# RESEARCH/INVESTIGACIÓN

# DISTRIBUTION, PREVALENCE, AND SEVERITY OF DAMAGES CAUSED BY NEMATODES ON YAM (*DIOSCOREA ROTUNDATA*) IN NIGERIA

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## ABSTRACT

Kolombia, Y. A., P. L. Kumar, O. Adewuyi, S. Korie, N. Viaene, W. Bert, and D. L. Coyne. 2020. Distribution, prevalence and severity of damages caused by nematodes on yam (*Dioscorea rotundata*) in Nigeria. Nematropica 50:1-18.

Nigeria is the main yam-growing country of the world. In the country, various plant-parasitic nematodes have been reported constraining yam production and the storability of tubers. This study established the damage level of nematodes on white yam tubers (*Dioscorea rotundata*) across the major production areas in the country for management purposes. Incidence and severity of symptoms (cracking, dry rot, and galling) associated with nematodes were assessed on 1,114 yam heaps (181 vendors) from 23 markets and on 2,502 tubers from 26 farmer storage areas (yam barns) in the Humid Forest (HF), Derived Savanna (DS) and Southern Guinea Savanna (SGS) agro-ecological zones (AEZ). On yam heaps, the symptom incidence averaged 55%, 35%, and 6% for galls, dry rot, and for cracks, respectively. Only the incidence of dry rot was significantly different ($P$<0.0001) across the AEZ. On yam tubers, the incidence averaged 24%, 8%, and 2% for galls, dry rot, and for cracks, respectively. The incidence for galls was higher in the SGS than in the DS ($P$=0.0018) whereas the incidence of cracks was higher in the DS than in the SGS ($P$=0.0080). The actual values of symptom severity were, in general, low in the AEZ compared with the predicted values except for dry rot. A significant positive correlation was found between galls and *Meloidogyne* and between dry rot and *Scutellonema*. *Pratylenchus* was also recovered from a few yam tubers; however, no link with symptoms on yam tubers could be established. Vendors and farmers, based on the answers from a questionnaire, were very familiar with nematode symptoms on yam tubers, but awareness of nematodes was low. This study shows that *Meloidogyne* and *Scutellonema* are the major nematode constraints to yam production in the three AEZ of Nigeria and calls for effective yam nematode management in Nigeria and in other yam-producing countries.

*Key words:* Awareness, *Dioscorea*, *Meloidogyne*, nematodes, *Pratylenchus*, root-knot nematodes, *Scutellonema*, symptoms

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## RESUMEN

Kolombia, Y. A., P. L. Kumar, A. Omowumi, S. Korie, N. Viaene, W. Bert, y D. L. Coyne 2020. Distribución, prevalencia y severidad de los daños causados por nematodos en ñame (*Dioscorea rotundata*) en Nigeria. Nematropica 50-1-18.

Nigeria es el principal país productor de ñame del mundo. En el país, se ha informado que varios nematodos fitoparásitos restringen la producción de ñame y la capacidad de almacenamiento de los tubérculos. Esta investigación se realizó para establecer el nivel de daño de nematodos en tubérculos de ñame blanco (*Dioscorea rotundata*) en las principales áreas de producción de ñame en el país para un propósito de gestión adecuado. La incidencia y severidad de los síntomas (grietas, pudrición seca y agallas) fueron evaluados en 1,114 pilas de ñame de 181 vendedores en 23 mercados; y de las 26 áreas de almacenamiento de ñame de los agricultores, la evaluación se realizó mediante la observación de 2502 tubérculos en tres zonas agro-ecológicas (ZAE): el bosque húmedo (BH), la sabana derivada (SD) y la sabana guinea del sur (SGS). La incidencia en las pilas de ñame fue en promedio de 55%, 35% y 6% para agallas, pudrición seca y grietas, respectivamente. Solo hubo diferencia significativa en la incidencia de la pudrición seca ($P$ <0,0001) a lo largo de la ZAE. La incidencia de síntomas en los tubérculos en las áreas de almacenamiento fue de en promedio de 24%, 8% y 2% para agallas, pudrición seca y grietas, respectivamente. La incidencia de agallas fue significativamente alta en el SGS que en el DS ($P$ = 0.0018), mientras que la incidencia de grietas fue significativamente alta en el DS que en el SGS ($P$ = 0.0080). Los valores reales de la severidad de los fue en general baja en los tres ZAE en comparación con los valores predichos a excepción de la pudrición seca. Una correlación positiva significativa se encontró entre agallas y la densidad de *Meloidogyne* y entre la pudrición seca y la densidad *Scutellonema*. También se obtuvieron nematodos del género *Pratylenchus* en los tubérculos de ñame, sin embargo, no se pudo establecer una relación con los síntomas. Los vendedores y los agricultores, según las respuestas del cuestionario, estaban muy familiarizados con los síntomas de nematodos en los tubérculos de ñame, pero el conocimiento de nematodos fue escaso. Este estudio muestra claramente que los nematodos en el ñame plantean grandes limitaciones a la producción de ñame en las tres zonas agro-ecológicas de Nigeria. Esto requiere de un manejo efectivo de los nematodos del ñame en Nigeria y en otros países productores de ñame.


*Palabras clave*: Conocimiento, *Dioscorea*, *Meloidogyne*, nematodos, *Pratylenchus*, nematodos formadores de agallas, *Scutellonema*, síntomas

## INTRODUCTION

Yam (*Dioscorea* spp.) is an economically important staple food in West Africa grown for its tubers, which are a rich source of carbohydrates, proteins, minerals, and vitamins (Orkwor, 1998; Lebot, 2009). In addition, yam is of major socio-cultural importance and is the food of choice at many ceremonies and festivals (Orkwor, 1998; Nweke, 2016). Yam cultivation and sales serve as a major income-generating activity (Onwueme and Charles, 1994; Nweke, 2016). Globally, more yam is produced in West Africa than in any other region. Nigeria alone accounts for over 66% of the global production with over 68 million tons produced in 2016 (FAOSTAT, 2016), primarily of the white yam (*Dioscorea rotundata*). Other food yams, *viz.* the water yam (*D. alata*), the yellow yam (*D. cayenensis*), the bitter or trifoliate yam (*D. dumetorum*), and the aerial yam (*D. bulbifera*), are also grown but on a relatively smaller scale than white yam (Onwueme and Charles, 1994; Nweke, 2016). In Nigeria, yam is mainly grown in the Humid Forest (HF), the Derived Savanna (DS), and the Southern Guinea Savanna (SGS) (Dumont *et al.*, 2006).

Despite its importance, yam production suffers from numerous constraints, such as low soil fertility, low quality and high cost of planting material (Atiri *et al.*, 2003; Ayanwuyi *et al.*, 2011). Pests, such as weevils, termites, beetles, mealybugs, and aphids, as well as diseases caused by nematodes, viruses, bacteria and fungi, pose a serious problem to tuber production and storability

(Scott *et al.*, 2000; Bridge *et al.*, 2005).

