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Yam Nematodes as Production Constraints in Ghana: A Socio-Economic Perspective

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Abstract: Yam (*Dioscorea* spp.) has been a prominent food and cash crop for most farmers in the yam production areas of Ghana, with the sales of yam in both domestic and international markets contributing significantly to the economy of the country. However, yam production by smallholder farmers is constrained by several challenges, including postharvest loss resulting from yam nematodes. This study conducted field surveys across seven districts across Ghana to collect data from randomly selected 150 yam farmers to investigate the status of nematode infestation, management practices and other socio-economic factors contributing to yam production in the country. The most common farm size for yam production from 2019 to 2022 was between 0.4 and 0.8 hectares. The majority of the farmers (56%) have been farming for over 15 years, with 6–10 years of experience in yam production, and preferred to use their own planting materials every year. Although most farmers (97.99%) experienced pests and diseases, most of them (77.33%) had no knowledge about nematode infestations in their farm causing damage to the tubers. Although yam farmers experienced yield losses, farmers were unable to manage nematode infestations in their farms. Twelve (12) genera of nematodes were identified in soils of yam rhizosphere across the seven districts. *Tylenchus* spp. (35.5%) and *Scutellonema* spp. (92.8%) were the most abundant nematode in soil samples and tuber peels, respectively while the second highest nematode in tuber peels was *Meloidogyne* spp. (4.0%). The presence of these parasitic nematodes in yam farms across Ghana suggests serious threats to the growth and yield of yams, although their presence is either not known or is usually neglected. Our result also confirmed the correlation between farmer storage practices and the management of nematodes, suggesting some storage practices such as barns may be effective in controlling nematodes. On the other hand, we find no association between pest occurrence in the field and nematode management. The lack of an association could be an indication that pest management in the field and nematode management in storage are separate activities and this underlines the importance of providing tailored postharvest training for smallholder farmers in effectively managing nematodes. It was therefore necessary to undertake this study and establish knowledge on the species as well as their prevalence in the farms across Ghana, contributing towards enhanced farmers' understanding on nematode management and effective storage of yams to prevent losses caused by nematode infestation.

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1. Introduction

Yam production stands as a cornerstone of agricultural livelihoods and cultural heritage in West Africa, with Ghana being one of the foremost producers of this staple crop [1]. Ghana is known for its significant contributions to the global agricultural supply chain through yam production and exports. Ghana's main exportable yam varieties include *Pona*, *Larebako*, *Asana*, *Dente*, and *Muchumudu*. These varieties are of high quality and taste, and they are primarily grown by small-scale rural farmers using mostly traditional production methods. According to the Ghana Export Promotion Authority [2], Ghana was the world's top exporter of yams in 2021. The country's yam export value has increased since 2018, from USD 38.5 million to USD 48.2 million by 2021. Ghana has a global share of 24.1%, with an annual growth rate of 14% between 2020 and 2021 and an average growth rate of 9% from 2017 to 2021 [2].

As a staple food and a key economic commodity, yams (*Dioscorea* spp.) support the sustenance and financial stability of millions of smallholder farmers across different yam-producing areas around the world, because this crop contains minerals, micronutrients and essential amino acids [3–5]. However, the productivity and profitability of yam cultivation are increasingly compromised by various biotic stresses, among which the parasitic nematodes pose one of the most formidable challenges [6–8]. The nematode infection of yam tubers, leading to the insidious dry rot disease, has far-reaching implications that extend beyond agricultural yields to encompass profound socio-economic consequences. In their study in West Africa, Coyne et al. [9] discovered that yam tubers from Ghana suffered the highest physical damage by nematodes, mainly *Scutellonema bradys,* and this damage cuts across different yam species.

Nematodes inflict direct damage on yam crops by causing lesions and necrosis in tubers, which not only diminish the harvestable yield but also severely degrade the quality of the produce [10]. Nematode infections in conjunction with various other pests and pathogens, have been implicated in the alarming reduction of healthy seed material in yams [11]. Being vegetatively propagated, the use of infected planting material without treatment and proper management ensures the persistence of the disease cycle, resulting in a progressive deterioration of seed quality and crop yield. The economic ramifications for farmers are immediate and severe, manifesting as reduced marketability of their crops, lower incomes, and increased expenditures on pest management [7,8,12]. This financial strain is exacerbated by postharvest losses, as infected yams exhibit significantly shortened shelf life, further undermining farmers' revenues and the overall market supply.

The economic burden imposed by nematode infection extends to the broader community and national levels. In regions where yam is a predominant crop, the pest's impact can destabilize local economies, leading to increased poverty and food insecurity [13]. The reduction in yam availability can drive up food prices, strain household budgets, and diminish food security, thereby amplifying the vulnerability of rural communities to economic shocks [14]. The compounded effects of reduced income and higher costs can trap farmers in a cycle of poverty, impeding their ability to invest in other agricultural inputs or diversify their livelihoods.

Beyond its economic impact, the infestation of yams by nematodes holds significant cultural and social implications. In Ghana, as in much of West Africa, yams are not merely a source of sustenance but also a cultural symbol deeply embedded in social rituals, festivals, and traditional ceremonies. The decline in yam production thus threatens not only the economic welfare of farming communities but also the preservation of cultural practices and social cohesion.

While cultivation and marketing of yam tubers play a crucial role in the socio-economic conditions of smallholder yam farmers in Ghana, the high prevalence of nematode infestations has significantly hindered the productivity of the farmers and profitability of the enterprise, with farmers attaining yields of only approximately 10 t ha^{-1} [15], which is merely 20% of the potential yield of 50 t ha^{-1}. This study is significant to better understand the socio-economic challenges posed by nematodes in yam production and storage among smallholder farmers in Ghana. The main objectives of this study were to: (i) describe the socio-demographic characteristics of yam farmers, (ii) investigate production practices and land use intensity by yam farmers, (iii) evaluate farmers' perception and knowledge of yam nematodes including the symptoms and causes, and (iv) characterization of nematode populations present in soils from yams farms and in yam tubers.

2. Methodology

2.1. Study Area and Sample Selection

This study was conducted in seven major yam-growing districts in Ghana. The selected districts included are the Nkoranza, Jaman South, Botokrom, Kpando, Grubi, Buya, and Sabari districts (Table 1; Figure 1), which were chosen based on a combination of factors including yam production volumes, reports of nematode infestations, and the diversity of agricultural practices. These districts represent a range of agro-ecological zones in Ghana (Table 1), providing a comprehensive understanding of the conditions under which yam farming occurs and the challenges faced by farmers. These span from semi-arid northern regions to more humid southern areas. Each district represents unique characteristics in terms of soil type, rainfall patterns, and temperature, which are critical factors influencing yam cultivation and incidence of pests and diseases.

Table 1. Agro-ecological zones, locations, and the GPS coordinates of the selected districts.

Agro-Ecological Zone	Location	Global Positioning System	
Semi-Deciduous Rainforest	Kpando Gbefi	6°59′44.05″ N	0°22′40.85″ E
Semi-Deciduous Rainforest	Grubi	8°18′41.4″ N	0°17′17.4″ E
Guinea Savanna	Buya	8°20′51.67″ N	0°3′55.28″ E
Forest Savanna Transition	Dotobaa	77°31′53.3″ N	1°48′21.5″ W
Forest Savanna Transition	Botokrom	7°31′12.39″ N	2°45′7.15″ W
Forest Savanna Transition	Abirikasu	7°29′52.51″ N	2°49′40.63″ W
Guinea Savanna	Sabari	9°16′47.14″ N	0°15′32.18″ E

Ghana's climate, like that of the other countries along the Guinea coast, is determined largely by the interplay of two air masses: a hot, dry continental air mass that forms over the Sahara and a warm, humid maritime tropical air mass that forms over the South Atlantic. The dry continental air mass is more dominant in the northern part of Ghana where the ecology is characterized by savanna, while the humid tropical air mass is more dominant in the southern part where the ecology is partly moist evergreen forest and partly deciduous forest. The country's agro-ecological zones from north to south are Sudan Savanna, Guinea Savanna, Transitional, Semi-deciduous Forest, Rainforest, and the Coastal Savanna. In the savanna region of northern Ghana, there are distinct seasonal variations characterized by a dry season from November to March, marked by hot days and cool nights under clear skies, and a wet season peaking in August and September. The mean annual precipitation ranges between 1020 and 1400 mm, but a prolonged, intense dry season results in a significant moisture deficit. In contrast, the forested region of southern Ghana experiences a mean annual precipitation ranging from 1270 to 2180 mm from north to south, with a bimodal rainy season occurring from April to July and a shorter one from September to November. This region also experiences two relatively dry periods: during the Harmattan season from December to February and in August, which is typically cool and misty along the coast. The temperature in the study areas ranged from 25 °C (minimum) to 31 °C (maximum).

