Enset (Ensete ventricosum) landraces associated parasitic nematodes and their relationship with Xanthomonas wilt disease in Gurage, Ethiopia

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ABSTRACT

Enset production in Ethiopia is constrained by nematode disease. This study has examined the type, abundance and distribution of plant parasitic nematodes (PPNs) and their relationship with Xanthomonas wilt of enset. Stratified random sampling technique was used to collect soil and root samples, and nematodes were extracted from the soil and fresh root samples. Eight nematode genera including, Pratylenchus, Meloidogyne, Helicotylenchus, Tylenchorhynchus, Meloidodera, Mchiroposthonia, Scutellonema and Xiphinema were recovered from the soil samples as well as Pratylenchus and Meloidogyne from the root samples. All roots and 87.7% of the soil samples possessed one or more nematode genus. Pratylenchus was the most abundant and frequently occurring nematode, accounting for 99.9% and 51.6% of the total nematode density recovered from the root and soil samples, respectively. The studied enset landraces significantly differed in the nematode they harbored, of which *Agerteremmat*, *Shertye*, *Kbvnar* and *Guurya* were the top for *Pratylenchus* but was lowest on *Lemnat*, *Yrigye*, *Beshute*, *Woka*, *Derewetye*, *Gufemne*, *Charaka* and *Emirye* landraces. Nematode density was significantly higher in samples collected from agro-ecologies at higher altitudes. Moreover, the density of *Pratylenchus*, *Meloidogyne* and *Helicotylenchus* was remarkably higher on acidic compared with alkaline soils. Enset plants infected by *Xanthomonas* wilt showed significantly higher densities of *Pratylenchus*, *Helicotylenchus* and *Tylenchorhynchus*. This study provided additional evidence on the distribution and level of damage caused by nematodes on enset crops that is important to all the relevant stakeholders across the crop's value chain in designing and implementing feasible integrated pest management approaches.

1. Introduction

Enset (Ensete ventricosum (Welw.) Cheesman) is a herbaceous perennial root crop widely cultivated in the South and Southwestern Ethiopia. Nearly 20 million of the country’s population depends on enset for food, fiber, animal forage, construction materials and medicines (Brandt et al., 1997; Zippel, 2002). Gurage is among the major enset producing zones in the Southern region of the country with rich diversity of landrace enset (Gerura, 2007; Worku, 1996; Tsegaye and Struik, 2002). It is the single most important staple crop for the Gurage people ensuring food security, mainly due to its inherent drought tolerance, and enset products are storable for an extended period without spoilage (Brandt et al., 1997; Gerura et al., 2019).

The enset based farming system as a whole and whole enset crop in particular is the major livelihood source for the people of Gurage Zone stands first in terms of area coverage (129233 ha) which is equivalent to 29.9% of the total area (Bethel et al., 2021). From the total area, a yield of 93940.1 tons was produced in the year 2020 (Bethel et al., 2021).

In recent years, enset production has been challenged by various biotic and abiotic factors, of which severe drought and diseases are among the most important (Tsegaye and Struik, 2002; Tenaye and Geta, 2009; Almaz et al., 2002). Bacterial wilt caused by *Xanthomonas campestris* pv. *musacearum* is the most destructive disease of enset crop (Bobosha, 2003). The root lesion nematode, *Pratylenchus goodeyi*, is also among the most important constraints of enset production, which is often found in large numbers, associated with *Xanthomonas* wilt affected plants (Kidane et al., 2020; Peregrine and Bridge, 1992). The nematode increases the plant’s susceptibility to bacterial wilt by damaging the roots and playing a role in the transmission of the disease, and thus plays an
important role in the development and severity of the bacterial wilt (Peregrine and Bridge, 1992; Quimio and Tessera, 1996).

