response</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation</td>
<td>33</td>
<td>66.0</td>
</tr>
<tr>
<td>No rotation</td>
<td>17</td>
<td>34.0</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Table 4. Period of land fallow practiced by yam farmers
4.1.10 Farmers knowledge, perception and experiences concerning prevalence of dry rot disease of yam of farm

All of the farmers (100%) had experienced diseased conditions in their yam farms. However, majority (62%) were not aware that nematodes were the cause of the disease, although all the farmers were familiar with the diseases in yam, 38% knew that the disease is caused by nematodes (Figure 10).

![Figure 10. Knowledge about causal agent of dry rot disease of yam](http://ugspace.ug.edu.gh)

4.1.11 Varieties susceptible to nematodes infestation

Majority of the farmers (84%) were of the view that the ‘Pona’ variety is more susceptible to nematode infestation than the other varieties in the study area (Fig 11).
Figure 11. Varieties of white yam mostly cultivated by farmers in the Krachi Nchumuru District

4.1.12 Farmers Knowledge on nematode parasitism on yam plant

Majority (62%) of the farmers reported their yams were affected by reduced rooting but the (38%) did not observed these symptoms on their farm.

Most of the farmers rotting and discoloration of vegetative organs, (74%) while the rest (26%) did not notice any symptoms while (26%).

A greater proportion (76%) of the farmers observed dwarfing, stunting and resetting symptoms. Other noticed dwarfing only while the rest observed stunting and resetting on crops (74%), no dwarfing (24%) or stunting and resetting (26%). Most of the respondents (52%) observed necrotic lesions on the roots while the rest (48%) did not (Table 5).
Table 5. Farmer’s knowledge on symptoms of nematode parasitism of yam plants in Krachi Nchumuru District

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Frequency</th>
<th>Percentage responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Necrotic streaks or lesion on roots</td>
<td>26</td>
<td>52</td>
</tr>
<tr>
<td>reduced rooting system</td>
<td>31</td>
<td>61</td>
</tr>
<tr>
<td>Internal discoloration of vegetative organs</td>
<td>37</td>
<td>74</td>
</tr>
<tr>
<td>Dwarfing</td>
<td>38</td>
<td>76</td>
</tr>
<tr>
<td>Stunting and resetting</td>
<td>39</td>
<td>78</td>
</tr>
</tbody>
</table>

4.1.13 Type of soils associated with nematodes parasitism

Farmers in the study area indicated that they had nematode infestation in all types of soils. Lowland sandy soils (38%) well drained sandy soils (10%), sandy loam (16%), sandy clay loam soil (18%), loamy soil (4%) clay soil (18%) (Figure 11).

![Figure 11. Type of Soil associated with nematode parasitism of yam tubers](http://ugspace.ug.edu.gh)
4.1.14

All farmers in the study area stored yams tubers in the farm or at home. A greater proportion of farmers (82%) stored their yam tubers in barns either in the farm or at home. Others stored theirs under trees (16%) in the farm or in the house (2%). Majority of the farmers (98%) encountered pests and diseases during storage in their yam tubers and setts infected with nematode (Figure 12).

![Graph showing method of storage of yam tubers after harvest]

**Figure 12.** Method of storage of yam tubers after harvest

4.1.15. **Farmers knowledge on symptoms of nematode parasitism of yam tubers in storage in the Krachi Nchumuru District of the Volta Region**

Majority (88%) of the respondents observed external cracks on the tubers while the rest (12%) did not. Also most of the them (82%) noticed weight loss in tubers during storage while the rest 18% did not.
Majority of the respondents (84%) had observed yellow lesion below the outer skin of the tuber while 16% did not. Majority of the farmers (84%) indicated that they observe rotting of the outer 1-2cm layer of the tuber, while the rest (16%). Most of the farmers observed flaking of external coverings with dark brown patches (80%) while the rest (20%) did not.

A greater proportion of the farmers (88%) experienced decay of yam tubers during storage while the rest (12%) did not (Table 6).

Table 6. Farmer’s knowledge on symptoms of nematode parasitism in stored yam tubers

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>External cracks on skin and tubers</td>
<td>44</td>
<td>88</td>
</tr>
<tr>
<td>Significant weight loses in tubers</td>
<td>41</td>
<td>82</td>
</tr>
<tr>
<td>Light yellow lesion below the outer skin</td>
<td>42</td>
<td>84</td>
</tr>
<tr>
<td>Rotting of outer 1-2cm layer of yam tuber</td>
<td>42</td>
<td>84</td>
</tr>
<tr>
<td>flaking off of external coverings expressing patches of dark brown colorations</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>General decay</td>
<td>44</td>
<td>88</td>
</tr>
</tbody>
</table>

4.1.17 Farmers knowledge, perception and experiences concerning the spread of nematodes infestation of yam tuber in the field and storage

All farmers in the study area indicated that the use of infected tubers as a planting material is not advisable as the setts will not sprout. A few of them reported that the use of infected tubers can spread nematodes. They perceived various methods by which the spread of nematodes could be
controlled. Among the farmers (10%) were of the view that nematodes could be managed through crop rotation. Another (10%) believed they could be managed through land rotation while others (20%) believed that it could be managed through the destruction of infected yam setts. Some (10%) believe that nematodes could be controlled with the use of nematicides, while (50%) thought otherwise (Table 7).

