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(Research Article)

Characterization and distribution of *Meloidogyne* species associated with tomato cultivation in Côte d'Ivoire

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Abstract

The fight against *Meloidogyne* is a major concern for market garden producers. This study aims to characterize and map the species of *Meloidogyne* associated with tomato cultivation in Ivory Coast. Thus, the incidence and severity of damage caused by nematodes were assessed. The observed symptoms presented significantly different incidences depending on the region. Indeed, the incidences of wilting, dwarfing, reduced leaves and yellowing of the central zone were respectively 30.66 ± 8.12^c, 19.55 ± 10.52^b, 26.88 ± 10.15^b et 36.22 ± 11.76^c while those in the northern zone were respectively 12.88 ± 5.01^b, 9.35 ± 4.28^a, 7.51 ± 4.77^a and 7.51 ± 5.93^b. Also, the prevalence of galls in the central zone (32.44 ± 10.71^b) was the highest and that of the northern zone (13.20 ± 2.17^a) the weakest. As for the severity of the galls, it was greater in the central-west zone (54.61 ± 28.47^b) and weaker in the east (10.94 ± 3.04^a). The extraction of nematodes made it possible to identify three species: *Meloidogyne arenaria*, *Meloidogyne incognita* and *Meloidogyne javanica*. The central area had the highest density (497.77 ± 234.61^b) and the lowest density (138.33 ± 66.56^a) to the east. This study provides important data to support decision-making in tomato cultivation.

Keywords: Root-knot nematodes; Tomato; Symptoms; Characterization; Distribution

1. Introduction

Agriculture is one of the main sectors of activity contributing to the socio-economic development of populations. It employs more than 40% of the world's working population, including more than 52% in Africa and Asia [1]. Within this sector, market gardening plays an important role in human nutrition [2]. According to [3], tomatoes are one of the most widely consumed vegetable crops in the world, as they are a major source of vitamins and a significant source of income for smallholders and commercial farmers with medium-sized holdings [4]. According to statistics from the Food and Agriculture Organization of the United Nations (FAO), global tomato production amounted to 165.5 million tonnes for a surface area of 4.77 million hectares [5]. However, these figures only take into account marketed production, and do not include family and food production, which can be significant in some regions. Defined as highly specialised agriculture, market gardening is one of the most productive agricultural systems in Africa [2]. In West Africa, it is one of the main components of urban and peri-urban agriculture and plays a vital role in the economic development of cities [2]. In Côte d'Ivoire, tomato production averages 10 t/ha [6], which is insufficient to cover the needs of the country's growing population, estimated at 100,000 tonnes of tomatoes a year [7]. Many factors can be cited to explain this low production. These include the influence of environmental factors causing abiotic or non- parasitic diseases and the high parasitic pressure of wetlands causing biotic or parasitic diseases. Nematodes of the *Meloidogyne sp*. genus, commonly known as root-knot nematodes or root-knot nematodes, are the most damaging pests of vegetable crops in tropical countries [8] and even worldwide [9; 10]. These nematodes are considered to be the most damaging. They top the list of the ten plant- parasitic nematode genera most closely followed by the scientific community because of their

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economic importance [11]. According to [12], the intensive use of synthetic organic plant protection products to control these nematodes has led to a considerable boom in agricultural and food production. However, the ecological problems that have subsequently arisen demonstrate the urgent need to find alternative, complementary and innovative methods of protecting market garden crops.

2. Materials and methods

2.1. Study environment

Our study was carried out in the regions of Haut-Sassandra (Daloa), (Bongouanou and Arrah), Indénié -Djuablin (Abengourou), Poro (Korhogo and Sinématiali), Tchologo (Ferkessédougou) and in the District of Yamoussoukro. The Haut-Sassandra, Moronou and Indénié-Djuablin regions have a hot, humid climate and average annual rainfall of between 1,000 and 1,500 mm. The average annual temperature in these regions varies between 21 and 35°C, with dense, humid forest vegetation that has been altered over time. This forest develops on alkaline to sub-alkaline soils with a sandy-clay texture and on ferralitic soils in the Haut-Sassandra, Moronou and Indénié-Djuablin regions respectively [13]. Yamoussoukro District has a transitional tropical climate with a dry season from November to March and a rainy season marked by two rainfall peaks, one in June and the other in September-October. The average annual temperature is 25.8°C, with pre-forest savannah vegetation dotted with trees and interspersed with forest galleries and patches of woodland. The soil is sandy and well-drained. The Poro and Tchologo regions have a subtropical climate, with average annual rainfall of between 1,100 and 1,300 mm. The terrain is relatively flat, with clay-textured soils.