There are only a few studies on the extent of damage caused by nematode on enset, but a significant annual yield loss of 56% in Ghana (Speijer et al. 1997) and 60% in South Africa (Speijer and Fogain, 1999) has been reported on banana, the closest relative to enset. The association of root lesion nematodes (RLN) with both banana and enset in Ethiopia was first reported by O’Bannon (1975). These nematodes are migratory endoparasites causing extensive damage to cortical cells in plants during migration and feeding activities (Castillo et al., 1998). Infection caused by RLN has been the major reason for farmers’ complaints of topping of mature whole plants of enset, even in light winds (Peregrine and Bridge, 1992). In particular, *Pratylenchus goodeyi* was reported causing damage to roots and the outer cortex of the corm of enset, which appears as characteristic lesions that develop into cavities of up to 2 cm diameter (Kidane et al., 2020; Peregrine and Bridge, 1992).

Over the past few years, nematological surveys across the enset production regions of Ethiopia detected important PPNs genera of enset, predominantly *P. goodeyi*, followed by *Meloidogyne* spp. and *Aphelenchoides ensete*. The population density of *P. goodeyi* was different across sampled enset producing areas and cultivars, and the Agena area of the Gurage zone was identified as the hot spot infestation area (Bogale et al., 2004; Kidane et al., 2020).

Cultural practices of the area that the farmers growing enset are performing is believed to favour the accumulation of nematode population over time. The perennial nature of the crop (6–12 years to mature) together with the absence of crop rotation and changing cultivation allowed the nematodes to multiply efficiently and invade the crop in the course of production.

However, no comprehensive surveys were performed that considered the existing enset landraces of Gurage zone across the different enset growing altitudes and soil characteristics. Consequently, information on the association of PPNs density with enset landraces, altitude and soil differences, and bacterial wilt disease is scant. Therefore, this study was aimed to assess the biodiversity and abundance of enset associated PPNs within enset landraces, altitude and soil differences in relation to the prevalence of Xanthomonas wilt disease.

2. Materials and methods

2.1. Survey site

The study was conducted in Gurage zone of the Southern Nations Nationalities and Peoples Regional State (SNNPRS), Ethiopia located between 7.4°–8.3° North latitude and 37.2°–38.5° East longitude of the equator (Figure 1). Gurage zone consisted 410 peasant association (PA, smallest administrative unit), of which enset is cultivated in 350 of the PAs (GFEDD, 2018).

Based on the Ethiopian Ministry of Agriculture (2000) agroecological classification, the enset producing areas of Gurage fall into two classes i.e., Woina Dega (midlands) with altitudes ranging from 1500–2300 masl, and Dega (highlands) from 2300-3200 masl. Among the enset producing PAs, 65.2% are located in the midlands, and the rest (34.8%) are found in the highland agro-ecologies. The study followed a stratified random sampling procedure and was designed to represent two enset growing altitude classes. In each stratum, high enset producing PAs were randomly selected proportional to the number of PAs in each stratum. PAs with comparatively higher enset production coverage in each stratum were selected based on crop coverage data obtained from the Gurage Zonal Finance and Economic Development Department.

A total of 23 enset producing PAs, of which 15 i.e., Aqaj-treh, Azer, Boketa, Desene, Emdebera, Gasore, Kochira, Lay-geraba, Luke, Mekana, Merab-embor, Welensho, Workat and Wudiget representing the midlands called “Woina Dega” in the local language and eight i.e., Wasamar, Dakuna, Agata, Kuneber, Dega-nurena, Gedeb, Endebuyu and Jemboro representing the highlands referred to “Dega” in the local language were randomly selected for the study. Similarly, enset farms within the PAs were selected based on the level of enset landrace diversity (Figure 1). A

![Figure 1. Map showing nematode sampling sites in Gurage Zone, Ethiopia.](image-url)
maximum possible number of enset landraces in triplicates were sampled from each PA.