Among the plant-parasitic nematodes that affect yam, the root-knot nematodes (RKN) (*Meloidogyne* spp.), the yam nematode (*Scutellonema bradys*), and the root-lesion nematodes (RLN) (*Pratylenchus* spp.) are the most important. The RKN cause galling and "crazy root" syndrome on tubers, distorting tubers and reducing quality. Infection with the yam nematode or RLN results in a dry rot disease. The dry rot and cracking of the tuber surface affects tuber production and quality (Bridge, 1972; Bridge *et al.*, 2005; Coyne *et al.*, 2006; Humphreys-Pereira *et al.*, 2014, 2017; Kolombia *et al.*, 2014, 2017). Nematode problems are reported on yam from all production areas in Nigeria and across West Africa (Unny and Jerath, 1965; Adesiyan and Odihirin, 1978; Nwauzor and Fawole, 1981; Coyne *et al.*, 2006). However, despite their economic importance, the information available on current nematode incidence, the severity of symptoms the nematodes cause, and nematode distribution in the main yam-growing areas of the country is limited or outdated. This information is needed to design an adequate nematode management program aimed at the reduction of yield losses, especially in light of the rapidly adapting and changing agricultural scene (intensification of land use, degradation of land and depletion of soil nutrients), increased of the population pressure and disruption of climate patterns (Akinola and Owombo, 2012; Mustapha *et al.*, 2012). The current study was undertaken to assess the prevalence of nematodes and the severity of damage caused on yam across the three principal yam growing agro-ecological zones (AEZ) of Nigeria, as well as growers' awareness of this problem.

## MATERIALS AND METHODS

### *Survey area and tuber sampling*

The survey was conducted in February 2013 at the peak of the yam-marketing period in Nigeria (Coyne *et al.*, 2006) in the yam production areas of the AEZ of DS, HF, and SGS. Sampling was conducted in Anambra state in the HF, Benue, Edo, Ekiti, Enugu, Kogi, and Oyo states in the DS, and in Nasarawa and Niger states and the Federal Capital Territory (FCT) Abuja in the SGS (Fig. 1, Table 1). In each state, at least two key markets

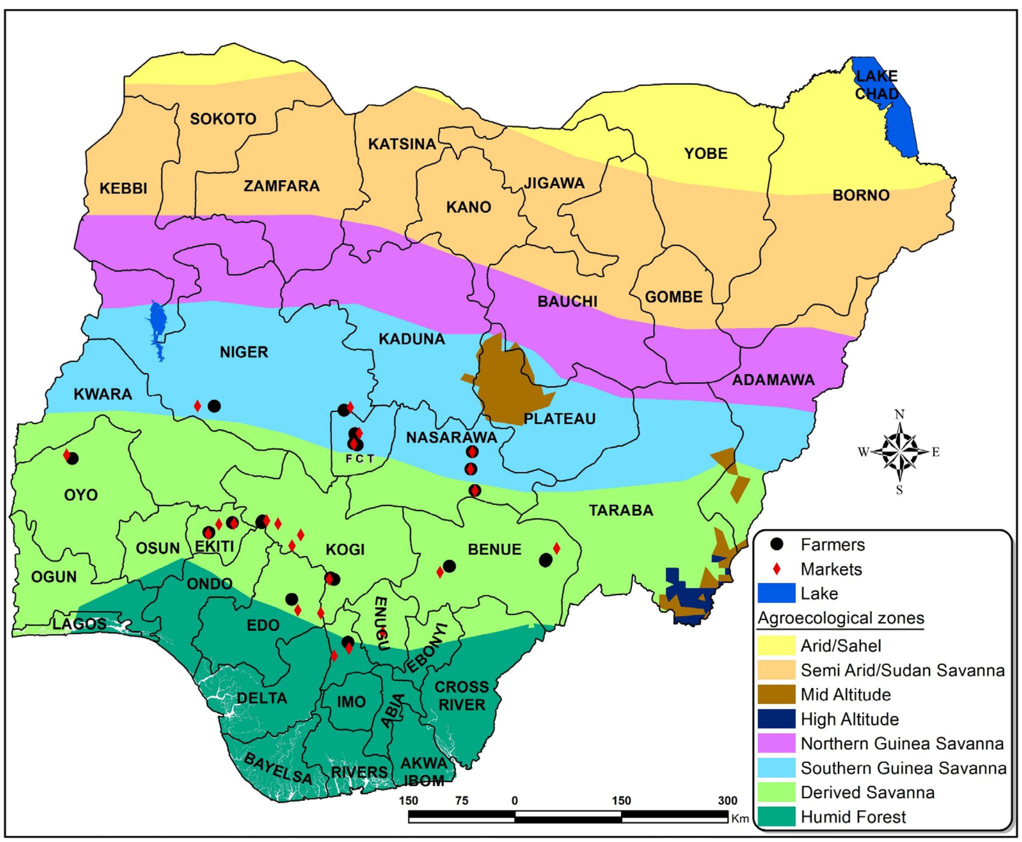


Figure 1. Map of survey sites, Nigeria.

Table 1. Market places and farmers' sampling locations with the number of vendors, heaps, barns, and tubers scored.

| State | LGA[x] | Market | | | Farmer | | |
|---|---|---|---|---|---|---|---|
| | | Locality | N[y] Vendors | N Heaps | Locality | N Barns | N Tubers |
| Abuja | Gwagwalada | Gwagwalada | 10 | 43 | Kutunku | 3 | 300 |
| | Kwali | Kwali | 11 | 45 | Kwali | 1 | 100 |
| | | | | | Ijah | 1 | 100 |
| Anambra | Anambra East | | | | Igbariam | 2 | 200 |
| | Oyi | Nkwo-Akwuzu market | 8 | 42 | | | |
| | Ogbaru | Ogbaru Relief Market | 11 | 58 | | | |
| Benue | Gwer West | | | | Tsiabie | 2 | 200 |
| | Kastina Ala | | | | Akugh | 1 | 100 |
| | | | | | Kwaza | 1 | 100 |
| | Otukpo | Otukpo May market | 10 | 52 | | | |
| | Ukum | Zaki-Biam | 20 | 118 | | | |
| Edo | Esean North east | Uromi | 4 | 34 | | | |
| | Esean South East | Akpalaji | 10 | 99 | | | |
| | Esean West | Oyomo | 1 | 20 | | | |
| | Etsako West | | | | Agbede | 1 | 100 |
| Ekiti | Ikole | Ajebamidele | 5 | 24 | | | |
| | Irepodum-Ifelodum | Oduro | 4 | 23 | Aroto | 1 | 98 |
| | | | | | Odoro | 1 | 5 |
| | Oye | Mile 2 Oye market | 5 | 17 | | | |
| Enugu | Udi | 9th Mile | 8 | 55 | | | |
| Kogi | Igalamela-Odolu | | 10 | 63 | Igalamela | 1 | 100 |
| | Idah | Ega / Ofuroba market | | | Idah | 1 | 100 |
| | Ijumu | Ikoyi market | 1 | 10 | Abekpe | 2 | 200 |
| | Kabba/Bunu | Okene | 1 | 4 | | | |
| | | Okene check | 1 | 20 | | | |
| Nasarawa | Keana | Kadarko | 10 | 53 | Kadarko | 1 | 99 |
| | Lafia | Rimiuka | 11 | 65 | Aguantifio | 1 | 100 |
| | Nasarawa Eggon | Eggon | 10 | 95 | Eggon | 1 | 100 |
| Niger | Gurara | Lambata | 10 | 59 | | | |
| | | | | | Tufakampani | 1 | 100 |
| | Mokwa | Mokwa | 10 | 56 | | | |
| | | | | | Kpaki | 2 | 200 |
| Oyo | Saki West | Saki | 10 | 59 | Agadagudu | 2 | 200 |
| Overall | | 23 | 181 | 1,114 | | 26 | 2,502 |