<table>
<thead>
<tr>
<th>Control measures</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>land rotation</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Crop rotation</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Nematicides</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Destruction of infected tubers</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Use of organic fertilizers</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Others</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No control</td>
<td>25</td>
<td>50</td>
</tr>
</tbody>
</table>

4.1.18 Economic impact of nematodes associated with stored yam tubers

Minority of the farmers (6%) cultivated yam only for their own consumption 22% cultivated yam only for income in order to purchase assets such as building and vehicle. The others (72%) cultivated yam for both food security and income generation (Figure 13).
4.1.19. Postharvest losses of harvested yam due to nematodes

In 2013, losses up to (50%) was observed in yam during storage. Some farmers (24%) incurred tubers losses less than (10%) of the total harvest. Another (20%) of the farmers incurred losses between 10-19%. About half of the respondents (50%) incurred losses between 30 and 50% while (6%) of the farmers had over 50% tuber losses.

The trend was almost the same in 2014, 2015 and 2016. Majority of the farmers (80%) experience less than (20%) tuber loss while the rest experienced more than (50%) loss. Farmers who incurred tuber losses greater than (50%) were always less than (10%) of all respondents (Figure14).
Figure 14. Losses of yam tubers incurred by farmers from dry rot from 2013 to 2016.

On the influence of the nematode on socio economic impact on the farmers in the Krachi Nchumuru District, only 10% of the respondents said they can pay their children school fees easily while 90% said they could not pay children school fees.

The survey revealed that 88% of yam farmers could not pay loans contracted for yam farming due to dry rot disease of tubers while 10% could pay.

Twelve percent of the respondents could not purchase assets such as tractors with implements and building houses. On payment of medical bills 82% of the respondents could not pay when they are indisposed while only 18% could pay medical bills as well as that of their spouses and children.

4.1.20

Majority of respondents (98%) have good relationship with Agricultural Extension Agents (AEA), and contact him for advice while (2%) have no relationships with the AEAs because one farmers claims he knows how to cultivate yam better than the AEAs (Table 8).
Table 8. Influence of dry rot of yam tubers on socio economic activities of farmers in Krachi Nchumuru

<table>
<thead>
<tr>
<th></th>
<th>Money to pay loans</th>
<th>Money to buy assets</th>
<th>Money to pay medical</th>
<th>Money to pay children school fees</th>
<th>Relationship with spouse and neighbors</th>
<th>Relationship with extension officer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy /cordial</td>
<td>10%</td>
<td>12%</td>
<td>12%</td>
<td>10%</td>
<td>78%</td>
<td>98%</td>
</tr>
<tr>
<td>Difficult/not cordial</td>
<td>90%</td>
<td>88%</td>
<td>88%</td>
<td>90%</td>
<td>22%</td>
<td>2%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

4.2 Genera of plant parasitic nematodes associated with soils in yam rhizosphere soil and stored yam tubers

4.2.1. Nematodes genera associated with soil in yam rhizosphere

Twelve (12) general belonging to 7 families of the Orders Rhabdida and Dorylaimida were identified and isolated from rhizosphere soil (Table 8). The twelve (12) genera found in the soil sample were, *Tylenchus* spp. *Pratylenchus* spp. (lesion nematode), *Helicotylenchus* spp. (spiral nematode), *Rotylenchulus* spp. (Reniform nematode), *Scutellonema* spp. (Yam nematode), *Meloidogyne* spp. (Root knot nematode), *Tylenchulums* spp., *Ditylenchus* spp., *Longidurus* spp., *Heterodera* spp., *Rotylenchus* spp. and *Aphelenchoides* spp.
The family Hoplolaimidae had the highest genera of four out of the twelve Tylenchulidae had three genera and the rest of the families (Aphelenchoididae, Pratylenchidae, Longidoridae, Anguinae and Tricodoridae) had one genus each. All the nematodes genera were present in all the communities surveyed (Table 9).

Table 9. Plant parasitic nematodes extracted from soil in yam rhizosphere soil.

<table>
<thead>
<tr>
<th>Order</th>
<th>Sub Order</th>
<th>Family</th>
<th>Genus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rhabditida</td>
<td></td>
<td>Pratylenchidae</td>
<td>Pratylenchus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hoplolaimidae</td>
<td>Helicotylenchus</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Heterodera</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rotylenchulus</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Scutellonema</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aphelenchoididae</td>
<td>Aphelenchoides</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meloidogynidae</td>
<td>Meloidogyne</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tylenchulidae</td>
<td>Tylenchulus</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Paratylenchus</td>
</tr>
<tr>
<td>Dorylaimida</td>
<td>Dorylaimia</td>
<td>Longidoridae</td>
<td>Longidurus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Anguinae</td>
<td>Ditylenchus</td>
</tr>
</tbody>
</table>

4.2.2 Nematode genera associated with stored yam.

Nine (9) genera of nematodes were found in the yam peels of stored yam tubers. These are *Scutellonema* spp., *Melodogyne* spp., *Paratylenchulus* spp., *Heterodera* spp., *Bursaphelenchulus* spp. and *Tylenchulums* spp. The identification was based on the following: Lip region, position of the vulva, Stylet length, Tail length etc.