2.2. Plant material

The tomato varieties (Solanum lycopersicum L) grown in the sample plots are 'UC 82 B', 'Cobra F1- 26' and 'Raja F1'. These varieties have determinate growth, medium vigour and 150/200 g/ 250 m2 of nursery space.

2.3. Methods

2.3.1. Description of foliar and root symptoms

Symptoms were described by observing chlorosis and leaf reduction, wilting and dwarfing of plants and root deformation with the naked eye.

2.3.2. Assessing the incidence of symptoms

For each symptom, the incidence was obtained by dividing the number of plants showing the symptom by the total number of plants, using the following formula:

$$I(\%) = \Sigma [(N_i) / N_t] \times 100 \ldots\ldots\ldots\ldots\ldots(1)$$

I: incidence; Ni: number of plants showing the symptom in question; Nt: total number of plants.

2.3.3. Assessment of the prevalence and severity of galls

Following an X pattern, 100 plants were selected along the two diagonals of the plantation. On each diagonal, 50 plants of approximately equal distance were selected and the number of plants showing galls was recorded. The prevalence of galls was calculated using the following formula:

$$PM (\%) = [(P_t) / N] \times 100 \ldots\ldots\ldots\ldots..(2)$$

PM: Average prevalence of galls; Pt = number of plants with galls; N = total number of plants selected

The severity of the galls was assessed using the Zeck (1971) scale, where:

0 = root system completely free of galls;
1 = a few rare, small galls detected during close observation;
2 = a few rare, small galls easily detected;
3 = numerous small galls
4 = numerous small galls, a few large galls;
5 = 25% of the root system affected by galls and non-functional (absence of rootlets) ;

6 = 50% of the root system affected by galls;
7 = 75% of the root system affected by galls;
8 = 9 = root system in the process of decomposing;
10 = dead plant.

The severity of the galls was calculated using the Mckinney (1923) formula shown below:

$$S (\%) = [\Sigma (n_i \times n) / (N_t \times n_{ie})] \times 100$$

S (%): severity of galls
ni: severity score assigned to galls on the plant
n: number of plants to which the score ni was assigned
Nt: total number of plants used
nie: highest severity score recorded in this study

2.4. Extraction of nematodes

2.4.1. Extraction of nematodes from soil samples (Whitehead method described by Coyne et al. (2010))

For each site, the soil samples collected were homogenised and then sieved to remove plant debris and stones. The soil obtained after the first sieving was homogenised again to obtain a composite sample. This composite sample was then divided into five 100 mg sub-samples. These sub-samples were then spread out on filter paper contained in 25µm mesh sieves mounted on saucers containing tap water. The water must wet the soil without overcoming it. The cultures were incubated in the laboratory for 48 hours in the dark at room temperature (28± 2°C). After 48 hours of incubation, the sieves were drained and removed from the saucers. The water from the saucer was collected and filtered through the 25 µm mesh sieve, then the sieve containing the nematodes was rinsed with 100 mL of tap water. The nematode suspensions were collected in the flasks.

2.4.2. Extraction of nematodes from root samples (Method of Whitehead described by Coyne et al. (2010))

The roots of plants showing galls were cut into explants approximately five mm long using a pair of scissors. The explants were divided into 10 g sub-samples and ground in a household blender in 150 mL of tap water. The crushed material was then spread onto filter paper contained in 25 µm sieves mounted on saucers containing water. The water in the saucers should wet the grindings without overcoming them. The cultures were incubated for 48 hours in the dark at room temperature (28 ± 2°C) in the laboratory. The sieves were drained and the water in the saucers was filtered through the 25 µm mesh sieve.

The sieve containing the nematodes was rinsed with 100 ml of tap water and the nematode suspension was collected in the vials.

2.5. Statistical analysis

The results were subjected to an analysis of variance (ANOVA 1) using R software. In the event of equality of variance, the means were compared using the DE Turkey test with a threshold of 5%.

3. Results

3.1. Symptoms observed on tomato plants

Observation of the diseased plants revealed wilting, yellowing of the leaves (chlorosis), shrinking of the leaves, dwarfing and galling of the roots.