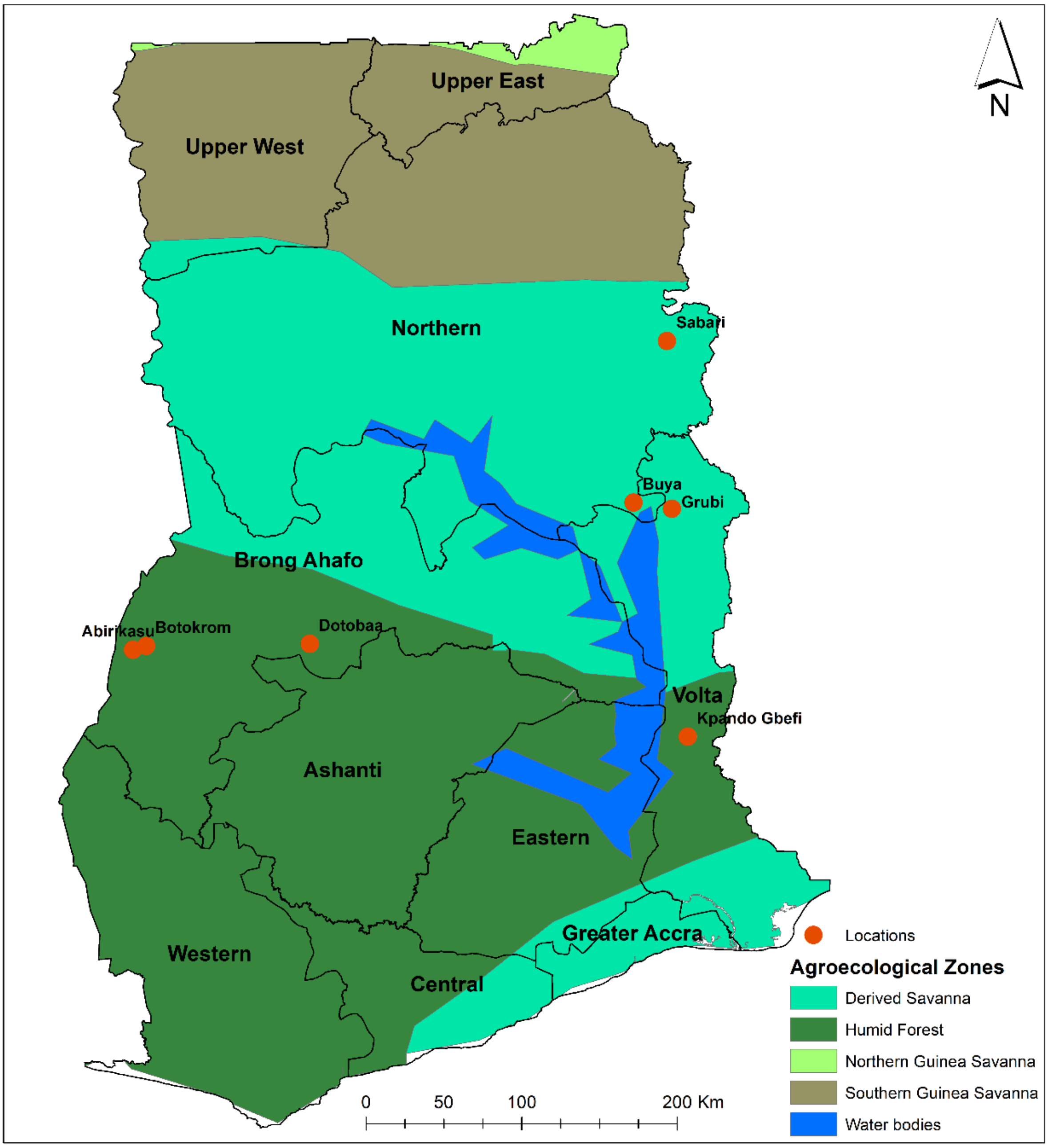


Figure 1. Map of Ghana, showing the study and sampling sites.

2.2. Sampling Procedure

A purposive sampling technique [16], was used to select five yam farms and random sampling was used to select 150 farmers across seven districts for this study. The details of study area demographic details of the farmers are provided in Figure 1, respectively. A structured questionnaire (Supplementary S1) was administered between November 2023 and January 2024 by trained enumerators from the University of Ghana. This was to assess farmers' sources of planting materials, soil type in their farms, methods of yam storage, pest management practices, and knowledge and perceptions of nematode infestations. Educational materials on yam nematodes and dry rot samples were made available to farmers to facilitate the interview. Verbal consent was obtained from each participant before conducting interviews. To assess the importance of postharvest losses, farmers were asked about the prevalence of distinct symptoms on their harvested yams such as (1) hardened and dried tissues with varying discolorations, (2) external cracks on the skin of tubers, (3) significant weight loss in tubers, (4) light yellow lesions below the outer skin of the tuber, (5) rotting of the outer 1–2 cm layer, (6) flaking off- of external coverings exposing patches of dark brown, (7) general decay of tubers.

2.3. Data Collection and Analysis

Data was collected based on interviews with selected farmers using a structured questionnaire (Supplementary S1) administered by trained enumerators and directly visiting yam farms and observing yam production practices. These trained enumerators from the University of Ghana were selected based on their familiarity with local languages, survey methodology, and past experiences with existing pests and disease situations in yam production. Demographic details were captured about the farmer (age, gender, level of education, and years of experience in yam production) and the farm (area under yam, varieties grown, prevalent pests and diseases, management practices used, including fungicide or pesticide applications, etc.). To assess the level of occurrence of nematodes, farmers were asked to rate prevalent pests and diseases, in terms of yield loss, using a scale of 1–4 developed for this study wherein 1 represented yield loss <10% (low), 2: 11–20% (medium), 3: 21–30% (high), and 4: >30% (very high).

The data collected in this study were analyzed using descriptive statistics and graphs in Stata software version18.0.

2.4. Extraction of Nematodes from Soils Collected from Yam Farms and from Tubers

Nematodes were extracted from soil using the sucrose centrifugation method [17]. Sucrose was prepared by dissolving 454 g of sugar in distilled water and topped up to 1 L. Soil samples collected from yam farms across seven districts were thoroughly mixed and passed through coarse sieves to remove any debris. About 200 cm^3 was used as bulk and transferred to a beaker for the extraction process. Twice this volume of water was added and stirred thoroughly to mix and break up the clods in the soil samples. The solution was then allowed to settle for 3 min and poured through a stack of 90 μm, 70 μm, and 36 μm mesh sieves. The soil residue in suspension collected through the 36 μm sieve was gently washed into 50 mL centrifuge tubes in equal volumes. The centrifuge tubes were then placed in the MR 23i benchtop centrifuge (Jouan-Thermo Scientific, Bend, OR, USA) to balance. The tubes were spun at 1700 rpm for 5 min and allowed to settle for 5 min. The supernatant was discarded, and sucrose solution was added to each centrifuge tube in an equal volume and stirred well using a spatula to break up the pellet. The tubes were then spun at 1000 rpm for 1 min and the supernatant was poured through the 36 μm mesh sieve and transferred into freshly labeled tubes to a final volume of 10 mL.

Nematodes were extracted from yam tubers using the modified Baermann funnel method [18]. The tubers were washed and peeled with a knife and 50 g of yam peel was collected from each sample. The peels were bulked and cut into smaller pieces and blended for 5 s and transferred through a plastic mesh with a plastic cup beneath it to collect nematodes by pouring water gently on the mesh. The set-up was left for two days and then poured through a 36 μm mesh sieve. A wash bottle was then used to collect the nematodes into centrifuge tubes to 10 mL final volume.

A compound light microscope (Exacta-OptechBiostar B5P, München, Germany) was used to examine, identify and count the nematodes by transferring 5 mL of suspension to a counting dish. They were identified to the genus level based on the distinct morphological features of adults [19] and the University of Nebraska Lincoln nematode identification website (https://nematode.unl.edu/ (accessed on 30 August 2024)).

3. Results and Discussion

3.1. Socio-Demographic Characteristics of Yam Farmers

Table 2 indicates that out of the 150 sampled yam farmers across seven districts, a significant majority, 135 (90%), were male. In contrast, only 15 farmers (10%) were female. This substantial gender disparity suggests that yam farming is predominantly a male-dominated activity in the surveyed districts. Similar under-representation of female farmers in yam production have been reported in Ghana [20,21]. Male dominance in yam farming may reflect traditional gender roles and cultural norms, affecting access to resources, decision-making, and training [22,23]. Women and men from the same community perceive pests and diseases in different ways [24]. Women possess different knowledge levels about pests and diseases, and are differently involved in their management practices. Therefore, under-representation of female farmers, who face limited access to land, credit, and inputs (such as farm labor), hinders effective yam nematode management and yield improvement. Additionally, women farm to support their household therefore gender inclusive agricultural programs and a better representation of them in decision-making is crucial in gaining a new perspective in the management of yam nematodes [25].