2.2. Sample collection

Soil and root samples from similar age group (5–6 years) of enset landraces were collected from the different locations and agro-ecologies. To examine the relationship between nematode damage and enset *Xanthomonas* wilt prevalence, soil samples from both healthy and *Xanthomonas* wilt diseased enset landraces were collected and nematodes extracted, following all the sanitary protocols. A total of 530 composite soil samples were collected using an auger from a depth of 20 cm around the enset root zone and from 30 cm radius of the pseudo stem. In addition, 66 enset root samples were also collected from enset plants in the

![Figure 2](image1.png)

**Figure 2.** Frequency (%) and abundance of nematode genera associated with enset in soil biosphere.

![Figure 3](image2.png)

**Figure 3.** Heat map showing abundance of nematode genera based on sampled PAs of Gurage Zone, Ethiopia. The dendrogram on the top of the heat map demonstrates the clustering of nematode genera based on their abundance in sampled PAs, while on the left represents the clustering of PAs based on their nematode abundance. On the right hand side and at the bottom of the heat map are the names of the PAs sampled and the genera of nematodes in which dense red colour represents the greatest abundance of a genus in the corresponding PA and with decreasing nematode density the colour intensity decreases to yellow to light whitish yellow colour. Grey colour represents absence of a nematode genus.
survey area. The collected soil and root samples were put in labelled plastic bags and taken to plant disease diagnostics lab of Jimma University, Ethiopia for analysis. Samples were kept in a refrigerator at 5°C until extraction of nematodes.

2.3. Nematode extraction, identification and quantification

Each soil sample was thoroughly mixed, and an aliquot of 100 ml was taken for nematode extraction using the modified Baermann tray method (Hallmann and Subbotin, 2018). Similarly, root samples were washed-off adhering soil with running tap water, 10 g samples taken, teased and cut into pieces using a scalpel and incubated; nematodes were recovered after 48 h. Nematodes were identified to the genus level using key morphological (Siddiqi, 2000) and quantified under a compound microscope from a duplicate of 1 ml nematode suspension in a counting dish. Each nematode genus was expressed as the total number per 100 ml of soil and 10 g of fresh root.

2.4. Statistical analysis

Nematode densities of each genus were subjected to analysis of variance to determine the statistical significance of differences among the enset landraces, locations and agro-ecologies. The frequency of nematode occurrence and prevalence values were calculated following the method described by De Waele et al. (1998). Nematode abundance was also calculated as the sum of nematodes/L for all the samples containing that nematode, divided by the number of positive samples for that nematode and expressed as a decimal logarithm (log x + 1). The threshold of abundance and frequency of nematodes was determined following Sawadogo et al. (2009). Accordingly, nematodes were considered abundant in the soil, if abundance is > 2.3 (200 individuals/L of soil), and in roots, if abundance is ≥1.3 (20 individuals/g of roots), and frequent, when observed in at least 30% of the soil samples. Soil pH classes were determined following the recommendation of USDA Natural Resources Conservation Service (1998). Soil pH was measured in the supernatant suspension of a 1:2.5 soil:water ratio mixture using pH meter (Rayment and Higginson, 1992). The relationship between soil pH with nematode density was determined using ANOVA and bivariate correlation analysis. Independent sample t-test was performed to determine the relationship between enset Xanthomonas wilt disease occurrence and nematode density. ANOVA and other statistical analyses were performed using SPSS version 20 software (SPSS, 2011). The abundance of nematode genera across the studied locations was represented as a heatmap using pheatmap 1.0.12 package (Kolde, 2019) in R software version 4.0.3 (R Core Team, 2020). Geographical distribution and abundance of Pratylenchus nematode was performed using Geo-Statistics model of ArcGIS application version 10.1.

Table 1. Mean density of parasitic nematodes from enset rhizosphere in 100 ml soil across elevation differences.

| Altitude (masl)   | Mean of each nematode genera 100 ml⁻¹ soil* |
|-------------------|-------------------------------------------|
|                   | Praty | Meloi | Helic | Tylen | Xiph | Scut | Mach | Meld |
| 1500–2300 (midlands) | 73.5  | 25.9  | 24.1  | 2.0   | 0.43 | 0.08 | 0.09 | 5.70 |
| 2300–3200 (highlands)| 90.6  | 38.1  | 55.8  | 16.7  | 0.00 | 0.00 | 0.15 | 0.07 |

* Praty = Pratylenchus, Meloi = Meloidogyne, Helic = Helicotylenchus, Tylen = Tylenchorhynchus, Xiph = Xiphinema, Scut = Scutellonema, Mach = Machroposthonia and Meld: Meloidodera; NS = Not significant.
3. Results

