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Occurrence, abundance and distribution of plant-parasitic nematodes associated with rice (*Oryza* spp.) in different rice agroecosystems in Togo

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ABSTRACT

Rice is the second most important cereal in Togo. Among constraints that affect rice production, plant parasitic nematodes are of great importance. The objective of this study was to determine the distribution, abundance and frequency of plant nematodes in different agroecological zones of Togo. A total of 50 composite soil and root samples (25 each) were taken from 25 fields (5 per zone) randomly selected from the five agroecological zones. Nematodes were extracted from 100 ml soil and 1g fresh root samples using the Hermann techniques. Nematodes were then fixed and mounted on slide and identified to genus level using identification keys. The survey documented twelve plant-parasitic nematode genera among which ten, (*Hirschmanniella* spp., *Meloidogyne* spp., *Xiphinema* spp., *Scutellonema* spp., *Helicotylenchus* spp., *Heterodera* spp., *Criconema* spp., *Pratylenchus* spp., *Trichodorus* spp. and *Tylenchid* spp.), were recorded from lowland, two (*Helicotylenchus* and *Scutellonema)* from upland and five (*Dolichodorus* spp., *Helicotylenchus* spp., *Tylenchorhynchus* spp., *Scutellonema* spp. and *Xiphinema* spp.), from flooded ecosystem. *Hirschmanniella* spp., *Meloidogyne* spp and *Helicotylenchus* spp. were the most frequent and abundant plant-parasitic nematode genera recorded from more than 71% of the samples. *Helicotylenchus* spp., *Hirschmanniella* spp., *Meloidogyne* spp. and *Scutellonema* spp., were recorded in both soil and root samples while *Pratylenchus* spp., *Heterodera* spp. and *Tylenchorhynchus* spp., were found to be associated to root and *Trichodorus* spp., *Tylenchid* spp., *Xiphinema* spp., *Criconema* spp. and *Dolichodorus* spp., were recorded from soil samples only. The high diversity of nematode genera recorded in the survey is attributed to the rice ecosystem, which is mostly characterized by lowland ecosystem with intensive cropping. This study established the evidence that nematodes could be important constraints for rice production, suggesting further research focusing on their damage potential and development of effective rice nematode management strategy for sustainable rice production in Togo.

Keywords: plant parasitic nematode, abundance, occurrence, rice ecosystem, distribution.

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INTRODUCTION

A major challenge facing agricultural scientists today is the need to secure food for an increasing world population which is projected to 35% increase by 2050 (World Bank, 2008). Increasing population suggests an increase in food demand which is estimated to be of about 75% due to economic development and changes in food preferences (Keating et al., 2010). Among crops that play an importance role in world food security for human being, rice (*Oryza* sp.) occupies an important place. Grown in about 110 countries around the world, rice is the second most important grain crop after wheat for more than 75% of world population (Ju-Kon and Krishnan, 2002; Correa et al., 2007). Despite this increase in both rice production and consumption, sub-Saharan Africa and particularly West Africa, remains the largest importer of rice (Mendez del Villar and Bauer, 2013).

In Togo, rice ranks third among cereals grown after maize and sorghum. The country has enormous human and agroecological potential for rice production. The country has large alluvial plains with rice production potential of about 86,000 ha and lowland areas of more than 185,000 ha. In spite of the enormous rice production potentialities available in Togo, this country continues to import huge quantities of rice to cover national production gap. National rice needs were estimated at 90,000 tons per year for a population of about 7 million inhabitants (DSID, 2003). In order to satisfy an average of 15 kg of rice per inhabitant per year, Togo has to import 100,000t/year of rice. According to the Agricultural Statistics Department (DSID, 2016), despite an increase of 53.26% in cultivated rice areas from 1999 to 2015, paddy rice production in Togo is expected to decline by 4.7% in the 2015/16 (October/September) season. Among factors that limit rice production worldwide, plant-parasitic nematodes are often cited as one of the most damaging pests (Bridge et al., 2005). Over 4100 species of plant-parasitic nematodes described to date (Decraemer and Hunt, 2006) are known to represent an important constraint on the delivery of global food security. They pose a significant threat to crop production in Africa due to extensive damage and substantial yield losses they cause to a wide range of agricultural crops (Bridge et al., 2005). Moreover, nematode attack can lead to plants' infection by other pathogens (De Waele and Elsen, 2007) either through mechanical damage or on a genetic basis. The direct and indirect damage caused by various plant parasitic nematode species results in delayed crop maturity, toppling, reduced yields and quality of crop product, high production costs and consequently income loss (Sikora and Fernández, 2005; Onkendi et al., 2014). Global damage caused by plant nematodes has been estimated to $US 80 billion per year (Nicol et al., 2011; Navia et al., 2017).

Although over 4,100 species of plant-parasitic nematodes that can be endo- or ecto-parasites depending on their lifestyle and attack all the organs of a plant, have been identified (Decraemer and Hunt, 2006), new species are continually being described while others, previously viewed as secondary or non-damaging, are becoming pests as cropping patterns change (Nicol, 2002). Moreover, the distribution of nematode species varies greatly. Some are cosmopolitan, such as *Meloidogyne* spp. while others (*Heterodera* spp.) are restricted geographically or are highly host specific.

Among the nematode species known to be associated with rice (Decraemer and Hunt, 2006), only 29 species were reported to be responsible for significant yield losses (Bridge et al., 2005). Despite the daily use and consumption of rice by millions of people in Togo, and its growing importance as a cereal crop, very little is known about the associated plant-parasitic nematodes. Preliminary surveys targeting plant-parasitic nematodes in Togo revealed the presence of *Pratylenchus, Meloidogyne, Scutellonema, Heterodera* and *Hirschmanniella* in different rice growing ecologies (De Waele and Elsen, 2007). Although a few surveys of rice nematodes have been conducted in Togo, changes in land use, intensification of agricultural production, and the introduction of new varieties could contribute to shifts in the occurrence and density of nematode species or emerging nematode species under different rice agro-ecosystems. Hence, the objective of this study was to analyze the frequency of the occurrence, distribution, and plant-parasitic nematode population densities associated with rice in different agro-ecological zones of Togo.

MATERIALS AND METHODS

Study site

Soil and root samples were collected for nematode analysis from 25 rice fields in the five different agroecological zones of Togo, here referred to as Zone 1, Zone 2, Zone 3, Zone 4 and Zone 5 (Figure 1) during the 2015 growing season (from September to December 2015). The survey site is characterized by savannah and mountain forest and gallery forest (Kokou et al., 2006). The vegetation is dominated by Combretaceae in the northern plains (Zone 1), *Isoberlinia* spp Caesalpiniacea in the northern mountains (Zone 2) (Dourma et al., 2012). In the central plains (Zone 3), *Anogeisus leiocarpa* (Combretaceae) and *Pterocarpus erinaceus* (Fabaceae) are the most representative (Adjonou et al., 2010) vegetation. The flora is more diversified with *Celtis mildbreadii* Eng (Cannabaceae), *Terminalia superba* Eng & Diels (Combretaceae), *Ricinodendron heudelotii* (Baill.) (Euphorbiacea) in the southern mountains (Zone 4) while in the southern plains (Zone 5) the mangrove is particularly developed (Adjonou et al., 2010).