Table 2. Socio-demographic characteristics of interviewed yam farmers.

Variables	Frequency	Percentage
Sex		
Male	135	90.00
Female	15	10.00
Age (years)		
≤20	1	0.67
21–30	23	15.33
31–40	42	28.00
41–50	40	26.67
>50	44	29.33
Education		
None	47	31.33
Primary	32	21.33
Middle school	45	30.00
Secondary	21	14.00
Tertiary	5	3.33

Most of the farmers (84%) were between the ages of 31 and over 50 years. The largest age group were farmers over 50 years old, comprising 29.33% of the total. Farmers aged 31–40 were 28%, while those aged 41–50 accounted for 26.67%. Young farmers under 20 were the least represented at 0.67%, and those aged 21–30 constituted 15.33%. The predominance of farmers in the 31–50 age range suggests a wealth of experience and stability within this demography. These farmers likely possessed substantial practical knowledge of yam cultivation and nematode management practices. However, the high percentage of farmers over 50 years indicated an aging workforce approaching retirement age, which could present challenges for the long-term sustainability of yam farming [26]. Older yam farmers may be reluctant to adopt new technologies and innovations in the control and management of yam nematodes. The relatively low representation of younger farmers (under 30 years) is a cause for concern. This trend could be due to younger individuals migrating to urban areas in search of more lucrative employment opportunities or perceiving agriculture as less attractive compared to other careers [27]. The generational gap observed in our data indicates a shortage of skilled farmers in the future, potentially affecting the continuity of and innovation in yam farming practices.

A significant portion of the sampled farmers, 31.33%, had no formal education, and 21.33% had only primary education (Table 1). Middle school education was the second most common level, accounting for 30% of the farmers. A smaller percentage of farmers had completed secondary education (14%), and an even smaller proportion had attained tertiary education (3.33%). The high percentage of farmers with little to no formal education suggested that many yam farmers may lack access to advanced agricultural knowledge and modern farming techniques. This lack of education can hinder their ability to effectively manage nematode infestations on their farms, and implement innovative agricultural practices that could improve yield and sustainability. This underscores the fact that there is a need for regular training of farmers on good agricultural practices including identification and management strategies for pests and diseases, irrespective of their level of education.

The data showed that the most common farm size across interviewed yam farmers consistently ranged between 0.4 and 1.6 hectares (Figure 2), while there was an increase in the number of farmers with more than 3 hectares of farmlands from 2019 to 2022, suggesting possible expansion or reallocation of farm sizes. For example, the pooled percentage in the 0–0.4 hectares category decreases from 21.33% in 2019 to 16.67% in 2022. Meanwhile, the proportion of farms in the largest category (>3.2 hectares) grows from 16% to 21%, suggesting an increasing number of larger farms over time.

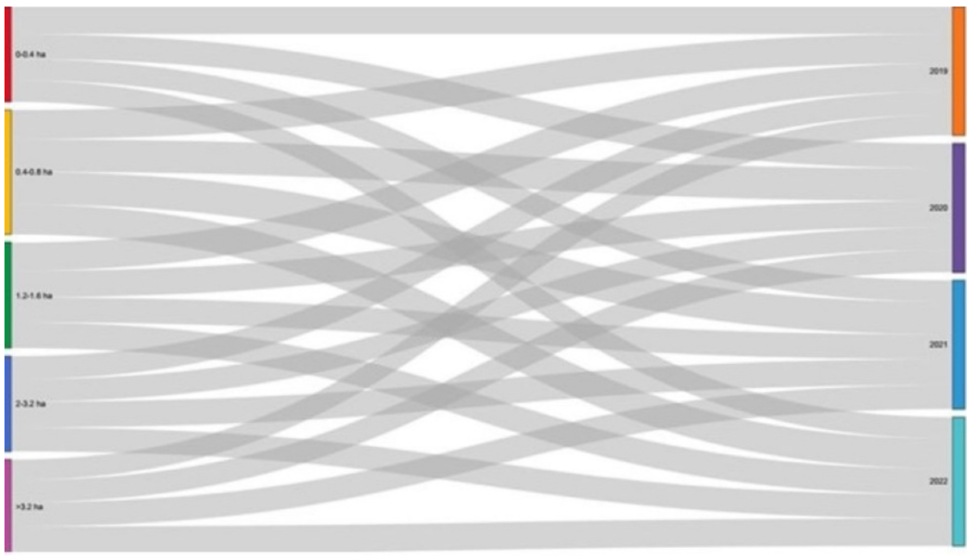


Figure 2. Land distribution of yam farmers (n = 150) by farm size from 2019 to 2022 (percentage).

We further disaggregated the data according to the sex of the respondent and the results are presented in Table 3. The gender disparities regarding the farm size reveal several key insights and trends. We observed that a significant proportion of female producers are concentrated in the smallest farm size category (0–0.4 hectares). For instance, in 2022, 53.33% of the female producers operated within this range, compared to only 12.59% of male producers. Male producers are more likely to operate larger farms, with increasing representation in the >3.2 hectares category. By 2022, 23.7% of the male producers managed farms in this largest category, whereas the female producers were not represented. This phenomenon underscores gender-based challenges and may reflect constraints or barriers to accessing more land among female yam producers. Land ownership is an important characteristic for the application of disease management practices, and this is more critical for women as their ownership of farmlands in most parts of Ghana is limited [15].

Table 3. Farm size distribution by gender (percentages) from 2019 to 2022.

Farm Size (Hectares)	2019		2020		2021		2022	
	Male (n = 135)	Female (n = 15)	Male (n = 135)	Female (n = 15)	Male (n = 135)	Female (n = 15)	Male (n = 135)	Female (n = 15)
0–0.4	17.78	53.33	16.30	46.67	13.33	46.67	12.59	53.33
0.4–0.8	22.22	26.67	23.70	40.00	24.44	33.33	22.96	26.67
1.2–1.6	23.70	6.67	22.96		21.48		21.48	6.67
2–3.2	18.52	13.33	17.78	13.33	20.00	20.00	19.26	13.33
>3.2	17.78		19.26		20.74		23.70	

Farmers within the studied districts showed three main ways of generating their planting materials, which showed that the primary source of planting material was from farmers' own farms (around 65–69% each year), market sources (about 28%), and family members (about 10%) (Figure 3). There was a slight increase in reliance on market sources from 23% in 2020 to 27% in 2022, possibly indicating the availability of better planting materials like yam mini-setts in the market.

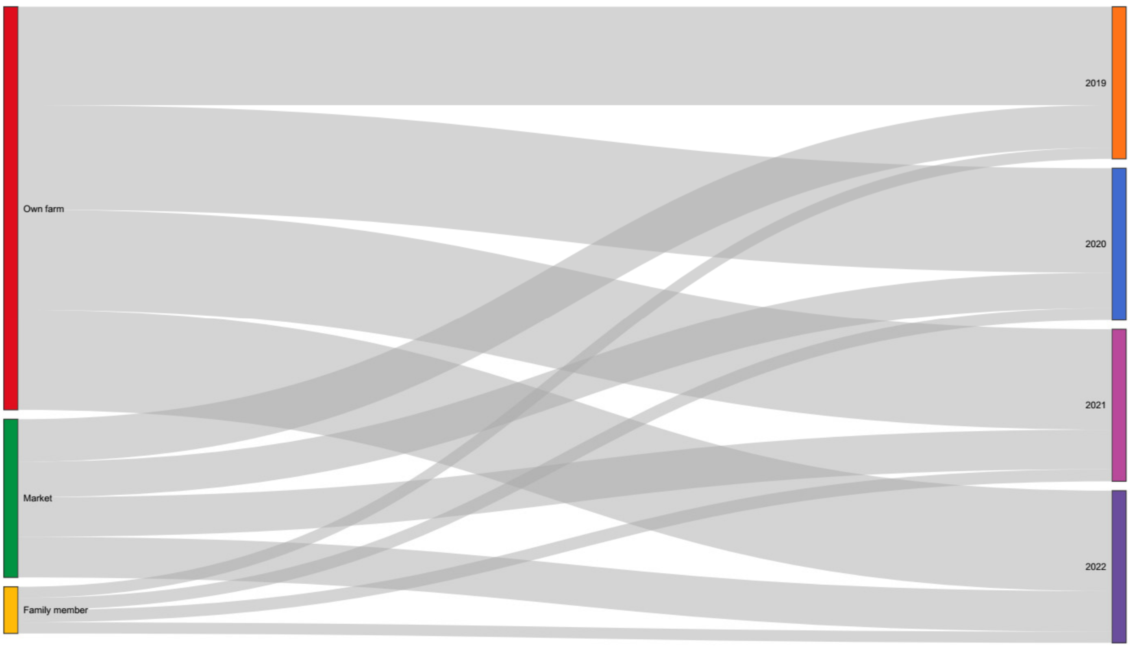


Figure 3. Farmers' source of planting material from 2019 to 2022 (percentage).