3.1. Plant parasitic nematodes of enset rhizosphere

A total of eight plant parasitic nematode genera were identified from the enset rhizosphere. These include *Pratylenchus*, *Helicotylenchus*, *Meloidogyne*, *Tylenchorhynchus*, *Machroposthonia*, *Scutellonema*, *Meloidodera* and *Xiphinema* (Figure 2). Among the genera identified, *Pratylenchus* was the predominant genus with a total nematode density of 39,707 and frequency of occurrence 72.6%, followed by *Helicotylenchus* (18,292 total density and 27.7% frequency of occurrence) and *Meloidogyne* (15,319 total density and 49.8% frequency of occurrence) (Figure 2).

### Table 2. Mean density of nematode genera 100 g⁻¹ soil associated with the different enset landraces. Nematode counts were first Log (x + 1) transformed and analyzed.

| Landraces   | Number of samples | Praty  | Meloi  | Helic  | Tylen  | Xiph  | Scut  | Mach  | Meld |
|-------------|-------------------|--------|--------|--------|--------|-------|-------|-------|------|
| Ageremremat | 12                | 440.0a | -      | -      | 6.9a   | -     | -     | -     |      |
| Shertye     | 9                 | 383.2ab| 24.7   | -      | 60.3ab | -     | -     | -     |      |
| Kilnaw      | 6                 | 240.0ab| 25     | 90bc   | 28.3bc | -     | -     | -     |      |
| Nesero       | 6                 | 212.5ab| 60     | 5ef    | 7.5f   | -     | -     | -     |      |
| Yiregiiye   | 9                 | 179.1ab| 132.7  | 11.8de | 7.3f   | -     | -     | -     |      |
| Anzela       | 9                 | 171.2ab| 33.3   | 10be   | -      | -     | -     | -     |      |
| Tetteret     | 9                 | 169.2ab| 35.8   | 33.3de | 4.2f   | -     | -     | -     |      |
| Edebo       | 12                | 156.7ab| 23.3   | 6.7ef  | -      | -     | -     | -     |      |
| Beresiye     | 9                 | 148.3bc| -      | -      | 21.7f  | -     | -     | -     |      |
| Badehet      | 12                | 130.6bc| 35     | 48.5ed | 12b    | -     | -     | -     |      |
| Kanchiwe     | 16                | 124.5bc| 68.8   | 14.9de | 4.9f   | -     | -     | -     |      |
| Ankefyye     | 12                | 111.5bc| 71.3   | 15bc   | 24.1f  | -     | -     | -     |      |
| Deree        | 15                | 111.1bc| 14.4   | 25.6de | 34.4b  | -     | -     | -     |      |
| Gimbwe       | 12                | 93.2bc | 45.8   | 100.8ab| 20.4b  | -     | -     | -     |      |
| Guarye       | 18                | 82.2bc | 37.1   | 175.3f | 4.2f   | -     | -     | 52.4  |      |
| Eniba        | 12                | 77.0bc | 54     | 13bc   | 2f     | -     | -     | -     |      |
| Beshute      | 12                | 76.7bc | 17.5   | 93.3bc | 1.7f   | -     | -     | -     |      |
| Separa       | 18                | 75.8bc | 25.3   | 29.3de | 5.5f   | 3.7   | 0.3   | 0.3   | 1.3  |
| Usmai        | 9                 | 74.4bc | 10     | 81.1bc | -      | -     | -     | 3.3   |      |