4.3 Morphological Description of some common nematode genera identified during the survey
4.3.1 *Rotylenchulus* spp.

Juveniles are short (0.35-0.45µm) the head region is rounded and striated, stylet is sclerotized and short approximately (13 -15 µm) and stylet knob is rounded and anteriorly flattened. The esophagus overlaps the intestine ventrally and the tail is rounded. The cephalic framework of the males is weakly developed and the stylets are short (12-15 µm) the meta corpus is poorly developed but conspicuous.

The female is sedentary and eggs are laid in gelatinous matrix, which often covers the female. The female’s posterior portion can be embedded into a root tissues while other parts remains external.

4.3.2 *Meloidogyne* spp.

*Meloidogyne* is usually long (1-2 mm) and cylindrically shaped. It has short stylet usually (18-20µm). The esophageal region overlaps the intestine ventrally. The tail of male is short and rounded, there is no bursa. In the females the vulva region and anus are terminal. It loses its tail and becomes obese, sedentary and feeds endo-parasitically.

4.3.3 *Pratylenchus* spp.

It has a slender body and width which increases from the pharyngeal bulb towards the vulva. The anterior region is broad and the head is blunt. It has a short stylet which is scleroinized with large and prominent metacarpus. The esophagus overlaps intestine ventrally. The tail tapers strongly
with narrow tip. Male tip is pointed and bursa edges faintly crenated (Figure 15

![Image of Pratylenchus spp. (Juvenile)](image)

**Figure 15. Pratylenchus spp. (Juvenile)**

4.3.4. *Tylenchulums* spp.

Tylenchus have stronger stylets and tis differentiate it from Meloidogyne, it has more posterior excretory pore and the absence of pharyngeal overlap. It has slender body length and width and the tail is elongated and attenuated.

4.3.5 *Scutellonema* spp.

*Scutellonema* identification was done based on morphological features of the male and female

4.3.5.1. Female

It has a straight to acruate body when relaxed; The annulus is about 1.6 μm near the middle. The lateral fields are about one fifth of the body-width, lip region is knob-like which offset by
constriction. The labial disc is 6 to 8 annuls and lack longitudinal striations. The spear is well developed and accompanied by large oval to rounded basal knobs. Esophageal glands elongate overlapping intestine dorsally and dorso-ventrally. Vulva of *Scutellonema* is a transverse slit with cuticular thickening which is conspicuous towards the ends. Tail is obtuse and rounded to striated terminus.

![Image](image_url)

**Figure 16. Female Scutellonema bradys**

**4.3.5.2 Males**

Male scutellonema is similar to the female with large bursa and crenate enclosing the tail. The specules are slightly cephalated which is ventrally arcuate and distal flanges which are large. There is a prominent capitulum which is about 10µm long. Cuticle is non-protoplasmic with terminal portion of the tail.

**4.3.6 Helicotylenchus spp.**

When relaxed the body is spiral; lip region rounded and bearing five annules. It has long starlets with cupped knobs. Behind the stylet is the dorsal esophageal gland outlet Plate 6.
Figure 17. Helicotylenchus spp.

4.4.1 Frequency of occurrence of plant parasitic nematodes rhizosphere soil

The frequency of occurrence of nematodes extracted from rhizosphere soil in the study area are Scutellonema spp. (131), Meloidogyne spp. (70) Longidorus spp. (52), Tylenchulus spp. (52) Helicotylenchus spp. (46), Ditylenchus spp. (42), Heterodera spp. (18), Pratylenchus spp. (10), Paratylrenchus spp. (10) Rotylenchus spp. (10) Bursphlenchoides spp. (3) and Appelenchoides spp. (2). The genera Scutellonema recocorded the highest number (131) while the genera Appelenchoides spp also recorded the lowest. (Figure 14).
Only *Scutellonema* spp. was present (100%) in all the 20 soil samples from all the communities. The relative abundance was 31.5%. *Meloidogyne* spp. was not present in all communities but had (75%) The relative abundance was 16.8%. *Longidorus* spp. was present in 17 farms with relative abundance of (12.5) *Helicotylenchus* spp. relative abundance of (11.1%), this nematode was present in 11 farms (55%), while *Tylenchulus* spp. was present in 11 farms (55%), however, it relative abundance was (12.5%). The rest of the nematodes were not in all the farms and their relative abundance value were less than (5%) each (Table 10).

**Figure 18. Nematode population in the yam rhizosphere soil**
Table 10. Relative abundance of nematode in rhizosphere soil

<table>
<thead>
<tr>
<th>Nematode genera</th>
<th>Frequency of occurrence</th>
<th>%Frequency rating*</th>
<th>Nematode population/200 cc soil</th>
<th>Relative Abundance %**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scutellonema spp.</td>
<td>20</td>
<td>100</td>
<td>131</td>
<td>31.5</td>
</tr>
<tr>
<td>Meloidogyne spp.</td>
<td>15</td>
<td>75</td>
<td>70</td>
<td>16.8</td>
</tr>
<tr>
<td>Helicotylenchus spp.</td>
<td>11</td>
<td>55</td>
<td>46</td>
<td>11.1</td>
</tr>
<tr>
<td>Longidorus spp.</td>
<td>17</td>
<td>85</td>
<td>52</td>
<td>12.5</td>
</tr>
<tr>
<td>Ditylenchus spp.</td>
<td>2</td>
<td>10</td>
<td>3</td>
<td>0.7</td>
</tr>
<tr>
<td>Rotylenchus spp.</td>
<td>4</td>
<td>20</td>
<td>10</td>
<td>2.4</td>
</tr>
<tr>
<td>Bursaphelenchus spp.</td>
<td>3</td>
<td>15</td>
<td>3</td>
<td>0.7</td>
</tr>
<tr>
<td>Paratylenchus spp.</td>
<td>6</td>
<td>30</td>
<td>10</td>
<td>2.4</td>
</tr>
<tr>
<td>Pratylenchus spp.</td>
<td>5</td>
<td>25</td>
<td>19</td>
<td>4.6</td>
</tr>
<tr>
<td>Apenlenchoides spp.</td>
<td>2</td>
<td>10</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>Heterodera spp.</td>
<td>9</td>
<td>45</td>
<td>18</td>
<td>4.0</td>
</tr>
<tr>
<td>Tylenchulums spp.</td>
<td>11</td>
<td>55</td>
<td>52</td>
<td>12.5</td>
</tr>
</tbody>
</table>