3.2. Yam Farmers' Experience and Intensity of Land Use

From the respondents' details, it was evident that a majority of the farmers (56%) had more than 15 years of experience in yam farming, indicating a high level of expertise and familiarity with the traditional farming practices. A significant portion of these farmers (20.67%) had 6–10 years of experience, while smaller percentages had 11–15 years (12%) and 1–5 years (11.33%) of experience. The predominance of farmers with more than 15 years of experience suggests that the agricultural sector in the surveyed districts relied heavily on experienced farmers who had likely honed their skills over decades. This extensive experience was a valuable asset, as these farmers possessed in-depth knowledge of local agricultural conditions, pest dynamics, and effective traditional farming practices [28]. In previous studies, it has been reported that the focus of yam production in Ghana has shifted significantly from food crop to cash crop, and the sale of yam tubers provided income for yam-based farming households [1,5].

About 34% and 26.67% of the farmers had cultivated their land for 4–6 years and more than 15 years, respectively. However, the smaller percentages (17.33%, 16.67%, and 5.33%) of these farmers reported that they had been cultivating their land for 1–3 years, 7–10 years, and 11–15 years, respectively (Table 4). The high percentage of farmers who had cultivated their land for >4 years suggested their stability and familiarity with the farming environment. This allowed farmers to understand the specific characteristics of their land such as soil type, fertility, and pest prevalence for better management practices. However, long-term land use for yam cultivation (>15 years) also can have both positive and negative implications. On the positive side, long-term cultivation can lead to a deep understanding of the land and its capabilities while prolonged cultivation without sustainable practices can lead to soil degradation, reduced fertility, and increased vulnerability to pests and diseases.

Table 4. Farming experience of interviewed yam farmers and land use intensity.

Variables	Frequency	Percentage
Farming experience (years)		
1–5	17	11.33
6–10	31	20.67
11–15	18	12.00
>15	84	56.00
Reason for yam cultivation		
Food	9	6.00
Income	141	94.00
Cultivation of other crops on land (years)		
1–3	26	17.33
4–6	51	34.00
7–10	25	16.67
11–15	8	5.33
>15	40	26.67
Period of yam cultivation (years)		
1–3	43	28.67
4–6	51	34.00
7–10	15	10.00
>10	41	27.33
Rotation of yam crops		
Yes	121	80.67
No	29	19.33
Period of crop rotation (years)		
None	29	19.33
1–2	100	66.67
3–5	18	12.00
>5	3	2.00
Land fallow practice		
Yes	113	75.33
No	37	24.67
Period of land fallow (years)		
None	33	22.00
1	53	35.33
2–4	48	32.00
5–10	16	10.67

Most farmers (80.67%) practiced crop rotation in their farms (Table 4) with different crops such as maize, cassava, cocoyam, okra, pepper, guinea corn, cowpea, plantain, millet and pigeon pea, which was a positive indication of sustainable agricultural practices. Among these farmers, the majority practiced crop rotation for 1–2 years (66.67%) while a smaller percentage practiced for longer durations (3–5 years at 12% or more than 5 years at 2%). Crop rotation is known to have several benefits, including breaking pest and disease cycles, improving soil fertility, and enhancing crop yields [29]. For yam farming, crop rotation helps to manage nematode populations, reduce incidence of soil-borne diseases, and improve overall soil health [30,31]. Longer rotations can provide more comprehensive benefits for soil health, allowing more time for soil recovery and nutrient replenishment, however this may be challenging for many farmers due to land availability and economic constraints.

Similarly, fallowing of farmland is a traditional practice that helps restore soil fertility, reduce pest and disease pressure, and improve overall soil structure [6]. The survey showed that most of the farmers (75.33%) had practiced land fallow in the past and it was for relatively short period (1–4 years), while a smaller percentage of farmers left their land fallow for longer durations (5–10 years) (Table 3). Bamire and Amujoyegbe [32] opined that, smallholder farmers embrace shorter fallow periods because of the population pressure on available arable land, economic constraints and the need for continuous land use.

3.3. Farmers' Perception and Knowledge of Yam Nematodes

Most farmers (97.99%) in the study areas experienced pests such as termites and diseases such as wet rot and root-knot nematodes that infected their yam crops (Table 4), although the majority of them (77.33%) did not know what nematodes were, while only 22.67% of farmers recognized nematodes as pests. In a previous study, Jamani et al. [33], reported that 83.00% of their sampled yam farmers in Ghana lacked knowledge on nematodes as pests. The low level of awareness about nematodes among farmers highlights a significant gap in knowledge that can hinder effective pest management. Therefore, it is critical that pest and disease management becomes a top priority for extension services, research, and policy interventions in yam production in Ghana, to prevent reduction in quantity and quality of yam outputs, and farmers' livelihoods.

The visual symptoms observed and identified by farmers were necrotic streaks or root lesions (93.33%), and internal rotting and discoloration of vegetative organs (96.67%) in their yam crops. These symptoms are characteristic of nematode infection, which may lead to substantial yield losses and reduced crop quality. In addition, several farmers noticed other symptoms such as dwarfing, stunting and resetting in their yam crops (Table 4). These conditions can be caused by a variety of factors, including nematode infection, soil nutrient deficiencies, water stress, and other diseases.

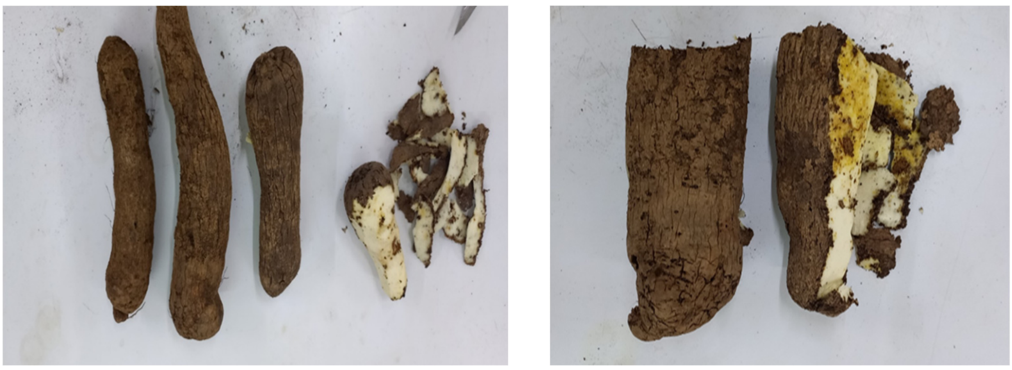
Edaphic factors were also considered in the studied yam farms that may enhance disease incidence on yams. Based on farmers' perceptions, a majority (65.33%) indicated loamy followed by sandy-clayey (19.33%) soil conditions that enhanced pest and disease incidence. However, other farmers indicated sandy (8%), clay (6%), and well-drained (1.33%) soil as contributing factors for pest and disease incidence (Table 4). Yam being a tuber crop, soil conditions play a very important role in growth and tuber formation of the crop, as well as prevalence of pests and diseases [34]. The soil structure has an impact on yam production; loamy soils were especially ideal for ease of harvesting, and the yams had less bruises with better tuber qualities [35]. A previous study reported the presence of nematodes in all types of soils with 38% in sandy soils and 4% in loamy soils [36].