| Ginjive      | 6                 | 71.5bc | -      | 32b    | -      | -     | -     | -     |      |
| Agorgur      | 12                | 66.3bc | 4.3    | -      | -      | -     | -     | -     |      |
| Agade        | 18                | 66.2bc | 19.7   | 77.6bc | 16.8b  | -     | -     | -     |      |
| Aywene       | 9                 | 63.3bc | 6.7    | 3.3ef  | 13.3b  | -     | -     | -     |      |
| Wanadiye     | 9                 | 61.2bc | 14.2   | 49.2ed | 4.2f   | -     | -     | -     |      |
| Kibot        | 9                 | 60.0bc | 8      | 166a   | 6f     | -     | -     | -     |      |
| Yehiraqinpe  | 15                | 55.6bc | 31.5   | 1.5ef  | 4.5f   | 0.4   | 0.3   | 0.7   |      |
| Zober        | 9                 | 54.0bc | 2      | -      | 74f    | -     | -     | -     |      |
| Lemat        | 15                | 53.9bc | 17.9   | 12bc   | 2.5f   | -     | -     | -     | 0.7  |
| Astara       | 15                | 51.5bc | 11.6   | 14.3de | -      | -     | -     | -     | 0.7  |
| Fereziye     | 15                | 47.5f | 21.5   | 27.5de | 10.4f  | -     | -     | -     | 4.8  |
| Aneretiye    | 15                | 43.8f | 33.5   | 2.2ef  | 1f     | -     | -     | -     | 4.8  |
| Bazeriye     | 15                | 38.0f | 22.8   | 9.8bf  | -      | -     | -     | -     | 3.3  |
| Oret         | 7                 | 38.0f | 26.1   | 14.3bc | -      | -     | -     | -     | 3.3  |
| Nechiwe      | 15                | 34.6f | 34.6   | 3.5ef  | -      | -     | 1.2   | 3.5   |      |
| Teriye       | 9                 | 28.2f | 48.2   | -      | 6.6f   | -     | -     | -     |      |
| Gogote       | 9                 | 23.3f | 30     | 26.2ede| -      | -     | -     | -     |      |
| Bisere       | 9                 | 20.0f | 3.3    | 26.2ede| 30b    | -     | -     | -     |      |
| Chalute      | 9                 | 20.0f | 6.7    | 273.3f | 6.7f   | -     | -     | -     |      |
| Kerewete     | 6                 | 18.0ed| 33.3   | 16.7de | -      | -     | -     | -     | 0.7  |
| Yegyeswe     | 12                | 15.0ed| 25.3   | 2ed    | -      | -     | -     | 0.7   |      |
| Egendiye     | 9                 | 15.0ed| 65     | -      | -      | -     | -     | -     |      |
| Emirye       | 9                 | 15.0ed| -      | -      | -      | -     | -     | -     |      |
| Charkma      | 9                 | 10.0ed| 3.3    | -      | -      | -     | -     | -     |      |
| Gufene       | 6                 | 10.0ed| 3.3    | -      | -      | -     | -     | -     |      |
| Ashakit      | 9                 | 6.7ed | 10     | 100ab  | -      | -     | -     | -     |      |
| Buocehe      | 9                 | 6.0ed | 16     | -      | -      | -     | -     | -     |      |
| Derewete     | 9                 | -     | -      | -      | -      | -     | -     | -     |      |
| Woka         | 6                 | -     | -      | -      | -      | -     | -     | -     |      |
| Sig.         | *** NS *** NS NS NS NS NS NS NS NS |