[x]LGA=Local government area
[y]N = number.

were selected, either identified on site or preselected as main yam markets in two separate local government administrations. Two farmers' yam stores (yam barns) were surveyed to compare household stored yam with marketed yam. In total, yams from 23 markets and 26 yam barns were sampled (Table 1).

A questionnaire was administered to vendors and farmers to obtain data related to their experience in farming, storing, and sales of yam. Questions pertained to the type of diseases commonly encountered on tubers, their ability to recognize diseased tubers, and control methods used (if any). A total of 26 farmers and 157 marketers from 23 markets were questioned.

*Assessment of tuber symptoms*

Prior to disease assessment, the geographic coordinates, yam species, and cultivars planted were recorded (Rehm, 1994; IPGRI/IITA, 1997; Diop, 1998). Symptoms of nematode damage on yam tubers *viz.* galls, dry rot, and cracks were scored from yam barns and from markets. From yam barns, whenever possible, up to 100 tubers were randomly selected to individually record the presence of the symptoms and severity of symptomatic tubers. Symptoms were rated using a scale of 1 to 5, where: 1 = no symptoms on tuber surface, 2 = slight damage (1-25% of symptoms on tuber surface), 3 = mild damage (26-50% symptoms on tuber surface), 4 = heavy damage (51-75% symptoms on tuber surface), and 5 = severe damage (>75% symptoms on tuber surface) (Fig. 2).

In each market, 10 vendors were randomly selected and a maximum of 10 yam tuber heaps of each vendor was scored whenever possible. The markets were very active and engaged with vendors and buyers, so it was not easy to construct a sampling frame. Therefore, the selection was carried out on an ad hoc basis. At first, an overview and a rough estimate of vendors with at least 10 yam heaps were made in the market. Then 10 vendors with 10 or more yam heaps were taken from positions in such a way that the entire market was covered. For sampling 10 yam heaps from each of the selected vendors, the order of selection was conducted to cover the entire display (in a blind selection). Due to the on-going marketing and/or the large size of some heaps, scoring of tubers in the markets was based on an overall visual estimation of the heap for a particular

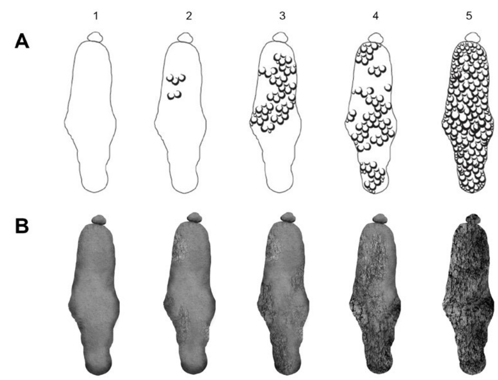


Figure 2. Root-knot (A) and dry rot (B) score on yam. Symptoms were rated using a scale of 1 to 5, where: 1 = no symptoms on tuber surface, 2 = slight damage (1-25% of symptoms on tuber surface), 3 = mild damage (26-50% symptoms on tuber surface), 4 = heavy damage (51-75% symptoms on tuber surface), and 5 = severe damage (>75% symptoms on tuber surface).

symptom and not on individual tubers. The severity of symptoms in heaps was assessed by rating heaps on a scale of 1 to 5 as mentioned above on yam tubers as it was conducted in farmer's barns. A total of 1,114 heaps of white yam (*D. rotundata*) was assessed from 181 vendors in markets located in three agro-ecological zones and 2,502 tubers were scored from yam barns (Table 1).

*Nematode extraction and identification*

Tubers exhibiting nematode symptoms were collected from each market and yam barn with a total of 239 samples from markets and 161 from yam barns. The samples were transferred to the IITA nematology unit laboratory for nematode extraction. Nematodes were extracted from tubers by peeling the outer cortex/skin (2-3 cm deep), finely chopping, and thoroughly mixing tubers. Three 5-g subsamples were taken for each tuber and used for nematode extraction on a modified Baermann tray (Coyne *et al.*, 2014). Nematodes were counted from 2-ml aliquots for each subsample and mean densities per 5 g of peels estimated for each tuber as given in the formula a and b below. Plant-parasitic nematodes were identified to genus with the aid of a Leitz Laborlux S compound microscope (Laborlux S, Wild Leitz GMBH) using identification keys (Mai and Mullin, 1996; Siddiqi, 2000).

**a) Total number of nematodes in 5 g subsample si (si: s1, s2, s3):**

$$Nematodes\ in\ si = \frac{Number\ of\ nematodes\ counted\ in\ si\ x\ Volume\ of\ the\ extract\ (mL)si}{2}$$

**b) Total number of nematodes in 5 g of tuber:**

$$Total\ number\ of\ nematodes\ in\ 5\ g\ of\ tuber = \frac{\sum_{i=1}^{3} Nematode\ si}{3}$$

*Data analysis*

Data collected from both markets and yam barns were used to calculate the incidence and severity of nematode symptoms. The symptoms incidence was recorded as follows: presence of galls = 1, absence = 0. Dry rot and crack rates were similarly recorded.