3.1.1. Sudden and permanent wilting without yellowing

This wilting is caused by a reduction in the turgidity of the constituent tissues, leading to more or less pronounced wilting of the foliage. The plants become weak, the leaves wither as if they were lacking water, dry up and then die (Figure 1).

Figure 1 Wilt of a tomato plant

3.1.2. Leaf yellowing

The yellowing of tomato leaves is due to a disruption in the absorption of water and nutrients. This disruption is caused by galls in the roots. The yellowing appears as yellowish spots and numerous sinuous galleries on the leaves, which subsequently dry out (Figure 2).

Figure 2 Tomato leaves with yellowish spots

3.1.3. Reduced, spoon-shaped leaves

This symptom is characterised by stunted plant growth, chlorosis and spooning of the leaves. The leaves take on a light colour (white or yellow) or a mosaic of light and dark green tones. They turn yellow and curl downwards or upwards. Interveinal chlorosis of the leaves can also be observed, with the leaf blades sometimes purplish (Figure 3).

Figure 3 Tomato leaves reduced and curled into spoons

3.1.4. Plant dwarfing and dieback

This symptom manifests itself as reduced plant development. Plant growth slows and then stops, and leaves may or may not be discolored. Affected plants show significant growth retardation, which can lead to significant crop loss in the event of severe infestation (Figure 4).

Figure 4 Tomato plant showing dwarfism

3.1.5. Root galls

Root-knot nematodes are characterised by the formation of nodules on roots. By attaching themselves to the host plant, Meloidogyne females cause mitosis of the plant cells, resulting in the formation of multinucleate cells. These form feeding sites for the nematode. In response to the parasite's bites, the host's cortical cells hypertrophy, producing galls 2 to 4 mm in diameter on small roots when caused by a single individual, but can become larger in the case of several attacks. The size and shape of the galls depend on the Meloidogyne species and the host plant (Figure 5).

Figure 5 Tomato plant showing galls

3.2. Nematode species identified in the sampling zones

Microscopic observation of the extractions made it possible to identify 3 species of nematodes from the cultivation soil and tomato roots showing galls. The identification of these species was based essentially on microscopic morphology. Microscopic characteristics were observed using an electron microscope with a x 40 objective. The figures below summarize the microscopic characteristics of the species identified (figures 6, 7 and 8).