A majority of farmers (90.67%) stored their yams in a yam barn within their farm, while a smaller percentage stored their yams in a pit at the farm (6%), or in a store at home

(3.33%) (Figure 4a,b). The predominant use of yam barns for storage reflects a traditional and widely adopted practice in postharvest handling of yam tubers. Yam barns were typically constructed to provide adequate ventilation and protection from environmental factors, which can help in reducing spoilage and extending the shelf life of yams [37]. This method also helps in maintaining the quality of yams by minimizing exposure to pests and diseases. Storing yams in pits, although less common, was another traditional method. Pits can provide a controlled environment for yams, protecting them from direct sunlight and maintaining a relatively stable temperature and humidity [38]. However, pits might pose risks such as increased vulnerability to pests and diseases if not managed properly. The maximum storage life of yams in the barns is about six months during which losses are reported as 10–15% in the first three months and more than 40% after six months [39]. In this study, the farmers reported storage losses to an extent of 63.33% (Table 4), characterized by hardened and dried tissues with discoloration (63.33%) and external cracks on the skin (60.67%) of their stored yam tubers (Figure 5a,b). The current result also showed that 62% and 58.67% of the farmers observed light yellow lesions below the outer skin and rotting of the outer 1–2 cm layer of their yam tubers, respectively. The results further showed that 56% of the farmers observed flaking off the tuber skin resulting in patches of dark brown color on yam tubers, while 60.67% farmers observed general decay of yam tubers, and 59.73% of the farmers observed weight loss in their stored yam tubers. All these are typical symptoms of pests and diseases during storage causing severe economic losses due to reduced marketable value and edible portions of the tubers [40,41].

(a) (b)

Figure 4. Yam storage facilities used by surveyed farmers, (**a**) storage in farms; (**b**) yam barn.



(a) (b)

Figure 5. Yam diseases during storage, (**a**) diseased yam showing cracks and dark brown patches beneath skin; (**b**) dry rot symptoms and yellowing beneath skin.

From the survey results, most farmers (90%) identified soil as the primary method of nematode spread, while 6% and 2.67% indicated infected tubers and heat, respectively, as the means of nematode spread on their yam farms (Table 5). Plant parasitic nematodes can persist in soil for extended periods and transfer to healthy plants [42]. This is coupled with the spread of nematodes through infected tubers used by farmers as planting materials. With increasingly intensified yam cropping systems in Ghana, it is important to identify and develop nematode management strategies including resistant cultivars and use of nematode-free planting materials [43].

Table 5. Farmers' perception and knowledge of nematode infestations in their farms.

Variables	Frequency	Percentage
Pests and diseases experience		
Yes	146	97.99
No	3	2.01
No answer	1	0.67
Knowledge of nematodes		
Yes	34	22.67
No	116	77.33
Necrotic streaks or root lesions		
Yes	140	93.33
No	10	6.67
Internal rotting and discoloration of vegetative organs		
Yes	145	96.67
No	5	3.33
Dwarfing of yam plant		
Yes	85	56.67
No	65	43.33
Stunting and resetting		
Yes	82	54.67
No	66	44.00
No answer	2	1.33
Soil condition during disease prevalence		
Well drained soil	2	1.33
Sandy clayey	29	19.33
Sandy soil	12	8.00
Loamy soil	98	65.33
Clayey soil	9	6.00
Yam storage after harvest		
In a pit at the farm	9	6.00
Yam barn at the farm	136	90.67
In a store at home	5	3.33
Storage losses due to pests and diseases		
Yes	95	63.33
No	55	36.67
Hardened dried tissues		
Yes	95	63.33
No	55	36.67
External cracks on skin of tubers		
Yes	91	60.67
No	59	39.33
Significant weight loss in tubers		
Yes	89	59.73
No	60	40.27
No answer	1	0.67

Table 5. *Cont.*

Variables	Frequency	Percentage
Light yellow lesions below the outer skin of tuber		
Yes	93	62.00
No	57	38.00
Rotting of the outer 1–2 cm layer		
Yes	88	58.67
No	62	41.33
Flaking off of external coverings		
Yes	83	55.33
No	66	44.00
No answer	1	0.67
General decay of tubers		
Yes	91	60.67
No	59	39.33
Method of nematode spread		
Infected tubers	9	6.00
Soil	135	90.00
Heat	4	2.67
Prolonged drought	1	0.67
Heavy rainfall	1	0.67

3.4. Yam Farmers' Knowledge in Control and Management of Nematode Infestation

The survey results showed that 72% of the interviewed farmers were unable to manage or control nematode infestations effectively, with 71% of these farmers indicating that their inability to control nematode infestations because they lacked the know-how, while a very small percentage (1.33%) provided no specific reason (Table 6). These results suggest that there is a knowledge gap among the farmers about nematode diseases and effective nematode management, thus underscoring the need for comprehensive training and educational programs tailored to the needs of yam farmers [13]. For 26% of the farmers managing these infestations, crop rotation and land rotation were the most commonly used practices, followed by the use of nematicides and fertilizers. Crop rotation helps break the life cycle of nematodes by alternating with non-host crops, thereby reducing nematode populations in the soil [44]. Land rotation, which involves changing the location of yam cultivation periodically, also disrupts nematode life cycles and reduces soil infestation levels. The relatively low use of nematicides (2.67%) and fertilizers (2%) among interviewed farmers indicated that although use of chemicals and soil nutrient management can play a role in nematode control, they relied more on rotational practices (Table 5). Claudius-Cole [13], reported that application of nematicides and fertilizers is not a common practice by yam farmers in West Africa.

We further examined the relationship between the socio-economic factors and type of storage with the farmers' management of nematodes (Table 7). Our results suggest that there is a relationship between the farmer's method of storage and the management of nematodes and, thus, some of these storage practices may also be effective in controlling nematodes. For instance, farmers who store their yams in a barn have a higher likelihood of controlling nematodes than other growers do. Interestingly, the prevalence of pests in the field is independent of nematode control. Some of these findings may have arisen from the lack of an association between the field pest management practices and measures adopted for controlling pests in storage. The disconnection can be attributed to the fact that field pest management practices have not been associated with pest control implemented on stored products. Smallholders could perceive pest and disease management in the field as a separate entity from storage pests. Because of this, the measures of control used in the field may differ from those used when managing nematodes after harvest.

Nematode management is also constrained by the fact that many smallholders do not have the means or knowledge to properly control and prevent nematode infections in storage. Though farmers may use some treatments to control the easily observable pests, storage-related pests may not receive attention, or are harder to control because of costs and inadequate training. Farmers do not factor in the same conditions used in the field for pest management as those used in storage, where nematodes require different and usually more selective treatments. The lack of an association could be an indication that pest management and nematode management in storage are separate activities and underlines the importance of providing tailored postharvest training for smallholder farmers in efectively managing nematodes.

Table 6. Control and management of nematode infestation.

Variables	Frequency	Percent
Able to manage or control nematode infestation		
No	108	72.00
Yes	42	28.00
Reason for not being able control nematode infestation		
No reason	2	1.33
I do not know how to control them	106	70.67
Controlled	42	28.00
Management practices used on yam farm?		
Crop rotation		
Yes	40	26.67
No	110	73.33
Nematicides		
Yes		2.67
No	146	97.33
Land rotation		
Yes	39	26.00
No	111	74.00
Use of organic or inorganic fertilizer		
Yes	3	2.00
No	147	98.00

Table 7. Association between nematode infection control and socio-economic variables.

Variable	Management of Nematode Infection (Frequency, %)		χ2/Fisher's Exact Test
	Yes	**No**	
Yam storage after harvest			
In a pit at the farm	0 (0.00)	9 (8.33)	0.056 *
Yam barn at the farm	42 (100)	94 (87.04)	
In a store at home	0 (0.00)	5 (4.63)	
Pest and disease occurrence			
Yes	41 (97.62)	105 (98.13)	1.00
No	1 (2.38)	2 (1.87)	
Knowledge of nematode			
Yes	13 (30.95)	21 (19.44)	0.136
No	29 (69.05)	87 (80.56)	
Education			
No education	11 (26.19)	21 (19.44)	0.247
Formal education	31 (73.81)	87 (80.56)	

Table 7. *Cont.*

Variable	**Management of Nematode Infection (Frequency, %)**		**χ2/Fisher's Exact Test**
	Yes	**No**	
Years in yam farming			
1–5 years	5 (11.90)	12 (11.11)	
6–10 years	8 (19.05)	23 (21.30)	0.685
11–15	3 (7.14)	15(13.89)	
>15 years	26 (61.90)	58 (53.70)	

Note: *: Significance at $p = 0.001$.

3.5. Loss of Yam Tubers in Storage Due to Nematode Infection

The trend in the percentage loss of yam tubers due to nematode infection from 2019 to 2022 is presented in Figure 6. The trend indicated that a significant portion of farmers consistently experienced losses each year, with some variation possibly due to changing environmental conditions or management practices. However, it is evident that nematode infestations have been becoming more severe every year, leading to higher losses over time. Increased losses directly translate to reduced yields, lower incomes, and heightened food insecurity, signifying an urgent need for research to develop nematode-resistant yam varieties and effective pest management strategies to curb the spread of nematodes and protect yam crop in Ghana. More so, it is critical to carry out targeted interventions, such as farmer education through extension and other advisory services and support for sustainable agricultural practices as an immediate action to mitigate the impact of nematodes on yam production, enhance yield stability, and improve the livelihoods of yam farmers in the country.

