MANAGEMENT OF PLANT PARASITIC NEMATODES OF WHITE YAM (*DIOSCOREA ROTUNDATA)* USING ABAMECTIN TREATED BANANA PAPER IN KRACHI NCHUMURU DISTRICT

BY

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This thesis is submitted to the University of Ghana, Legon in partial fulfillment of the requirements for the award of MPhil Crop Science degree

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DECLARATION

I, FRANCIS GIFFA ATTOESI, do hereby declare that except for references cited which have been duly acknowledged; this thesis "Management of Plant Parasitic Nematodes of White Yam (*Dioscorea Rotundata)* Using Abamectin Treated Banana Paper in Krachi Nchumuru District" is the result of my own research. It has never been presented either in part or in whole for the award of any degree.

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DEDICATION

I dedicate this work to the Almighty God and my family.

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ABSTRACT

Plant parasitic nematodes are important crop pests threatening food security and causing huge pre-harvest and post-harvest losses in crops including yam. The aim of this research was to evaluate the efficacy of abamectin pretreated banana paper for controlling the key plant parasitic nematodes of yam (*Dioscorea rotundata*) in the field and in storage. A survey was conducted to ascertain farmers knowledge about plant parasitic nematodes and their control. Field trials were then conducted to test the efficacy of abamectin in controlling key plant parasitic nematodes of yam using the "wrap and plant" technology, where seed yams were wrap before they were planted. After the harvest of yam tubers, storage experiment was conducted to test the effect of the treatments on yam tubers at storage. A laboratory experiment was conducted to ascertain plant parasitic nematode population dynamics in response to the treatment. The results from the survey revealed that majority (97%) of the yam farmers interviewed were aware of the problem of plant parasitic nematodes, but lacked the necessary knowledge, skills, and resources to control these important pests in their yam farms. Majority of the farmers (79.2%) estimated up to 50% of their yam tuber lost to plant parasitic nematodes both in field and in storage and this seriously affected their livelihood. Consequently, more than 80% of the farmers could not pay their children's school fees, medical bills, and repayment of bank loans. Only about 12% of the farmers admitted they knew plant parasitic nematodes could be controlled with the use of nematicide. However, 81% of the farmers were ready and willing to adopt the abamectin pretreated banana paper technology. Field trials revealed no significant effect of the abamectin on the number of yam tubers harvested per plot and the number of mounds harvested because the treatments had no effect on germination of seed yams. However, the abamectin pretreated banana paper (A) produced yam tubers which were significantly higher ($p<0.05$) in weight and length as compared to only banana paper without

abamectin (B) and the control which is the farmer's practice (FP). For the storage experiment, treatment A reduced the plant parasitic nematode damage significantly ($p < 0.05$) on stored yam tubers compared with the B and FP. There was no significant difference in weight loss of yam tubers across the treatment during storage as the percentage weight loss for A, B and FP after five months were 33.16%, 32.37% and 32.74% respectively. The benefit cost ratio of abamectin pretreated banana paper was 1.37 and 2.56 for wet and dry seasons respectively which indicate profitability. These results confirm that abamectin pretreated banana paper can be used in the management of plant parasitic nematodes of yam for improved yield and storability of yam tubers.

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CHAPTER ONE

1.0 INTRODUCTION

Yam is an important root and tuber crop that supports the nutrition and livelihoods of millions of people especially in tropical countries (Muimba-Kankolongo, 2018). The contribution of yam to Ghana's food security cannot be over emphasized. This is seen in the all-year-round availability of yam at local market places, aiding the prevention of food shortages, particularly in urban areas due to longer storage potentials of the commodity (Ridolfi *et al.*, 2018**;** Aidoo, 2011). Many people in the yam value chain rely on it for income and employment (Osei-Adu *et al.*, 2016). Being the world's largest exporter with approximately 30% influence on the global yam market (Anaadumba, 2013), Ghana stands at advancing her economic benefits through increasing her production. This advantage comes from increases in local, regional, and international demand for yam tubers, hence the need to improve production and storage (Tortoe *et al*., 2014). Aside its nutritional and economic importance, yam serve medicinal, and socio-cultural purposes (Pamphile & Nassirou, 2021; Chandrasekara & Josheph Kumar, 2016).

With an annual production of 8.29 million tonnes, Ghana is the world's second-largest yam producer (FAOSTAT, 2020). In 2017, Ghana cultivated 493, 000 hectares of yam across the country, yielding 8.25 million tonnes (Ministry of Food and Agriculture [MOFA], 2018). Yam is grown in practically every part of the nation, although the Brong Ahafo, Northern, Eastern, Ashanti, Upper East, and Volta regions produce the most (Cugala *et al.*, 2012). The Krachi Nchumuru District produced 107482 tonnes of yam in 2020, accounting for 20% of volta region's total production (MOFA, 2021).

Plant-parasitic nematodes threaten yam production in the Krachi Nchumuru District, and other yam growing communities in Ghana causing significant losses both in the field and during storage (Nyaku *et al.*, 2018). These losses are compounded when yams are cultivated year after year on the same plot of land with no definite crop rotation or land fallowing practices (Sikora, *et al.*, 2018). Weight loss, cracking, dry rot, and galling are some common symptoms of plant parasitic nematode infestation in yam tubers. Although many species of plant parasitic nematodes exist (Olabiyi *et al.*, 2020), *Scutellonema bradys* (yam nematode), *Meloidogyne* spp. (root knot nematodes,) and *Pratylenchus coffeae* (lesion nematode) are dominant problem-causing plant parasitic nematode species that attack yam in Ghana (Nyaku *et al*., 2018). For example, dry rot caused by *Scutellonema bradys* with symptom of yam tuber decay is known to cause some 21% and 30% postharvest losses in yam from Ghana's transition and Guinea Savannah zones, respectively. (Bridge *et al*., 2005; Kwoseh *et al.*, 2007). *Meloidogyne* spp. on the other hand, causes galling on yam tuber with more than 75% damage effects within 16 weeks of storage, hence lowering the economic value of yam tubers (Mudiope *et al*., 2012). *Pratylenchus coffeae* is responsible for the cracking of the yam tubers that leads to significant reduction in economic value (Sikora, *et al*., 2018). Seed yam and soil are the key sources of plant parasitic nematode inocular in yam fields (Affokpon, 2018)

Attempts to addressing the challenge have been by synthetic pesticides, biological agents, cultural and physical control or management methods (Coyne *et al*., 2018; Reddy, 2015). However, a suitable approach is yet to be identified due to inherent challenges associated with effectiveness, toxicity, high costs, and environmental pollution. For instance Dibromo-chloropropane (DBCP) and Methyl bromide were widely used to control plant parasitic nematodes but are now banned in most countries for health and environmental reasons (Sikora *et al*., 2015).

Abamectin is a commonly used nematicide with minimal toxicity to non-target organisms as demonstrated by several research and therefore safe for agricultural use (Muzhandu *et al.*, 2014). It is a bio-pesticide derived from the soil microorganism *Streptomyces avermitilis* and has been effective against various plant parasitic nematodes, by paralyzing them as it binds to their muscle and nerve cells (Cao *et al.*, 2016). Abamectin is a contact nematicide that has been used to manage plant parasitic nematodes in various crops including potato (Ochola *et al*., 2020), tomato (Ullah *et al*., 2015), and tobacco (Sasanelli *et al*., 2020). Since abamectin is a biopesticide, it is less harmful to humans and the environment including non-target organisms. Despite abamectin's effectiveness in controlling plant parasitic nematodes, its efficacy in yam production has not been much explored in Ghana.

Abamectin is typically applied to crops by spraying onto the soil surface; however, this route of application can tightly bind the Abamectin to the soil surface due to its low mobility in the soil thereby making it unable to fully protect the root system beneath the surface. To address this issue, wrap and plant technology which involves the use of banana paper to ensure efficient and controlled release of abamectin has been proposed (Pirzada *et al*., 2020). The use of banana paper as a controlled release matrix for Abamectin is a cheaper alternative. Using abamectin-pretreated banana paper as wrap around seed yams before planting (wrap and plant technology) for the management of key plant parasitic nematodes of yam is the focus of this study.

While it might seem satisfying to introduce new, cutting-edge agricultural technologies to improve the quality of life of farmers and enhance food security, it is likely that such technologies will meet with some level of resistance by certain sectors of the society (Adekunle *et al.*, 2016). One of the major factors that influence adoption of agricultural innovation is the socioeconomic characteristics of the farmers. Hence, it is imperative to consider this area for a successful adoption of the technology. Low adoption of modern agricultural production technologies amongst farmers in Ghana has been identified as one of the main reasons for the low agricultural productivity in the country (Akudugu *et al*., 2012).

Successful use of the wrap and plant technology to solve the challenge of plant parasitic nematodes in yam production will lead to improved livelihoods of yam farmers and others in the yam value chain. It will also improve the economy and provide more foreign exchange as more yam tubers are exported.

1.1 OBJECTIVES

The aim of this study was to assess the efficacy and yield influence by using abamectin wrap and plant technology in the management of plant parasitic nematodes infestation during yam productions and storage in Krachi Nchumuru district in Ghana. The specific objectives were to:

1. Assess farmer agronomic and management practices, and knowledge on plant parasitic nematode management in yam production in Krachi-Nchumuru District of Ghana
2. Evaluate the efficacy and yield potential of abamectin wrap and plant technology in the management of plant parasitic nematodes in yam production.
3. Assess the perception of farmers on the use and adoption of Abamectin pretreated banana paper technology.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Yam (*Dioscorea* spp.) - Origin and classification

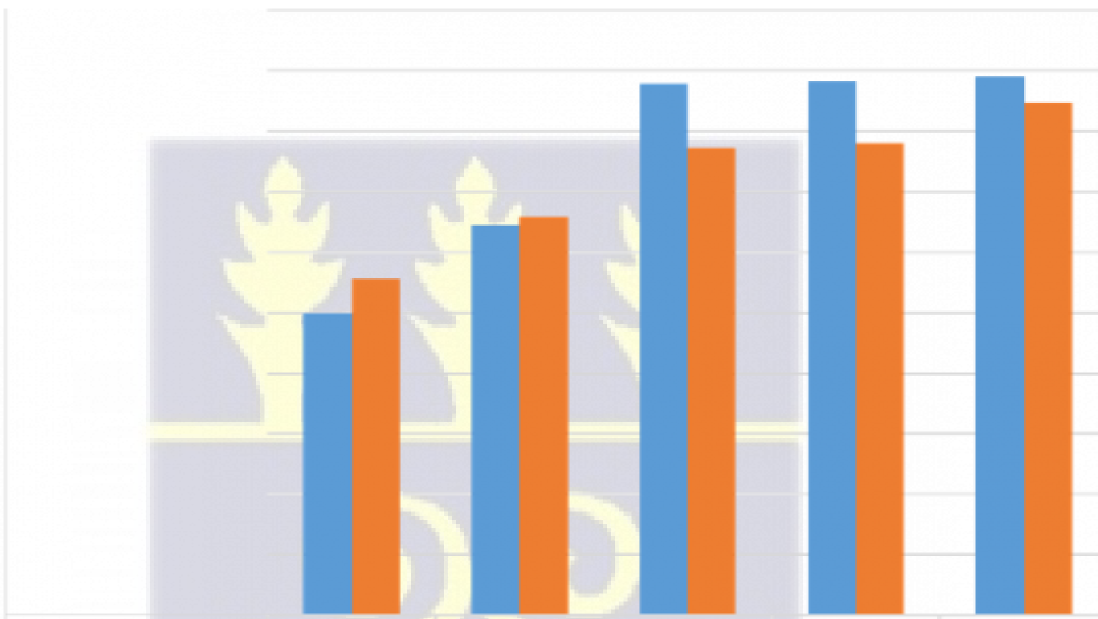
Yams (*Dioscorea* spp.) are members of the family *Dioscoreaceae* and the genus *Dioscorea* (Orkwor *et al.*, 1998). Given the fact that there are more than 600 species of the genus *Dioscorea*, just a few are cultivated for food (Andres *et al*., 2016). The main food species are *D. rotundata* (white Guinea yam), *D. alata* (water yam, winged yam, or greater yam), *D. cayenensis* (yellow yam or yellow Guinea yam), *D. esculenta* (lesser yam, potato yam or Chinese yam), *D. dumetorum* (bitter yam or trifoliolate yam), *D. bulbifera* (aerial potato yam), *D. trifida* (cush-cush yam), *D. opposita* also known as *D. japonica* (cinnamon yam) (Lebot, 2009). *Dioscorea* species come from a variety of geographical locations. However, West Africa, Southeast Asia, and tropical America are the three main places of origin. *Dioscorea rotundata* originated in Africa and represents the most important species in terms of volume of production as well as the preferred yam species (Darkwa *et al*., 2020). In Ghana, the Pona cultivar of white yam (*Dioscorea rotundata*) is the most preferred for local consumption and export. It is however, the most susceptible to infection by pathogens including plant parasitic nematodes (Plowright *et al*., 2000; Cornelius, 1998).

2.2 Importance of yam

Yam (*Dioscorea* spp.) is a crop of prestige due to its multiple uses. This crop is the world's fourth most valuable root and tuber, and staple crop (Affokpon & Waeyenberge, 2017). Yam is Africa's second most valuable root and tuber crop after cassava (Andres *et al*., 2016). About five million people in yam-growing countries rely on the yam value chain for food and income (Mignouna *et al*., 2020). People in West Africa and beyond would love to eat more yam if it would reach the market at more affordable prices (Nweke, 2013). Moreover, farmers would grow more yam if the crop could be produced profitably at lower costs. Hence, yam gives a plethora of possibilities for addressing people's economic and hunger issues, especially in yam-growing areas. (Claudius-Cole *et al*., 2016). In Ghana, yam is very central in the food system (Tortoe *et al*., 2020). For many Ghanaians, it is a vital staple food, contributing to 11% of total consumption (Anaadumba, 2013). In terms of yield and food security, cassava is the most cultivated root and tuber crop followed by yam (Andres *et al*., 2016) although yam is preferred to cassava due to its high palatability and absence of hydrogen cyanide. The wide consumption of yam among other things is a result of its palatability and nutritional benefits (Tortoe *et al*., 2020). Yam generally has high moisture and dry matter content composed of carbohydrates, vitamins, minerals, and other nutrients (Fauziah *et al*., 2020). Cooked yam has about 2% protein as in potatoes but twice that of cassava (Otoo, 2008). A yam meal may provide an adult male with 100% of his calorie and protein needs, 13% of his calcium needs, and 80% of his iron needs (Oke, 1990) in (Etudaiye, 2020). Furthermore, yam contains trace amounts of phenolic compounds such as tannins, steroid-based chemicals like diosgenin and dioscorine as well as alkaloids (Muzac-Tucker *et al*., 1993).

As a treasured ceremonial and traditional crop, yam performs critical functions in social festivities throughout West Africa and other growing regions (Aighewi *et al*., 2002). This role sets it apart from other food crops. Social values of yam include celebration of traditional festivals such as the new Yam Festivals celebrated in Ghana, Nigeria and other yam growing countries. It is also customary in some regions of Africa for a bride's parents to present yams for cultivation as an asset to assist the young couple in establishing a family (Opara, 2003). White yams are also part of dowry in some yam growing communities. Furthermore, white yam has high economic value for those involved in its value chain including rural poor producers, processors, and consumers (Babaleye, 2005).

It is a high-income crop in West Africa's yam growing zone, notably in Ghana. Ghana produces large quantities of white yams and exports them throughout the year (**Fig. 2.1**), contributing more than 94% of total West African white yam exports (Anaadumba, 2013) and 10.3% of world export in 2016 (Ghana Export Promotion Authority [GEPA], 2021))



Year	2016	2017	2018	2019	2020
Qty Exported in MT	25,014	32,230	43,936	44,172	44,508
USD'000	27,772	32,962	38,636	39,001	42,385

Figure 2. 1 Fresh White Yam Export from Ghana

Source: Ghana Export Promotion Authority (2021)

Since it may be sold all year round by the farmer or merchant, stored yam acts as stored riches (Aidoo, 2011). Apart from their excellent nutritional value, several white yam species are high in antioxidant and being used medicinally to treat ailments (Joy & Siddhuraju, 2017). Hence, yam tubers have an immense potential to be used as nutraceutical ingredients in disease risk reduction and wellness (Chandrasekara & Kumar, 2016).