* n/N x 100 (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)

4.4.2 Mean densities of nematodes rhizosphere soil

The highest number of nematodes were obtained from rhizosphere soil from Chinderi while the lowest number of nematodes are from soil in Banda.

In all the soil samples Scutellonema spp. was found to be high in number. Scutellonema spp. was present in all the soils sampled however, other genera were not found in all the soils (Table 11)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Borac</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Malla</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Chindeiri</td>
<td>8</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
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<td>0</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>Zongo</td>
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<td>0</td>
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<td>0</td>
<td>1</td>
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<td>Banda</td>
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<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Kaliako</td>
<td>8</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Kokorosse</td>
<td>6</td>
<td>0</td>
<td>5</td>
<td>6</td>
<td>9</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bejamese</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Grubs</td>
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<td>2</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Boafri</td>
<td>8</td>
<td>5</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>65</td>
<td>23</td>
<td>12</td>
<td>26</td>
<td>21</td>
<td>5</td>
<td>3</td>
<td>10</td>
<td>7</td>
<td>22</td>
<td>26</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 11. Mean densities of Nematodes in rhizosphere soil

University of Ghana  http://ugspace.ug.edu.gh
4.4.3. Densities of plant parasitic nematodes associated with stored yam

A higher number of *Scutellonema*, spp. *Meloidogyne* spp. and *Pratylenchus* spp. were extracted from yam tuber peels of stored yam tubers. Nematode genera that were associated with peels of stored yam tuber can be seen (Figure 15).

![Image of nematode populations](http://ugspace.ug.edu.gh)

**Figure 19. Population of nematodes extracted from peels of yam tuber**

The genera *Scutellonema* spp. *Meloidogyne* spp. and *Pratylenchus* spp. were found in all the yam tubers collected in storage. Their frequency rating was (100%) each. The other six genera were not found in all the soils collected. *Scutellonema bradys*. had the highest relative abundance of 87.4% followed by *Meloidogyne* spp. with relative abundance of 6.3% (Table 12).
Table 12. Occurrence and relative abundance of plant parasitic nematodes associated with stored yam tubers

<table>
<thead>
<tr>
<th>Nematode genera</th>
<th>Frequency of occurrence</th>
<th>% frequency rating*</th>
<th>Nematode population /50g peels</th>
<th>Relative Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Scutellonema</em> spp.</td>
<td>20</td>
<td>100</td>
<td>34,086</td>
<td>87.4</td>
</tr>
<tr>
<td><em>Meloidogyne</em> spp.</td>
<td>20</td>
<td>100</td>
<td>2,471</td>
<td>6.3</td>
</tr>
<tr>
<td><em>Paratylenchus</em> spp.</td>
<td>20</td>
<td>100</td>
<td>2,053</td>
<td>5.3</td>
</tr>
<tr>
<td><em>Heterodera</em> spp.</td>
<td>2</td>
<td>10</td>
<td>70</td>
<td>0.2</td>
</tr>
<tr>
<td><em>Bursaphelenchus</em> spp.</td>
<td>1</td>
<td>5</td>
<td>40</td>
<td>0.1</td>
</tr>
<tr>
<td><em>Helicotylenchus</em> spp.</td>
<td>1</td>
<td>5</td>
<td>40</td>
<td>0.1</td>
</tr>
<tr>
<td><em>Pratylenchus</em> spp.</td>
<td>4</td>
<td>20</td>
<td>140</td>
<td>0.4</td>
</tr>
<tr>
<td><em>Radopholus</em> spp.</td>
<td>2</td>
<td>10</td>
<td>16</td>
<td>0.1</td>
</tr>
<tr>
<td><em>Tylenculus</em> spp.</td>
<td>1</td>
<td>5</td>
<td>60</td>
<td>0.1</td>
</tr>
</tbody>
</table>

* n/N x 100 (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)

The highest and least nematodes populations were from Kaliako (8,067) and Bejamse (69) respectively. The top three nematode species were *Scutellonema* spp. (15,619), *Meloidogyne* spp. (1055), and *Pratylenchus* spp. (580). The nematode with the least population was *Radopholus* spp. (16) (Table 13).
Table 13. Mean densities of nematodes from yam tubers in storage in Krachi Nchumuru District

<table>
<thead>
<tr>
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<tr>
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<td>100</td>
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<td>Zongo Michire</td>
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<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Boafri</td>
<td>2000</td>
<td>20</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>15619</strong></td>
<td><strong>1054</strong></td>
<td><strong>580</strong></td>
<td><strong>16</strong></td>
<td><strong>19</strong></td>
<td><strong>90</strong></td>
<td><strong>180</strong></td>
<td><strong>60</strong></td>
<td><strong>10</strong></td>
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</table>
4.5. Morphometric characteristics of female Scutellonema bradys

The mean total body length of the S. bradys populations ranged from 747 µm to 861 µm (Table 13). The ratio ‘a’ ranged from 17.4 to 30.0 with the mean of 25.4. The range of ratio ‘c’ was 82.4 µm -130.6 with a mean of 100.6. The ratio ‘c’ ranged from 0.3 to 0.5. The stylet length ranged between 18 µm and 28.1 µm, with the nematode populations from Banda having the highest mean stylet length (23.9 µm).