For a binary or binomial response variable, i.e,. the presence or absence of an attribute of interest, a logit model for analysis of variance was used (Nelder and Wedderburn, 1972; Balew *et al.*, 2014; Seidu, 2014). The hypothesis tested was the equality of proportions, and maximum likelihood predicted values for the proportions were then obtained and compared using the likelihood ratio Chi-square test-statistic. Covariates such as state and AEZ were included in the model to test the equality of proportions obtained at different levels of the covariate(s). Here the important hypothesis of interest was that the proportion of disease incidence (Gall, Dry rot or Crack) was the same for all States/AEZ's. The logit transformation of the proportions of disease incidence and the likelihood ratio chi-square test-statistic in SAS GENMODE procedure (SAS Institute, 2015) were used to test for significant differences between these mean proportions obtained in different states/AEZ (SAS Institute Inc., 1993).

The nematode symptom severities were measured on a scale of 1-5, with 1 as no symptom and 2-5 measuring the level of severity in an increasing order (Fig. 2). However, because of low numbers recorded at some levels, a recode was performed as follows: gall rate = 1 was recoded = 'None'; gall rate = 2 or 3 recoded = 'Low'; and gall rate = 4 or 5 were recoded = 'High'. Dry rot and crack rates were similarly recoded. Thus, the severity rates were translated to severity levels for the statistical analysis: none, low, and high. A table of counts (or frequencies) of yam tubers with different severity levels by State/AEZ, similar to a contingency table, was obtained. The hypothesis of interest is that the distribution of the counts of severity levels for each type of symptom (gall, dry rot, or crack) was the same for all states/AEZ. In the multinomial contingency table, the log-linear transformation of the cell counts and again the likelihood ratio chi-square test-statistic in SAS GENMODE procedure (SAS Institute, 2015) were used to test for significant differences between observed and expected cell frequencies (SAS Technical Report, 1993).

Nematode densities were compared between states and AEZ using the General Linear Models (GLM) ANOVA procedure from SAS. When overall mean differences were significant, means were separated using the Student Newman-Keuls test ($P \leq 0.05$). Normality of nematode population densities was checked and normalized, using the log10(X + 1) transformation prior to analysis.

## RESULTS

*Visual assessment of nematode damage incidence*

Tubers without physical nematode symptoms are presented in Fig. 3A-B. Typical symptoms of tuber galling (Fig. 3C-F), galling and crazy roots (Fig. 3G-K), dry rot of tubers (Fig. 3L-Q) and cracks in tubers (Fig. 3R-W) were observed from market stalls and yam barns. At market stalls, tuber galling on yam heaps was the most prevalent nematode symptom across the three AEZ, with a mean incidence of 55%. This was followed by dry rot (35%) and cracks (6%) (Table 2). There was less dry rot incidence in the SGS (17%) (P< 0.0001) than in the HF (44%) and the DS (43%) (Table 2). However, no difference in galls ($P$=0.6229) and cracks ($P$=0.0649) (Table 2) across the AEZ was observed (Table 2).

In farmers' yam barns, galling was the most prevalent nematode symptom (24%) compared with dry rot (8%) and cracks (2%) (Table 3). Differences in galling incidence among AEZ was observed ($P$=0.0018), with SGS having a greater

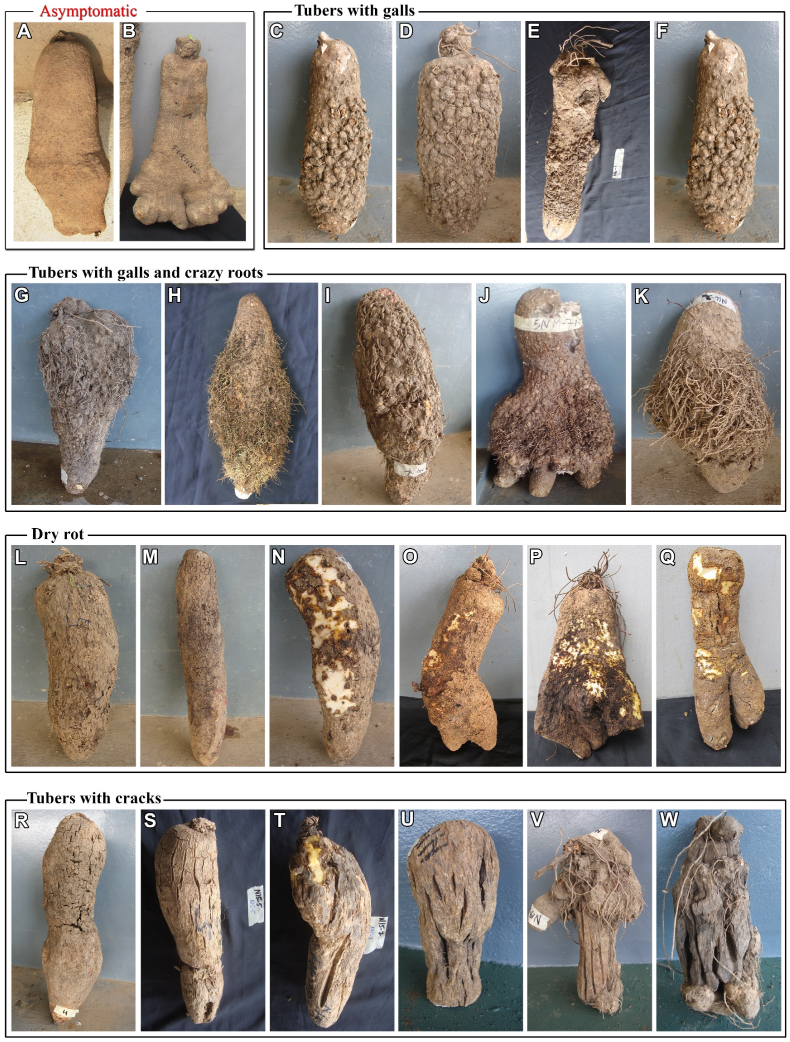


Figure 3. A-B: Tubers without physical nematode symptoms, C-F: typical symptoms of tuber galling), G-K: galling and crazy roots, L-Q: dry rot of tubers, and R-W: cracks in tubers.

galling incidence (27%) than DS (22%) (Table 3). Tubers in the DS (3%) had more ($P$=0.0080) cracks compared with those in the SGS (1%) (Table 3). No statistical difference was observed between the dry rot symptom incidence across the AEZ (Table 3).

Across the states, the highest symptom incidence in the markets for tuber galling, dry rot, and cracks was recorded in the FCT Abuja (96%), Ekiti (70%) and Edo states (16%), respectively. However, in the farmers' barns, the highest percentage of tubers with symptoms was found in Edo (67%), Ekiti (30%) and Anambra states (6%) for tuber galling, dry rot and cracks, respectively (Table 4, 5).

*Visuals assessment of nematode damage severity*

Nematode symptoms on yam heaps in the markets were, in general, of low severity (Table 2). There was no significant difference in the distribution of galling severity in the three AEZ (Table 2). On the dry rot severity, significantly higher differences were observed in the distribution of heaps with low and high dry rot severity than the predicted values in the DS (Table 2). In the SGS, a significantly lower dry rot distribution was observed for both the low and high severity level of the actual values compared with the predicted values (Table 2).