2.3 Yam production

At the commencement of the rainy season, seed yams or tuber pieces are sown into mounds or ridges to begin the production phase. The yield of yam tubers is mainly determined by when, how, and where the planting materials are grown, the size of the mounds, interplant spacing, supply of stakes, yam species, and harvest tuber sizes desired (Reddy, 2015). This was also confirmed by Aighewi *et al*.,(2020), who found out that early planted seed yams yielded 137% more than late-planted ones. Additionally, diseases and pest infestation also influence the yield of yam tubers.

Planting nematode-free seed yams is a dependable and cost-effective way of avoiding plant parasitic nematode damage and spread (Akinbo, 2016). The high cost of seed yams, which accounts for nearly half of the production cost, limits yam cultivation. Seed yams are difficult to store and transport for an extended period. Farmers may replant up to 30% of their harvested tubers the following season if they do not purchase new seed yams (Iseki & Matsumoto, 2020). Yams are normally vegetatively propagated from seed tubers (seed yams), portions of tubers weighing between 400g to 500g (setts) or bulbils (Sikora *et al*., 2018). Yam setts may be pregerminated in moist sawdust before planting in the yam mounds. Three types of setts can be obtained from a whole tuber – head setts, middle setts, and tail setts. According to Andres *et. al*., (2016), the headsets are the best to plant because of the presence of eyes, which give rise to the new plants. Yams may be planted as monocrop, or intercropped with maize, groundnut, cowpea, cassava, and other crops. When grown as a monocrop, yam is planted in rows with a 100 cm interrow spacing and a 50–100 cm row to row spacing. The seed yams are usually planted on ridges or mounds with plant residues used as mulch.

2.4 Climatic Requirements

Climatic factors such as rainfall, temperature and light significantly influence the growth and yield of all crops including yams. Yam thrives in climates with 1000-1500mm of rain spread out over 6 to 7 months of the cropping season (Orkwor *et al*., 1998). This may be because the crop requires water for vine and leaf growth, tuber initiation and bulking during its active growth stage. Also, when yams are intercropped, moisture tension affects them more, causing tuber initiation to be delayed. Hence, mulching is essential for preserving moisture, particularly when planting in the dry season. The optimal temperature range for growing yam is between 25°C and 30°C (Muimba-Kankolongo, 2018). Temperature affects the sprouting of yams and with temperatures between 25°C and 30°C ideal for yam sprouting, whereas temperatures below 5°C or above 35°C inhibits sprouting (Orkwor *et al*., (1998). Generally, yam setts planted in shallow depths may desiccate and fail to germinate because of exposure to high soil temperatures just above the setts on the soil surface.

Light is a significant growth factor in yam cultivation; consequently, the rate of yam growth is greatly affected by light interception in the field (Budiadi *et al*., 2020). Crop yield in the field is affected by how the crop canopy is displayed for solar energy absorption and the crop's ability to generate photosynthates. Consequently, when yams are usually intercropped with other arable crops, there is a competition for light, space, moisture, nutrients, and other resources. Daylength affect yam tuber initiation and morphological development. Short daylengths of about 12 hours, as are generally found in the tropical yam- growing ecologies, are known to promote tuber initiation while longer daylength of about 14 hours inhibit tuber initiation (Shiwachi *et al*., 2000). Furthermore, staking is done to aid in the exposure of the leaves on the twining yam stems to draw enough solar energy for effective photosynthesis.

2.5 Soil and Land Preparation

The condition and properties of the soil at the time of planting are important determinants of yam yield (Aighewi *et al*., 2015). Traditional yam farming involves planting yam as the first crop after clearing the field of big trees or after a long period of fallow. While loamy soils are best for yam cultivation, they can also be grown in sandier savannah soils (Orkwor *et al*., 1998). For fast penetration and swelling of the tubers, the crop requires loose soil with high organic matter levels since they do not produce satisfactory yields when cultivated on compacted or shallow soils (Ennin *et al*., 2009). Even though yams require a lot of nutrients from the soil, especially Nitrogen and Potassium, they have historically been grown without fertilizer, which results in low yields. *D. rotundata* yields, for example, are usually around 8 t ha^{-1} fresh tubers, despite the theoretical yield being projected to be around 30 t ha^{-1} (Andres *et al*., 2016). A few farmers use soil fertility conservation methods such as crop rotation and manure application to achieve reasonable yields. However, the combination of NPK and poultry manure can be used for production of yam that is not for storage since mineral fertilizer hasten yam tuber rot in storage (Yahaya, 2012).

2.6 Agronomic Practices

Mulching of yam mounds is done just after planting. A layer of fresh or dried grass or leaves are place on top of the mounds and covered with soil to ensure that the mulch is not blown away by wind. Mulching is usually done to reduce the direct effects of solar radiation on planted yam seeds and decrease soil temperature in the mounds as well as conserve moisture. Mulching can also stimulate the microbial antagonism potential of the soil which can lead to a reduction in plant parasitic nematode inoculum densities and consequently increase yield (Lebot, 2009). Proper crop rotation and fallowing is recommended in yam production to ensure restoration of soil fertility after yam cultivation (Roland, 2015). Maize, cassava, bananas, and vegetables are commonly intercropped with yams. Cowpea, pigeon pea, and soybean are all legumes that are also alternated with yam. Since yam is a climbing crop, staking is required to ensure that the leaves receive adequate sunlight during their growth. The larger the surface area of the leaves exposed to sunlight, the higher are the yields obtained. Farmers use bamboo branches, or shrub branches as staking materials (Nweke, 2013). Non- staked cultivation is also practiced in some yam growing areas. Although this method suppresses weed growth, tuber yield is likely to be low. Soon after emergence, yam plants are normally staked. For optimum yam yields, weed management is essential. Hoes are often used to control weeds in yam farming. Weeding must be done with extreme caution so as not to harm the young and developing root structure. Weeding should be done three to four times during the season. Andres *et al*., (2016) observed that delay in weeding negatively impacted yield leading to yield reduction of up to 90%.

2.7 Pests and disease associated with tubers of yam

The problem of pests and diseases are among the key factors responsible for the decline in tuber yield of yam per unit area. Hence, their proper management is necessary to improve yield (Kolawole *et al*., 2018).

2.7.1 Pests

Yams are susceptible to a range of pests both during and after harvest. The yam beetle, mealy bugs, termites, and plant parasitic nematodes are all significant yam pests. The dry matter and germination capability of yam tubers are both reduced by these pests (Opara, 2003). Furthermore, the damage they cause to the skin of tubers can lead to secondary infections by other microorganisms including fungi and bacteria, resulting in significant storage losses (Andres *et al*., 2016). One of the serious threats to yam crops is plant parasitic nematodes, especially if the crop has been cultivated repeatedly on the same field without appropriate crop rotation. They mainly infect growing crops and stay on the tubers after they have been harvested. Even though plant parasitic nematodes are not normally considered to be significant in stored tubers, they cause necrotic areas on stored yam tubers which lead to huge postharvest losses.

2.7.2 Diseases

Yams are prone to several diseases caused by viruses, bacteria and fungi leading to poor yield and tuber rot especially in storage. The tuber may be infested either in the field or during storage. However, fungi and bacteria are the main causes of postharvest rots of yam tubers (Okigbo, *et al*., 2015). Soft rots are yam diseases mostly caused by *Fusarium* spp. and *Botryodiploda* spp. (MOFA, 2011).

2.8 Harvesting of tubers

Yams takes between 7–9 months to grow to maturity. Maturity is verified by yellowing leaves and normal vine dieback. Harvesting may be done before the yam reaches full maturity and before the soil gets too dry to increase yield and avoid bruises on the yam tuber. Once the vines have been cut, hand tools are used to carefully root out the tubers, taking care not to damage them (Andres *et al*., 2016).

2.9 Storage

It is almost impossible to produce yam throughout the year. Storage is essential to improve white yam availability between harvests and minimize major changes in supply and, as a result, price (Osagie, 1992). Since the bulk of white yam tubers produced are used in the fresh state, extending the shelf life of fresh yam tubers is crucial in ensuring the continuous availability of fresh yam tubers. Apart from mechanical damage on yam tubers during or after harvest, losses during storage are caused mainly by preharvest pathogens of which plant parasitic nematode is important. Plant parasitic nematode infection often starts before harvest in the field and continues in storage (Reddy, 2015).

Yam is often stored in barns constructed of vertically stacked wooden poles and palm leaf midribs. Another method is to bury the tubers in a ditch with soil and materials such as coconut leaves to protect them. Tubers that have been stored for a long time should be examined on a regular basis. To keep rats and other pests from attacking the tubers, the barns are locked. Traps and baits are also used to catch these rodent pests. After 3–4 months of dormancy, the tubers may begin to sprout while in storage (Andres *et al*., 2016). The respiration rate of yam tubers is reduced when stored at cold temperatures. Chilling at temperatures below 10–12°C, on the other hand, may trigger internal tissue breakdown, increasing water loss and tuber decay. The optimal temperature for the storage of white yam is 14–16°C (Muimba-Kankolongo, 2018). Certain white yam cultivars store better than others. In Ghana, the Pona white yam cultivar (*Dioscorea rotundata*) is the most popular for local consumption and export. Nonetheless, both in the field and in storage, it is very susceptible to pathogens such as plant parasitic nematodes (Cornelius, 1998).

2. 10 Nematodes

Nematodes belong to the kingdom Animalia (Agrios, 2004). Eighty percent of animals on earth are nematodes, making them the most abundant and diversified group in the animal kingdom (Chen *et al*., 2004). In the animal kingdom, nematodes are second only to insects in terms of species diversity. However, only about 3% of all nematode species have been investigated and classified (Ravichandra & Ravichandra, 2014). Nematodes are either free-living or parasites of plants and animals. Plant parasitic nematodes are significant globally and their devastating effects on crops have severe economic and social impacts. Plant parasitic nematode contributes substantially to hunger globally especially in the tropics (Abolusoro *et al*., 2020). The most serious plant parasitic nematode issues develop when good host crops are cultivated on the same field repeatedly and for too long period of time (Reddy, 2015). The severity of plant injury caused by plant parasitic nematode activity is determined by several factors, including the combination of plant and the nematode species, as well as current environmental variables such as rainfall, soil types, land contour, and cultural practices (Ravichandra & Ravichandra, 2014).

Plant growth is negatively affected by plant parasitic nematodes, as they tear down cell structure, remove cell contents, alter physiological processes, and change gene expression in the host (Chen *et al*., 2004). They can attack the aerial parts of plants provided that the humidity is high enough to facilitate movement (Sikora *et al*., 2018). In nematodes parasitism, the inoculum may be adult nematodes, nematode juveniles, or eggs and they enter plants either by direct penetration or through natural openings although not all penetration leads to infection. After penetration into a cell, it generally secretes increased amounts of enzymes that presumably soften or dissolve the opposite cell wall and make its penetration easier. Plant parasitic nematodes are economically significant. Majority of them live in the soil and are one of the most difficult pests to identify and control. Plant damage caused by plant parasitic nematodes is frequently neglected due to general symptoms such as stunting, yellowing, and slow growth, which can equally be ascribed to nutritional and water-related issues (Stirling *et al*. 1998). Farmers and plant parasitic nematode management experts frequently underestimate their negative impact, although it is estimated that plant parasitic nematode damage accounts for about 10% of global crop production (Sikora *et al*., 2015). The prohibition of some synthetic nematicides necessitates the development of alternate control measures.

2.11 Feeding Relationship of Plant Parasitic Nematodes

Ectoparasitic, endoparasitic, and semi-endoparasitic nematodes are the three main types of plant nematode parasitism. Ectoparasitic nematodes do not enter plant tissues but rather stay in the soil. They usually feed by puncturing plant cells with their stylet. The longer the stylet the deeper it can feed within the plant tissues (Sikora *et al*., 2018). *Tylenchorhynchus* and *Xiphinema* are two examples. The complete nematode enters the root tissue in endo-parasitic parasitism. Migratory endoparasites, such as *Pratylenchus, Radopholus*, and *Scutellonema*, maintain mobility and have no set feeding site inside plant tissue, whereas sedentary endoparasites, such as *Meloidogyne*, have a fixed feeding site and induce a complex trophic system of nurse cells or syncytia. (Roland, 2015). The creation of a specific feeding site improves the flow of nutrients from the host, allowing the females to become sedentary and fat in appearance while yet being extremely fertile. Before establishing a feeding spot, sedentary endo-parasites go through a migratory phase. Only the J2 and adult males of *Meloidogyne* and Heterodera/Globodera migrate, but in Nacobbus, all juvenile stages, the male, and the immature vermiform female migrate, with only the mature female remaining stationary (Sikora *et al*., 2018). For semi-endoparasitic nematodes, only the anterior part of the nematode penetrates the root, with the posterior part remaining in the soil. Depending on the host, semi-endoparasitic may become migratory ectoparasite (Bridge, 2007)

2.12. Symptoms of Plant Parasitic Nematode Damage on Crop

Most plant parasitic nematodes do not exhibit signs that are distinct and easily identifiable, making it difficult to recognize them as the cause of crop damage. The damage caused is often non-specific and easily misinterpreted with symptoms of other abiotic or biotic deficiencies (Bridge, 2007). For instance, chlorosis can be caused by a lack of nitrogen or by plant parasitic nematodes; poor growth can also be caused by poor soil fertility, moisture stress, or by plant parasitic nematodes. Knowledge of the crop, cropping history, and management methods may help identify the plant parasitic nematode(s) causing crop damage. Plant parasitic nematode infestation can be seen both above and below ground. Gall formation or abnormal swelling of seeds, discoloration of leaves, disordered tissue growth (e.g., *Ditylenchus*), internal stem necrosis, inflorescence necrosis, and chlorosis of leaves are examples of above-ground signs.

Most plant parasitic nematodes are found in the soil hence, attack the roots of plants (Vidhyasekaran, 2004). Below-ground symptoms may be detailed enough to allow nematode identification. To detect the symptoms, plants must be uprooted, or roots must be dug out. Root galling, stubby roots, root lesions, root or tuber necrosis, rotting or death root or tuber cracking and deformed roots are some of the below ground symptoms of plant parasitic nematode infestation (Kimenju *et al*., 2009).

2.13 Major Plant Parasitic Nematodes associated with Yam tubers

Many different plant parasitic nematode species have been found associated with yams. Those known to cause serious damage by mainly reducing tuber yield and quality are *Scutellonema bradys*, *Pratylenchus coffeae*, and *Meloidogyne* spp. (Hunt *et al*., 2005; Affokpon & Waeyenberge, 2017). With all these plant parasitic nematode pests, it is mainly the tuber stage of the yam crop that is most seriously damaged (Bridge, 2007).

2.13.1 *Meloidogyne* spp.

The root-knot nematodes (*Meloidogyne* spp.) are sedentary endoparasitic nematodes that can infect a wide range of plant species globally and results in approximately $70 billion in crop losses annually (Caboni *et al*., 2012). They are found on yams in Africa and other parts of the world. They are regarded among the five most dangerous plant pathogens of crops worldwide (Kayani *et al*., 2013). The species of *Meloidogyne* identified as parasites of yams are *M. arenaria*, *M. enterolobii, M. incognita* and *M. javanica.* However, *M. incognita* is the most important globally (Coyne *et al*., 2018). *Meloidogyne incognita* was one of the most prevalent and widespread nematodes on yam in Ghana (Kwoseh, 2000). The typical symptom of damage is galling of yam tuber. Internal rotting of tubers has also been found associated with *Meloidogyne* spp. in certain yam species. On *D. rotundata* and *D. alata* tubers, *M. incognita* causes evident galling (Kwoseh, 2000). The root knot nematodes usually complete their life cycle within their host roots. However, they can survive in the soil as eggs and second stage juveniles. Mature females of root knot nematodes deposit eggs up to 1000 or more in a gelatinous matrix called egg sac or egg mass (Hunt *et al*., 2005). The eggs are protected from dehydration by this sac (Pattison, 2007). Juveniles often invade host roots right beyond the root tip area and establish permanent feeding sites (giant cells) in the root's vascular tissues (Hunt *et al*., 2005). The sedentary nematodes continue to feed, grow, and molt three times as the giant cells provide them with nourishment. Root cells near feeding sites swell and develop galls (knots) and producing extensive secondary root and branching of the primary root. *Meloidogyne* spp. adversely affects the marketable value of tubers because of the unappealing, warty appearance, and they are associated with the rot of stored yams. It is therefore crucial to manage them so as to reduce the yield losses in quality and quantity both in the field and in storage (Abolusoro *et al*., 2020).