Nematode sampling

Nematode communities and population densities were assessed from 25 fields (5 per ecological zone) according to Hermann (2006). In each field, rice plants and soil were sampled from five points selected along the diagonals. Twenty plants were uprooted at 30 cm deep using machete from each of the four corners, but avoiding the edges, and at the intercept of the two diagonals. Samples from each field were mixed to form a total of 25 composite soil and root samples. All samples collected were kept in freezer and brought to the "Laboratoire de Recherche sur les Agroressources et la Santé Environnementale" of Université de Lomé-Togo. The samples were processed for extraction within 24 h after collection and further identification of extracted nematodes. In each sampled field, rice cropping system was recorded while fields were georeferenced using GPS.

Extraction and identification of nematodes

Each soil sample was thoroughly mixed, and a subsample of 100 ml soil was assayed for nematodes using the Whitehead tray technique (Hooper et al., 2005). For the root samples, a subsample of 10 g roots were washed, chopped into 1 to 2 cm pieces and ground for 1 to 2 minutes using a blender (Orisajo and Fademi, 2012) and nematodes were extracted using the above mentioned technique. Nematodes were recovered after an incubation period of 48 h and identified to genus level in a count plate under a binocular microscope. To confirm the observation with a magnifying binocular microscope and refine the identification a post-lethal observation of individuals killed by heat was carried out. Nematodes were fixed in 4% formalin, processed in glycerol, and mounted on a glass slide based on a standard procedure (Coyne et al., 2007). Observations were done under the microscope (Motic, Model B1) at X4, X10, X40 and X100 following the identification keys (Siddiqi, 2000). Three subsamples with equal volume (10 ml) were counted three times, and the average was used to estimate the nematode population prevalence and densities. Prevalence computed as frequency and mean nematode density of the recorded genera in each zone were calculated according to Tayllor and Loegering methods as modified by Araya (2002):

Prevalence: [(number of field positive for genus)/(total number of fields in zone)] x 100

Mean density in root or soil: [(total number per g root or 100 ml soil)/number of fields positive for genus)].

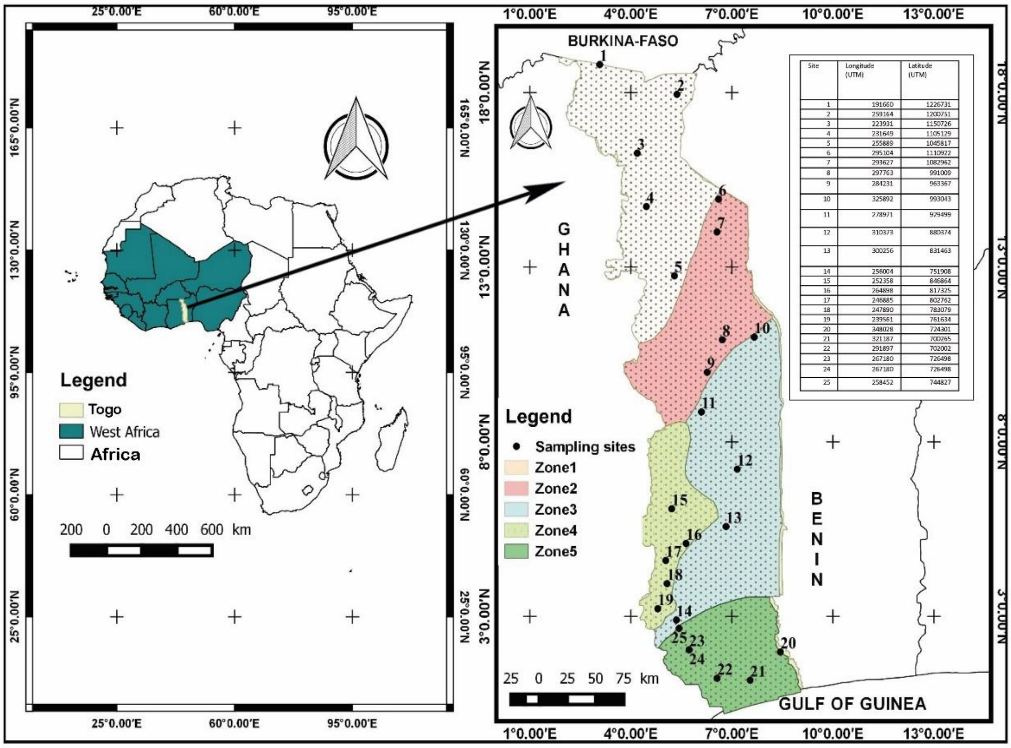


Figure 1: Sample collection sites.

RESULTS

Diagnostic survey

A total of 12 nematode genera (*Criconema*, *Dolichodorus*, *Helicotylenchus*, *Heterodera*, *Hirschmanniella*, *Meloidogyne*, *Pratylenchus*, *Scutellonema*, *Tylenchorhynchus*, *Trichodorus*, *Tylenchid* and *Xiphinema*) were found to be associated to rice cultivation in this survey. The Figure 2 showed the morphology of the main genera of nematodes recorded in the present survey.

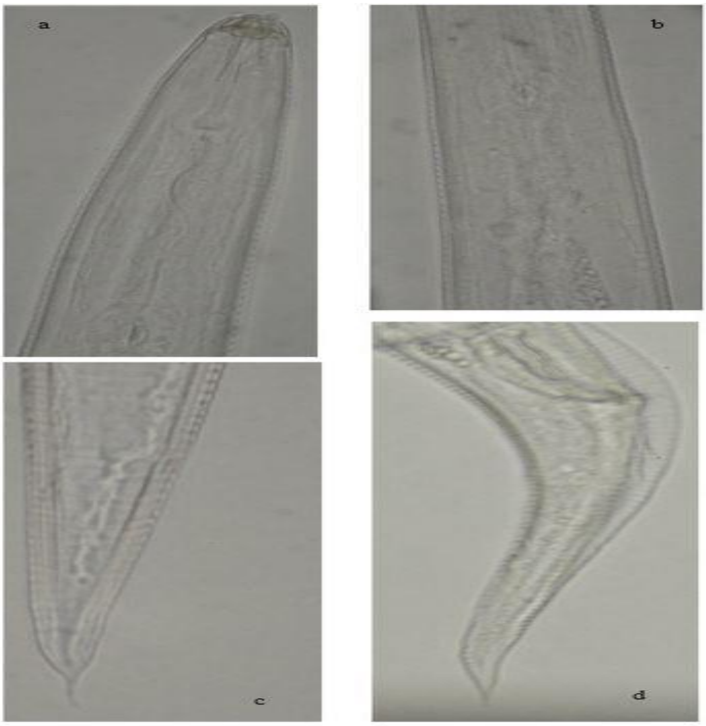
The prevalence of most genera was low, ranging from 20 to 80% (Table 1). *Hirschmanniella* (80% in zone 3) and *Xiphinema* (80% in zone 2) were the most prevalent followed by *Meloidogyne* (60% in zone 2 and zone 3) and *Scutellonema* (60% in zone 3). Plant parasitic nematode density varied with agroecological zones and nematode habitat, with higher densities recorded from soil samples compared to rice root (Table 1). Some nematodes such as *Meloidogyne* and *Pratylenchus* occurred on rice at population densities as high as 194 and 120 per g root, respectively. Similarly, *Hirschmanniella* occurred at population density as high as 495 per 100 ml soil and 80 per g root.