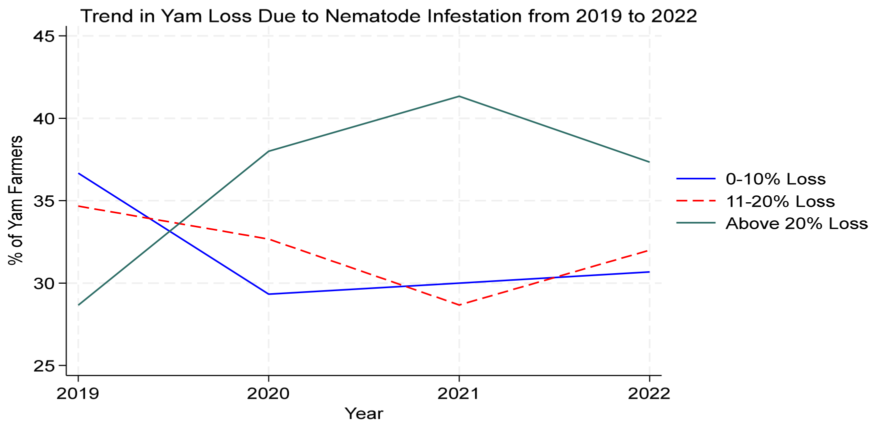


Figure 6. Loss of yam tubers experienced by interviewed farmers due to nematode infection.

3.6. Plant Parasitic Nematode Genera Associated with Soils and Yam Tubers

Twelve (12) genera of plant parasitic nematodes were associated with soils of yam rhizosphere across all seven districts (Table 8). The districts Dotobaa, Buya, Sabari and Jaman South represented nine (9) genera while Gbefi, Grubi and Botokrom had eight nematode genera. The twelve nematode genera belonged to the orders *viz* Rabditida (10) and Dorylaimida (2). Four (4) nematode genera namely *Scutellonema* spp., *Helicotylenchus* spp., *Tylenchus* spp. and *Longidorus* spp. occurred in all seven (7) yam farming districts while *Meloidogyne* spp. occurred in six (6); Gbefi, Grubi, Buya, Sabari, Botokrom and Jaman South. *Pratylenchus* spp. also occurred in Dotobaa, Gbefi, Grubi, Buya, Sabari and Jaman South. Again, *Paratylenchus* spp. occurred in Dotobaa, Gbefi, Grubi, Sabari, Botokrom and Jaman South. *Aphelenchus* spp. also occurred in five (5) districts namely Dotobaa, Gbefi, Buya, Sabari and Botokrom. Similarly, *Xiphinema* spp. occurred in Buya, Sabari, Botokrom and Jaman South. *Heterodera* occurred in Dotobaa, Buya and Jaman South. *Mesocriconema* spp. occurred in Dotobaa and Buya while *Ditylenchus* spp. occurred in Gbefi and Grubi. *Scutellonema bradys* populations per 200 cc soil ranged from 2 to 47 for Dotobaa and Buya, respectively. *Tylenchus* spp. ranged from 19 to 248 for Dotobaa and Grubi, respectively. Sabari had the largest number of nematodes (661) per 200 cc of soil, while Dotobaa had the lowest (192).

Table 8. Plant parasitic nematode genera in soil (200 cc) of seven yam-growing areas in Ghana.

Community	Scu	Mel	Hel	Pra	Mes	Tyl	Het	Lon	Ape	Par	Dit	Xip	Total
Dotobaa	2	0	57	28	10	19	25	35	14	2	0	0	192
Gbefi	23	85	1	27	0	145	0	25	11	6	2	0	325
Grubi	44	141	99	13	0	248	0	45	0	10	2	0	602
Buya	47	146	66	9	1	183	10	75	7	0	0	10	554
Sabari	7	126	85	7	0	231	0	49	2	2	0	102	611
Botokrom	5	60	28	0	0	64	0	20	1	29	0	22	229
Jaman South	4	103	18	4	0	99	1	22	0	19	0	13	283
Total	132	661	354	88	11	989	36	271	35	68	4	147	2796

Scu—*Scutellonema bradys*, Mel—*Meloidogyne* spp., Hel—*Helocitylenchus* spp., Pra—*Pratylenchus* spp., Mes—*Mesocriconema* spp., Tyl—*Tylenchus* spp., Het—*Heterodera* spp., Lon—*Longidorus* spp., Ape—*Apelenchus* spp., Par—*Paratylenchus* spp., Dit.—*Ditylenchus* spp., Xip—*Xiphinema* spp.

Among all identified genera, *Tylenchus* spp. were the most abundant (35.5%) followed by *Meloidogyne* spp. (23.7%) and *Helicotylenchus* spp. (12.7%) (Table 9). *Scutellonema bradys*, the most commonly observed nematode in West Africa, only constituted 4.7% of the total population in soil samples. *Mesocriconema* spp. and *Ditylenchus* spp. had the least representation in the soils of studied districts with 0.4% and 0.1%, respectively. The nematode genera identified in the current study coincides with those reported [45–49].

Table 9. Abundance of various plant parasitic nematodes in soils of yam rhizosphere from 35 farms across seven districts.

Nematode Genera	Order	Population/200CC Soil	Frequency of Occurrence	% Frequency Rating *	Relative Abundance (%) **
Scutellonema bradys	Rabditida	132	19	54	4.7
Meloidogyne spp.	Rabditida	661	30	86	23.7
Helicotylenchus spp.	Rabditida	353	29	83	12.7
Pratylenchus spp.	Rabditida	88	20	57	3.2
Mesocriconema spp.	Rabditida	11	4	11	0.4
Tylenchus spp.	Rabditida	989	35	100	35.5
Heterodera spp.	Rabditida	36	5	14	1.3
Paratylenchus spp.	Rabditida	68	18	51	2.4
Aphelenchus spp.	Rabditida	35	8	23	1.3
Ditylenchus spp.	Rabditida	4	3	9	0.1
Longidorus spp.	Dorylaimida	271	34	97	9.7
Xiphinema spp.	Dorylaimida	137	14	40	4.9

* n/NX100 (n = frequency of individual nematode occurrence. *n* = sample size (35) ** In/TN (In individual genera in all samples, TN = Total Nematode population in all genera).

Similarly, thirteen (13) genera were found in yam peels across seven districts (Table 10). Yams from Sabari (6533) had the highest population per 50 g of yam peel followed by Buya (4931) and Gbefi (3387). Botokrom (515) had the least number of nematodes per 50 g of yam peels. Dotobaa had the highest number of genera (11) present with Gbefi and Jaman South having eight (8) each. Sabari had six (6) genera, followed by Grubi and Buya with five (5) each and Botokrom had the least with four (4) genera. *Scutellonema* spp. and *Meloidogyne* spp. were found in yam peels from all seven (7) districts. *Heterodera* spp., *Helicotylenchus* spp., *Mesocriconema* spp. and *Ditylenchus* spp. occurred only in Dotobaa with *Hoplolaimus* spp. occurring in Jaman South.

Table 10. Plant parasitic nematode genera in yam peels (50 g) of seven yam-growing areas in Ghana.

Community	*Scu*	*Mel*	*Pra*	*Het*	*Hel*	*Tyl*	*Ape*	*Mes*	*Lon*	*Dit*	*Par*	*Xip*	*Hop*	Total
Dotobaa	347	129	39	16	7	72	37	2	6	43	2	0	0	700
Gbefi	3290	43	8	0	0	4	33	0	4	0	3	2	0	3387
Grubi	2556	224	0	0	0	3	117	0	0	0	27	0	0	2927
Buya	4840	41	10	0	0	7	33	0	0	0	0	0	0	4931
Sabari	6299	117	5	0	0	0	78	0	0	0	11	23	0	6533
Botokrom	374	138	2	0	0	1	0	0	0	0	0	0	0	515
Jaman South	600	104	0	0	0	15	2	0	1	0	16	1	1	740
Total	18,306	796	64	16	7	102	300	2	11	43	59	26	1	19,733

Scu—*Scutellonema bradys*, Mel—*Meloidogyne* spp., Pra—*Pratylenchus* spp., Het—*Heterodera* spp., Tyl—*Tylenchus* spp., Ape—*Apelenchus* spp., Mes—*Mesocriconema* spp., Lon—*Longidorus* spp., Hel—*Helocitylenchus* spp., Dit.—*Ditylenchus* spp., Par—*Paratylenchus* spp., Xip—*Xiphinema* spp., Hop—*Hoplolaimus* spp.