Tail length of the S. bradys ranged between them was 5.7 µm and 9.3 µm. The average lip region diameter of S. bradys was 9.8µm and range was between 7.3 µm and 11.9. The diameter at the head region was between 11.3 µm and 27.8µm.

The tail diameter ranged between 15.4 and 17.6 µm in all the samples with a mean of 15.6 µm. The highest value of 17.6 µm was obtained from Banda and the lowest value 14.3 µm was also obtained from Chinderi. The stylet knob height was 4.4 µm at Zongo Macheri and lowest 3.8µm with a mean of 4.1 µm. The lowest scutellum height of 3.8 was obtained from all the rest of the communities. The stylet knob width had a value which ranged between 3.1 and 5.9µm (Figures 20 and 21, Table 14).
Table 14. Morphometrics characteristics of *Scutellonema bradys* females

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

<table>
<thead>
<tr>
<th>Location</th>
<th>Borae</th>
<th>Kaliako</th>
<th>Korkorse</th>
<th>Banda</th>
<th>Malla</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body length</td>
<td>754.4±11.0(624.6-886.5)</td>
<td>767.2±1.8(624.6-932.3)</td>
<td>747.3±18.1(624.6-952.6)</td>
<td>756.5±6.8(624.6-932.3)</td>
<td>786.5±21.1(624.6-955.8)</td>
</tr>
<tr>
<td>A</td>
<td>25.8±11.0(24.3-28.0)</td>
<td>26.3±1.8(24.3-30.0)</td>
<td>24.8±18.1(12.1-24.3)</td>
<td>23.0±6.8(17.1-24.3)</td>
<td>27.0±21.1(23.7-28.0)</td>
</tr>
<tr>
<td>C</td>
<td>99.1±0.0(99.7-110.3)</td>
<td>101.0±0.0(106.5-110.3)</td>
<td>99.8±0.1(100.7-110.3)</td>
<td>100.7±0.1(102.9-110.3)</td>
<td>101.5±0.1(102.9-100.3)</td>
</tr>
<tr>
<td>c'</td>
<td>0.5±0.0(0.4-0.5)</td>
<td>0.5±0.0(0.4-0.5)</td>
<td>0.5±0.0(0.4-0.5)</td>
<td>0.3±0.2(0.3-0.4)</td>
<td>0.5±0.1(0.4-0.5)</td>
</tr>
<tr>
<td>S</td>
<td>1.5±0.1(1.4-1.6)</td>
<td>1.4±0.0(1.5-1.7)</td>
<td>1.4±0.1(1.5-1.7)</td>
<td>1.5±0.1(1.4-1.6)</td>
<td>1.4±0.0(1.5-1.6)</td>
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<tr>
<td>Stylet length</td>
<td>22.6±0.5(19.1-25.4)</td>
<td>22.9±0.1(19.1-25.4)</td>
<td>22.9±0.1(19.1-26.4)</td>
<td>23.9±0.9(19.7-26.0)</td>
<td>23.1±0.1(18.1-28.1)</td>
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<td>Diameter at mid body</td>
<td>29.2±0.9(25.7-33.2)</td>
<td>29.1±1.0(25.7-33.2)</td>
<td>30.2±0.0(25.7-77.2)</td>
<td>32.9±2.8(30.1-35.7)</td>
<td>29.2±1.0(26.2-33.2)</td>
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<td>Tail length</td>
<td>7.6±0.0(5.7-9.3)</td>
<td>7.6±0.0(5.7-9.3)</td>
<td>7.5±0.1(5.7-9.3)</td>
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<td>Lip region diameter</td>
<td>9.8±0.4(7.4-11.8)</td>
<td>9.9±0.3(7.4-11.8)</td>
<td>9.8±0.4(7.4-11.8)</td>
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<td>Diameter at head region</td>
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<td>16.3±0.6(11.5-17.8)</td>
<td>24.1±7.1(11.5-27.8)</td>
<td>16.7±0.2(11.5-17.8)</td>
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<tr>
<td>Diameter at tail region</td>
<td>15.4±0.7(13.2-17.6)</td>
<td>15.4±0.7(13.2-17.6)</td>
<td>15.5±0.6(13.2-17.6)</td>
<td>17±0.9(15.3-17.3)</td>
<td>15.7±0.5(13.2-17.6)</td>
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<td>Styel knob height</td>
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<td>3.8±0.1(3.3-4.5)</td>
<td>3.8±0.7(3.3-4.5)</td>
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<td>Styel knob width</td>
<td>4.9±0.0(3.8-5.9)</td>
<td>4.9±0.0(3.8-5.9)</td>
<td>4.8±0.1(3.8-5.9)</td>
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<td>5.1±0.2(3.8-8.0)</td>
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<tr>
<td>Lip region height</td>
<td>4.6±0.1(3.4-6.0)</td>
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<td>5.1±0.4(3.4-6.0)</td>
<td>4.7±0.0(3.4-6.0)</td>
</tr>
<tr>
<td>Position of vulva to interior</td>
<td>362.3±15.6(304.5-412.5)</td>
<td>366.8±11.1(304.6-456.8)</td>
<td>362.9±15.0(304.6-412.5)</td>
<td>461.0±83.1(304.6-456.8)</td>
<td>363.0±14.9(304.6-412.5)</td>
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<td>Scutellum height</td>
<td>6.4±0.1(5.4-7.7)</td>
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<td>6.3±0.1(5.4-7.7)</td>
<td>6.4±0.1(5.4-7.7)</td>
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<td>Measurement (µm) and ratios</td>
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<td>Scutellum width</td>
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</table>