2.13.2 *Scutellonema bradys*

The yam nematode (*Scutellonema bradys*) is one of the most important migratory endo-parasitic nematodes associated with yams (Claudius-Cole *et al*., 2016). Dry rot of yam produced by *S. bradys* results in a significant decline in quality, marketable value, and edible portion of tubers, as well as up to a 50% loss in storage (Sikora *et al*. 2015). After 4-6 months of storage, up to 50% of the stored supply of yams is typically lost, especially in Africa. They also reduce seed yam viability and make tubers more susceptible to subsequent infections and decay. Dry rot shows itself most severely in mature tubers during storage, when it is connected to general degradation (Bridge, 2007). Symptoms begin as light yellow or brown lesions beneath the outer skin, progressing deeper into the tuber as the nematodes feed and grow, turning infected tissues dark to black. The outer cortex of the tuber may crack and peel off, exposing necrotic tissue, or it may stay intact, giving the false impression of a healthy tuber (Coyne *et al*., 2006).

2.13.3 *Pratylenchus coffeae*

Pratylenchus coffeae are commonly referred to as “lesion nematodes”. They are migratory endoparasitic nematodes with symptoms similar to those of *S. bradys* (Kimenju *et al*., 2009). They are mostly found in the tuber skin and cause severe necrosis and deep cracks in the outer tissue layers leading to deterioration of tuber quality and, finally, a significant loss in market value (Lebot, 2009). Furthermore, the nematode causes small, necrotic root lesions which may lead to stunting of vines and a significant reduction in the quality of the tubers (Reddy, 2015).

Severe infection can affect seed yam viability by preventing sprouting of tubers (Bridge, 2007).

2.14. Plant Parasitic Nematode Disease Complex

Plant-parasitic nematodes may interact with other plant pathogens to cause a disease complex (Kimenju *et al*., 2009). The combined pathogenic potential of plant parasitic nematodes and other pathogens is sometimes far greater than the sum of the damages either of the pathogens can produce individually (Khan & Sharma, 2020). The complex may be nematode-fungi, nematode-bacteria, or nematode-virus disease complex. Plant parasitic nematodes, commonly create disease complexes with fungi that cause wilt and root rot. *Meloidogyne* spp., *Pratylenchus* spp., and *Rotylenchulus reniformis* nematodes enhance the frequency and severity of *Fusarium* spp, *Verticillium* spp., and *Pythium* spp. wilt in a variety of plants (Sikora *et al*., 2018). Disease-causing bacteria *Clavibacter Pseudomonas* and Agrobacterium interact with *Meloidogyne* spp., *Pratylenchus, Anguina,* and *Ditylenchus* to increase the severity of the disease. Plant parasitic nematodes injure plants by piercing them with a micro-puncture or rupturing or splitting cells. They might either transfer a pathogen onto or within their bodies, or help a pathogen already present on the plant cell surface enter. Bacteria penetrate plants mostly through wounds; therefore, wounding is very essential for their infection of yam tubers. Besides creating wounds the nematodes also modify the host tissue to enrich the substrate nutritionally to the advantage of the bacteria (Kimenju *et al*., 2009). However, there is limited information available regarding potential economic losses associated with synergistic and antagonistic interactions between plant parasitic nematode species and the involvement of them in disease complexes (Ravichandra & Ravichandra, 2014).

2.15 Management of plant parasitic nematodes associated with yam tubers on the field and in storage

There are several methods used in the management of plant parasitic nematodes. However, factors such as efficacy, expense, environmental pollution, and types of crops, may influence the types of control methods employed. Control may be through:

1. Cultural practices, among which are use of clean planting material, crop rotation with non-host crop, bush fallow, and cover crops

2. Biological control with resistant varieties and certain other means, including organic amendments and natural or genetically engineered antagonistic or parasitic bacteria and fungi. For instance, *Meloidogyne javanica* and *Pratylenchus* spp. are parasitized by the bacterium *Pasteuria (Bacillus) penetrans*. (Agrios, 2004)

3. Physical agents, such as tillage, solarization, and flooding

4. Control with chemicals, such as various types of fumigants and non-fumigant nematicides.

To ensure effectiveness, several methods are usually employed for controlling plant parasitic nematode diseases of plants.

2.16 Nematicides

Nematicides are pesticides used to control unwanted nematodes which cause damage to crops by feeding on or in plant tissues (Perry, 2015). They either kill the nematodes, reduce their reproduction and or limit them from being vectors of plant viruses. This will lead to a reduction in crop damage and decrease productivity in terms of quality and quantity (Tobin *et al*., 2008). Also, nematicides help in the production of nematode-free crops in the future. Nematicide application provides several advantages, including greater food production, increased earnings for farmers, and disease prevention. Even though plant parasitic nematodes destroy substantial percentage of agricultural crops, it is likely that they would destroy a higher percentage, if nematicides are not used. Farmers may boost revenues by producing more crops since they have more produce to sell. Nematicides also help farmers save money on labor expenditures and shortens the time it takes to control plant parasitic nematodes. Nematicides may be contact (kill nematodes directly) or nemastistatic (immobilize nematodes for a period). The application of nematicides has significantly reduced the wide range of plant parasitic nematodes (Etudaiye, *et al*., 2020; Eisenhauer *et al*., 2010). However, application of nematicide will need to be combined with other control measures such as crop rotation for maximum impact (Perry, 2015)

2.17 Biopesticides for control of plant pests

The ever-increasing global population has posed a huge challenge to the agricultural industry in terms of food production and supply (Thomas *et al.*, 2020). Pests have become a significant source of concern for food stakeholders (Dwijendra, 2014). Few pests, such as plant parasitic nematodes, are gaining popularity because of their ability to attack a wide variety of hosts crops. There are many integrated approaches to plant parasitic nematode management, including cultural practices such as sanitation and crop rotation, as well as chemical methods. Chemical control has many health and environmental drawbacks. Alternative approaches that contain less pollution and pose fewer health threats have become necessary in recent years. Biopesticides play an important role in this context (Ali *et al.*, 2015). They are better alternative to chemical pesticides in crop protection particularly plant parasitic nematode management. Chemical pesticides have drawn public attention due to their hazardous nature and chemical pollution which negatively affects the survival and welfare of all living creatures and humans on the planet. Biopesticides are materials derived from natural materials used in crop protection and are less dangerous to humans and the environment, leave no hazardous traces, and are normally more selective to the pests they target (Ullah *et al.*, 2015). Mostly, they only damage the target insect and closely associated populations, reducing the effect on non-target species significantly.

Pesticide contamination of soil, air, water, and other eco-systems has attracted worldwide concern, causing a revolution in attitude to explore and establish alternative approaches (Dwijendra, 2014). Biopesticides are effective at keeping plant parasitic nematode populations below the economic threshold level (Desaeger & Rao, 2000).

2.18. Abamectin (a biopesticide and a nematicide)

Abamectin was discovered in 1979 (Perry, 2015) and is gaining importance in the management of plant parasitic nematodes. It is a macrocyclic lactone derived from the soil bacterium *Streptomyces avermitilis* and is known to have nematicidal activity against major plant parasitic nematodes (Sasanelli *et al.*, 2020). It is a mixture containing 80% B1a and 20% B1b avermectins. Abamectin is registered as an acaricide/insecticide in more than 50 countries and in 2015 it was registered in the EU as a nematicide against root-knot nematodes with the commercial name Tervigo SC (Qiao *et al*., 2012). Abamectin causes an ion imbalance in the nervous system of nematodes, resulting in their paralysis (Sasanelli, *et al*., 2020). It offers nematode control in varying agricultural commodities (Cao *et al*., 2016).

It has controlled plant parasitic nematodes in cotton (Rudianto, 2010), corn (Da Silva, 2013), potato (Sasanelli *et al*., 2020), tomato (Ullah *et al*., 2015) and tobacco (Qiao *et al*., 2012, Muzhandu, *et al*., 2014). The densities of *Scutellonema bradys* in yam tubers were reduced by up to 85 percent in a field trial in Benin using abamectin-treated bananas, and yield increased by up to 22 percent over farmer's practice (Affokpon, 2018). Abamectin is also less harmful to humans and the environment. Abamectin is a contact nematicide and distribution in soil is required for acceptable control (Gannon *et al.*, 2017). However, poor mobility of abamectin in the soil weakens its nematicidal efficacy against plant-parasitic nematode.

2.19 Control Release of Pesticides

The high financial cost of nematicides calls for efficient use to provide the maximum benefit of nematode control leading to improved crop yield (Perry, 2015). The persistence and buildup nature of pesticides on various stages of food chain and environment affects humans negatively.

Also, excessive use of synthetic pesticides has resulted in development of resistance in pest populations (Pirzada *et al*., 2020). When applying pesticides, farmers use a variety of techniques. Many of these techniques were created after years of research. However, wrong choice of pesticide application methods can trigger issues such as overapplication, failure to reach pest habitat by using the least amount of pesticide, and deposit of hazardous residues (Thomas *et al*., 2020). Proper application strategies not only help in efficiency, but also ensure worker welfare, public safety, and environmental security (Mohanty *et al*, 2013). The proper application methodology leads to obtaining the desired output (Khan *et al*., 2015). Controlled pesticide release may be implemented to reduce pesticide overuse, farmer safety and environmental sustainability. With this method, pesticides are released in a controlled manner, which helps to decrease pesticide concentrations and increase the half-life of pesticides.

Banana fibre-based matrices as controlled release of abamectin infused into banana paper have been investigated (Pirzada *et al*., 2020a).

2.20 Banana Paper

Paper is traditionally made from wood, which comes from trees usually obtained from forest. Consequently, large portions of rainforest are lost every year to ensure that wood fibre is available (Ramdhonee & Jeetah, 2017). However, benefits from producing paper from the non-wood fiber may be higher than that of producing paper from wood fiber. Agricultural residues and non-wood crop residues such as banana pseudo-stem are good sources of non-tree fiber (K. Li *et al*., 2010). Banana pseudo-stem has been known as a potential fibre, though usually discarded as agricultural waste (Khan *et al*., 2014). The decomposition of this massive waste biomass leads to the release of greenhouse gases which contributes significantly to global warming. However, banana fiber is an environmentally sustainable raw material for papermaking that can be used for the controlled release of biopesticides such as abamectin (Pirzada *et al*., 2020). Banana paper contain lignin and cellulose. It is also porous and has tubular morphology which ensures slowed and sustained release of active ingredients for weeks, while remaining intact in the soil but allowing root penetration. Abamectin pretreated banana paper provides a targeted delivery of relative concentration of abamectin, which has poor mobility in the soil to up to 1000 times less than the commercially recommended application rate of the registered product Tervigo SC (Ochola *et al*., 2022). Additionally, the use of banana pseudo-stem for paper production for controlled release of abamectin will lead to environmental and economic benefits (Vigneswaran *et al*., 2015).

2.21. Socio-Economic Assessment of the Wrap and Plant Technology

In the past, most of the increases in agricultural production have been achieved through the expansion of cultivated land and intensive use of labour, rather than the use of improved farming technologies. However, as fertile land becomes scarce due to increased population growth, the rise in environmental problems coupled with other factors, the use of improved agricultural technologies has become essential (Boahene *et al*., 1999). However, low adoption of modern agricultural production technologies amongst farmers in Ghana has been identified as one of the main reasons for the low agricultural productivity in the country. Farm households' agricultural technology adoption decisions depend on their socio-economic circumstances and institutional effectiveness (Akudugu *et al*., 2012). Socio-economic impact assessment (SEIA) is a useful tool to help understand the potential range of impacts of technology and the likely responses of those impacted if the change occurs. For a new technology in the yam industry, the perceptions of the use and adoption can be examined through a focus group discussion with key actors in the yam value chain. This will help to gather information on awareness, effectiveness, challenges, and concerns of the stakeholders to benefit directly and indirectly from the new technology.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

The study was carried out in three phases:

(i) field questionnaire survey conducted on yam farms in four communities in the Krachi Nchumuru District of Ghana,

(ii) socioeconomic survey of the wrap and plant technology through focus group discussion, and

(iii) storage experiment and laboratory assessment of plant parasitic nematode densities at the Pathology Laboratory of the Crop Science Department, University of Ghana, Legon. The study communities included Borae, Chinderi, Grubi and Lumbusi which were randomly selected from the Krachi Nchumuri District in Oti region of Ghana. The district is located between Latitude 70 4" N and 80 25' N Longitude 00 25' W and 00 20' E in the North-Western corner of the region. The district is a major yam growing community found in the Transitional agro-ecological zone of Ghana. It has a tropical climate, with a mean maximum temperature of 30 ℃ in March and a mean lowest temperature of 25.5 ℃ in August. Every year, the district has alternating rainy and dry seasons with an average annual rainfall of 1,300 mm. The relative humidity is highest in the rainy season (85%) and relatively lowest in the dry season (5%) (Ghana Statistical Service, 2014).

3.2 Assessment of farmers' land use intensity, perception, knowledge, experiences, and management of yam nematodes.

A field survey was conducted to obtain baseline data regarding farmers' perception, land use intensity, knowledge, experiences, and management of plant- parasitic nematodes in the four yam growing communities in the Krachi Nchumuru District. Semi-structured questionnaires consisting of both close-ended and open-ended questions were administered to a total of 68 yam farmers who form about 30% of farmers in the district. Areas covered by the questionnaire included land use intensity, knowledge and experiences on detection, incidence, spread and management of plant parasitic nematodes, associated with yam tubers (Appendix 1).

3.3 Evaluation of the effect of abamectin wrap and plant technology (WPT) on nematode population control and yield of yam tubers

The assessment of abamectin wrap and plant technology on plant parasitic nematode control and yield of yam tubers was undertaken. The Abamectin pretreated banana paper and the banana paper without abamectin were obtained from the Forest Biomaterial Department of the North Carolina University, USA. The activities undertaken included field preparation and soil sampling, planting and growth determination of yam, extraction of plant parasitic nematodes from soil, and yam tubers, and tuber yield determination.

3.4 Field preparation and soil sampling

Eight farms from the four communities (two from each community) were randomly selected and used as trial fields (**Table 3.1**). The fields were first cleared, and yam mounds raised with hoes at 100 x 100 cm planting distance. The cleared weeds were later used as mulch materials after planting. Soils samples were then taken from the yam mounds at a depth of 15 – 30 cm using soil augur. The soil samples were kept in plastic polyethene bags in ice chest with ice blocks and transported and stored in a cold room for about a week at the Plant Pathology laboratory of the University of Ghana for soil analysis and initial plant parasitic nematode population density analysis of the trial field. In sampling the soil, a total of four mounds were selected from the middle rows, omitting those in the boundaries. Sampling equipment including the soil auger, and footwears were cleaned before and after use at each sampling site to avoid cross contamination and spread of plant parasitic nematodes. Furthermore, to ensure that results from soil samples were representative of the total population, soil samples were taken before 9:00 am to avoid extreme wet or dry conditions that negatively impact the collection and preparation of samples for examination (Shurtleff and Averre, 2000).