The genus *Scutellonema* occurred in all five agroecological zones of the country, with the species *S. bradys* occurring in Zone 2, while *Tylenchorhynchus*, *Trichodorus*, *Heterodera*, *Pratylenchus* and *Dolichodorus*, seem to be agroecologically restricted. *Meloidogyne* and *Hirschmanniella* were the most diversified occurring in four of the five agroecological zones, while *Xiphinema* occurred in three zones (Table 2).

With regard to nematode habitat, five out of twelve genera, *Criconema*, *Dolichodorus*, *Trichodorus*, *Tylenchid* and *Xiphinema*, were recorded from soil samples only, while three, *Heterodera*, *Pratylenchus* and *Tylenchorhynchus* were found to be associated only to rice roots. The remaining four genera, *Helicotylenchus*, *Hirschmanniella*, *Meloidogyne* and *Scutellonema* were recorded from both soil and root samples (Figure 3 and Table 2). From the 3,880 individual uncounted, 2,230 individuals (57.47%) and 1,650 individuals (42.53%), were recorded from soil and root samples, respectively (Figure 3). Out of the 50 composite soil samples, the prevalent nematodes encountered were *Hirschmanniella*, *Helicotylenchus*, *Xiphinema*, and *Scutellonema* with 29.12, 9.54, 6.96, and 5.1% frequency of occurrence, respectively (Figure 3). *Meloidogyne* followed by *Hirschmanniella* with respectively 25.52 and 5.15% of the recorded nematodes, were the most prevalent genera from the 25 collected root samples (Figure 3).

When comparing rice ecosystem, the highest plant-parasitic nematode population diversity and density were recorded from lowland rice ecosystem, with 1,910 individuals (85.65%) per 100 ml soil and 1,490 individuals (90.30%) per g of fresh root weight. With ten out of twelve genera (*Hirschmanniella* (1290 individuals), *Meloidogyne* (1010 individuals), *Xiphinema (*240 individuals), *Scutellonema* (230 individuals), *Helicotylenchus* (160 individuals), *Heterodera* (160 individuals), *Criconema* (130 individuals), *Pratylenchus* (120 individuals), *Trichodorus* (40 individuals) and *Tylenchid* (20 individuals)), the lowland ecosystem shows more nematode diversity than the upland and flooded ecosystems considered together. The latter two rice ecosystems accounting for two (*Helicotylenchus* and *Scutellonema)* and five (*Dolichodorus, Helicotylenchus, Tylenchorhynchus*, *Scutellonema* and *Xiphinema*) genera, respectively (Figures 4 and 5).

Total nematode densities of 170 individuals per 100 ml soil and 80 individuals per g root, were counted from flooded rice ecosystem, while 150 individuals per 100 ml soil and 80 individuals per 1 g were registered from upland rice ecosystem (Figures 4 and 5).



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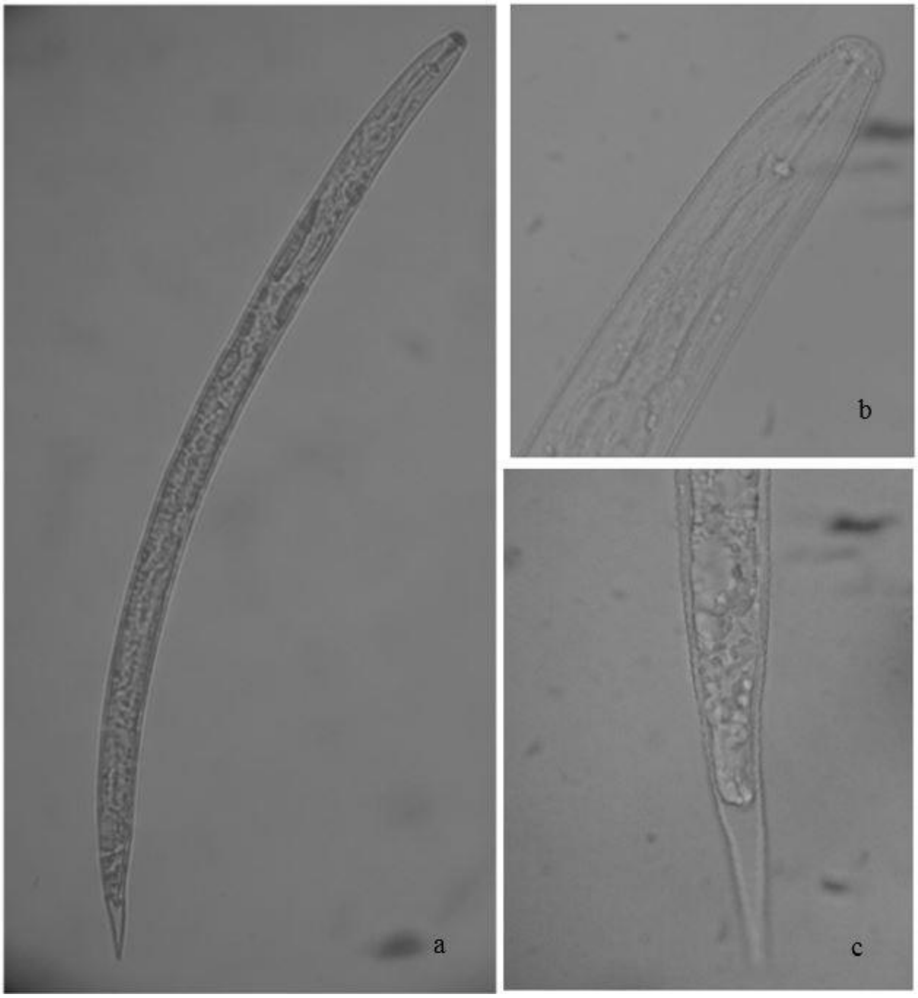