Scutellonema spp. was the most abundant (92.8%) among all genera of nematodes extracted from all farms with the second highest being *Meloidogyne* spp. (4.0%) (Table 11). *Heterodera* spp., *Longidorus* spp. and *Xiphinema* spp. made up 0.1% of the entire population. *Helicotylenchus* spp. and *Hoplolaimus* spp. were the least abundant. In a previous study conducted in Ghana the three most prevalent nematodes with high relative abundances from yam peels were *Pratylenchus* spp. (32.4%), *Scutellonema bradys* (18.2%) and *Meloidogyne* spp. (21.3%) [32].

Table 11. Abundance of various plant parasitic nematodes in yam peels (50 g) from 35 farms.

Nematode Genera	Order	Population/50 g Yam Peel	Frequency of Occurrence	% Frequency Rating *	Relative Abundance (%) **
Scutellonema bradys	Rabditida	18,306	35	100	92.8
Meloidogyne spp.	Rabditida	796	33	94	4.0
Pratylenchus spp.	Rabditida	64	12	34	0.3
Heterodera spp.	Rabditida	16	2	6	0.1
Helicotylenchus spp.	Rabditida	7	4	11	0.0
Tylenchus spp.	Rabditida	102	18	51	0.5
Aphelenchus spp.	Rabditida	300	26	74	1.5
Mesocriconema spp.	Rabditida	2	1	3	0.0
Ditylenchus spp.	Rabditida	43	4	11	0.2
Paratylenchus spp.	Rabditida	59	15	43	0.3
Hoplolaimus spp.	Rabditida	1	1	3	0.0
Longidorus spp.	Dorylaimida	11	5	14	0.1
Xiphinema spp.	Dorylaimida	26	5	14	0.1

* n/NX100 (n = frequency of individual nematode occurrence. *n* = sample size (35) ** In/TN (In individual genera in all samples, TN = Total Nematode population in all genera).

4. Conclusions and Implications

In summary, most of the interviewed yam farmers were male, relatively old, experienced in yam farming, but with limited years of formal education. The majority of them were smallholder farmers with 1–2 acres of land, although the percentage of medium-scale farmers are gradually increasing. The majority of the farmers practiced land fallowing, with only a few fallowing their farmland beyond 5 years. Plant parasitic nematodes have been identified in all the targeted districts, which may be the reason for substantial yield losses. There is an urgent need for the farmers to gain knowledge on the identification of nematode infestation in their farms, related symptoms in yam tubers, and effective nematode management practices. Furthermore, the study found a heavy reliance of farmers on self-sourced planting materials, which may be one of the reasons for the spread of nematodes. Our results also showed a relationship between farmer storage practices and the management of nematodes, suggesting some storage practices such as barns may also be effective in controlling nematodes. On the other hand, we found no association between pest occurrence in the field and nematode management. The lack of an association could be an indication that pest management and nematode management in storage are separate activities and underlines the importance of providing tailored postharvest training for smallholder farmers in effectively managing nematodes.

Our study findings did not incorporate robust econometrics models to examine the drivers of storage practices and the linkage of socio-economic and social factors due to a smaller sample size and less variability in some outcome variables. Hence, future studies should empirically examine the causality of the conditioning factors for storage practices and the awareness of nematodes using a large sample size to provide external validity.

Addressing these challenges requires a multifaceted approach that includes enhancing extension services, improving access to certified planting materials, promoting sustainable agricultural practices, and supporting research and development to breed improved nematode-resistant and high-yielding yam varieties. Additionally, developing market infrastructure, providing financial services, and strengthening farmer cooperatives can significantly improve the economic viability of yam farming in Ghana.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su17020482/s1, Supplementary S1: Structured questionnaire.

Author Contributions: B.O.W. collected data, reviewed literature, and drafted the manuscript; G.M.Y. performed data analysis and reviewed the manuscript; S.T.N. designed the research, overall supervision and revised the manuscript; C.F.B., D.A. and D.D. revised the manuscript; R.B. participated in data validation; reviewed literature, reviewed the manuscript and supervision. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was approved by the Ethics Committee of University of Ghana (ECBAS 071/22-23; 25 August 2024) for studies involving nematodes.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data generated in this study has been included in the manuscript as Tables and Figures.

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References

1. Nweke, F.; Aidoo, R.; Okoye, B. Yam consumption patterns in West Africa. *Gates Open Res.* **2019**, *3*, 637.
2. Ghana Export Promotion Authority (GEPA). Analysis of 2021 Non-Traditional Exports Statistics. 2022. Available online: https://www.gepaghana.org/export-statistic/nte-annual-report-2021-full/ (accessed on 17 October 2024).

3. Wu, Z.G.; Jiang, W.; Nitin, M.; Bao, X.Q.; Chen, S.L.; Tao, Z.M. Characterizing diversity based on nutritional and bioactive compositions of yam germplasm (*Dioscorea* spp.) commonly cultivated in China. *J. Food Drugs Anal.* **2016**, *24*, 367–375. [CrossRef]
4. Mignouna, D.B.; Abdoulaye, T.; Alene, A.; Akinola, A.A.; Maroya, N. *Baseline Protocols: The Case of Yam Improvement for Income and Food Security in West Africa (YIIFSWA) Project*; YIIFSWA working paper series, No. 4; SIDALC: Turrialba, Costa Rica, 2014.
5. Owusu Danquah, E.; Danquah, F.O.; Frimpong, F.; Dankwa, K.O.; Weebadde, C.K.; Ennin, S.A.; Opoku, A.Y. Sustainable intensification and climate-smart yam production for improved food security in West Africa: A review. *Front. Agron.* **2022**, *4*, 858114. [CrossRef]
6. Carsky, R.J.; Asiedu, R.; Cornet, D. Review of soil fertility management for yam-based systems in West Africa. *Afr. J. Root Tuber Crops* **2010**, *8*, 1–17.
7. Kolombia, Y.A.; Fabiyi, O.A. Nematode problems in tuber crops and their sustainable management. In *Nematode Diseases of Crops and Their Sustainable Management*; Academic Press: New York, NY, USA, 2023; pp. 251–278.
8. Nzeako, S.O.; Barisuka, G.A.; Torle, M.E.; Imafidor, H.O.; Eze, C.N. Plant parasitic nematodes status of seed yams in Khana LGA, Rivers State, Nigeria. *Int. J. Sci. Res. Environ. Sci.* **2015**, *3*, 266.
9. Coyne, D.L.; Tchabi, A.; Baimey, H.; Labuschagne, N.; Rotifa, I. Distribution and prevalence of nematodes (*Scutellonema bradys* and *Meloidogyne* spp.) on marketed yam (*Dioscorea* spp.) in West Africa. *Field Crops Res.* **2006**, *96*, 142–150. [CrossRef]
10. Mignouna, B.D.; Kumar, P.L.; Coyne, D.; Bandyopadhyay, R.; Ortega-Beltran, A.; Bhattacharjee, R.; De Koeyer, D. Identifying and managing plant health risks for key African crops: Yam, taro and cocoyam. In *Critical Issues in Plant Health*; Burleigh Dodds Science Publishing: Chambridge, UK, 2019; pp. 213–228.
11. Green, K.R.; Florini, D.A. Pests and pathogens of yams in storage. *Workshop Rep. Afr. J. Root Tuber Crops* **1996**, *1*, 38–42.
12. Ntui, V.O.; Uyoh, E.A.; Ita, E.E.; Markson, A.A.A.; Tripathi, J.N.; Okon, N.I.; Tripathi, L. Strategies to combat the problem of yam anthracnose disease: Status and prospects. *Mol. Plant Pathol.* **2021**, *22*, 1302–1314. [CrossRef] [PubMed]
13. Claudius-Cole, A. Importance and integrated nematode management of the yam nematode (*Scutellonema bradys*) in yam cropping systems of West Africa. In *Integrated Nematode Management: State-of-the-Art and Visions for the Future*; CAB International: Wallingford, UK, 2022; pp. 374–380.
14. Ackah, D.; Agboyi, M.R.; Gyamfi, L.A. An investigation of yam ingestion customs in Ghanaian urban communities, Ghana. *Int. J. Sci. Basic Appl. Res.* **2014**, *17*, 411.
15. Acheampong, P.P.; Owusu Danquah, E.; Dissanayake, H.G.; Hayford, P.; Weebadde, C. A socioeconomic study of transition zone yam farmers addressing constraints and exploring opportunities for integrating pigeonpea into yam cropping systems. *Sustainability* **2019**, *11*, 717. [CrossRef]
16. Palinkas, L.A.; Horwitz, S.M.; Green, C.A.; Wisdom, J.P.; Duan, N.; Hoagwood, K. Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Adm. Policy Ment. Health Ment. Health Serv. Res.* **2015**, *42*, 533–544. [CrossRef] [PubMed]
17. Jenkins, W.R. A rapid centrifugal flotation technique for separating nematodes from soil. *Plant Dis. Report.* **1964**, *48*, 692.
18. Whitehead, A.G.; Hemming, J.R. A comparison of some quantitative methods of extracting small vermiform nematodes from soil. *Ann. Appl. Biol.* **1965**, *55*, 25–38. [CrossRef]
19. Siddiqi, M.R. *Tylenchida Parasites of Plants and Insects*, 2nd ed.; CABI Publishing: Wallingford, UK, 2000.
20. Adam, H.; Zakaria, H.; Abujaja, A.M. Sociocultural implications on innovation adoption: The case of adoption of yam minisett technology among farmers in Northern Region. *J. Agric. Ext. Rural Dev.* **2014**, *1*, 105–113.
21. Zakaria, H.; Salifu, W.Y.; Abujaja, A.M.; Adam, H. Socioeconomics analysis of smallholder yam production in north eastern corridors of northern Ghana: Does type of planting material used makes any difference. *Int. J. Agric. Innov. Res.* **2014**, *3*, 1043–1051.
22. Mignouna, D.B.; Abdoulaye, T.; Akinola, A.A.; Alene, A.; Nweke, F. Factors influencing the use of selected inputs in yam production in Nigeria and Ghana. *J. Agric. Rural Dev. Trop. Subtrop.* **2015**, *116*, 131–142.
23. Obidiegwu, J.E.; Akpabio, E.M. The geography of yam cultivation in southern Nigeria: Exploring its social meanings and cultural functions. *J. Ethnic Foods* **2017**, *4*, 28–35. [CrossRef]
24. Kawarazuka, N.; Damtew, E.; Mayanja, S.; Okonya, J.S.; Rietveld, A.; Slavchevska, V.; Teeken, B. A gender perspective on pest and disease management from the cases of roots, tubers and bananas in Asia and sub-Saharan Africa. *Front. Agron.* **2020**, *2*, 7. [CrossRef]
25. Kerubo Rogena, B. Analysis of coping mechanisms by emancipated women to combat household food security in Kalagala sub-County of Luweero, Uganda. *Am. Based Res. J.* **2017**, *6*, 12.
26. Ufondu, H.E.; Maziya-Dixon, B.; Okonkwo, T.M. Yam production in some South East and North Central zones of Nigeria beyond COVID-19 for acceleration towards inclusive sustainable development. *Agro-Science* **2021**, *20*, 1–7. [CrossRef]
27. Leavy, J.; Hossain, N. Who wants to farm? Youth aspirations, opportunities and rising food prices. *IDS Work. Pap.* **2014**, *439*, 1–44. [CrossRef]