Table 3. 1 Farm locations at Krachi- Nchumuru District for dry and wet season trials

SITE NUMBER	TOWN	GPS LOCATION
DRY SEASON		
SITE 1	Chinderi	$8^0$8'47"/ $0^0$9'28"
SITE 2	Borae	$8^0$8'47"/ $0^0$8'49"
SITE 3	Grubi	$8^0$11'11"/ $0^0$14'24"
SITE 4	Lumbuisi	$8^0$10'14"/ $0^0$17'9"
WET SEASON		
SITE 1	Chinderi	8°9'32"/0°6'10"
SITE 2	Borae	8°8'59"/O°9'28"
SITE 3	Grubi	8°6'34"/0°15'18"
SITE 4	Lumbuisi	8°8'40"/0°16'56"

3.5 Extraction of plant parasitic nematodes from soil

The Sieve and Sucrose Centrifugation technique was used to extract plant parasitic nematodes from soil (Jenkins, 1964). Each soil sample was properly mixed, and a sub-sample of 250 cm^3 taken from the bulk soil for nematode extraction, identification, and quantification. The soil was soaked in a container of running water until it was covered by double its volume. The soil suspension was then aggressively stirred for three minutes, and the liquid supernatant filtered through a 36μm mesh sieve nestled under a 90μm mesh sieve. The 90μm mesh sieve was thoroughly cleaned with water to remove as much clay and other small particles as possible. The nematode-infested portion of the sample was then transferred to a 50 ml centrifuge tube. An MR 23i benchtop centrifuge (Jouan – Thermo Scientific, U.S.A.) was used to centrifuge the samples for five minutes at 1700 rpm. The supernatant was discarded, and further samples centrifuged until a final pellet was produced from the nematode population. The tubes were filled with room temperature sucrose solution and the pellets broken up using a spatula. The supernatant was passed through a 36μm mesh sieve filter and placed into marked vials up to the 10 ml mark using a fine spray water bottle after centrifugation at 1000 rpm for one minute. Identification and counting of plant parasitic nematodes were done under a compound light microscope (Exacta-Optech Biostar B5P, Germany) at 25–40X magnification after transferring the 10 mL of each suspension into a counting dish. Based on morphological characteristics, plant parasitic nematodes were identified to the genus or species level as described by (Luc, *et al*.,1990) and the University of Nebraska Lincoln nematode identification website (http://nematode.unl.edu/konzlistbutt.htm).

3.6 Extraction of plant parasitic nematodes from yam tubers

The modified Baermann funnel method was used to extract plant parasitic nematodes from infected yam tuber peels (Whitehead and Hemming, 1965). Tubers from the field were peeled using kitchen peeler and the peels were then chopped into pieces after which 10 g subsample of were weighed. The peels were then blended in short bursts for two to five seconds and transferred into glass funnel lined with two-ply tissue paper on wire mesh and the set-up was left for 48 hours. The filtrate (containing plant parasitic nematodes) was poured separately into 250 ml glass beaker. The filtrate was then poured through 90 µm mesh on 36 µm sieve. A spray water bottle was used to wash the nematodes into falcon tubes to a final volume of 10 ml. Enumeration of plant parasitic nematodes was undertaken by, transferring the 10 mL of each suspension into counting dishes, counted directly under a compound light microscope (Exacta-Optech Biostar B5P, Germany) at 25–40X magnification. Based on morphological characteristics, plant parasitic nematodes were identified to the genus or species level as described by (Luc *et al.*, 1990) and the University of Nebraska Lincoln nematode identification website (http://nematode.unl.edu/konzlistbutt.htm). Identification was mainly based on second stage juveniles (J2).

3.7 Planting and growth determination in yam

Seed yams of Pona cultivar were planted after clearing the fields and preparing mounds. The three treatments used in the study were banana paper with abamectin (A), banana paper without abamectin (B) and the farmer practice which is the control (no abamectin and banana paper). The banana paper with or without abamectin were wrapped on seed yams and planted in mounds. This technology is called 'wrap and plant'. Individual plots consisted of six rows of six mounds (36 mounds per plot) and the trial was laid out in randomized complete block design with four replicates. The experiments were rainfed (no additional irrigation), received no fertilizer or additional pesticide aside the treatment applied. Germination percentage was determined for each plot by counting the number of emerged vines as a percentage of the number of seed yams planted in a plot. Weeding was manually done using hoe in the second and fourth month after planting. During weeding care was taken not to damage the growing roots of yam plants.

3.8 Yield determination

Yam tubers were harvested at maturity and during harvesting, data were taken on number of mounds harvested per plot, number of tubers per plot, tuber weight and tuber length. These data were analyzed to determine the yield and yield parameters.

3.9 Plant parasitic nematode identification and yam tuber damage assessments

In each plot, yam tubers were sampled for plant parasitic nematode extraction. The samples were taken from middle mounds after excluding the border rows. The middle mounds consisted of four rows of four mounds each. Nematode population densities from the key genera *Scutellonema*, *Meloidogyne* and *Pratylenchus* were determined in yam tuber peels. To assess nematode densities in tubers, a representative 50 g sub-sample of tuber peels (outer cortex) was removed from bulked samples peel that was obtained from peeling tubers with kitchen vegetable peeler (Coyne *et al.*, 2006). Plant parasitic nematodes were extracted from each sub-sample using the modified Baermann method (Coyne *et al.*, 2007). From the suspension, the number of *Meloidogyne* spp., *Scutellonema bradys*, *Pratylenchus* spp. and other species were identified and counted using nematode counting dish mounted on a compound microscope.

3.10 Assessment of Plant Parasitic Nematode Damage of yam tubers at Harvest

Plant parasitic nematode damage on yam tubers after harvest was undertaken by first visually assessing the yam tubers. Before removing peels from the selected yam tubers, they were assessed for visible symptoms of nematode damage. Tuber cracking, galling and dry rot severity were assessed on a scale of 1-5 as shown in **Table 3.2**

Table 3. 2 Scale for Nematode Damage Severity

Scale	Nature of damage
1	Clean tuber
2	1-25% tuber skin showing cracking, galling or dry rot symptoms (low level of damage)
3	25-50% of tuber skin symptoms (low to moderate level of damage)
4	51-75% tuber skin symptoms (moderate to severe level of damage)
5	76-100% tuber skin symptoms (high level of damage).

The percentage of tubers exhibiting symptoms of dry rot and cracking (due to attacks of *S. bradys*) and of root-knot nematode galling (*Meloidogyne* spp.) was calculated using the above scale developed by Coyne *et al*., (2006).

3.11 Nematode Reproductive Factor

The nematode reproductive factor of the soil from the trial field was calculated using the initial and final nematodes extracted from the soil. The nematodes extracted from the soil at the beginning of the study represent the initial nematode population (Pi). The nematodes extracted from the soil at the end of the study formed the final nematode population (Pf). The reproduction factor (Rf) was calculated as follows:

$$\textbf{Reproductive factor} = \frac{\textbf{Initial nematode population}}{\textbf{Final nematode population}}$$

3.12 Assessment of plant parasitic nematode damages at storage

To assess the effect of the seed yam treatment on tuber in storage, tubers from all three treatments were sampled during harvest and stored in yam barn to investigate nematode population build-up and symptoms of nematode damage such as dry rot, general decay of tubers, significant weight loss and external cracking on the skin of tubers. Tubers were arranged in shelves in a yam barn (roofed and open sided surrounded with wire mesh) at the Senna Garden of the Crop Science Department at the University of Ghana. Data collected were tuber length and tuber weight at 0, 1, 2, 3, 4, and 5 months after harvest. Furthermore, after visual evaluation for symptoms of nematodes infestation, nematodes were extracted from tubers in storage at 3 and 5 months after harvest.

3.13 Socio-economic study on the use of abamectin technology in yam production.

A socio-economy study was conducted to assess the perceptions of the use and adoption of the technology through a focus group discussion with key actors in the yam value chain in the Krachi Nchumuru district. In all, 18 actors consisting of farmers, traders, processors, consumers, and agricultural extension agents participated in the discussion. The participants were selected from 2 communities within the district with the aid of agricultural extension agents in the district. Participation in the focus group discussion was based on willingness of the respondents to join and provide the relevant information. The selection of participants was done irrespective of socio-economic profile. The gender composition of the participants for the focus group discussion was 8 males and 10 females comprising of Agricultural Extension Agents, Farmers, Processors, Traders and Consumers in the Krachi Nchumuru District. Participants were assured of the anonymity of their responses and the use of the data solely for the purpose of this study. The objective of the focus group discussion (FGD) was to gather information on the perceptions of the use and adoption of the Banana Paper Abamectin Technology under awareness, effectiveness, challenges, and general comments for implementation.

3.14 Statistical analysis of data

Data collected in the questionnaire survey were coded and subjected to descriptive statistical analysis using Statistical Package for Social Sciences (SPSS) version 20 and Microsoft Excel 2016. Additionally, all the agronomic data collected were checked for normality using the histogram. Where necessary, data were square-root or log-transformed before analysis of variance (ANOVA) test ($p < 0.05$) was used to determine significant differences and means separated using least significant difference test (LSD 5%). Also, the covariance analysis (ANCOVA) test was carried out to examine the influence of abamectin treatments on reducing weight loss in stored yam tubers infested by plant parasitic nematode. Tuber weight at harvest was used as covariate in the ANCOVA test since the yam tubers used for the storage experiment had varied weights. Statistical analyses were performed in GenStat Edition 12 Statistical software.

CHAPTER FOUR

4.0 RESULTS

4.1 Characteristics of farmers and their agronomic practices

Out of 68 yam farmers interviewed during the study, majority (98.6%) were males, and the remaining were females. The farmers were mostly above 30 years with a quarter of them (25%) being below the age 30 years. In terms of education, some 66.1% of the farmers had received some form of formal education, while less than 30% had no formal education (**Figure 4.1**). Majority of the farmers representing 42.6% had cultivated yam for more than 15 years while about 14.7% had cultivated the crop for 1 to 5 years (**Figure 4.2**). The farmers planted the crop on varied sizes of land (farms) with 5.9% of them cultivating less than an acre of land, while 32.3%, 32.4%, and 29.4% cultivated lands in the ranges of 1 – 4 acres, 5 – 8 acres and more than 8 acres, respectively.

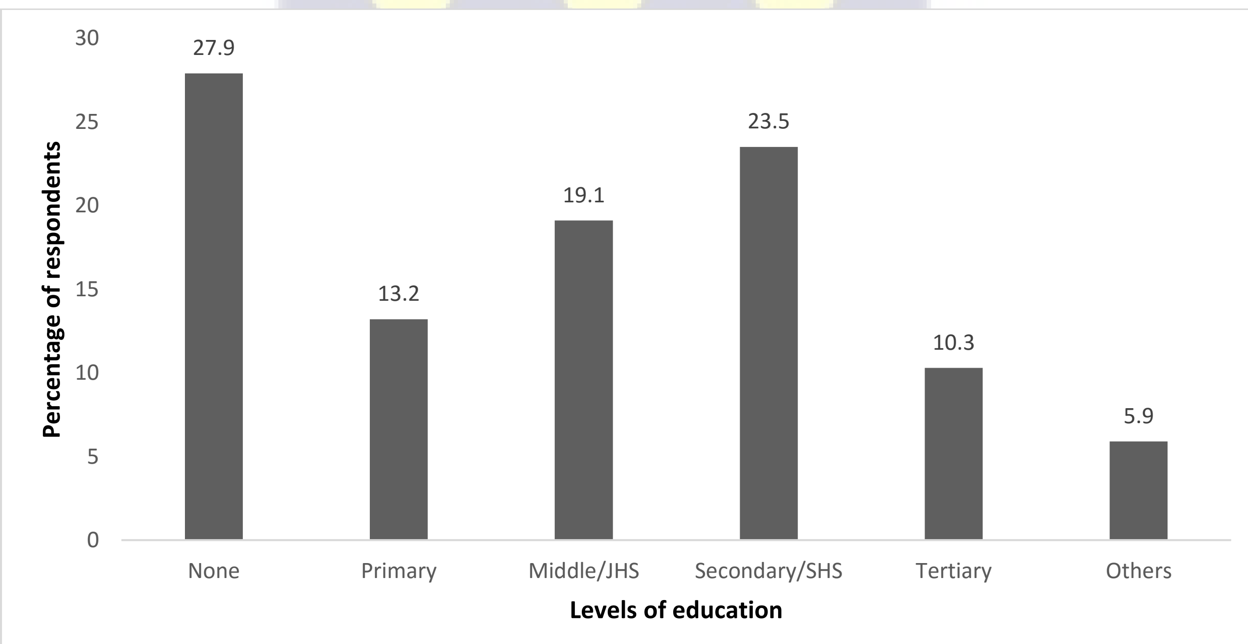


Figure 4. 1 Educational characteristics of respondents (farmers)

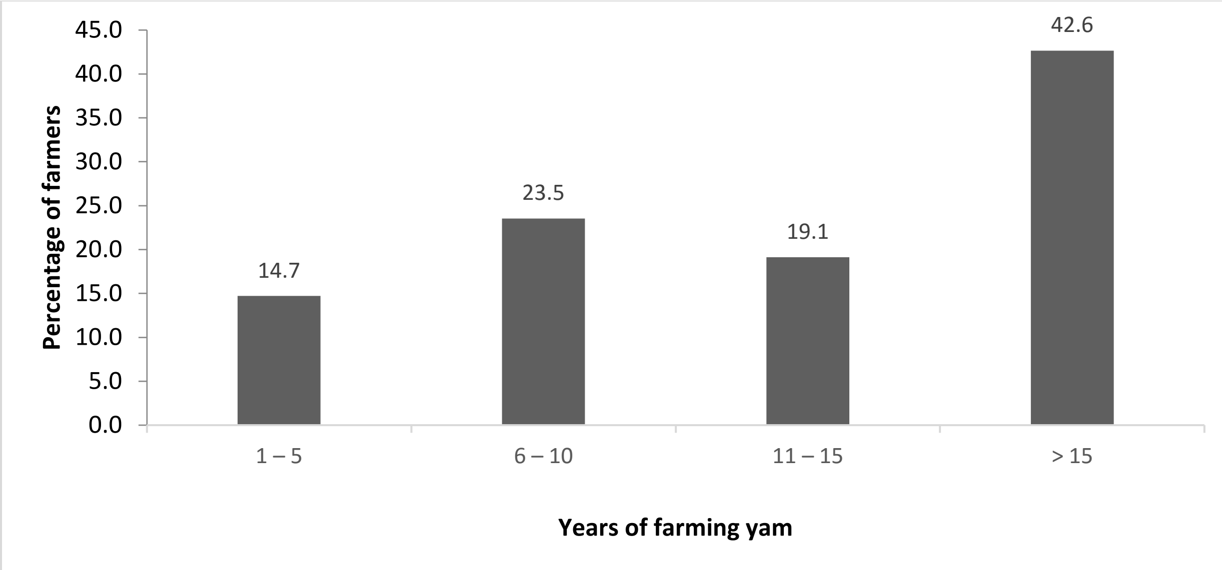


Figure 4. 2 Duration of farmers engagement in yam cultivation

Sources of planting materials (seed yams) included seed yams from previous harvest (own farm) (48.5%), seed yams from family members (19.1%), seed yams purchased from the market (27.9%) and other unspecified sources (4.4%). In terms of variety, most farmers (88%) cultivated the 'Pona' variety while the rest (12%) planted other varieties including 'Olondo', 'Asobayere', 'Kplinjo', 'Nyame nti', and 'Kununku'. Most of the farmers (60.3%) had farmed in their respective land for 1-3 years, followed by those who had used the same land for 4 -10 years (26.6%), more than 15 years (11.8) and the 11 – 15 years (3%). The farmers intercropped yam with maize, groundnut, cassava, cowpea, sorghum, and vegetables (e, g okra, pepper, and tomatoes). The proportions of farmers who used the various crops are illustrated in **Figure 4.3**. Majority of the farmers (69.8%) indicated they fallowed their land while 30.2 % continuously cropped without fallowing but rotated with other crops such as groundnut and maize. Up to 83.8% of the farmers rotated their land at least every – 4 years while the rest (16.2%) rotated theirs every 5 - 10 years.