Praty = *Pratylenchus*, Meloi = *Meloidogyne*, Helic = *Helicotylenchus*, Tylen = *Tylenchorhynchus*, Xiph = *Xiphinema*, Scut = *Scutellonema*, Mach = *Machroposthonia* and Meld = *Meloidodera*.
Comparatively, high density of Pratylenchus was recorded with a mean value of 79.9 individuals/100 ml of soil, followed by Helicotylenchus and Meloidogyne with 35.9 and 30.5 individuals/100 ml of soil, respectively. The densities and frequencies of occurrence of the rest nematode genera (Meloidodera, Tylenchorhynchus, Machroposthonia, Scutellonema and Xiphinema) were relatively low. Figure 2 below clearly shows that the genus Meloidogyne is relatively more frequent, but less densely populated than Helicotylenchus.

### 3.2. Parasitic nematodes across locations

Nematode density of Pratylenchus, Meloidogyne, Helicotylenchus and Tylenchorhynchus differed significantly (\( p > 0.006 \)) across locations. Pratylenchus was recovered with the highest mean density of 346.9 individuals/100 ml of soil from Merab-embor, while the least density (8 individuals/100 ml of soil) was from Emdebera (Figures 3 and 4). Pratylenchus and Meloidogyne genera were found to be cosmopolitan as they were recorded in all the survey locations. The highest density of Meloidogyne was from Dakuna PA with 142 individuals/100 ml of soil; while the least (<3 individuals/100 ml soil) were from Adoshe, Luke, Emdebera and Gedeb PAs (Figures 3 and 4). The highest mean nematode density (335.5 individuals/100 ml of soil) of Helicotylenchus was recorded at Adoshe PA, followed by at Jemboro (175.8 individuals/100 ml of soil) (Figures 3 and 4). Although no Helicotylenchus was recovered from Mekana, Luke and Gedeb PAs, the genus was widely distributed across the study locations next to Pratylenchus and Meloidogyne genera. The densities (individual/100 ml soil) of Machroposthonia, Scutellonema, Xiphinema and Meloidodera were nearly comparable across locations and were distributed only rarely. The genus Meloidodera was recorded only in two locations, Dakuna and Wudget, while Scutellonema and Machroposthonia recovered only from a single PA, Merab-embor and Gasore, respectively.

The heat map (Figure 3) demonstrates clustered PAs based on the abundance of nematode types they harbored in the enset soil. The PAs Merab-embor, Dakuna, Kuneber and Azer displayed the highest Pratylenchus nematode abundance; while Adoshe, Jemboro, Endebuyu and Dega-nurena harbored the highest Helicotylenchus nematode abundance. Wasamar and Gedeb were found to harbor the highest density of Tylenchorhynchus.

The nature of the distribution of Pratylenchus in the study area is shown in Figure 4. PAs around the highlands of Meskan areas appeared to be the hot spots for Pratylenchus and are highlighted in red (highly abundant), followed by pink and cream colors. Locations shaded in yellow color also possessed a substantial amount of Pratylenchus nematode, while those shaded in green possessed few or no Pratylenchus nematode.

### 3.3. Parasitic nematodes across the different altitudes

Enset growing highlands of Gurage zone (2300–3200 masl) were found to harbor significantly (\( p < 0.05 \)) higher genera of Meloidogyne, Helicotylenchus and Tylenchorhynchus compared to midlands (1500–23 00). However, the mean densities of Pratylenchus, Xiphinema, Scutellonema, Machroposthonia and Meloidodera did not differ statistically between the two altitude classes (Table 1).
3.4. Occurrence of parasitic nematodes among enset landraces

Ageremremat enset landrace harbored significantly (P < 0.05) higher Pratylenchus mean density of 440 individuals/100 ml of soil followed by Shertye, Kibnar and Nesero with 383.7, 383.7 and 240.0 individuals/100 ml of soil, respectively. Conversely, Pratylenchus mean density was low on the other landraces (Table 2).

Significant Helicotylenchus and Tylenchorhynchus mean density variation was observed among the studied enset landraces. Higher density of Helicotylenchus was recovered from Chalute, Guarye and Kibot landraces, and the lowest from Nesero, Eleso, Aywene, Yeshreaqine, Aneratyiye, Nechwe and Yegeywe (Table 2). Tylenchorhynchus density was high on the landrace Shertye, and low on Ageremremat, Nesero, Yiregye, Teteteret, Kanchiwe, Guarye, Eniba, Beshute, Separa, Wenaditye, Kibot, Yeshreaqine, Fereziye, Aneratyiye, Terye and Chalute.

There were no plant parasitic nematodes that are recovered in the samples collected from Woka and Derewetye landraces. By contrast, all of the eight genera of plant parasitic nematodes encountered in this study were present only on Separa landrace.