28. Midega, C.A.; Murage, A.W.; Pittchar, J.O.; Khan, Z.R. Managing storage pests of maize: Farmers' knowledge, perceptions and practices in western Kenya. *Crop Prot.* **2016**, *90*, 142–149. [CrossRef]
29. Reddy, P.P. Crop Rotation. In *Agro-Ecological Approaches to Pest Management for Sustainable Agriculture*; Springer: Singapore, 2017. [CrossRef]
30. Claudius-Cole, A.O.; Fawole, B.; Asiedu, R. Population changes of plant-parasitic nematodes associated with cover crops following a yam (*Dioscorea rotundata*) crop. *Trop. Plant Pathol.* **2015**, *40*, 193–199. [CrossRef]
31. Uyoh, E.A.; Ita, E.E.; Ntui, V.O. Strategies for the production of disease-free yam planting materials: Implications for improved yam production in Nigeria. In *Agricultural Biotechnology, Biodiversity and Bioresources Conservation and Utilization*; CRC Press: Boca Raton, FL, USA, 2022; pp. 101–126.
32. Bamire, A.S.; Amujoyegbe, B.J. Economic analysis of land improvement techniques in smallholder yam-based production systems in the agro-ecological zones of Southwestern Nigeria. *J. Hum. Ecol.* **2005**, *18*, 1–12. [CrossRef]
33. Jamani, Y.; Nyaku, S.T.; Lutuf, H.; Cornelius, E. Plant-parasitic nematodes associated with yam in the two agro-ecological zones of Ghana. *Niger. J. Nematol.* **2016**, *3*, 1–12.
34. Neina, D. Ecological and edaphic drivers of yam production in West Africa. *Appl. Environ. Soil Sci.* **2021**, *1*, 5019481. [CrossRef]
35. Wumbei, A.; Gautier, S.K.N.; Kwodaga, J.K.; Joseph, D.F.; Galani, Y.J.H. *State of the Art of Yam Production*; CCCU Research Space Repository: Canterbury, UK, 2022.
36. Enchill, A.; Nyaku, S.T.; Osabutey, S.; Lutuf, H.; Cornelius, E. Prevalence of yam nematodes in diverse soil communities, and their morphometrics in the Krachi-Nchumuru District of Ghana. *Afr. Crop Sci. J.* **2023**, *31*, 319–336. [CrossRef]
37. Amponsah, S.K.; Akowuah, J.O.; Adu-Kwarteng, E.; Bessah, E. Design and construction of improved yam storage structure using locally-available materials. *Int. J. Res.* **2015**, *1*, 1–11.
38. Nwakonobi, T.U.; Obetta, S.E.; Iorwtsav, H. Evaluation of ventilated underground pit structures for yam (Dioscorea spp.) storage. *Res. J. Appl. Sci. Eng. Technol.* **2012**, *4*, 393–397.
39. Nwaigwe, K.N.; Okafor, V.C.; Asonye, G.U.; Nwokocha, J.C. Analysis of tuber storage techniques in Africa: A review. In Proceedings of the 2015 ASABE Annual International Meeting, Detroit, MI, USA, 29 July–1 August 2015; American Society of Agricultural and Biological Engineers: St. Joseph, MI, USA, 2015; p. 1.
40. Amusa, N.A.; Adigbite, A.A.; Muhammed, S.; Baiyewu, R.A. Yam diseases and its management in Nigeria. *Afr. J. Biotechnol.* **2003**, *2*, 497–502. [CrossRef]
41. Kwoseh, C.K.; Plowright, R.A.; Bridge, J.; Asiedu, R. Yam-based farm practices and nematode problems in stored yams *(Dioscorea* spp.) in Ghana. *J. Sci. Technol.* **2005**, *25*, 35–43. [CrossRef]
42. Obuezie, C.B.; Ikpeze, O.O. Parasitic Nematodes of maize in farms at Oba, Idemili south Local Government Area of Anambra state Nigeria. *J. Occup. Saf. Environ. Health* **2012**, *1*, 73–78.
43. Aighewi, B.A.; Asiedu, R.; Maroya, N.; Balogun, M. Improved propagation methods to raise the productivity of yam (*Dioscorea rotundata* Poir.). *Food Secur.* **2015**, *7*, 823–834. [CrossRef]
44. Kayode, O.; Claudius-Cole, A. Host efficiency of *Scutellonema bradys* in yam companion crops in Nigeria. *Int. J. Plant Soil Sci.* **2017**, *15*, 1–10. [CrossRef]
45. Adegbite, A.A.; Saka, J.O.; Agbaje, G.O.; Owolade, O.F.; Olaifa, G.O.; Lawal, A.; Ojo, S.T. Survey of plant-parasitic nematodes associated with yams in Edo, Ekiti and Oyo states of Nigeria. *Afr. J. Agric. Res.* **2006**, *1*, 125–130.
46. Adegbite, A.; Saka, J.; Agbaje, G.; Osuloye, F. Survey of plant-parasitic nematodes associated with yams in Ogun and Osun states of Nigeria. *J. Plant Prot. Res.* **2008**, *48*, 421–428. [CrossRef]
47. Adam, M.; Heuer, H.; Ramadan, E.M.; Hussein, M.A.; Hallmann, J. Occurrence of plant-parasitic nematodes in organic farming in Egypt. *Int. J. Nematol.* **2013**, *23*, 82–90.
48. Vincent, C.D.; Nwankwo, E.N.; Ogbonna, C.U.; Onyido, A.E.; Adewuyi, O. A survey of plant-parasitic nematodes of yam farms in Awka-North local government area, Anambra state, Nigeria. *J. Appl. Biosci.* **2015**, *95*, 8950–8957.
49. Kingsley, E. Investigation of Plant-parasitic nematodes of yam in selected yam farms in two local Government areas of Rivers State. *Trop. Agrobiodivers.* **2021**, *2*, 67–71. [CrossRef]