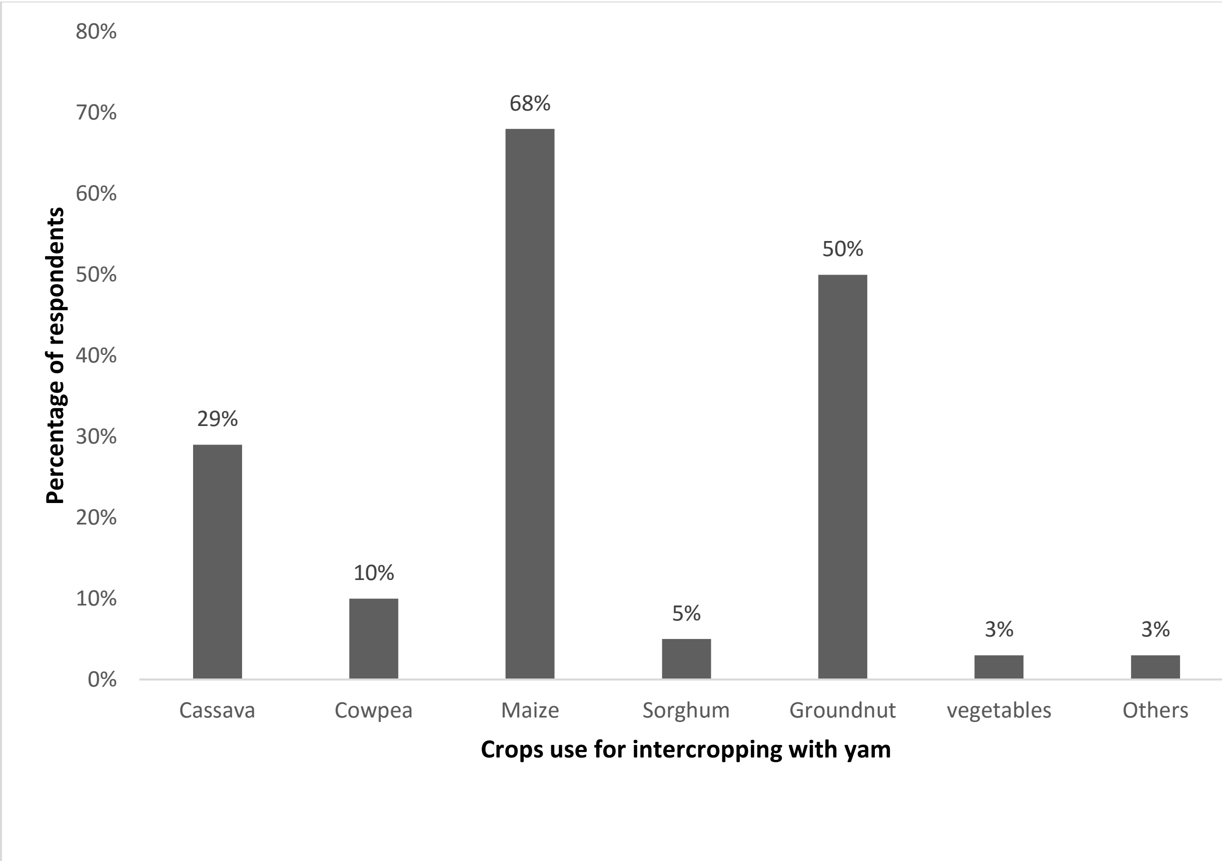


Figure 4. 3 Crops used by farmers to intercrop yam

4.2 Farmer perceptions on nematode diseases

Almost all farmers (97%) had experienced disease conditions on their farms with some 75% indicating awareness of plant parasitic nematodes as causal agent of the diseases on their farms. About 76% of the respondents observed nematode symptoms on Pona while 24% observed the symptoms on other varieties. Regarding storage, the farmers interviewed stored their yams tubers in three locations, namely barns in farm or at home (78%), in a pit at the farm (8%) and in a farmstead (13%). Majority (88%) of the farmers observed hardened and dried tissues with varying discoloration on the harvested tubers. Also, most of them (82%) noticed weight loss in tubers during storage while 84% of the farmers observed yellow lesion below the outer skin of the tuber. Similarly, majority of the farmers (84%) observed rotting of the outer 1-2cm layer of the yam tubers and flaking off of external coverings with dark brown patches (62%) (**Figure 4.4**).

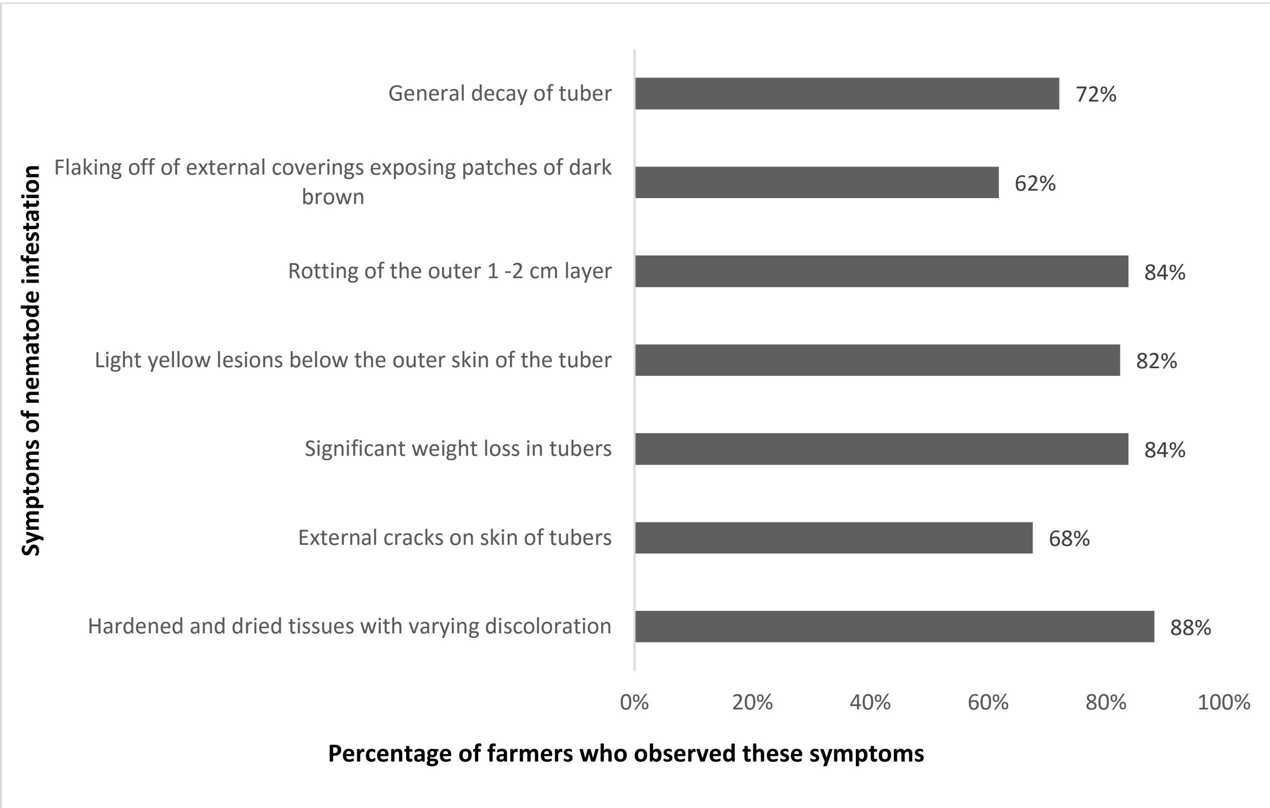


Figure 4. 4 Farmer's knowledge on symptoms of nematode parasitism in stored yam tubers

The farmers reported varying degrees of nematode postharvest losses over the years. Majority (79.2%) of farmers reported 50% postharvest damages due to plant parasitic nematodes, while some18.2%, and 17.7% of the farmers reported between 31- 40% and 11 – 20% losses respectively. 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. Many of the farmers (47.2%) reported that the use of infected tubers can spread plant parasitic nematodes while 33.3% believed infested soil can lead to the spread of plant parasitic nematodes.

Some of the farmers suggested various methods by which they try to control the spread of plant parasitic nematodes. Among the farmers (41%) were of the view that plant parasitic nematodes could be managed through crop rotation. Another (39%) believed they could be managed through land rotation. Some (12%) believe that plant parasitic nematodes could be controlled with the use of nematicides (**Fig. 4.*5***) such as Velum Prime.

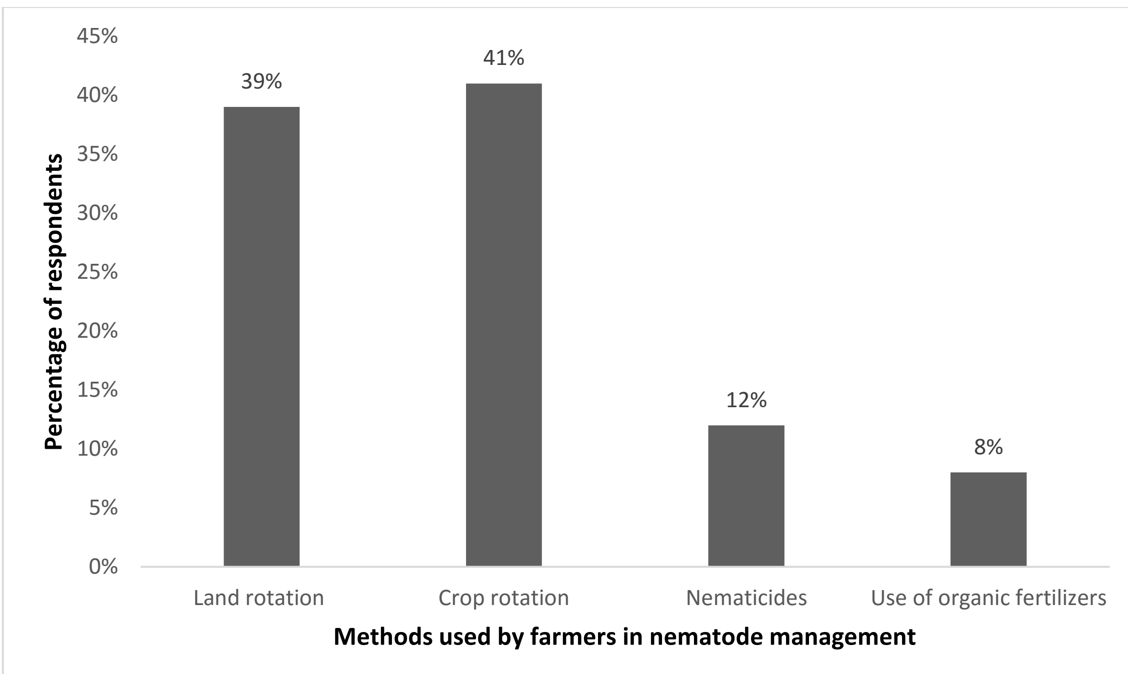


Figure 4. 5 Plant parasitic nematode management methods used by farmers

4.3 Farmer perception on socio-economic impact of nematode infestation

The response of the farmers to the questionnaires revealed that 83.9% of the farmers had difficulty paying the school fees of their children due to the postharvest losses caused by nematode damage to their yam during storage. Another 85.2% defaulted in loan repayment and 59.3% could not pay medical bills due to postharvest losses they incurred during the storage of their yam tubers. About 51.9% of the farmers said they consulted AEAs for technical advice while 48.1 percent depended on their spouses and neighbors for assistance.

4.4 Perceived challenges for technological approach to plant parasitic nematode control

Some of the farmers (37.8%) admitted they had heard about abamectin treated paper banana paper for control of plant parasitic nematode. Majority of them (81%) of the farmers were ready and willing to adopt the abamectin treated banana paper for the management of the key parasitic nematodes of yam. However, high cost (41%), adverse side-effect (35%) and non-availability (14%) were some of the factors that the farmers mentioned could hinder them from adopting the use of the technology (**Figure 4.6**).

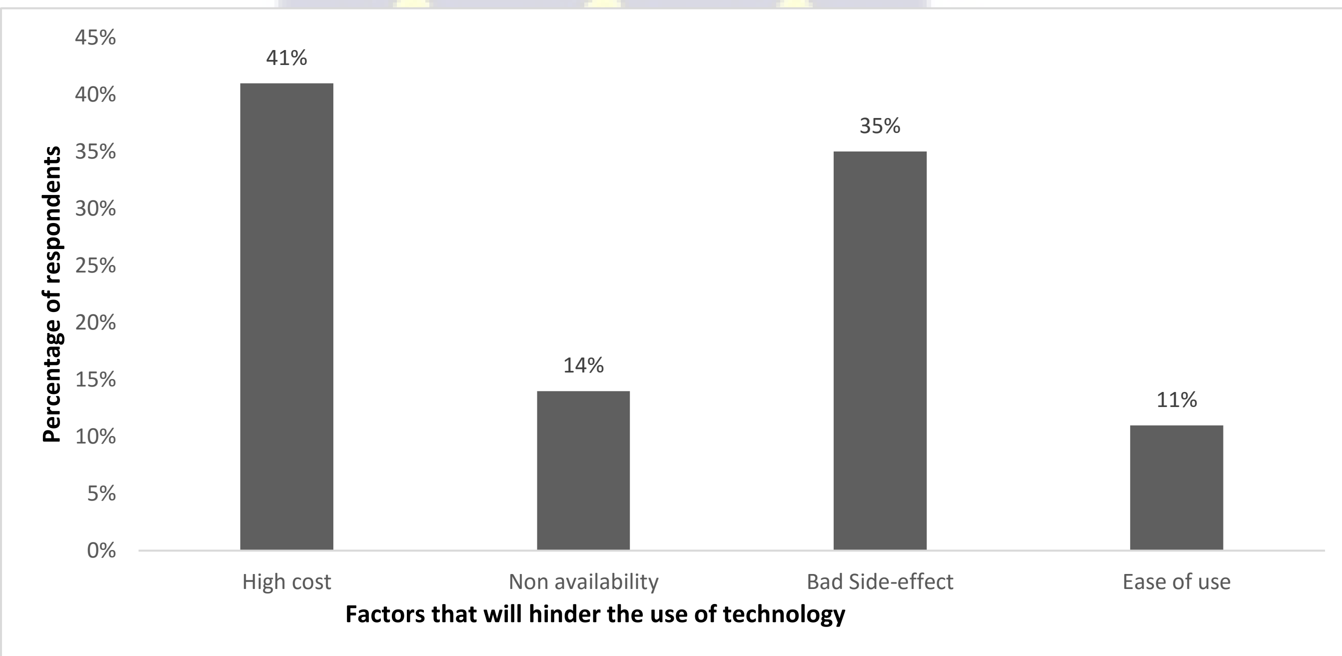


Figure 4. 6 Factors that will hinder the use of technology

4.5 Agronomic and Laboratory Experiments

4.5.1 Soil analysis

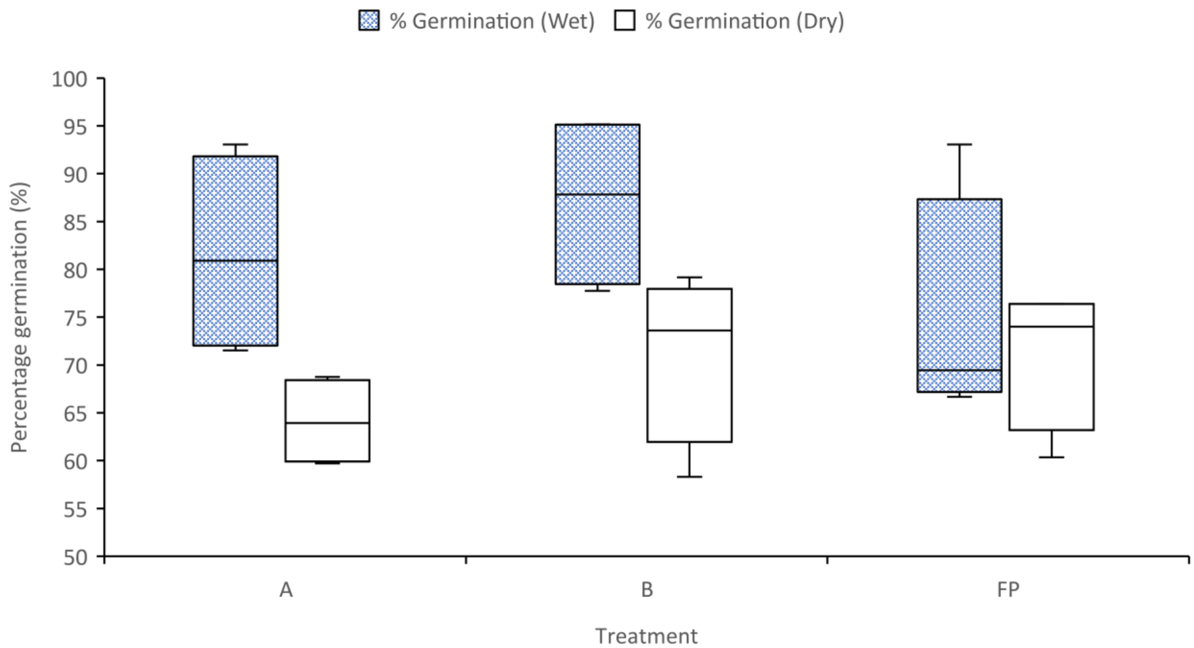
The results from the soil analysis conducted as shown in **Table 4.1** revealed that the soil at the trial fields were slightly acidic with a pH range from 5.6 - 6.7. This falls within the suitable pH range for arable crop production (5.5-7.0). The electrical conductivity ranged from 269.2 uS/cm -337.6 uS/cm3. This indicates that the soils are not saline and are suitable for production. The organic carbon (O.C.) content from the depth 0-20 cm ranged from 0.97 to 1.57% with a mean of 1.3%. Generally, the soil total nitrogen (N) content of the soil ranged from 0.07% to 0.1%**.** The average nitrogen content for the topsoil (0-20 cm) is 0.1% which is classified as low and thus below the optimum level for crop production. The available phosphorus content of the soil ranges from 105.9 mg/kg -441.3 mg/kg. The average P content of the soil was 221.3 mg/kg. This was classified as very high and could be sufficient for the growing season. The values of the exchangeable bases such as Ca, Mg, and K from the results are generally low. Calcium and Mg values were in the ranges of 1.5- 2.8 and 1.5 – 2.5 $cmol_c$/kg, respectively. These values are classified as low and thus are below optimum level for crop production. Also, Potassium, K and sodium Na average values 0.1 and 0.35 cmol/kg respectively were below the optimum level of crop production. The soil texture for Krachi Nchumuru has sand content ranging from 45.35 % to 49.98%, silt content ranges from 28.7 % to 35.9% whiles the clay content is about 18.8 to 21.3%. The soils from all the four sites were classified as loam.