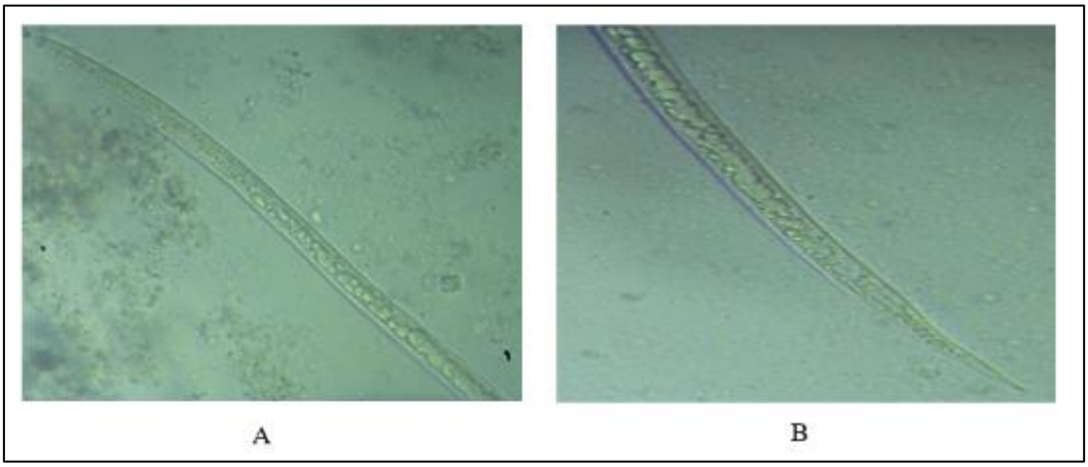

Figure 6 Labial part (A) and tail (B) of Meloidogyne arenaria

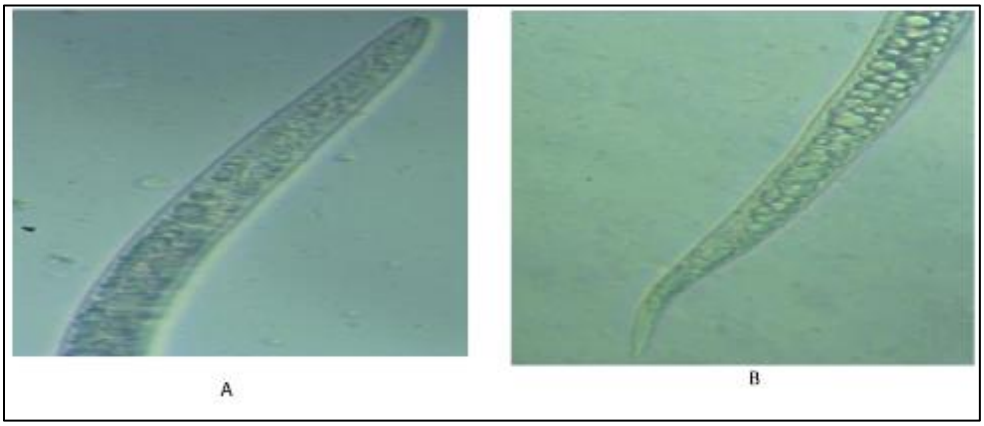

Figure 7 Labial part (A) and tail (B) of Meloidogyne incognita

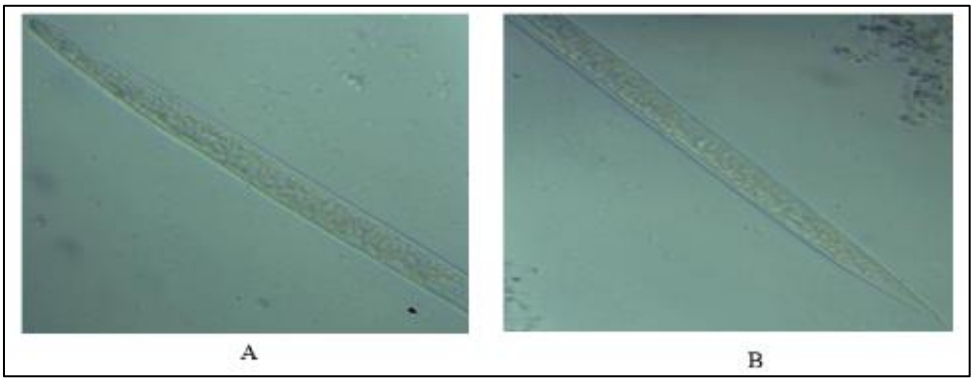

Figure 8 Labial part (A) and tail (B) of *Meloidogyne javanica*

3.3. Incidence and severity of leaf and stem symptoms in the four regions

Variance analysis of symptom incidence and foliar symptom severity showed significant differences. Tomato plant wilt was more significant in the Yamoussoukro region than in the other regions. The Korhogo region showed the lowest rate of plant wilting. Plant dwarfing was most prevalent in the East, Centre-West and Centre regions. The North region had the lowest incidence of plant dwarfing. The highest incidence of leaf yellowing was observed in the Yamoussoukro zone. The Eastern and Central-Western zones showed average incidences and the Northern region had the lowest incidence. The number of plants with reduced leaves was higher in the Yamoussoukro zone. The Daloa zone showed the average incidence of this symptom, and the lowest incidences were observed in the North and East zones.

Foliar symptoms were more severe in the Yamoussoukro and the lowest percentages were observed in the East, Centre-West and North zones (Table 1).

Table 1: Incidence of symptoms according to sampling area

Zones		**Incidence of symptoms (%)**			**Severity of foliar symptoms (%**	
	Withered (%)	**Nan (%)**	**red leaf (%)**	**Jau (%)**	**fire red sf (%**	**Jau sf (%**
East	18.44 ± 11.08(ab	16.66 ± 7.21(b	14.11 ± 5.96(a	16.66 ± 7.54(ab	12.37± 4.88(ab	13.00 ± 5.43(a
Centre-West	26.88 ± 10.15(ac	15.77 ± 2.30(b	17.55 ± 14.13(ab	19.33 ± 9.89(ac	11.08 ± 8.50(a	10.81 ± 4.14(a
North	12.88 ± 5.01(b	9.35 ± 4.28(a	7.51 ± 4.77(a	7.51 ± 5.93(b	5.25 ± 2.83(a	4.81 ± 2.85(a
Centre	30.66 ± 8.12(c	19.55 ± 10.52(b	26.88 ± 10.15(b	36.22 ± 11.76(c	20.48 ± 7.96(b	26.24 ± 10.91(b
p-value	0.0002342 (ts	0.02909 (s	0.0008013 (ts	0.0006597 (ts	0.0002268 (ts	0.0005963 (ts