In farmer's yam barns, symptom severity across the AEZ was, in general, low, and no significant differences between the proportion of the actual values and the predicted values were noted except for the low galling severity level

Table 2. Incidence (%) and severity of nematode damage (galls, dry rot, cracks) of heaps with yam tubers in markets in different states in Nigeria.

| AEZ[w] | n[x] | Gall | | | Dry rot | | | Cracks | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Incidence | Severity[z] | | Incidence | Severity | | Incidence | Severity | |
| | | (%)[y] | Low | High | (%) | Low | High | (%) | Low | High |
| DS | 598 | 53 a | 276 (272)+ | 43 (48)- | 43 a | 210 (169)+* | 45 (29)+* | 7 a | 42 (34)+ | 1 (1)- |
| HF | 100 | 58 a | 50 (46)+ | 8 (8)+ | 44 a | 39 (28)+ | 5 (5)+ | 7 a | 7 (6)+ | 0 (0)- |
| SGS | 416 | 53 a | 181 (189)- | 38 (33)+ | 17 b | 66 (117)-* | 4 (20)-* | 4 a | 15 (24)- | 1 (0)+ |
| Mean | | 55 | | | 35 | | | 6 | | |
| *P* | | 0.6229 | | | <0.0001 | | | 0.0649 | | |

[w]AEZ= Agro-ecological zone; DS=Derived Savanna; HF=Humid Forest; SGS=Southern Guinea Savanna.

[x]n= number of heaps evaluated.

[y]% = Incidence of heaps containing yam tubers with nematode symptoms. Incidence followed by same letters in the same column are not significantly different $P< 0.05$ according to Chi Square test.

[z] Severity: Low= yam tubers in the heap with nematode symptoms at rate 2 & 3 and high = yam tubers in the heap with nematode symptoms at rate 4 & 5 expressed on a 1 to 5 scale where 1= no tubers with visual symptoms, and 5= above 75% of the tubers with visual symptoms. Data presented are the distribution of the actual and expected values expressed in a format of actual value (predicted value) with + and – when the actual value is higher or lesser than the predicted value, respectively.

* indicates significant difference at $p < 0.005$.

Table 3. Incidence (%) and severity of nematode damage (galls, dry rot, cracks) of yam tubers in yam barns in different agro-ecological zones in Nigeria.

| AEZ[w] | n[x] | Gall | | | Dry rot | | | Cracks | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Incidence (%)[y] | Severity[z] Low | Severity[z] High | Incidence (%) | Severity Low | Severity High | Incidence (%) | Severity Low | Severity High |
| DS | 1403 | 22 b | 229 (271) -* | 76 (67)+ | 9 a | 93 (91)+ | 28 (24)+ | 3 a | 34 (25)+ | 3 (2)+ |
| SGS | 1099 | 27 a | 255 (213)+* | 43 (53)- | 8 a | 70 (72) - | 14 (19) - | 1 b | 11 (20)- | 1 (2)- |
| Mean | 1251 | 24 | | | 8 | | | 2 | | |
| P | | 0.0018 | | | 0.4329 | | | 0.0080 | | |

[w]AEZ= Agro-ecological zone; DS=Derived Savanna; HF=Humid Forest; SGS=Southern Guinea Savanna.

[x]n= number of tubers evaluated

[y]% =Incidence of nematode symptoms on yam tubers in the yam barns. Incidence followed by same letters in the same column are not significantly different *P*< 0.05 according to Chi Square test

[z]Severity: Low= yam tubers in the barn with nematode symptoms at rate 2 & 3 and high = yam tubers in the barn with nematode symptoms at rate 4 & 5 expressed on a 1 to 5 scale where 1= no tubers with visual symptoms, and 5= above 75% of the tubers with visual symptoms. Data presented are the distribution of the actual and expected values expressed in a format of actual value (predicted value) with + and – when the actual value is higher or lesser than the predicted value, respectively. * indicates significant difference at $p < 0.005$.

Table 4. Incidence and severity of nematode damage (galls, dry rot, cracks) of heaps with yam tubers in markets in different States in Nigeria

| State | $n^x$ | Gall Incidence $(\%)^y$ | Gall Severity$^z$ Low | Gall Severity$^z$ High | Dry rot Incidence (%) | Dry rot Severity Low | Dry rot Severity High | Cracks Incidence (%) | Cracks Severity Low | Cracks Severity High |
|---|---|---|---|---|---|---|---|---|---|---|
| Abuja | 88 | 95.5 a | 57 (40.05)+* | 27 (7.03)+* | 17.1 cd | 15 (24.91)- | 0 (4.27)- | 8.0 ab | 7 (5.06)+ | 0 (0.16)- |
| Anambra | 100 | 58.0 c | 50 (45.51)+ | 8 (7.99)+ | 44.0 b | 39 (28.3)+ | 5 (4.85)+ | 7.0 b | 7 (5.75)+ | 0 (0.18)- |
| Benue | 170 | 74.1 b | 120 (77.37)+* | 6 (13.58)- | 27.7 c | 45 (47.83)- | 1 (8.2)- | 2.9 bc | 5 (9.77)- | 0 (0.31)- |
| Edo | 153 | 51.6 c | 66 (69.63)- | 13 (12.22)+ | 66.7 a | 84 (43.3)+* | 18 (7.42)+* | 15.7 a | 24 (8.79)+* | 0 (0.27)- |
| Ekiti | 64 | 12.5 e | 8 (29.13)-* | 0 (5.11)- | 70.3 a | 28 (18.11)+ | 17 (3.11)+* | 14.1 ab | 9 (3.68)+ | 0 (0.11)- |
| Enugu | 55 | 56.4 c | 29 (25.03)+ | 2 (4.39)- | 43.6 b | 22 (15.57)+ | 0 (2.67)- | 1.8 bc | 1 (3.16)- | 0 (0.1)- |
| Kogi | 97 | 46.4 cd | 24 (44.15)-* | 21 (7.75)+* | 15.5 d | 6 (27.45)-* | 9 (4.71)+ | 1.0 c | 0 (5.57)- | 1 (0.17)+ |
| Nasarawa | 213 | 39.9 d | 81 (96.94)- | 4 (17.02)-* | 16.9 d | 37 (60.28)-* | 0 (10.33)-* | 0.9 c | 2 (12.24)-* | 0 (0.38)- |
| Niger | 115 | 43.5 d | 43 (52.34)- | 7 (9.19)- | 15.7 d | 14 (32.55)-* | 4 (5.58)- | 6.1 b | 6 (6.61)- | 1 (0.21)+ |
| Oyo | 59 | 50.9 cd | 29 (26.85)+ | 1 (4.71)- | 42.4 b | 25 (16.7)+ | 0 (2.86)- | 5.1 bc | 3 (3.39)- | 0 (0.11)- |
| Mean | | 52.5 | | | 33.5 | | | 6 | | |
| P | | <0.0001 | | | <0.0001 | | | <0.0001 | | |

[x]n= number of heaps evaluated

[y]% = Incidence of heaps containing yam tubers with nematode symptoms

[z]Severity: Low= yam tubers in the heap with nematode symptoms at rate 2 & 3 and high = yam tubers in the heap with nematode symptoms at rate 4 & 5 expressed on a 1 to 5 scale where 1= no tubers with visual symptoms, and 5= above 75% of the tubers with visual symptoms. Data presented are the distribution of the actual and expected values expressed in a format of actual value (predicted value) with + and – when the actual value is higher or lesser than the predicted value, respectively. * indicates significant difference at $p < 0.005$.