Table 4.1 Soil analysis

SEASONS	NO	pH	EC Us/	%C	%N	AV.P g/kg	Ca	Mg cmol/kg	K	Na	TEXTURE SAND	SILT	CLAY
DRY SEASON	1	5.6	337.6	0.97	0.09	105.9	2.5	1.8	0.1	0.3	41.9	35.0	23.1
	2	6.4	277.3	1.97	0.09	219.8	2.8	2.0	0.1	0.3	56.9	20.0	23.1
	3	6.2	269.2	1.57	0.08	118.3	3.0	2.5	0.1	0.4	59.4	20.0	20.6
	4	6.7	300.7	1.81	0.10	441.3	1.5	1.5	0.2	0.4	56.9	20.0	23.1
WET SEASON	1	6.5	71.9	0.72	0.07	31.2	2.59	1.77	0.32	0.20	45.35	35.9	18.8
	2	6.8	89.1	1.04	0.07	36.5	1.93	1.17	0.21	0.17	49.98	28.7	21.3
	3	6.3	71.3	0.96	0.07	29.9	3.42	2.27	0.35	0.17	42.88	35.8	21.3
	4	5.9	101.7	1.12	0.11	26.7	2.12	1.42	0.22	0.18	46.00	35.2	18.8

4.5.1 Sprouting of yam

There was no significant difference among the soils from the various fields. Similarly, no significant difference ($p = 0.282$) was found between total sprouting of seed yams across the treatments (**Figure 4.8**). However, there were seasonal variabilities in tuber yield



A = Abamectin pretreated banana paper, B = Banana paper without Abamectin, FP = Standard farmer practice (control)

Figure 4.7 Influence of Abamectin banana paper treatment and season on germination

4.5.2 Effects of Abamectin banana paper treatment, trial location, and season on nematode population in the soil

The study revealed that location, season, and treatment had no significant effect on the initial nematode population in the soil (**Table 4. 1**). However, there was a significant interaction ($p<0.05$) between location and seasons of the initial and final nematode population dynamics. The reproductive factor (RF) for treatment A (0.10) for dry season was the lowest in Chinderi, followed by B (0.17) and FP (0.17). For Grubi FP had the least RF of (0.05). The RF values for all treatments, both dry and wet seasons were below 1.0.

Table 4. 2 Initial nematode population before planting, final nematode population at harvest, and reproductive factors (RFs) of nematodes at Chinderi and Grubi in the wet and dry season respectively.

	Average nematode counts/ 200 cm^3 of soil				Reproductive factors (Pf/Pi)	
	Initial population (Pi)		Final population (Pf)			
Treatment	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Chinderi						
A	24	30	2	7	0.08	0.23
B	36	40	5	8	0.14	0.20
FP	16	32	4	9	0.25	0.28
	25	**34**	**4**	**8**	**0.16**	**0.24**
Grubi						
A	33	30	4	3	0.12	0.10
B	30	23	6	4	0.20	0.17
FP	55	29	3	5	0.05	0.17
	39	**27**	**4**	**4**	**0.10**	**0.15**
LSD at 5%						
Location (L)	NS		NS		NS	
Season (S)	NS		0.65		NS	
Treatment(T)	NS		NS		NS	
L * S	0.18		2.62		NS	
L * T	NS		NS		NS	
S * T	NS		NS		NS	
L * S * T	NS		NS		NS	

FP = Standard farmer practice (control), A = Abamectin pretreated banana paper, B = Banana paper without Abamectin. * Bolded face mean values are responses at each trial location with respect to the planting season. Values in the enclosed brackets were square root transformed prior to ANOVA. NS = Not significant based on ANOVA test (α = 5%).

4.5.3 Abamectin banana paper treatment, trial location, and season on nematode population in the yam tubers

The study also revealed that nematode population in harvested yam tubers was not significantly affected by location, season, nor treatment (**Table 4.3**). However, treatment significantly affected ($p<0.05$) mean nematode population in tubers at three months. Treatment A had the least nematode populations (1) and treatment B the highest nematode populations (50) for the wet season. There was also a significant ($p<0.05$) interaction between treatment and location on the mean nematode population in the tubers at harvest as Chinderi had significantly higher mean nematode population in tubers in both dry season (15) and wet seasons (22), compared with Grubi which had lower nematode populations in tubers both in dry season (6) and wet seasons (6) respectively.

Table 4. 3 Mean population of nematodes in yam tubers at harvest, 3 and 5 months after storage as influenced by abamectin banana paper treatment, trial location, and season.

	Average nematode population in 50 g sample of yam peels					
	At harvest		3 months after Storage		5 months after storage	
Treatment	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Chinderi						
A	9 (0.38)	11 (0.50)	2 (0.21)	1 (0.23)	0	2
B	25 (0.81)	29 (1.18)	2 (0.27)	50 (0.90)	1	3
FP	10 (0.69)	25 (0.82)	2 (0.32)	3 (0.25)	2	1
	15 (0.63)	**22 (0.83)**	**2 (0.27)**	**18 (0.46)**	**1**	**2**
Grubi						
A	6. (0.62)	6 (0.59)	0 (0.00)	1 (0.12)	0	0
B	2 (0.36)	2 (0.41)	11 (0.30)	1 (0.26)	1	4
FP	9 (0.69)	9 (0.68)	0 (0.08)	3 (0.32)	1	1
	6 (0.56)	**6 (0.56)**	**4 (0.13)**	**2 (0.23)**	**0.58**	**1.69**
LSD at 5%						
Location (L)	NS		NS		NS	
Season (S)	NS		NS		NS	
Treatment (T)	NS		0.23		NS	
L * S	NS		NS		NS	
L * T	0.39		NS		NS	
S * T	NS		NS		NS	
L * S * T	NS		NS		NS	

FP = Standard farmer practice (control), A = Abamectin pretreated banana paper, B = Banana paper without Abamectin. * Bolded face mean values are responses at each trail location with respect to the planting season. Values in the enclosed brackets were log-transformed before ANOVA. NS = Not significant based on ANOVA test (α = 5%).

4.5.4 Influence of abamectin banana paper treatment, trial location, and season on the yield components of yam tubers.

4.5.4.1 Number of mounds harvested and number of tubers

The number of mounds (hills) and yam tubers harvested were not significantly affected by the treatments. Location had no significant effect on number of mounds, but the number of tubers harvested were significantly higher in Grubi (38) than in Chinderi (34). Seasons had significant effect ($p<0.05$) on number of mounds and number of tubers harvested, as dry season produced more yam tubers (41) and number of mounds (30) harvested than wet season (**Table 4.4**).

Table 4.4 Effect of Abamectin pretreated banana paper treatments on the number of yam mounds and tubers harvested at Chinderi and Grubi in the wet and dry season, respectively.

	Average No of mounds	Average No of tubers
Treatment		
A	27	35
B	27	36
FP	27	37
Location		
Chinderi	26	34
Grubi	28	38
Season		
Dry	30	41
Wet	24	31
LSD at 5%		
Location (L)	NS	3.06
Season (S)	1.73	3.06
Treatment (T)	NS	NS
L * S	NS	NS
L * T	NS	NS
S * T	NS	NS
L * S * T	NS	NS

FP = Standard farmer practice (control), A = Abamectin pretreated banana paper, B = Banana paper without Abamectin. NS = Not significant based on ANOVA test ($\alpha = 5\%$).

4.5.4.2 Weight and length of yam tubers at storage

Treatment A produced significantly higher weight (1731.76g) and tuber length (38.47cm) than treatments B (1365.77g and 34.47cm) and FP (1568.41g and 36.92cm). Yam tuber lengths were significantly higher in dry season (39.82cm) than in the wet season (33.42cm). Although there was difference in the tuber weight at Chinderi and Grubi, the difference was not statistically significant (**Table 4.5**).

Table 4.5 Mean yam tuber weight and tuber length response to abamectin pretreated banana paper treatments, trial location, and season plus their interactions (3-month exp)

	Tuber weight at harvest (g)	Tuber length at harvest (cm)
Treatment		
A	1731.76	38.47
B	1365.77	34.47
FP	1568.41	36.92
Location		
Chinderi	1360.70	34.26
Grubi	1749.93	38.99
Season		
Dry	1577.67	39.82
Wet	1532.96	33.42
LSD at 5%		
Location (L)	213.80	2.06
Season (S)	NS	2.06
Treatment (T)	261.90	2.52
L * S	NS	NS
L * T	NS	NS
S * T	NS	NS
L * S * T	NS	NS

FP = Standard farmer practice (control), A = Abamectin pretreated banana paper, B = Banana paper without Abamectin. NS = Not significant based on ANOVA test (α = 5%).

4.5.5. Severity of plant parasitic nematode damage on yam tubers

Treatment A significantly reduced the severity of nematode damage on yam tubers at harvest, 3months of storage and 5 months of storage with means of 1.75, 2.15 and 2.02 for Chinderi and 1.72, 2.26 and 2.39 for Grubi respectively. There was also a significant interaction effect ($p<0.05$) of sampling location and season on severity of nematode damage at harvest and at 5 months of storage (**Table 4.6**).

4.5.6 Weight loss in tubers under storage

The effect of abamectin banana paper treatment and location storage on the weight of yam tubers in storage was evaluated for rate of weight loss. There was no statistically significant difference in the weight loss across the treatments for three months of storage. There was however, a statistically significant difference for location of storage in two months. There was a higher percentage weight loss in Nchumuru storage location (21.60) than in Legon storage location (19.26) for three months of storage (**Table 4.7**).

For five months of storage, location of storage was statistically significant for two months and four months of storage (**Table 4.8**). Percentage weight loss at Legon was 11.36% and 23.30 respectively for two and four months while that of Nchumuru was 15.31% and 33.49% for two month and four months respectively. There was no significant interaction between location of storage and treatment.

Table 4.6 Mean severity of nematode damage on yam tubers assessed at harvest, and after storing for 3 and 5 months

		Damage severity at harvest			Damage severity after 3 months of storage			Damage severity after 5 months of storage		
Sampling Location	**Treatment**	Dry season	Wet season	Mean	Dry season	Wet season	Mean	Dry season	Wet season	Mean
Chinderi	A	1.75	1.75	1.75	1.81	2.50	2.15	1.55	2.49	2.02
	B	2.75	3.00	2.88	2.25	3.30	2.78	2.73	3.48	3.10
	FP	2.63	2.13	2.38	2.53	3.65	3.09	2.21	2.61	2.41
		2.38	**2.29**	**2.33**	**2.20**	**3.15**	**2.67**	**2.16**	**2.86**	**2.51**
Grubi	A	1.75	1.69	1.72	1.83	2.68	2.26	2.54	2.25	2.39
	B	2.06	1.88	1.97	2.48	2.58	2.53	2.54	2.72	2.63
	FP	2.44	2.38	2.41	2.69	3.00	2.85	3.21	3.08	3.14
		2.08	**1.98**	**2.03**	**2.33**	**2.75**	**2.54**	**2.77**	**2.68**	**2.72**
LSD at 5%										
Sampling Location (SL)			NS			NS			NS	
Season (S)			NS			**0.27**			NS	
Treatment (T)			**0.38**			0.33			**0.40**	
SL * S			NS			NS			**0.46**	
SL * T			**0.54**			NS			**0.57**	
S * T			NS			NS			NS	
SL * S * T			NS			NS			NS	

FP = Standard farmer practice (control). NS = Not significant based on ANOVA test (α = 5%). * Bolded face mean values are responses at each trial location with respect to the season. Damage assessment of yam tubers was carried out visually using a 1 – 5 point damage severity scale: 1 = clean tubers, 2 = 1 – 25% tuber skin showing cracking, galling or dry rot symptoms (low level of damage), 3 = 25-50% of tuber skin symptoms (low to moderate level of damage); 4 = 51-75% tuber skin symptoms (moderate to severe level of damage); 5 = 76-100% tuber skin symptoms (high level of damage).

Table 4.7 Effect of abamectin banana paper treatments on the weight of nematode infected yam tubers stored at Legon and Nchumuru for 3 months.

	Percentage weight loss in yam tubers over 3 months (%)		
	1 month	**2 months**	**3 months**
Treatment			
A	6.18	15.04	20.47
B	7.54	14.68	19.20
FP	6.24	14.75	21.60
Store Location			
Legon	6.84	13.42	19.26
Nchumuru	6.47	16.23	21.60
LSD at 5%			
Store Location (L)	NS	2.8	NS
Treatment (T)	NS	NS	NS
L * T	NS	NS	NS

FP = Standard farmer practice (control). NS = Not significant based on ANCOVA test (α = 5%) with tuber weight at harvest as a covariate.

Table 4. 8 Effect of abamectin banana paper treatments on the weight of nematode infected yam tubers stored at Legon and Nchumuru for 5 months.

	Percentage weight loss in yam tubers over 5 months (%)				
	1 month	**2 months**	**3 months**	**4 months**	**5 months**
Treatment					
A	4.16	14.22	18.92	28.93	33.16
B	4.96	14.84	18.87	28.51	32.37
FP	3.95	10.94	19.38	27.74	32.74
Store Location					
Legon	4.82	11.36	17.98	23.30	30.93
Nchumuru	3.90	15.31	20.13	33.49	34.59
LSD at 5%					
Store Location (L)	NS	3.02	NS	3.53	NS
Treatment (T)	NS	NS	NS	NS	NS
L * T	NS	NS	NS	NS	NS

FP = Standard farmer practice (control), A = Abamectin pretreated banana paper, B = Banana paper without Abamectin. NS = Not significant based on ANCOVA test (α = 5%) with tuber weight at harvest as a covariate.