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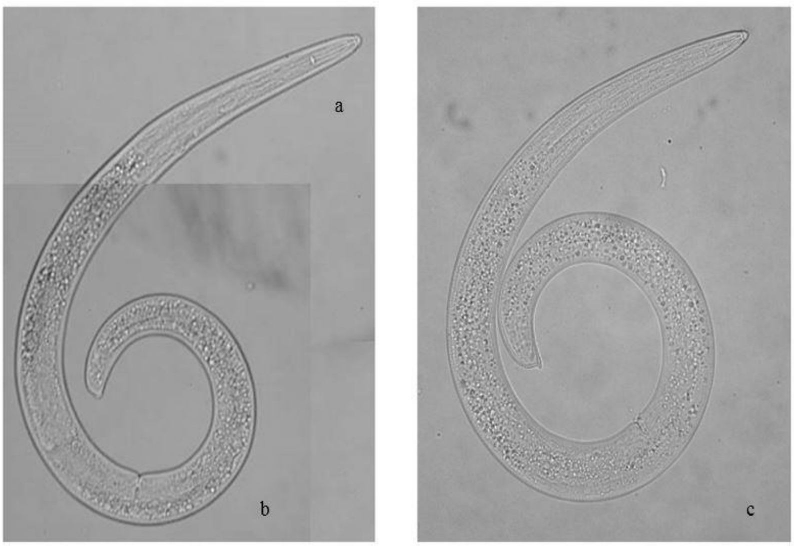

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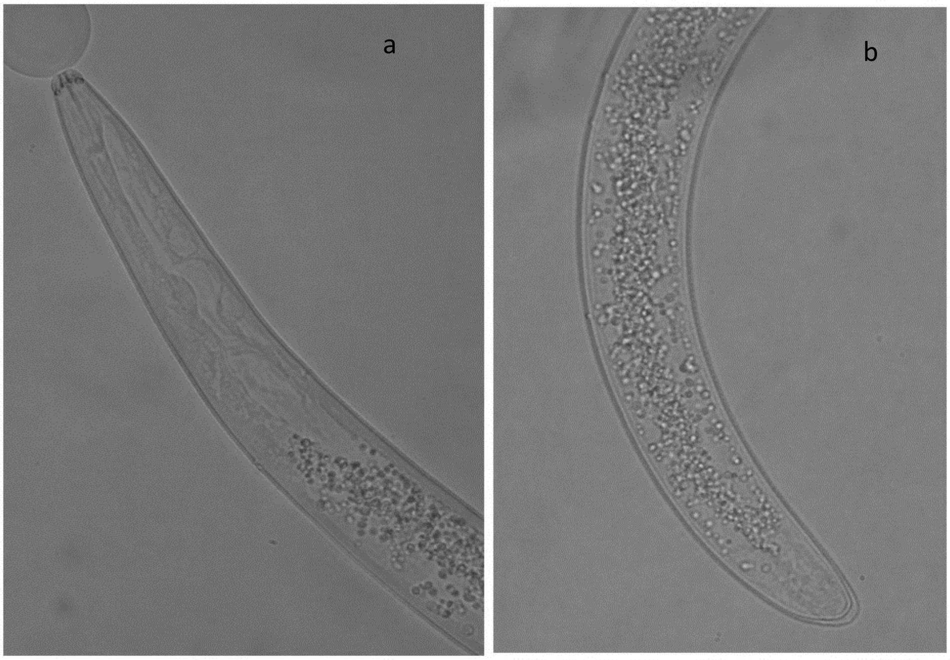

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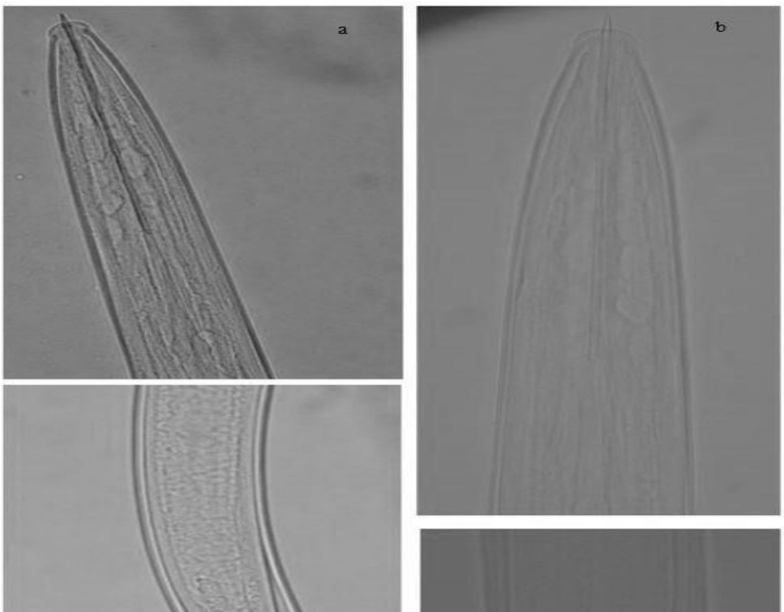