Table 5. Incidence (%) and severity of nematode damage (galls, dry rot, cracks) of yam tubers in yam barns in different states of three agro-ecological zones in Nigeria.

| | | Gall | | | Dry rot | | | Cracks | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Incidence | Severity[x] | | Incidence | Severity | | Incidence | Severity | |
| State | N[y] | (%)[z] | Low | High | (%) | Low | High | (%) | Low | High |
| Abuja | 500 | 42.0 b | 173 (96.72)+* | 36 (23.78)+ | 6.0 cd | 26 (32.57)- | 4 (8.39)- | 1.2 bc | 5 (8.99)- | 0 (0.8)- |
| Anambra | 200 | 47.0 b | 66 (38.69)+* | 27 (9.51)+* | 2.5 e | 5 (13.03)- | 0 (3.36)- | 5.5 a | 11 (3.6)+* | 0 (0.32)- |
| Benue | 400 | 20.5 c | 81 (77.38)+ | 0 (19.02)-* | 5.0 cde | 20 (26.06)- | 0 (6.71)- | 1.3 bc | 5 (7.19)- | 0 (0.64)- |
| Edo | 100 | 67.0 a | 46 (19.34)+* | 21 (4.76)+* | 0 f | 0 (6.51)- | 0 (1.68)- | 4 ab | 3 (1.8)+ | 1 (0.16)+ |
| Ekiti | 103 | 0.97 e | 1 (19.92)-* | 0 (4.9)- | 30.1 a | 16 (6.71)+* | 15 (1.73)+* | 3.9 ab | 3 (1.85)+ | 1 (0.16)+ |
| Kogi | 400 | 15.5 cd | 34 (77.38)-* | 28 (19.02)+ | 4.5 de | 17 (26.06)- | 1 (6.71)- | 2.0 b | 7 (7.19)- | 1 (0.64)+ |
| Nasarawa | 299 | 16.1 cd | 42 (57.84)- | 5 (14.22)- | 10.7 b | 27 (19.48)+ | 3 (5.02)- | 0.3 c | 1 (5.38)- | 0 (0.48)- |
| Niger | 300 | 14.0 d | 40 (58.03)- | 2 (14.27)-* | 8.0 bc | 17 (19.54)- | 7 (5.04)+ | 2.0 b | 5 (5.4)- | 1 (0.48)+ |
| Oyo | 200 | 0.5 e | 1 (38.69)-* | 0 (9.51)-* | 24.0 a | 35 (13.03)+* | 12 (3.36)+* | 2.5 ab | 5 (3.6)+ | 0 (0.32)- |
| Mean | 333 | 24.3 | | | 8.3 | | | 2 | | |
| P | | <0.0001 | | | <0.0001 | | | 0.006 | | |

[x]Severity: Low= yam tubers in the barn with nematode symptoms at rate 2 & 3 and high = yam tubers in the barn with nematode symptoms at rate 4 & 5 expressed on a 1 to 5 scale where 1= no tubers with visual symptoms, and 5= above 75% of the tubers with visual symptoms. Data presented are the distribution of the actual and expected values expressed in a format of actual value (predicted value) with + and – when the actual value is higher or lesser than the predicted value, respectively. * indicates significant difference at $p < 0.005$.

[y]n= number of tubers evaluated.

[z]% =Incidence of nematode symptoms on yam tubers in the yam barns.

Table 6. *Meloidogyne*, *Scutellonema,* and *Pratylenchus* population densities per 5 g peel of yam tubers collected from yam markets and from yam barns in Nigeria, 2013.

| | | | *Meloidogyne* | | | *Scutellonema* | | | *Pratylenchus* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Symptoms | Place[x] | n[y] | Mean[z] | Min | Max | Mean | Min | Max | Mean | Min | Max |
| Crack | M | 7 | 2 B | 0 | 7 | 9 B | 0 | 21 | 0 A | 0 | 0 |
| | F | 4 | 0 b | 0 | 0 | 11 b | 0 | 44 | 1 a | 0 | 0 |
| Dry rot | M | 100 | 8 B | 0 | 375 | 2401 A | 0 | 37500 | 5 A | 0 | 340 |
| | F | 38 | 12 b | 0 | 220 | 2096 a | 0 | 18750 | 1 a | 0 | 10 |
| Gall | M | 102 | 535 A | 0 | 12150 | 348 B | 0 | 12576 | 5 A | 0 | 334 |
| | F | 66 | 290 a | 0 | 2890 | 23 b | 0 | 544 | 15 b | 0 | 525 |
| No disease | M | 30 | 1 B | 0 | 15 | 514 B | 0 | 8488 | 0 A | 0 | 0 |
| | F | 53 | 1 b | 0 | 25 | 23 b | 0 | 375 | 1 a | 0 | 50 |
| Mean[z] | M | 7 | 232 | 0 | 12151 | 1218 | 0 | 37500 | 4 | 0 | 340 |
| | F | 4 | 122 | 0 | 2890 | 512 | 0 | 18750 | 7 | 0 | 525 |
| P | M | 100 | <0.0001 | | <0.0001 | 0.2720 | | | | | |
| | F | 38 | <0.0001 | | <0.0001 | 0.0178 | | | | | |

[x]Place: M=Market; F=Farmer's barn.

[y]n= Number of tubers.

[z]Mean number of nematodes per 5 g peel based on a same column were undertaken on $\log_{10}(X + 1)$ transformed values. Means followed by same letters in upper case (Markets) or small case (Farmer barns) in the same column are not significantly different $P < 0.05$ according to SNK test.

where the actual values were significantly lower in the DS and higher in SGS compared with the precticted values (Table 3).