4.5.7 Assessment of plant parasitic nematode density

Based on visual assessment of harvested yam tubers, it was observed that nematode infestation was generally low. However, there were symptoms of dry rot, galling and cracking on tubers when assessed across treatments. Farmer practice had the highest population density, followed by B with the least on A. Furthermore, yam tubers from the wet season showed more symptoms of nematode damage than tubers from the dry season**.** In all, 10 plant parasitic nematode genera were identified which were *Scutellonema bradys, Meloidogyne* spp., *Pratylenchus* spp., *Paratylenchus* spp., *Tylenchorhynchus* spp., *Heterodera spp.*, *Rotylenchus* spp., *Helicotylenchus* spp., *Aphelenchus* spp., *and Tylenchus* spp. Out of the total number of plant parasitic nematodes (1461), *Scutellonema.bradys* had the highest population density (991), followed by *Meloidogyne* spp. (211) then *Pratylenchus* spp. (90). The identification was based on morphological features such as lip region, position of the vulva, stylet length, and tail length.

4.5.8. Population 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. Plant parasitic nematode genera that were associated with peels of stored yam tuber can be seen in **Figure 4.9**. The genera *Scutellonema* spp. *Meloidogynae* 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 tuber samples collected. *Scutellonema bradys* had the highest relative abundance of 87.4% followed by *Meloidogyne* spp. with relative abundance of 6.3%.

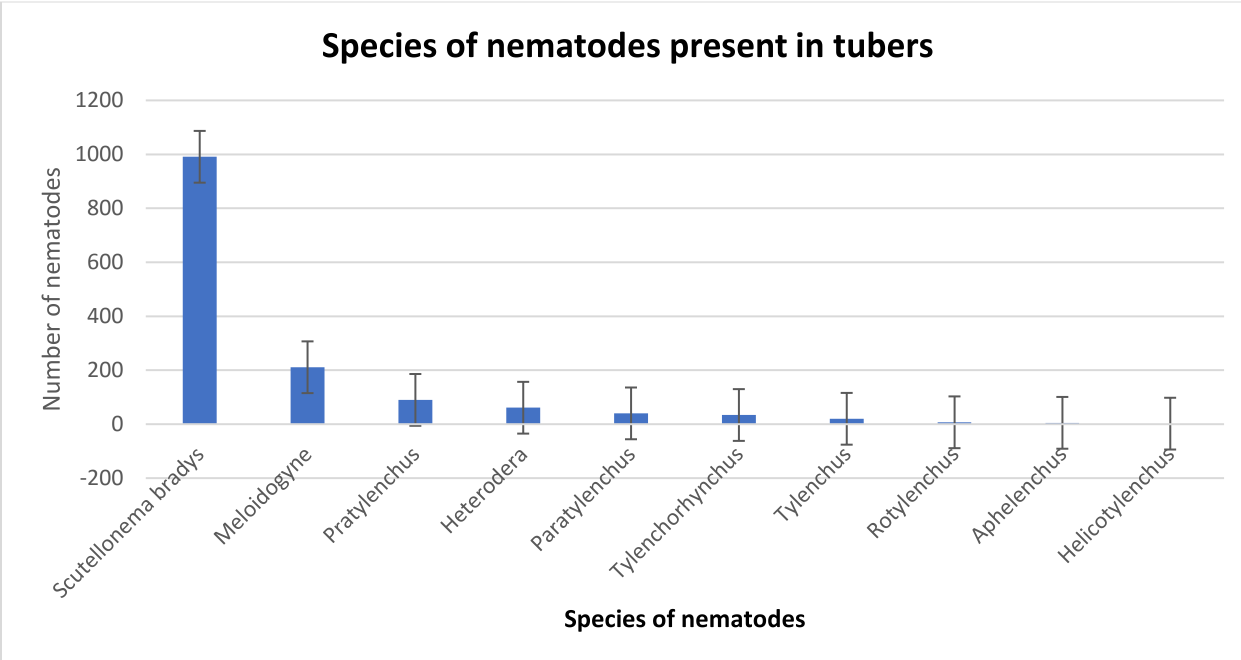


Figure 4.8 Plant Parasitic Nematodes Species and their Population Densities.

4.6. Socioeconomic Study on the Adoption of the Wrap and Plant Technology

4.6.1 Focus group discussion

All participants of the focus group discussion (AEAs, farmers, processor, and traders) stated that they were first introduced to the BP-Abm Technology by a team of researchers from the University of Ghana. On the effectiveness of the technology, all the agricultural extension agents and farmers stated that the harvested yams with ABM treatment looked fresh and healthy and there was no sign or presence of nematodes infestation. All the farmers were of the view that the technology is good in controlling plant parasitic nematodes because as compared with the other treatment methods, the ABM treated yams had a smooth skin and were bigger in sizes. All the traders and the only processor available stated that the harvested ABM treated yams looked healthy and fresh and were not rotten. However, all the farmers whose farms were used as demonstration plots stated that the ABM banana paper treated yams germinated late and their germination were also not uniform as compared with the traditional treatment methods. One of the farmers stated that ABM treatment involves a lot of work such as wrapping the yam sets with the ABM treated paper before planting and this might pose a challenge for farmers with large farm size.

4.6.2 Constraints faced by the yam farmers

Farmers were also interviewed on the constraints they faced in their yam production and sales. The farmers were asked to rank the constraints, with 1 being the most pressing constraint and 15 being the least. These constraints are presented in **Table 4.9**

Table 4. 9 Constraints faced by yam farmers in the Krachi Nchumuru District

Constraints		Mean Rank	Rank
High post-harvest losses		1.65	1
Incidence of pests and diseases		2.20	2
Difficulty in accessing credit		4.55	3
Low output prices		4.95	4
Inadequate rainfall		5.05	5
High cost of labour		5.60	6
Poor yields		7.70	7
Limited access to market		7.80	8
Limited storage facilities		8.20	9
Lack of capital		10.65	10
Lack of quality planting material		11.85	11
Untimely delivery of supplies		11.95	12
Delays in extension service delivery		12.10	13
Difficulty in accessing land		12.13	14
High temperatures		13.63	15
N	20		
Kendall's W[a]	0.76		
Chi-Square	212.73		
df	14		
Asymp. Sig.	0.00		

From the results, 76% of the farmers agreed among themselves in the ranking of the constraints. Since the Asymp. sig is 0.000, which is statistically significant, the null hypothesis which says that there is no agreement among the farmers was rejected in favour of the alternate hypothesis. The pressing constraints identified from the study were high post-harvest losses, incidence of pests and diseases, difficulty in accessing credit, low output prices and inadequate rainfall.

1) ***High post-harvest losses:*** Pests and diseases attack yam tubers both on the field and in storage leading to rot and spoilage. Bad road networks to farms and markets leads to losses during transportation to their destination.

2) ***Incidence of pests and diseases:*** Farmers stated that the incidence of pests, particularly plant parasitic nematodes, and diseases were major problems leading to poor germination of seed yams and rotting of yam tubers in the field as well as in storage.

3) ***Difficulty in accessing credit:*** Low investment capital causes farmers to borrow from financial institutions. Farmers tend to rely on loans from micro finance institutions which also comes with the problem of high interest rate. However, these institutions are sometimes reluctant to provide credit for agricultural activities due to the risky nature of farming.

4) ***Low output prices:*** Due to the difficulty in transporting yam to various markets for sale, farmers rely on marketers who buy their produce and sell them. These marketers mostly dictate prices to these farmers which are mostly not favourable to farmers. Some farmers also rely on middlemen who keep part of the revenue after the sale of the produce hence reducing the profit that farmers make from the sale of their produce.

5) ***Inadequate rainfall:*** Rainfed agriculture accounts for a large percentage of the total yam production in these rural areas in Ghana. Rainfall is thus the main water supply system for crop production. Most of the farmers complained that the rains were not forthcoming hence leading to low yields.

4.6.3 Perception About BP ABM Technology

All the respondents had no prior knowledge about the banana paper Abamectin technology before the introduction of this project. The major source of knowledge on the BP-Abm technology was through the Research Institutions (90%). The remaining respondents (10%) obtained knowledge on the technology through extension agents. All the respondents said that the technology was beneficial (**Figure 4.9**).

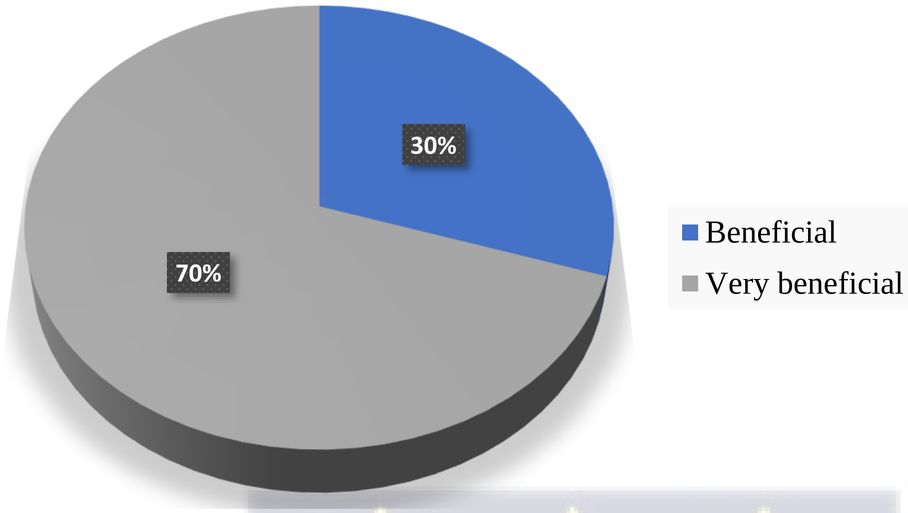


Figure 4.9 Level of benefit of BP-Abm Technology

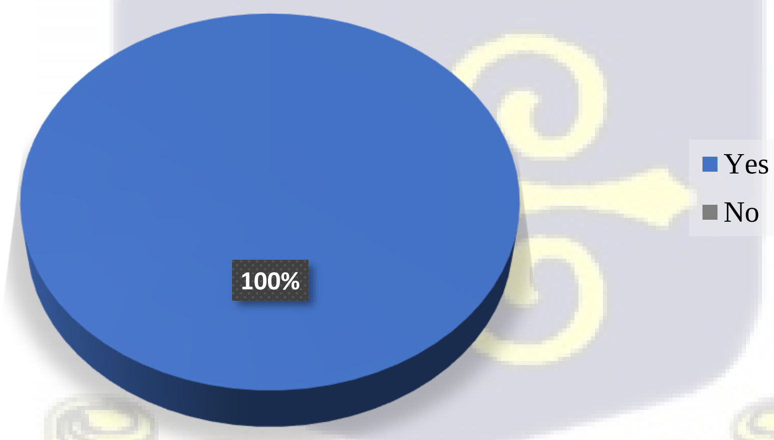


Figure 4.10 Willingness to Adopt the BP-Abm Technology

On the willingness to adopt this technology, all the respondents stated that they were willing and ready to adopt the BP-Abm technology for management of plant parasitic nematodes on their farms (**Figure 4.10**).

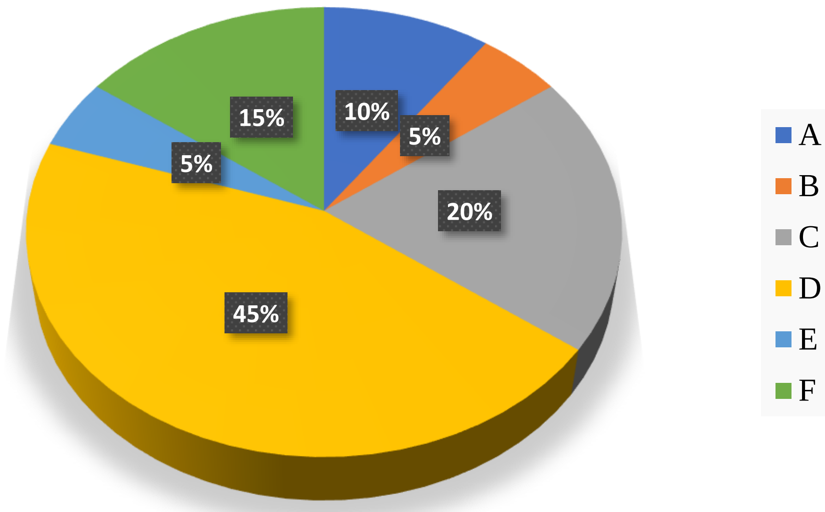


Figure 4.11 Benefits of BP-Abm Technology

Tthe various reasons why yam farmers are willing to adopt the BP-Abm technology is illustrated in **Figure 4.11** and summarized in **Table 4.11**.

Table 4. 10 Benefits derived by farmers from the ABM technology

A = Healthy yams	D = Healthy and fresh yams and no holes
B = Safer technology and healthy yams	E = Healthy and fresh yams and bigger sizes
C = Healthy and fresh yams	F = Healthy and fresh yams, no holes and no spoilage

4.6.4 Profitability of Yam Production Techniques

To assess the profitability of the use of the ABM technology on yam farming, the study carried out a Benefit-Cost Ratio (BCR) analyses on the three treatment methods namely Farmer Practice (FP), Banana Paper with Abamectin and Banana Paper without Abamectin. The breakdown of the various components of the analyses is given below:

4.6.4.1. Costs

A typical cost structure for setting up and carrying out operational activities on the demonstration plot (with 144 mounds) are outlined in **Table 4.11**.

Table 4. 11 Cost Components of Cultivating Yam

Cost (Demo Site) =144 Mounds			
Activities	**Unit**	**Price**	**Total (¢)**
Land Preparation	1	30	30
Weedicide Application	1	15	15
Labour for Application	1	10	10
Making Mounds (144)	1	20	20
Planting & Mulching	1	10	10
Weeding	1	10	10
Harvesting	3	10	30
Total Cost using Farmer Practice			**125**
Cost of Abamectin Paper	48	2.75	132
Total Cost using Abamectin Paper (125+132)			**257**
Cost of Banana Paper	48	2.75	132
Total Cost using Banana Paper (125+132)			**257**

The total cost of using the normal farmer practice amounted to GHS 125.00, the total cost of using the Abamectin paper technique amounts to GHS 257.00 and that of Banana Paper amounts to GHS 257.00.

4.6.4.2 Assumptions Made for Calculating Benefits

To compute the returns from yam farming using the benefit-cost ratio (BCR) analyses, some assumptions were made. These assumptions were:

1. The average price of a tuber of yam is GHS 3.00 based on information from yam sellers (traders and farmers).
2. The abamectin technology is likely to increase the price of yam from GHS 3.00 to GHS 4.00 which is approximately a 30% increase in the price of the yam. The price increase is because the use of abamectin helps to produce yams of better quality which commands a higher price as stated by the stakeholders of the project.

3. It is estimated that about 9.6% of yam is lost by farmers during storage (Ansah *et al*., 2018). The respondents stated the absence of rot due to the use of the abamectin. Hence, the percentage loss during storage is only calculated for the normal farmer practice.

4.6.5 Computation of Results

Quantity harvested: This is the total amount of yams harvested from the mounds created for each section of the demonstration site reserved for the farmer practice trial

Quantity lost: 9.6% of yam is likely to be lost after harvesting yams hence this percentage is expressed over the quantity harvested to give the remaining quantity after losses

Remaining quantity: Quantity harvested minus quantity lost gives the remaining quantity

Price: The average price for the yam is GHS 3

Revenue: The price multiplied by the quantity gives the revenue

Cost: Total cost for farmer practice technique on a demonstration site is GHS 125

Net Benefit: The revenue minus the cost gives the net benefit

Benefit-Cost Ratio (BCR): The ratio of the revenue (benefit) to the cost gives the BCR

Table 4. 12 Summary of BCRs for the techniques used for yam production in the district

Dry Season			
Trial fields	Farmer Practice	Abamectin Treated	Banana Paper
Chinderi Site 1	3.06	2.09	1.44
Chinderi Site 2	3.73	2.85	1.72
Grubi Site 3	4.30	2.73	1.75
Grubi Site 4	3.34	2.56	1.64
AVERAGE	**3.61**	**2.56**	**1.64**
Wet Season			
Trial fields	Farmer Practice	Abamectin Treated	Banana Paper
Chinderi Site 1	2.56	1.64	1.16
Chinderi Site 2	3.06	1.41	1.40
Grubi Site 3	1.99	1.59	1.13
Grubi Site 4	3.30	2.40	1.80
AVERAGE	**2.73**	**1.76**	**1.37**

CHAPTER FIVE

DISCUSSION

5.1 Background of Respondents

The result from the analysis of the survey revealed that, majority of the yam farmers were males. Yam cultivation had been described as male dominated probably due to the high manual labour required in yam cultivation such as land preparation, planting, staking, weeding and harvesting (Nweke, 2013). Only 14.7% of the farmers were 50 years and above. This implies that most of the farmers were below 50 years which is a positive indication that the youth and middle-aged of Krachi Nchumuru are into yam farming. When their eagerness to contribute to farming is combined with opportunity, young people may have a transformational influence on agriculture and economic growth. However, farming that appeals to the younger generation must be lucrative, competitive, and viable. These are the same qualities that agriculture needs to deliver growth, increase food security, and protect environment (Brooks *et al*., 2013). Only few of the respondents reached tertiary level which confirmed the high illiteracy rate among the people of the district which adversely affected dissemination of information, adoption of modern technology, particularly farmers (Composite Budget, 2021).