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.
Figure 20. Micrograph showing morphometric features of *S. bradys*, (A) stylet length and diameter at head region diameter (B) tail length
Figure 21. Micrograph showing morphometric features of *S. bradys*, (C) Stylet (D) diameter at mid body.
Correlation between morphometric characters for female *S. bradys* populations

There was a strong positive correlation between tail length and tail region diameter (r = 0.81) and also stylet knob height and vulva position (r = 0.68) (Table 16). There were moderate positive correlations were between lip region diameter and head region diameter (r = 0.46), lip region diameter and tail region diameter (r = 0.48) and also lip region height and scutellum length (r = 0.47). Most of the other variables were weakly correlated.
<table>
<thead>
<tr>
<th>Variables</th>
<th>body length</th>
<th>stylet length</th>
<th>diameter at mid region</th>
<th>tail length</th>
<th>lip region diameter</th>
<th>head region diameter</th>
<th>tail region diameter</th>
<th>stylet knob height</th>
<th>stylet knob width</th>
<th>lip region height</th>
<th>vulva position</th>
<th>scutellum height</th>
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<tr>
<td>head region diameter</td>
<td>-0.002</td>
<td>0.019</td>
<td>0.192</td>
<td>0.112</td>
<td>0.455</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tail region diameter</td>
<td>-0.032</td>
<td>-0.101</td>
<td>0.123</td>
<td>0.155</td>
<td>0.482</td>
<td>0.812</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>stylet knob height</td>
<td>0.206</td>
<td>0.310</td>
<td>0.099</td>
<td>-0.145</td>
<td>0.192</td>
<td>0.190</td>
<td>0.275</td>
<td>1</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>stylet knob width</td>
<td>0.140</td>
<td>0.109</td>
<td>-0.156</td>
<td>-0.241</td>
<td>-0.010</td>
<td>0.111</td>
<td>0.120</td>
<td>0.266</td>
<td>1</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>lip region height</td>
<td>0.031</td>
<td>-0.041</td>
<td>0.113</td>
<td>0.203</td>
<td>0.238</td>
<td>0.242</td>
<td>0.174</td>
<td>0.113</td>
<td>0.227</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vulva position</td>
<td>0.358</td>
<td>0.125</td>
<td>0.192</td>
<td>0.136</td>
<td>0.227</td>
<td>0.290</td>
<td>0.304</td>
<td>0.681</td>
<td>0.377</td>
<td>0.223</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 15. Correlation between matrix (Pearson) (n) of *S. bradys* female morphometric variables

<table>
<thead>
<tr>
<th>Scutellum Height</th>
<th>0.088</th>
<th>-0.050</th>
<th>0.291</th>
<th>0.195</th>
<th>0.075</th>
<th>0.118</th>
<th>-0.181</th>
<th>-0.039</th>
<th>-0.017</th>
<th>0.238</th>
<th>0.081</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scutellum Length</td>
<td>0.134</td>
<td>0.088</td>
<td>0.218</td>
<td>0.142</td>
<td>0.291</td>
<td>0.141</td>
<td>0.122</td>
<td>0.376</td>
<td>0.160</td>
<td>0.472</td>
<td>0.502</td>
<td>0.278</td>
</tr>
</tbody>
</table>
Agglomerative Hierarchical Clustering (AHC)

Agglomerative hierarchical clustering (AHC) revealed five groups at a dissimilarity of 90%. However, below 50% sub-groups were formed as nematodes from different sites clustered together, irrespective of their source. Nematodes from Groups one and two consisted only of nematodes from Banda community, however, the other groups were made of nematodes from varying communities (Figure 22).
Figure 22. Agglomerative Hierarchical Clustering (AHC) of nematodes from ten communities in Krachi Nchumuru District. 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 characterised from each community. Color codings: Light blue-Group 1 (Gp1), Red-Group 2 (Gp2), Green-Group 3(Gp3), Purple-Group 4, and Deep Blue-Group 5(GP5).
CHAPTER FIVE

5.0 DISCUSSION

Majority of farmers were males while females were few. This might be due to the physical nature of yam cultivation, women were perceived to be weak, and therefore did not engage in strenuous activities. Most of the farmers also had little or no formal education. In Ghana, most people with higher education seek for jobs in cities and thus, leave the farming in the hands of those with little or no formal education. In another study, farming in Sierra Leone was left in the hands of individuals with little or no formal education, while the highly educated sought for jobs in the cities (Sesay et al., 2013).