*Relation between tuber symptoms and nematode density*

Three nematode genera were identified from tubers: *Scutellonema*, *Meloidogyne*, and *Pratylenchus* (Fig. 4; Table 6). In tubers collected from yam heaps in market stalls, a higher ($P \leq 0.0001$) *Meloidogyne* spp. density was recorded from tubers with galls (535 nematodes/5 g peel) than from tubers showing cracks (2 nematodes/5 g peel) or dry rot (8 nematodes/5 g peel). For *Scutellonema* spp., the population density was higher ($P \leq 0.0001$) in tubers with dry rot symptoms (2,401 nematodes/5 g peel) than from tubers with galls (348 nematodes/5 g peel) or cracks (9 nematodes/5 g peel).

In yam barns, the population density of *Meloidogyne* spp. was higher ($P \leq 0.0001$) in tubers with galling than in tubers with other symptoms. Similarly, the population density of *Scutellonema* was higher ($P \leq 0.0001$) in tubers with dry rot symptoms than in tubers with others types of symptoms.

No significant differences ($P = 0.2720$) were observed in the population density *Pratylenchus* spp. with respect to symptoms from tubers collected from markets (Table 6). A significant difference ($P = 0.0178$) was observed for the population density of *Pratylenchus* spp. in respect to symptoms from tubers collected from farmer's barns (Table 6).

Comparing nematode population densities in tubers from markets across AEZ, differences ($P < 0.0029$) were only observed for RLN, which were greater in the HF (40 nematodes/5 g peel) compared with population densities in the DS (1 nematode/5 g peel) and SGS (4 nematodes/5 g peel) (Fig. 4). Comparing nematode population densities in tubers from farmers' barns across AEZ, a higher density ($P = 0.0420$) of *Meloidogyne* spp. was observed in the SGS (208 nematodes/5 g peel) compared with the DS (48 nemaotde/5 g peel). Similarly, population densities of *Scutellonema* spp. were greater ($P = 0.0005$) in the SGS (885 nemaotdes/5 g peel) compared with the DS (187 nematodes/5 g peel). No significant differences ($P = 0.3115$) were observed for *Pratylenchus* spp. across AEZ (Fig. 4C).

Overall, a positive correlation was found between galling and population densities of *Meloidogyne* spp. ($r = 0.56$; $P < 0.0001$) and between dry rot symptoms and population densities of *Scutellonema* spp. ($r = 0.60$; $P < 0.0001$).

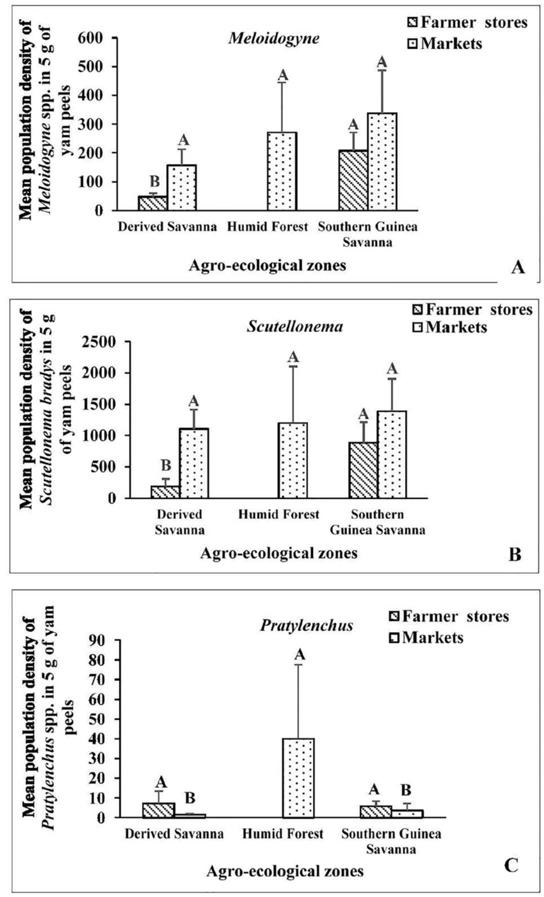


Figure 4. Population density of *Meloidogyne* (A), *Scutellonema* (B), and *Pratylenchus* (C) found in tubers of yam (*Dioscorea rotundata*) samples in farmer storage and markets in different agro-ecological zones of Nigeria. Bars with the same letter in a graph are not different according to a Student Newman-Keuls test ($P \leq 0.05$).

## DISCUSSION

The yam market system in Nigeria involves selling of ware (>1 kg) and seed yam (100 g-1 kg). Specialized seed yam production markets are uncommon (Aighewi *et al.*, 2014) and at the period of the survey, both ware and seed yam were sold in the same markets. Out of the 26 markets visited, only one specialized yam seed market was encountered. It clearly appeared that seeds used in yam production system in Nigeria are either from farmer's material or from common yam markets. The observed nematode symptoms were prevalent in all the AEZ sampled, confirming nematodes as major pests and a serious constraint to yam production (Bridge, 1972; Adesiyan and Adeniji, 1976; Coyne *et al.*, 2006; Humphreys-Pereira *et al.*, 2017). In general, low nematode symptom severities were observed. This is a consequence of perpetual sorting, removal, and discarding of tubers with high symptom severity during storage (farmer's barns) and in the market as these materials are less appealing with low marketable, edible, and seed values.

The observed high-galling incidence of affected tubers can be explained by the fact that the galling does not induce immediate rotting of the tubers, and therefore, tubers showing low-galling severity often remain in stalls and storage. Unfortunately, tubers with low-galling severity often continue to be used as planting material and, consequently, act as a main source of inoculum in new fields (Bridge, 1996).

Dry rot incidence was 34% on average on heaps, similar to that reported by Bridge (1972) (43%) in Nigeria, but higher than that reported for marketed yam in Mali (0.3%) and Ghana (7.5%) (Coyne *et al.*, 2006). However, the relatively low dry rot severity compared with galling is interesting and geographically marked. Dry rot symptoms were mostly recorded in the DS and HF compared with the SGS. This can be explained by the late harvest due to later planting in the SGS compared with the early planting and harvest time in the HF and DS. Tubers harvested earlier in the HF and in the DS are stored for a longer period than tubers from the SGS. The longer storage period can lead to the proliferation of *S. bradys*, the causal agent of dry rot. Dry rot disease symptoms tend to be better known as storage problems than galling. Nematode reproduction and feeding activities continue during storage, leading to greater damage expression of symptoms with duration of storage (Bridge, 1972; Bridge *et al.*, 2005). Hence, tubers harvested earlier (e.g., in DS and HF) will likely exhibit symptoms of dry rot to a greater extent than freshly harvested tubers (in the SGS), as they have been stored for 1 to 3 months, allowing time for disease symptoms to develop. Although, no clear mentioning of the sampled states was made by Bridge (1972), by referring to the former "Western State" as sampled area indicates that states from the western side of the country had a higher dry rot incidence. This is confirmed in current study and indicates that the situation prevails.