Farmers with more formal education are better able to obtain and absorb information, as well as seek relevant technology to improve their production, such as contemporary, efficient, and environmentally friendly disease and pest management methods (Akinbile & Otitolaye., 2008). On the other hand, most people with higher education chose white collar employment in cities, leaving farming to those with little or no formal education. Most of the respondents had little to no formal education, therefore it was possible that they may not have the fundamental expertise to deal with postharvest losses caused by plant parasitic nematodes. In terms of postharvest losses and their impact on food security and safety, this situation is extremely problematic. This is because it will take a long time and a lot of resources to teach the stakeholders in the yam industry to understand and accept the significance of postharvest losses of yam caused by plant parasitic nematodes. This assumption is supported by an endogenous regression analysis conducted in northern Nigeria to evaluate the effects of education on agricultural productivity under traditional and advanced technologies. According to the findings, education not only improved agricultural productivity because of technology, but also encouraged adoption of new technology for productivity and environmental sustainability. (Li *et al*., 2020).

5.2 Size of farm

Most of the respondents were small holder yam farmers with average farm sizes of less than 1 acre to 4 acres, although a few of them had farm sizes above 8 acres. In a previous study, it was observed that agriculture in Ghana was still rural and dominated by small holder farmers (Adjei *et al*., 2020). Smallholder farms were characterized by restricted use of high-quality inputs, lack of improved techniques for farming, limited access to improved cultivars, inadequate infrastructure networks, and poor pest and disease detection and management. Smallholder farmers typically have a basic awareness of plant parasitic nematodes but lacked the expertise to control their infestations (Coyne *et al*., 2018).

5.3 Varieties of white yam cultivated

Majority of the farmers cultivated the Pona variety of white yam, while a few of them cultivated other varieties including ‘Olondo’, ‘Asobayere’, ‘Kplinjo’, ‘Nyame nti’, and ‘Kununku’. This may be due to the pleasant taste and premium market price and high demand in both local and export markets (Boadu *et al*., 2018).

5.4 Yam intercropping

Farmers frequently intercropped their yam with maize, cowpea, groundnut, and other vegetables. This builds on the findings of Reddy (2015) and Andres *et al.* (2016), who found that yam producers intercropped legumes, grains, and vegetables with their yam. Since legumes release nitrogen into the soil, intercropping yam with leguminous crops helps improve soil fertility. As yams are generally produced without fertilizer, this is advantageous to yam farmers. Intercropping may also ensure maximum use of farmland. However, intercropping is thought to restrict farm expansion because of the high labor requirements and competition for light, nutrients, space, and moisture. When yams are intercropped, they are more susceptible to water stress, and intercropping also made mechanization problematic (Orkwor *et al*., 1998). Intercropping with crops that are alternate host of plant parasitic nematodes can exacerbate the nematode problem on the field.

5.5 Awareness of plant parasitic nematode pathogenicity in yam cultivation

Majority of the farmers (76%) were aware of plant parasitic nematodes as a disease causal agent but did not know how to control them. A greater number of farmers reported between 20% to 50% postharvest losses of yam tubers due to nematodes infestation (Mudiope *et al*., 2012). This high loss may be due to lack of knowledge and technology necessary for the control of the pathogen.

5.6 Negative Impact of Plant Parasitic Nematode Attacks on Socioeconomic Wellbeing of farmers

The role of plant parasitic nematodes on the socioeconomic wellbeing of yam farmers cannot be overemphasized. All farmers firmly agreed that plant parasitic nematode attack have a negative influence on their source of income, quality of life, higher crop management costs, and reduction in productivity and harvest quality. This led to their inability to provide for their children's education, pay back loans, afford medical bills, buy assets among other things (Kahan, 2008).

5.7 Effect of treatment on germination

Effective control of plant parasitic nematodes is necessary to optimize yam yields. This is because they may damage the yam tubers by decreasing their dry matter content, thus reducing germination capacity. Fortunately, the results from the study indicated that total germination of seed yam was similar ($p = 0.282$) across the treatments with seasonal variabilities. Banana paper did not negatively influence germination of seed yams. This is because banana paper is biodegradable and decayed gradually to release the active ingredient. In a previous study, banana paper did not hinder the sprouting of sweet potato seed nor disturb the chemistry of the soil (Pirzada *et al.*, 2020b).

5.8 The efficacy of the banana paper pre-treated with abamectin for the control of key yam parasitic nematodes and their effect on tuber yield, quality, and storability

Plant parasitic nematodes are important agriculture pests that cause huge pre-harvest and post-harvest crop losses. Abamectin is known to control plant parasitic nematodes in various agricultural crops including yam. The abamectin pretreated banana paper reduced nematode population in the soil and harvested tubers (Ochola *et al.*,2022), although the effects were not statistically significant. On the other hand, the wet season had a higher incidence of plant parasitic nematodes than the dry season. Moisture is necessary for the survival and reproduction and movement of plant parasitic nematodes both in the soil and in yam tuber. This has been reported by (Chen *et al*., 2004), who found out that high soil moisture and warm condition facilitated the hatching of nematode eggs and accelerated the release of juveniles from the nematode gall in the soil hence increased their population density. It is therefore likely that the increased soil moisture in the wet season increase the incidence of the nematodes in the field as well as in the harvested tubers. Chinderi site had the highest nematode population densities and lower number of harvested yam tubers, compared to Grubi site. Plant parasitic nematodes are known to reduce yield in agriculture crops by reducing the quantity and the quality of the crops. The yield component of yam tuber can be determined by the weight and length of the yam tubers. Treatment A had significantly higher tuber weight and tuber lengths compared to treatments B and FP. This is result is similar to that of (Qiao *et al*., 2012) who found out that effective control of plant parasitic nematodes led to significant increase in the yield of tomato. Also, yams planted in the dry season had a significantly higher tuber weight and length than those planted in the wet season (Okongor *et al.*, 2018).

Multiplication of key plant parasitic nematodes of yam is most severe during storage resulting in damage to the yam tubers. Severity of nematode damage in yam tubers, for treatment A had the least incidence of nematode damage at harvest, after 3 and 5 months of storage. Abamectin helps to control plant parasitic nematodes of yam tubers, which consequently improves storability. There was a significant interaction between storage location and treatment. This implied that A at Nchumuru storage location had a significantly higher plant parasitic nematode incidence than

Legon storage location. This could probably be due to variations in temperature and relative humidity which are factors that promote decay of yam tubers in storage. At Legon storage location, the temperature in the barn over the storage period ranged from 23.7℃ - 34.8℃ while that of Nchumuru ranged from 21.2℃ - 35.5℃. Relative humidity in the barn at Legon ranged from 45.7% – 93.2% while that of Nchumuru ranged from 46.1% - 98.7%. There was no significance difference in the rate of weight loss of tubers under storage for three as well as five months. However, yam tubers stored at Nchumuru had a significantly higher weight loss than those stored at Legon. This may probably be due to prevailing environmental conditions such as high temperature and high relative humidity the temperature in the barn at Nchumuru went as high as 35.5℃ while that of Legon storage barn had a maximum of 34.8℃. The relative humidity at Nchumuru storage location was as high as 98.7% while that of Legon storage location was 93.2 maximum. A similar result was obtained for five months of storage. High relative humility resulted in moisture retention in tubers which leads to tuber rot (Akrasi, 2017).

5.9 Focus Group Discussion

All the participants present at the FGD agreed that the technology was effective and yam farmers really needed it on a commercial scale. They agreed that the project yielded positive results on farms hence adoption in the major yam cultivating areas would be high if the application of the technology was not costly.

5.10 Benefit Cost Analysis

The benefit-cost ratio (BCR) used in the analyses helped in determining the relationship between the cost and returns and it also summarized the relationship between the benefits and costs of yam production in the study areas using the three production techniques. A BCR greater than one meant that the production of yam using the various techniques was profitable whereas a BCR less than one meant that production was not profitable. A BCR equal to one meant that the investment was at breakeven. From the results obtained, all the three production technologies used by yam producers were profitable since their BCRs were greater than one. However, the magnitude of their profitability differed.

The farmer practice (FP) obtained an average BCR of 2.73 and 3.61 during the wet and dry seasons respectively making it the most profitable technique among the three techniques used in the district followed by Abamectin technique with a BCR of 1.76 and 2.56 respectively in the wet season and dry season. Banana paper without abamectin, though profitable, was the least profitable technique with a BCR of 1.37 and 1.64. The results also showed that dry season yam production using the various technologies in the district was more profitable than in the wet season. This result is in contradiction to Chandra *et al*., (2021) who stated that drought stress reduced crop yield and hence became a threat to food security.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion on farmer's knowledge on plant parasitic nematode management in yam production in Krachi-Nchumuru District.

Yam farmers in the Krachi Nchumuru District were aware of the destructive effect of plant parasitic nematode in causing huge preharvest and postharvest losses of yam tuber. They however lacked the knowledge, skills, and resources in managing the key plant parasitic nematodes that attacked their yam tubers. This had negatively affected their livelihood and had led to their inability to provide for their children's education, pay back loans, afford medical bills, buy assets among other things.

6.2 Conclusion on efficacy and yield potential of abamectin wrap and plant technology in yam production.

Many genera of plant parasitic nematodes were extracted and identified but the most common ones were *Scutellonema bradys*, *Meloidogyne* spp., and *Pratylenchus* spp. The effectiveness of abamectin pretreated banana paper in controlling key plant parasitic nematodes of yam tubers as carried out in this study was encouraging. It improved tuber weight and tuber length. It also reduced the incidence of plant parasitic nematode effect in storage. Abamectin as a bio-nematicide is effective, has lower toxicity to humans and the environment, biodegradable and provides plant parasitic nematode suppression.

6.3 Conclusion on adoption and use of Abamectin pretreated banana paper technology.

From the focus group discussions, respondents were aware of the abamectin pretreated banana paper technology. Majority of them stated that the new technology was effective. Some positive effects of the use of the technology as given by the respondents included healthy and fresh yam tubers and the absence of rotten yam tubers upon harvesting. The summary of the BCRs for the three treatments used showed that, farmer practice obtained an average BCR of 2.73 and 3.61 during the wet and dry seasons respectively. Banana paper technique though also profitable, was the least profitable technique with a BCR of 1.37 and 1.64. This means that the costs of producing yam using farmer practice technology are 2.73 and 3.61 times the benefits. The results also showed that dry season yam production in the study area of the Krachi Nchumuru district was more profitable than wet season.

6.4 Recommendations

- Farmers should be given more education and resources in the managements of key plant parasitic nematodes of yam.
- The abamectin treated banana paper should be affordable so that yam farmers can used it to control key parasitic nematodes in their yam farms.
- The residual effect of abamectin treated banana paper to control yam nematodes for the next cropping season should be investigated.

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APPENDICES

APPENDIX 1

SURVEY ON NEMATODES ASSOCIATED WITH YAM PRODUCTION IN THE TRANSITIONAL AGROECOLOGICAL ZONE OF GHANA

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

QUESTIONAIRE NO ……….

A. Demographic characteristics

1. Name of farmer ………………………………………….

2. Sex: Male [1] Female [2]

3. Age of respondent:

< 20 = 1

21 – 30 = 2

31 – 40 = 3

41 – 50 = 4

> 50 = 5

4. Level of education: Primary [1] Middle sch. /JHS [2] Secondary/SHS [3] Tertiary [4] none [5]

Technical/Vocational [6] Other (Specify)………………………………………………………

5. Name of district ……………………………………………..

6. Name of community ………………………………………….

7. How long have you been cultivating yam? 1 – 5yrs [1]: 6 – 10yrs [2]: 11 – 15yrs [3] >15 [4]

8. Size of farm, year of cultivation and source of planting material

Year of cultivation	Size of farm (Acre)	Source of planting materials
2016		
2017		
2018		
2019		

Codes: Size of farm: 0-1 acre [1], 1- 2 acres [2], 3-4 acres [3] 5-8 acres [4] more than 8 acres [5]

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

9. What are the varieties of yam cultivated on your farm?

Variety	Proportion of farm

Code for proportions: < 1 acre [1], 1-2 acres [2], 3-5 acres [3], >5 acres [4]

B. Land use intensity (Refers to Main Plot)

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

11- 15years [4] more than 15 years [5]

11. What type of crop(s) have you planted on this piece of land in the past five (5) years?

Yam [1]

Cassava [2]

Pigeon pea [3]

Maize [4]

Others (specify)……………………………….

12. 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]

13. Have you practiced crop rotation on the plot where you have your yam before? Yes [1] No [2]

14. If yes, with what crop(s) did you rotate with?……………………….

15. What was the period of rotation?: 1-2 year [1], 3-5 years [2], More than 5years [3]

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

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

C. **Farmers knowledge, perception and experiences concerning occurrence of nematodes on farm and in storage.**

18. Do you experience any pests and disease problems in your yam field during the growing season?

Yes [1] No [2]

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

20. Which of your varieties do you observe these symptoms more: ………………………………

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

Symptom/Sign	Yes [1] / No [2]
1. Necrotic streaks or lesions on roots	
2. Reduced rooting system	
3. Internal rotting or discolorations of vegetative organs	
4. Dwarfing	
5. Stunting and resetting	

22. What are the conditions of the soil in your field where these signs/symptoms are prevalent?

a. Lowland (Waterlogged) [ ] b. Well drained soil [ ] c. Sandy - clayey [ ]

d. Sandy soil [ ] e. Loamy soil [ ] f. Clayey soil [ ] Other (Specify)……………………………..

23. Where do you store your yam after harvest? a. In a pit at the farm [ ] b. Yam barn at home/farm [ ] c. In a store at home [ ] d. In a farmstead [ ] e. Other Specify……………………………………………………..

24. Do you experience any loses in storage due to pests and diseases? Yes [1] No [2]

25. What proportion of stored yam is lost to pest and disease? A. 25% B. 50% C. 75% D. 100% E. Other Specify………………..

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

Sign/Symptom	Yes [1] / No [2]
1. Hardened and dried tissues with varying discolorations	
2. External cracks on skin of tubers	
3. Significant weight loses in tubers	
4. Light yellow lesions below the outer skin of the tuber	
5. Rotting of the outer 1 – 2cm layer.	
6. Flaking off- of external coverings exposing patches of dark brown	
7. General decay of tubers	

Codes for response: Yes [1] No [2]

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

26. How does nematodes spread? [A] Infected tubers [B] Soil [C] Heat [D] Prolong drought

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

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

Management Practice	Yes/ NO
1. Crop rotation	
2. Use of Nematicides	
3. Land rotation	
4. Use of organic/ inorganic fertilizers	
5. Others (specify)	

Response codes: Yes [1] No [2]

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

Potential use of Abemactin Technology

30. Have you heard about the use of treated banana paper to treat yam nematodes? A. Yes [1] No [2]

31. Abemactin Technology can treat yam nematodes successfully by planting yam seeds with the treated paper, are you interested to you use this technology to curb yam nematodes? A Yes [1] B. No [2]

32. What factors will make you not to use this technology………………………………………………………………………………………….. ………………………………………………………………………………………………………

33. What factors will make you use the AbemactinTechnology?

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