The lack of knowledge about yam nematodes may have been a contributory factor to the high prevalence of dry rot disease in yam tubers. The dry rot disease may also have resulted from improper farming practices, such as the non-removal of stubbles and volunteer crops during the off-season which may serve as alternative hosts for nematodes. Nematodes are capable of surviving on alternative host plants especially those with underground food storage (Luc et al., 2005; Sikora and Fernandez, 2005). Some farmers, however, were into continuous cultivation of yam without land or crop rotation, which could have resulted in the persistence of nematodes in most farmers’ fields. Many of the farmers had no knowledge about nematodes, therefore, could have attributed nematode infection to moisture stress and nutrient deficiency. They may have also encouraged their spread through soil adhering to farm tools and equipment and footwear (Hunt et al., 2005).

Yam is vegetative propagated by seed yam and setts, and farmers usually produce their own planting materials, buy from markets and also from relatives and these planting materials could be
a major source of inoculum for the yam nematodes (Kwoseh et al., 2005). The movement of the yam setts from one location to other contributes to the spread of the nematodes in farmers’ fields. Farmers grow different early maturing crops alongside yam (a late maturing crop) either as food security crop or for income generation. This practice also minimizes the risks associated with pest and disease, price variability, and ensure food availability all year round (Coursey and Booth, 1977).

High losses incurred by the farmers might have been due to the parasitic nature of *S. brays* which reduced both tuber yield and quality with estimated losses of 75% when infected yam tubers are stored for long periods (Jakata and Bridge 1990). Yam storage losses to nematodes up to 80% have also been recorded (Nwauzor, 1982; Hahn et al., 1989). Wachira et al. (2009), observed that the addition of organic manure into the soil decreases nematode populations, however none of the farmers applied organic manure in their yam farms.

Farmers in the Krachi Nchumuru District produce yam for consumption, income generation, and for purchase of assets. Therefore, failure to meet their production targets affect their ability to get enough food for the family throughout the year. Also their ability to pay medical bills, paying of children’s school fees, service old loans as well as their social responsibilities are affected. This could be overcome through farmer education on nematode parasitism and gearing research towards generating and maintaining sustainable healthy panting materials.

Twelve genera belonging to seven nematode families of order Rhabdida and Dorylaimida were identified in yam rhizosphere soils and nine genera in stored yam tubers. These were *Scutellonema* spp., *Meloidogyne* spp. *Longidorus* spp., *Tylenchulus* spp., *Helicotylenchus* spp., *Ditylenchus* spp., *Heterodera* spp., *Pratylenchus* spp., *Rotylenchus* spp., *Appenlenchoides* spp.,
and Bursaphelenchoides spp., Scutellonema spp. The predominant nematodes in both soil and yam tuber peels were Scutellonema spp., Meloidogyne spp., and Pratylenchus spp. There Adesiyan and Odihirin (1977) also isolated and identified Scutellonema spp., Pratylenchus spp., Meloidogyne spp., Helicotylenchus spp., Criconemoides spp and Xiphinema spp as the most important nematode species on yam in Mid-West State of Nigeria. In a similar study conducted in Ghana, the relative abundances of the top three nematodes from yam peels were Pratylenchus spp. (32.4%), Scutellonema bradys (18.2%), and Meloidogyne spp. (21.3%) (Jamani, 2015). However, in our study, the top three nematodes from the yam peels were Scutellonema bradys (87.4%), Meloidogyne spp. (6.3%), and Pratylenchus spp. (5.3%).

Nematodes infestation has also been reported to be a serious constraint in yam production in various parts of the world (Kwoseh, et al., 2005; Baimey, 2006; Kumar and Singh, 2010). The rise in number of Scutellonema bradys. in stored yam tuber compare to the number soil in yam rhizospere indicate that S. bradys can reproduce on stored yam tubers (Kwoseh et al.,2005).

A comparison of the morphometric measurements in our study with others described in literature show slight differences. In the current study, body lengths ranged from 624.6 μm- 996.1 μm, but, in another study, body lengths ranged from 624.6 μm -858.5 μm (Jamani, 2015). In this 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. In another study, S. brachyurus populations from 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 absence of similarities among the morphometrics within the populations.
studied. Significant morphological variation exists within female *S. bradys* populations, because of sub-group formations.
CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The results obtained from the study indicates that yam (*Dioscorea* spp.) farmers in the Krachi Nchumru District were of aware of the presence of nematodes parasitism, physical damage they caused to their yams from the fields and in storage. However, they were ignorant about the organism that causes the disease and the spread of it within and among farms. Most farmers in the district believed that nematode parasitism cannot be controlled, some farmers however used cultural methods such as crop rotation and land rotation to manage them. Nematode parasitism has negatively impact on the farmers which affect their livelihood.

- The major genera of nematodes extracted and identified from the soils and yam in storage were; *Scutellonema bradys*, *Meloidogyne* spp., and *Paratylenchus* spp.
- Agglomerative hierarchical clustering (AHC) revealed five groups at a dissimilarity of 90%. There were formations of sub-groups at dissimilarity values below 50%.
6.2 Recommendations

- Education of yam farmers in the Krachi Nchumuru District should be intensified. This can change the farmers’ perception on mode of spread of nematodes which will ensure effective management.