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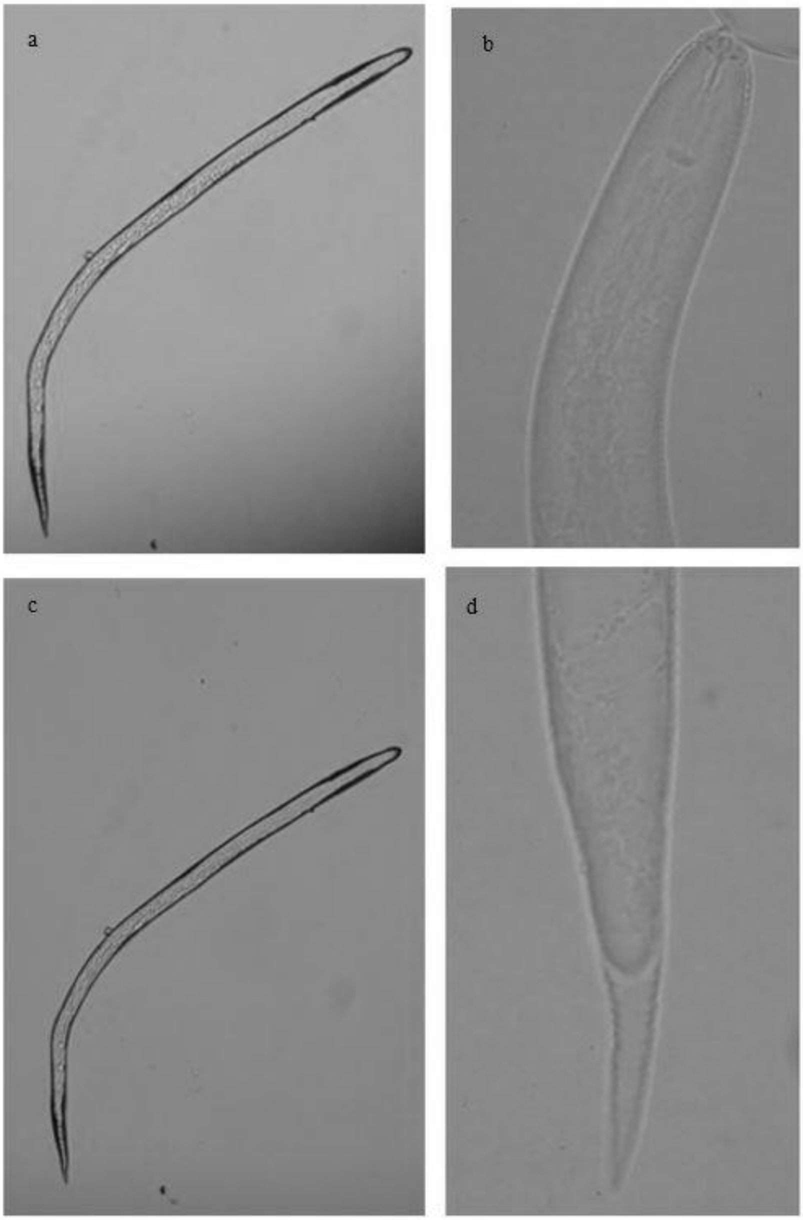

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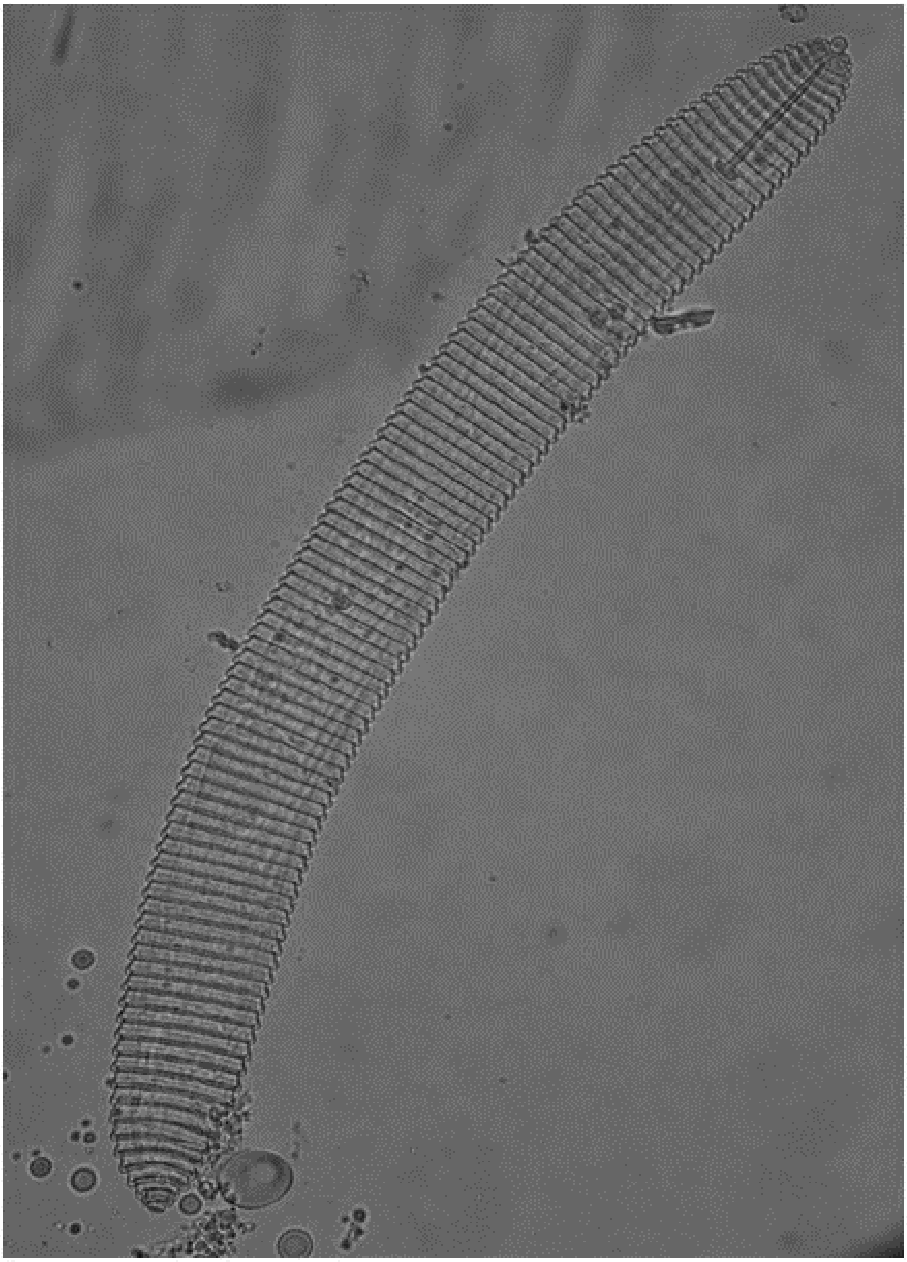

[G]

Figure 2: Morphology of the main plant-parasitic nematode genera recovered from the rice growing ecosystem in Togo: [A] *Hirschmanniella* spp.: Anterior region of the body (a), pharynx end (b), Posterior region of the female (c) and posterior region of the male (d); [B] *Meloidogyne* spp.: Entire body (a), anterior region of the body (b), posterior region of the body (c); [C] *Helicotylenchus* spp.: Anterior region of the body (a), posterior region of the body (b), entire body (c); [D] *Scutellonema* spp.: Anterior region of the body (a), posterior region of the body (b); [E] *Xiphinema* spp.: Anterior region of the body (a and b), posterior region of the body (c), base du pharynx (d); [F] *Heterodera* spp.: Entire body (a and c), anterior region of the body (b), posterior region of the body (d) and [G] *Criconema* spp.: entire body.

Table 1: Prevalence and mean density of plant parasitic nematodes in rice in different agroecological zones of Togo.