3.5. Biodiversity of plant-parasitic nematodes across pH gradient

Soil pH appeared to have significant effects on the mean densities of Pratylenchus, Meloidogyne and Helicotylenchus genera (Table 3). The highest mean Pratylenchus density (146.3 individuals/100 ml of soil) was recorded at a soil pH of between 5.6 and 6.0 (moderately acid). Likewise, significantly (P < 0.000) higher mean Meloidogyne density of 105.8 individuals/100 ml of soil was recorded in soil pH ranging from 5.6 to 6.0 (moderately acidic), and was not detected in strongly acidic soils. Higher mean Helicotylenchus densities of 167.1, 160.0 and 129.3 individuals/100 ml of soil were recovered from strongly, moderately, and slightly acidic soils, respectively, and not detected from strongly alkaline soils.

3.6. Xanthomonas wilt disease prevalence and nematode density

Xanthomonas wilt disease of enset is quite common in the enset farms of Gurage (Figure 5). Independent sample t-test revealed a significantly higher number of Pratylenchus and Helicotylenchus recovered from enset plants showing typical Xanthomonas wilt disease than wilt symptom-free plants. However, Meloidogyne revealed no significant density difference between Xanthomonas wilt-affected and healthy plants (Table 4).

3.7. Plant parasitic nematodes from roots of enset

Both Pratylenchus and Meloidogyne were identified from the enset root samples. The mean density of Pratylenchus was 3133.8 individuals/10 g fresh root (ranging from 44–15288) and the genus has occurred in all the collected root samples (with frequency of occurrence, FO = 100%) (Table 5). Roots and corms from which high density of Pratylenchus was recovered exhibited extensive black or purple necrotic cortical tissues (Figure 6). By contrast, Meloidogyne was recovered with a low mean density of 3.6 (0.0–74) individuals/10 g fresh root and limited to only a few root samples (FO% = 9.1%).

3.8. Abundance of nematodes on different enset landraces

A significant variation in the mean density of Pratylenchus was found among the different enset landraces (Table 6). The highest Pratylenchus mean density per 10 g of fresh root was recorded on enset landrace Bazeriye (11596), followed by Separa, Dere and Badedet with respective densities of 8226, 8168 and 6762. The lowest mean densities of 194, 273 and 288 Pratylenchus were recovered from Lemat, Yiregye and Beshute landraces, respectively. Even though there were no significant differences in the mean densities of Meloidogyne on the enset landraces, low number of Meloidogyne was recovered from roots of the landraces of Gesot, Aneratyiye, Guarye, Yegeywe, Nechwe and Kanchiwe.

The relative density and frequency of occurrence of important plant parasitic nematodes in both plant roots and soil rhizosphere is shown (Table 7). The number and frequency of occurrence of Pratylenchus was by far greater in plant roots than root rhizosphere. By contrast, the number and frequency of occurrence of Meloidogyne was greater in soil rhizosphere than in roots.

4. Discussion

This study provided an in-depth information on parasitic nematodes occurrence on enset crop in Gurage area of Ethiopia. Among the identified eight genera, Pratylenchus, Meloidogyne and Helicotylenchus were found to be prevalent in Gurage as the three genera of nematodes significantly excel the rest of the five nematodes in terms of density and frequency of occurrence and are above the standard limit (density of >2.3 and frequency of occurrence >30%). Pratylenchus was predominant in abundance and frequency in both soil rhizosphere and enset roots. Previously, P. goodeyi was reported as the dominant species on enset in the country (Peregrine and Bridge, 1992; Bogale et al., 2004; Kidane et al., 2020). Pratylenchus was also identified as the predominant genus of banana, a close relative of enset in Rwanda (Gaidashova et al., 2004), Tanzania and Burundi (Bridge, 1988) and Kenya (Gichure and Onidieki, 1977). The abundance and frequency of Meloidogyne and Helicotylenchus are...
Table 6. Nematode abundance per 10 g of fresh roots of the different enset landraces.