- Molecular characterization of the yam nematode should be explored to validate the presence of variation among *S. bradys* populations.
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APPENDIX (I)

SURVEY ON NEMATODES ASSOCIATED WITH YAM PRODUCTION IN THE KRACHI NCHUMURU DISTRICT OF THE VOLTA REGION OF GHANA

Documentation of farmers’ knowledge, perceptions, and experiences concerning occurrence and management of nematodes associated with yam production.

QUESTIONNAIRE NO...........

Demographic characteristics

Name of farmer..............................................................

Sex: Male 1  Female 2  ( )

Age of respondent:

< 20 = 1

21 – 30 = 2

31 – 40 = 3

41 – 50 = 4

> 50 = 5


Name of community......................................................


Size of farm, year of cultivation and source of planting material
<table>
<thead>
<tr>
<th>YEAR OF CULTIVATION</th>
<th>SIZE OF FARM (ACRE)</th>
<th>SOURCE OF PLANTING MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Source of planting material: own farm [1], family member [2], market [3], others (specify)…………….

1. What are the varieties of yam grown in your farm?

**VARIETY   PROPORTION OF FARM**


A. Land use intensity

2. How long have you cultivated this land 1-3 years [1] 4- 6 years [2] 7-10 years [3]

3. What type of crop(s) have you planted on this piece of land in the past five (5) years?
   • Yam [1]
   • Cassava [2]
   • Cowpea [3]
   • Maize [4]
   • Soybean [5]
Other (specify)........................................................................................................

4. How long have you planted yam on this piece of land:  1-3 years [1], 4-6 years [2]
   7-10 years [3], more than 10 years [4]

5. Have you rotated your yam crops before  Yes [1] No [1]

6. If yes, with what crop(s)...............................................................................................

7. What was the period of rotation:  1-2 year [1], 3-5 year [2], more than 5 years [3]

8. Have you practice land fallow in the past? Yes [1], No [2]

9. If yes, how long was the fallow period?  1 year [1], 2-4 years [2], 5-10 years [3]

B. Farmers’ knowledge, perception and experience concerning occurrence of nematodes on farm and in storage.

10. Do you experience any pests and disease problem in your yam crops during the growing season?
    Yes [1] No [2]

11. Do you know what nematodes are?  Yes [1] No [2]

12. Which of your varieties do you observe these symptoms more?

13. Which of these symptoms and signs do you observe in your yam field?

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Necrotic streaks or lesions on roots</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Reduced rooting system</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>internal rotting or discolorations of vegetative organs</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Dwarfing</td>
<td></td>
</tr>
</tbody>
</table>
Stunting and resetting

14. What are the conditions of the soil in your field in which these signs/symptoms are prevalent?
   a. Lowland sandy soil (waterlogged) [ ]
   b. Well drained sandy loam soil [ ]
   c. Sandy – clayey [ ]
   d. Sandy soil [ ]
   e. Loamy soil [ ]
   f. Clayey soil [ ]

15. Where do you store your yam after harvest?
   a. Under a tree in the farm [ ]
   b. Yam barn at home/farm [ ]
   c. In a store at home [ ]
   d. In a farmstead [ ]


17. If yes, what signs/symptoms do you observe in the stored tubers?

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hardened and dried tissues with vary discolorations</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>External cracks on skin of tubers</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Significant weight loses in tubers</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Light yellow lesions below the outer skin of the tuber</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Rotting of the outer 1–2cm layer</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Flaking off- of external coverings exposing patches of dark brown</td>
<td></td>
</tr>
</tbody>
</table>
General decay of tubers


C. Farmers knowledge, perception and experiences concerning control/management


19. Are you able to manage/control nematode infestation? a. [Yes] b. [No]

20. If Yes, what are some of the management practice used in your farm

<table>
<thead>
<tr>
<th>S/N</th>
<th>MANAGEMENT PRACTICE</th>
<th>YES/NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Crop rotation</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Use of Nematicides</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Land rotation</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Use of organic/inorganic fertilizers</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Others (specify)</td>
<td></td>
</tr>
</tbody>
</table>


21. If No, give reasons. A. [no reason] b. [I do not know how to control them] c. Other, (please specify)…………………………………………………………………

D. Farmer knowledge, perception and experiences concerning economic importance of nematodes

22. What are some of the reasons why you cultivate yam? ..............................................................

23. Estimated loses as result of nematode infestation.
<table>
<thead>
<tr>
<th>Year</th>
<th>Farm size (acres)</th>
<th>Expected yield (100 tubers)</th>
<th>Quantity harvested (100 tubers)</th>
<th>Quantity stored tubers</th>
<th>Percentage loses (%) due to nematodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td></td>
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<tr>
<td>2015</td>
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<tr>
<td>2016</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

24. Was yield higher than expected (1) yes (2) no

25. Where actual yields higher than expected yield, give reason:

No. reason [1], favorable rainfall [2], Use of inorganic/organic fertilizers [3], Higher soil fertility [4], Others (specify)……

26. Please explain the effect of nematodes parasitism on the following:

I. Money to pay children’s school fees……………………………………………………………………………………………………

II. Money to repay loans…………………………………………………………………………………………………………………………

III. Money to buy assets…………………………………………………………………………………………………………………………

IV. Money to pay medical bills……………………………………………………………………………………………………………………

V. Your relationship with extension officers………………………………………………………………………………………………

VI. Your relationship with spouse and neighbours…………………………………………………………………………………………