Nematode genera	Zone 1			Zone 2			Zone 3			Zone 4			Zone 5		
	P (%)	Root*	Soil*	P (%)	Root	Soil	P (%)	Root	Soil	P (%)	Root	Soil	P (%)	Root	Soil
Criconema	-	-	-	20	-	40	-	-	-	20	-	60	20	-	30
Dolichodorus	20	-	40	-	-		-	-	-	-	-	-	-	-	-
Helicotylenchus	-	-	-	40	-	110	-	-	-	40	40	150	-	-	-
Heterodera	-	-	-	-	-	-	-	-	-		-	-	20	80	-
Hirschmanniella	40	40	30	20	-	80	80	80	495	20	-	30			-
Meloidogyne	-	-	-	60	80	20	60	194	-	40	105	-	20	40	-
Pratylenchus	-	-	-		-	-	-	-	-	20	120	-	-	-	-
Scutellonema bradys	-	-	-	20	-	20	-	-	-	-	-	-	-	-	-
Scutellonema	40	-	60		-	-	60	30	30	20	40	-	20	-	40
Trichodorus	-	-	-	20	-	40		-	-	-	-	-	-	-	
Tylenchid	-	-	-	-	-	-		-	-	-	-	-	20	-	20
Tylenchorhynchus	20	40		-	-	-		-	-	-	-	-		-	
Xiphinema	-	-	-	80	-	110	40	-	30	-	-	-	20	-	20

*P: Prevalence (%); *: Nematode mean density;* root (g), soil (100 ml)

Table 2: Occurrence of plant parasitic nematode genera in soil and root samples from 25 fields of the 5 agroecological zones of Togo during the 2016 growing season**.**

	Agroecological Zones[a]									
Nématode genera	**Zone 1**		**Zone 2**		**Zone 3**		**Zone 4**		**Zone 5**	
	Soil	**Root**	**Soil**	**Root**	**Soil**	**Root**	**Soil**	**Root**	**Soil**	**Root**
Criconema	-	-	*	-	-	-	*	-	*	-
Dolichodorus	*	-	-	-	-	-	-	-	-	-
Helicotylenchus	-	-		**	-	-	**	**	-	-
Heterodera	-	-	-	-	-	-	-	-	-	*
Hirschmanniella	**	**	*	-	**	**	*	-	-	-
Meloidogyne	-	-	**	**	-	**	-	**	-	*
Pratylenchus	-	-	-	-	-	-	-	*	-	-
Scutellonema	**	-	*	-	**	**	-	*	**	-
Tylenchorhynchus	*	*	-	-	-	-	-	-	-	-
Trichodorus	-	-	*	-	-	-	-	-	-	-
Tylenchid	-	-	-	-	-	-	-	-	*	-
Xiphinema	-	-	**	-	**	-	-	-	*	-

Legend: (-): not observed; (*): frequency between 0 and 30; (**): frequency between 30 and 80; [a]composite samples were collected from growing rice plots.

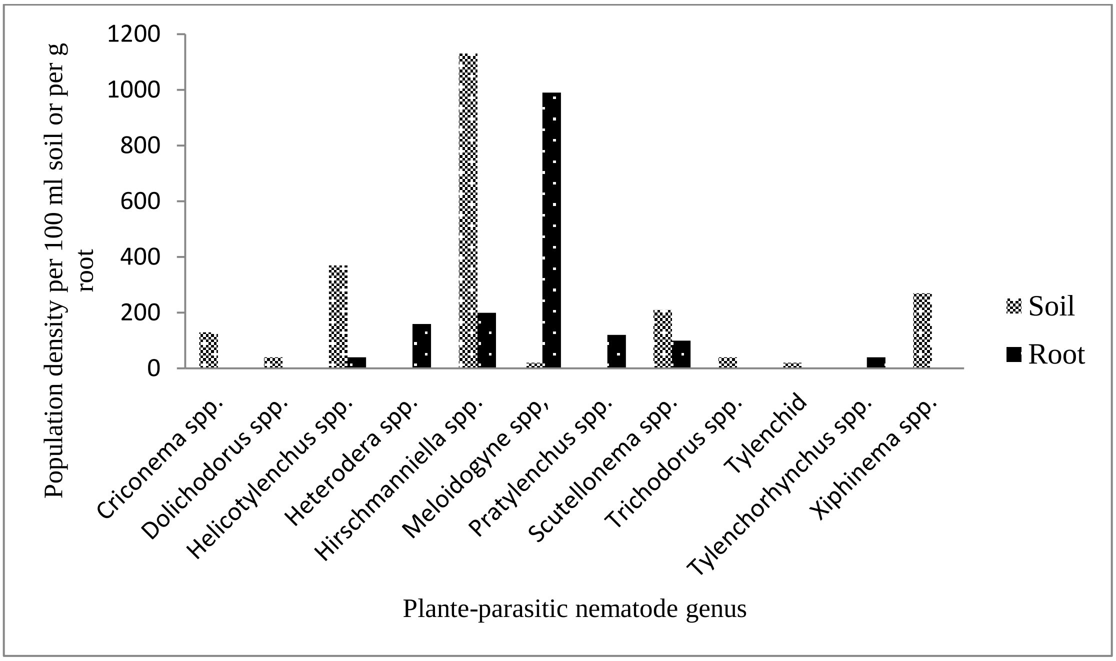

Figure 3: The plant parasitic nematode population density per 100 ml soil sample and per g fresh root weigh recovered in all the 5 rice agroecological growing zones in Togo, during the 2015 growing season.