| Enset landraces | Number of samples | Mean density of nematode genera (#/10 g\(^{-1}\) root) |
|-----------------|-------------------|--------------------------------------------------|
| Pratylenchus    |                   |                                                  |
| Baseriyé        | 3                 | 11596\(^{a}\)                                    |
| Separa          | 3                 | 8226\(^{d}\)                                     |
| Dere            | 3                 | 8168\(^{b}\)                                     |
| Badehet         | 3                 | 6762\(^{b}\)                                     |
| Gesot           | 3                 | 4460\(^{b}\)                                     |
| Amerewiye       | 3                 | 3766\(^{c}\)                                     |
| Guaye           | 3                 | 3669\(^{b}\)                                     |
| Yegyewiye       | 6                 | 3413\(^{c}\)                                     |
| Kibner          | 6                 | 3399\(^{b}\)                                     |
| Nechiwe         | 3                 | 3116\(^{c}\)                                     |
| Feresté         | 3                 | 2417\(^{b}\)                                     |
| Yeshiraqine     | 3                 | 1672\(^{d}\)                                     |
| Gimbe           | 6                 | 742\(^{d}\)                                      |
| Agade           | 3                 | 741\(^{d}\)                                      |
| Kanchiwe        | 3                 | 644\(^{d}\)                                      |
| Zeguiréd        | 3                 | 516\(^{b}\)                                      |
| Beshute         | 2                 | 285\(^{d}\)                                      |
| Yiregyé         | 2                 | 273\(^{d}\)                                      |
| Lemet           | 2                 | 194\(^{d}\)                                      |
| Significance    |                   |                                                  |

Table 7. Mean population density and frequency of occurrence of the important PPNs on soil rhizosphere and in roots of enset

| Nematode genera | Mean number and frequency of occurrence (FO) of PPN |
|-----------------|-----------------------------------------------------|
|                  | Soil rhizosphere Root |
| Pratylenchus     | 79.9 FO (%) 3133.8 FO (%) |
| Meloidogyne      | 30.5 49.8 3.6 9.1 |
| Helicotylenchus  | 35.9 27.7 0 0 |
| Significance     | *** *** |

The landraces Ageremremat, Shertye, Separa, Dere, Badehet, Gesot, and Baseriyé harbored high mean density of Pratylenchus. On the other hand, landraces like Yeshiraqine, Gimbe, Agade, Ranchiwe, Zeguiréd, Beshute, Yiregyé and Lemet with low Pratylenchus densities may indicate a possible presence of resistance to Pratylenchus, subject to further resistant screening. Derewete and Woka enset landraces did not harbor any of the nematode genera. This may be either because of the sampled enset landraces were not initially infected or are resistant to the nematode genera identified in the study area. Differences in Pratylenchus densities among enset landraces were previously reported (Bogale et al., 2004; Kidane et al., 2020). Relatively acidic soils of the study area harbored significantly higher mean density of Pratylenchus, Meloidogyne and Helicotylenchus nematodes than alkaline soils. Talawana et al. (2008) have also reported higher Pratylenchus density in acidic soil on maize crop. Deficiency of important plant nutrients on acid soils might have resulted in weak plants that predisposed to nematode attack and/or the nematode multiplication.

Enset Xanthomonas wilt disease was found to be highly correlated with Pratylenchus population density. Such a relationship may indicate that the nematode infestation might have helped the spread of the wilt disease of the crop. Similar finding, where Pratylenchus was alleged to be strongly associated with Xanthomonas wilt disease of enset caused by Xanthomonas campestris pv. musacearum was reported by Quimio and Tessara (1996). In fact, different enset landraces and individual plants of the same landraces show variation in Xanthomonas infections (Muzemil et al., 2021).

In conclusion, Pratylenchus, appears to be a prominent parasitic nematode of enset crop in the study areas. The genera Meloidogyne and Helicotylenchus were also evident. The occurrence of Pratylenchus was higher at higher altitudes than in lower altitudes, on enset landraces Ageremremat and Shertye than the rest of the landraces, and in a relatively acidic than alkaline soils. Moreover, wilt affected plants harbored greater plant parasitic nematode population density than healthy enset plants. The high nematode density detected could result in significant yield losses. Hence, quantification of yield loss due to nematode attack needs to be considered for appropriate planning and designing management strategies.

Declarations

Author contribution statement

Fetta N. Gerura; Beira H. Meressa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Abush Tesfaye: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Temesgen M. Olango: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest’s statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.
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