The positive correlation found between the galling symptoms and population density of *Meloidogyne* spp. and between dry rot and *Scutellonema* spp., confirms that the galls are caused by RKN, and the dry rot by the yam nematode (Bridge *et al.*, 2005; Coyne *et al.*, 2006). However, although at significantly lower densities, *Meloidogyne* was detected from dry rot tubers and *Scutellonema* from gall symptoms in some cases. This implies that mixed infection of nematodes on tubers may occur in tubers exhibiting mainly one type of symptom while symptoms of other nematodes are at a non-detectable level. A similar observation was made in Costa Rica (Humphreys-Pereira *et al.*, 2017). With respect to symptoms of tuber cracking, in most of the cases, few or no nematodes were retrieved and not associated with a specific nematode genus (data not presented). Different types of cracks are often observed in yam tubers, which may be a result of abiotic stress caused by high and low temperatures, irregular soil moisture, or biotic factors such as nematodes, viruses, fungi, or bacteria (Bridge *et al.*, 2005; Coyne *et al.*, 2012; Reddy 2015). Thus, cracks are a poor indication of nematode damage, and there is a need to properly re-describe cracks associated with nematode damage on yam tubers.

RLN were retrieved from yam tubers with galls and symptoms of "crazy roots" as well as tubers with dry rot symptoms. Thus, no specific symptoms were related to the presence of the RLN. Among *Pratylenchus* species that infect yam, *P. coffeae* causes a dry rot in Latin America (Coates-Beckford and Brathwaite, 1977; Moura *et al.*, 2001) and in Asia (Bridge, 1988; Huang *et al.*, 1994; Tsay *et al.*, 1994). However, in Africa, other RLN species such as *P. brachyurus* and *P. sudanensis* are known pests of yam (Miège, 1957; Luc and de Guiran, 1960; Unny and Jerath, 1965; Smit, 1967; Coyne *et al.*, 2003). Further identification of *Pratylenchus* populations to species level is required to establish whether it is the same *Pratylenchus* species that is associated with galls and dry rot tubers.

Yam tubers not presenting any nematode symptoms also contained nematodes, although at relatively low densities. Consequently, asymptomatic tubers can be infected, but for the expression of symptoms, a minimum nematode population density appears necessary (Bridge, 1972; Coyne *et al.*, 2012). This has important management implications and infers that all yams may be potentially infected with nematodes and that all planting material needs to be treated to reduce or prevent nematode damage. Another option for farmers is to use sources of nematode-free planting material (Aighewi *et al.*, 2015).

Results of the questionnaire showed that farmers and vendors are aware of and familiar with nematode symptoms on yam tubers but the majority lack the knowledge of nematodes as the causal agents (Fig. 5). The ability of nematodes to live and reproduce inside yam tubers makes infected tubers a primary source of inoculum when used as planting material (Fawole, 1988; Bridge *et al.*, 2005). Many approaches, including cultural practices (Adesiyan, 1976; Claudius-Cole *et al.*, 2016), hot-water treatment (Adesiyan and Adeniji, 1976; Coyne *et al.*, 2010), and use of nematicides (before storage or planting or field treatment) (Roman *et al.*, 1984; Castagnone-Sereno, 1988; Claudius-Cole *et al.*, 2014) have been recommended for nematode management on yam. However, application of these approaches by small-scale farmers is limited due to practicability, cost limitations, and, in some cases, farmer's unawareness.

In conclusion, nematodes appear to be a major problem on yam in Nigeria. In addition to the common nematode problem, dry rot symptoms, the high prevalence of galling on tubers raises a concern about the root-knot nematodes in the country. The ongoing demographic pressure and intensification of land use, coupled with the fluctuation in climatic patterns (excess rainfall, flooding, and drought), which negatively impact small-scale farming, will most likely amplify the current problem. This calls for more effective communication. Firstly, farmers need to be aware that the symptoms on tubers are caused by nematodes in order to take the appropriate measures. Secondly, farmers should be provided with the most effective and available approaches for nematode management. Further investigations are urgently required to propose new approaches such as the development of resistant germplasm and promotion of and dissemination of nematode-free planting material, and biological control agents. A more elaborated integrated approach of nematode management is required to reduce nematode incidence in yam-growing areas.

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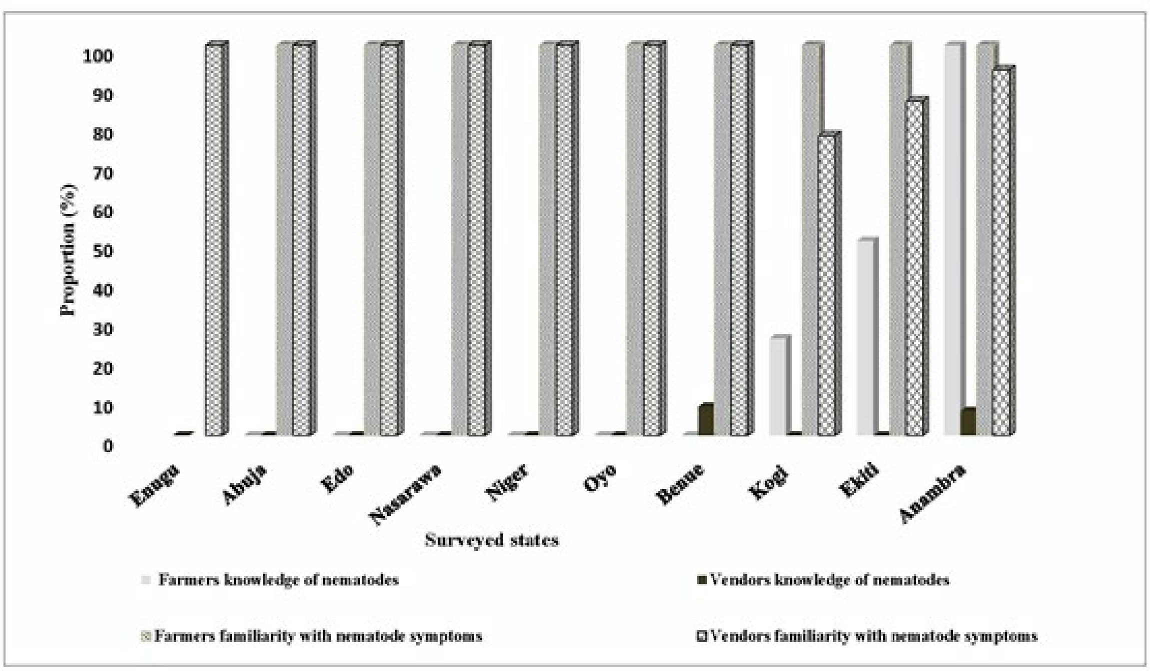


Figure 5. Proportion of yam farmers and vendors of yam in different states of Nigeria with knowledge of nematodes and with familiarity of symptoms associated with nematode infection of yams.

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