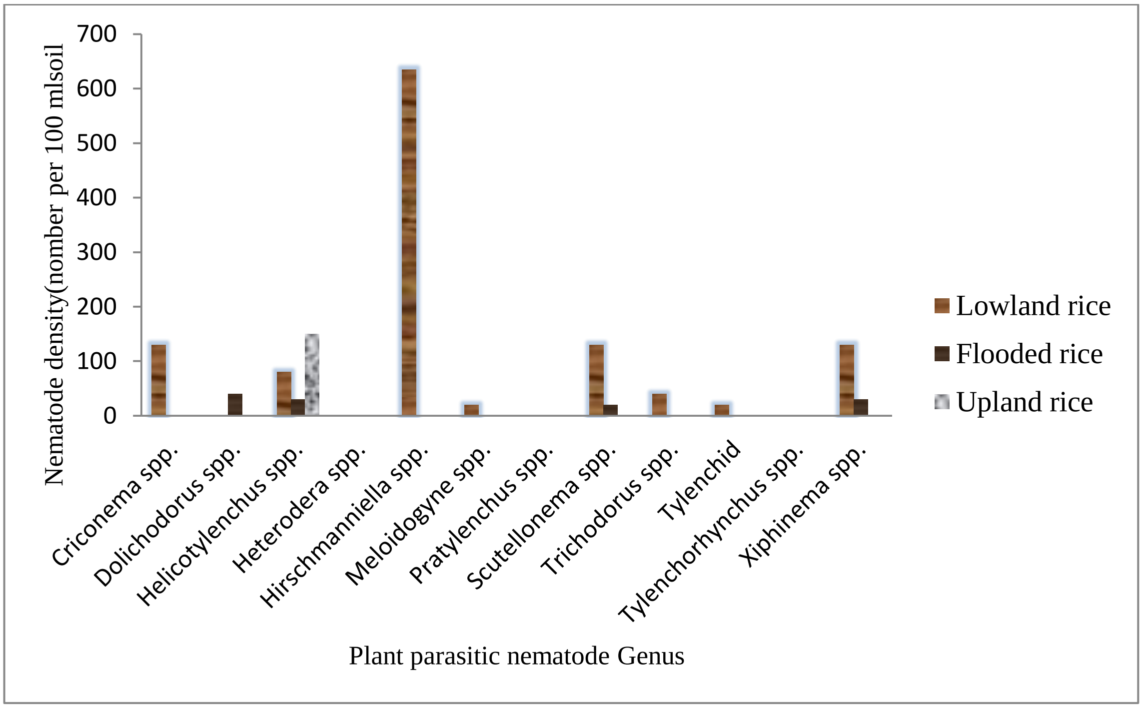

Figure 4: Mean population densities of nematodes in soil associated with flooded, lowland and upland rice ecosystems.

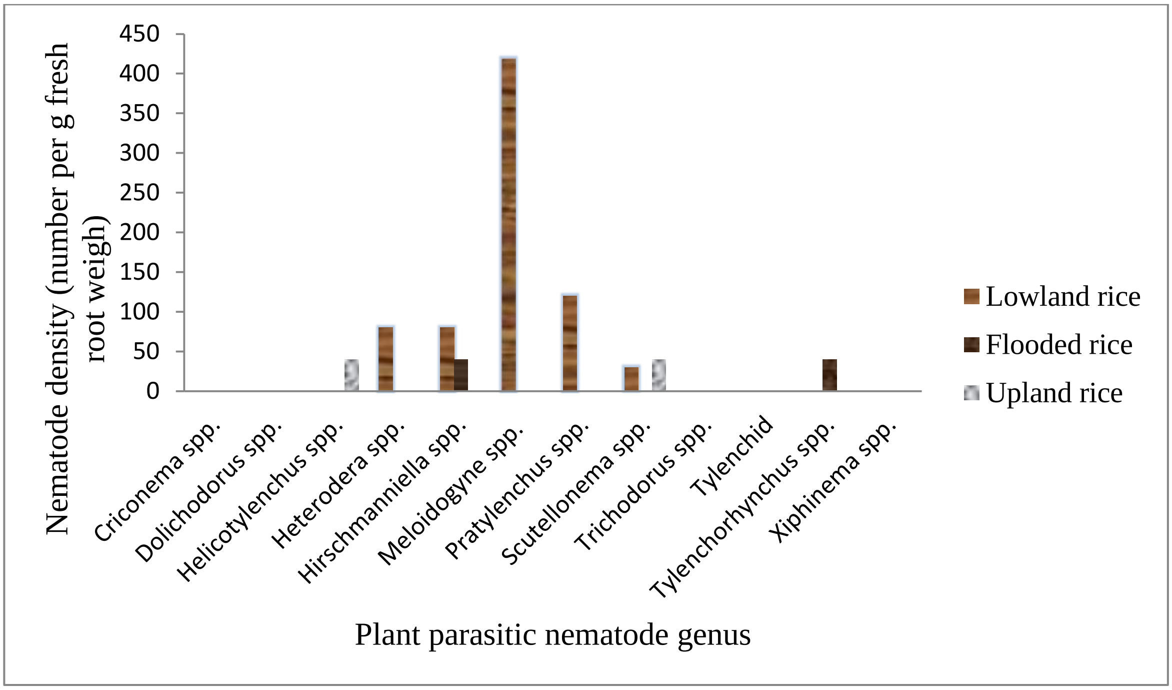

Figure 5: Mean population densities of nematodes in roots associated with flooded, lowland and upland rice ecosystems.

DISCUSSION

This study documented the occurrence, frequency and mean diversity of plant parasitic nematode genera associated with rice cultivation across agroecological zones of Togo targeting the major rice growing districts of the country. The results confirmed previous study from Coyne et al. (2000), who reported rice to be associated with plant parasitic nematodes in Togo. The inventory of parasitic nematodes associated with rice in Togo conducted in 1985 by Cadet and Mateille, cited by Coyne et al. (2000), showed that *Meloidogyne*, *Scutellonema*, *Heterodera*, *Hirschmanniella*, *Pratylenchus* and *Helicotylenchus*, were mainly observed to be associated with irrigated and strict rainfed rice production. Coyne et al. (2000) reported *Hoplolaimus clarissimus* and *Peltamigratus nigeriensis* to be associated with poor rice growth in Togo. The results of the current study have given a good indication of plant parasitic nematodes diversity on rice in different agroecological zones in Togo. Four of the twelve genera recorded *Heterodera*, *Meloidogyne*, *Pratylenchus* and *Xiphinema*, are known to be among the 10 top plant parasitic nematodes of scientific and economic importance (Jones et al., 2013). As noted by several other authors (e.g., Coyne et al., 1998), the prevalence and mean intensity of nematode genera varied with agroecological zones. With 12 plant parasitic nematodes genera recorded across the different rice production sites sampled, the present research identified in addition 6 plant parasitic nematode genera, namely *Criconema*, *Dolichodorus*, *Tylenchorhynchus*, *Trichodorus*, *Tylenchid* and *Xiphinema*, as compared with the previous surveys (Coyne et al., 2000). The genera richness is quite significant compared to the 35 nematode genera known to parasitize rice worldwide (Bridge et al., 2005). Recorded taxa are numerically comparable to those described in the Philippine (Pascual et al., 2014), particularly for the genera *Meloidogyne, Criconema, Hirschmanniella, Xiphinema Helicotylenchus, Pratylenchus* and *Tylenchorhynchus.* The variability of nematode genera observed in this survey could be attributed to the increasing intensification of rice production in the country. Different factors could have contributed to the distribution of these nematodes in the agro-ecological zones, including production systems, cultural practices employed. The noticeable occurrence of additional plant parasitic nematodes in rice growing systems could be due to changes in agricultural practices, particularly in use of new rice varieties and the practice of rice intercropping with other crops, mainly vegetables, gown for fresh market. Indeed, with the increasing scarcity of water and rainfall, most growers are often shifting from monoculture rice system to intensive and continuous intercropping with several other crops among which are vegetables known to be hosts of plant parasitic nematodes (Sharma et al., 2006; Anwar et al., 2007; Singh and Khurma, 2007; Anwar et al., 2013), particularly in lowland ecosystem initially dedicated to rice cultivation. In Togo, rice is grown mostly in lowland ecosystem where continuous production without interruption may result in an increase in nematode population diversity and densities, as documented in this study. The practice of rice intercropping with other crops, coupled with the continuous growing of rice, may tend to favor the development and buildup of a higher population density of nematode communities in rice agroecosystems (Eche et al., 2013) as observed here for *Helicotylenchus*, *Hirschmanniella*, *Meloidogyne* and *Scutellonema*. Among these, *Hirschmanniella* was found to be the most prevalent and abundant genus, occurring in both root and soil samples. These results confirm those of several research studies on rice parasitic nematode communities. Indeed, several studies have noted the predominance of nematodes belonging to the genus *Hirschmanniella* known as the most frequent and most damaging to rice in lowland and irrigated ecologies (Coyne et al., 2000; Ravichandra et al., 2003; Bridge et al., 2005; Maung et al., 2010; Udo et al., 2011; Thio et al., 2017).

In both soil and root samples, the genus *Meloidogyne* was recorded in lowland ecosystem at high frequency and density. No individual was however observed in either upland or flooded ecosystem although Bridge et al. (2005) reported *M. graminicola* to be well adapted to flooded conditions. The result of the current research confirmed however results from other investigations indicating that rice roots under continuous flooding are free from *M. graminicola*, and population levels of the this species may not build up during the wet monsoon season (Win et al., 2013).

The genus *Pratylenchus* has been identified only in Zone 4 of Togo (forest zone), although it has been encountered in Ghana in both shallow and upland rice ecosystems (Coyne et al., 2000). This type of nematode identified also in Côte d'Ivoire, Nigeria, Senegal and The Gambia (Fortuner, 1975, cited in Pascual et al., 2014; Udo et al., 2011) seems to be favored by a rice monoculture (Win et al., 2013). Moreover, *Pratylenchus* is widespread throughout sub-Saharan Africa (Coyne et al., 2000) and known to be common in upland ecologies (Bridge et al., 2005; Pascual et al., 2014). *S. bradys*, the yam nematode, known to be a major causal agent of dry rot in West Africa (Coyne et al., 2006), was recorded from soil samples only in zone 2, the main yam growing zone in Togo, indicating the role of intercropping practices in dissemination of plant nematode species.

In contrary to what has often been reported about the prevalence of rainfed rice nematode (Namu et al., 2018), only 2 genera (*Helicotylenchus* and *Scutellonema*) have been recorded from upland ecosystem in the study. The low nematode prevalence in the upland ecosystem as observed in this survey could be explained by the rice variety which is mainly cultivated in this area in Togo. Indeed upland rice cultivation is mainly characterized by the accessions of African rice, *O. glaberrima* Steud. (Poales) (Gnamkoulamba, 2012), known to be resistant to plant parasitic nematodes (Plowright et al., 2002). In this ecosystem, contrary to previous work that reported *Meloidogyne* and *Pratylenchus,* recognized as ubiquitous in rainfed rice ecosystems (Pascual et al., 2014), the two genera were not observed during this research work probably because of the recognized resistant potential for *O. glaberrima* against nematodes (Soriano et al., 2000). With only two genera recorded in upland ecosystem our results contradicted that of Pascual et al. (2014), who reported in Philippines, higher parasitic nematode diversity in upland rice ecology with nine out the fourteen (14) recorded.

The genera *Meloidogyne*, *Pratylenchus*, and *Hirschmanniella*, were observed in both lowland and upland roots implying that they were root parasites of rice as was indicated in previous reports (Bridge et al., 2005; Triviño et al., 2016). This suggests that rice in Togo is a good host for these nematode genera. Our results showed higher nematode densities and diversities from soil than root samples, with *Trichodorus* spp., *Tylenchid* spp., *Xiphinema* spp., *Criconema* spp. and *Dolichodorus* spp., being recorded only from soil samples, usually at relatively low densities. Our findings confirmed the genus *Criconema* to be associated only to soil sample as reported by Bridge et al. (2005). Although Bridge et al. (2005) recorded nematode genera such as *Tylenchorhynchus* and *Helicotylenchus* in soil samples, usually at relatively low densities, and without any clear established association with rice, our results showed that *Helicotylenchus* was associated with both soil and root samples, while *Tylenchorhynchus* was recorded from rice root samples both at high densities. Pascual et al. (2014) in Philippines, reported *Helicotylenchus,* as well as *Meloidogyne, Scutellonema* and *Hirschmanniella* from both soil and rice root samples establish their association with rice production.

The genus *Xiphinema*, viruses vector nematode (Demangeat, 2007), was not found associated to rice cultivation in the previous studies conducted in Togo although it was reported to be associated to several important economic crops including vegetables, sorghum, cassava, yam, coffee and cotton (Coyne et al., 2000). Our result recorded however *Xiphinema* from rice growing plot with high frequent but low density. Such occurrence might result from rice being intercropped with other crops as indicated above.

The twelve plant-parasitic nematodes recorded in this survey have all been associated with yield reduction in many crops worldwide (Afolami et al., 2014). From these, rice pest statute of some nematode genera such as *Meloidogyne, Hirschmanniella, Helicotylenchus, Tylenchorhynchus, Pratylenchus* and *Heterodera,* is well established (Padgham et al., 2004; Pascual et al., 2014; Triviño et al., 2016). *Tylenchorhynchus* is common to rice grown in all rice ecologies (Bridge et al., 2005), while *Heterodera* is mainly an important parasite of strict and lowland rainfed rice (Bridge et al., 2005). Among recorded genera, *Dolichodorus, Trichodorus, Tylenchid, Criconema,* and *Xiphinema*, registered only in soil samples, do not appear to be subservient to rice roots and some of which may not be included in the list of nematodes known or suspected to cause yield loss in rice (Bridge et al., 2005).

Conclusion

The taxonomic list of plant parasitic nematodes established in the present study showed that rice is attacked by various plant parasitic nematodes in Togo. Species belonging to the genera *Meloidogyne* and *Hirschmanniella* are the most common, in particular because of their large numbers counted. It is evident that cropping systems and the intensification of rice production have played an important role in the diversity and density of plant parasitic nematodes in rice growing ecologies of Togo. This would explain the significant dynamics of nematode numbers noted in the lowlands compared to the two other rice cropping systems. The genus diversity of plant parasitic nematodes recorded in rice producing ecologies in Togo requires further investigations on their damage potential on rice crop performance to establish the economic threshold level and estimate a cost-benefit analysis on management practices.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

GA conducted the field research work, with the technical support of TM and AAKM and wrote the article. The contributions of TM and AAKM can be estimated at 20% each. TAK supervised the completion of the study, from the protocol to the writing of the manuscript. He helped GA in writing the article. His contribution is estimated at 60%. The other authors contributed to the critical review of the article and their contribution can be estimated to 20%.

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