Means with the same superscript letters in the same column are not significantly different at 5% according to the Tukey test; Flétri = wilting; Nan = dwarfing; feuil réd = reduced leaves; Jau = yellowing; sf = leaf symptom. ns = not significant; s = significant; ts = very significant

3.4. Prevalence, severity of root galls and nematode density in the four regions

Analysis of the means showed a significant difference between the prevalence and severity of galls and the density of nematodes per gram of soil and per gram of fresh matter. Plants in the Centre-West and Centre zones showed the highest rates of root-knot prevalence. The lowest prevalence rates were observed in the Eastern and Northern zones.

As for the severity of galls, the highest rate was observed in the Centre-West zone and the lowest rates were obtained in the East, North and Centre zones.

Tomato soils in the central zone showed the highest nematode densities per gram of soil. The lowest densities per gram of soil were obtained in the Eastern, Central-Western and Northern zones. The number of nematodes per gram of fresh matter was highest in the Centre-West zone. The Centre zone had the highest average number of nematodes per gram of fresh matter. The Eastern and Northern zones showed the lowest densities of nematodes per gram of fresh matter (Table 2).

Table 2 Prevalence, severity of galls and number of nematodes according to sampling areas

Zones	**Pm of galls (%)**	**Severity of galls(%)**	**Nm/g of soil**	**Nm/g of fresh matter**
	Pm (%)	S (%)	n/g soil	n/g mf
East	20.11 ± 9.70^{a}	10.94 ± 3.04^{a}	138.33 ± 66.56^{a}	2777.77 ± 1009.67^{a}
CentreWes	31.33 ± 7.87^{b}	54.61 ± 28.47^{b}	171.66 ± 51.65^{a}	8511.11 ± 3225.07^{c}
North	13.20 ± 2.17^{a}	10.97 ± 4.35^{a}	175.00 ± 94.63^{a}	4335.55 ± 2384.90^{ac}
Centre	32.44 ± 10.71^{b}	12.63 ± 6.77^{a}	497.77 ± 234.61^{b}	6410 ± 2826.98^{bc}
p-value	0.0001231^{ts}	0.004034 ^{ts}	0.0005432 $^{\mathbf{ts}}$	0.0003444 ^{ts}

Means with the same superscript letters in the same column are not significantly different at the 5% level according to the test; Pm = average prevalence of galls; S= severity of galls; n/g soil = number of nematodes/ gram of soil; n/g mf = number of nematodes/ gram of fresh matter; ts = highly

3.5. Mapping of nematode species associated with tomato crops

3.5.1. At ground level

The maps below show the density of each nematode species associated with tomato cultivation in the main tomato-producing regions of Côte d'Ivoire. The circles used are proportional to the density of nematodes per site studied.

In the Poro, Tchologo and Haut-Sassandra regions, Meloidogyne incognita is the most widespread species in cultivated soils. The highest density of this species was found in the Ferkessédougou area (Tchologo region), Korhogo (Poro region) and Zahia (Haut-Sassandra region). In these three regions, Meloidogyne javanica was the species least present in crop soils. In the Bélier region, Meloidogyne incognita was the most prevalent species in tomato soils. Meloidogyne arenaria had the average density and Meloidogyne javanica the lowest density despite its presence on the different crop sites sampled. The highest densities of nematodes extracted from the soil were obtained in the Moronou and Indénié Juablin regions. In the Moronou region, Meloidogyne javanica had the highest density. Moreover, this species is the only one found in cultivated soils in the Arrah area. Meloidogyne arenaria was the most widespread species in cultivated soils in the Indénié Juablin region (Figure 9A).

3.5.2. At root level

The density of nematode species extracted from root galls varied from region to region. In the Poro, Tchologo and Bélier regions, Meloidogyne incognita and Meloidogyne javanica had the highest and lowest densities respectively. In the Haut-Sassandra region, Meloidogyne incognita had the highest density, especially at the Zahia sites where all the root galls were caused by this species. Meloidogyne arenaria had the lowest density and was only identified at the Gonaté sites. In the Moronou and Indénié Juablin regions, Meloidogyne arenaria was the species most present in root galls. Meloidogyne javanica was the only species present at the sampling sites in both regions. In addition, it was the only species identified in tomato roots at the Arrah sites. In both regions, Meloidogyne incognita had the lowest density of Meloidogyne-infested plants (Figure 9B).

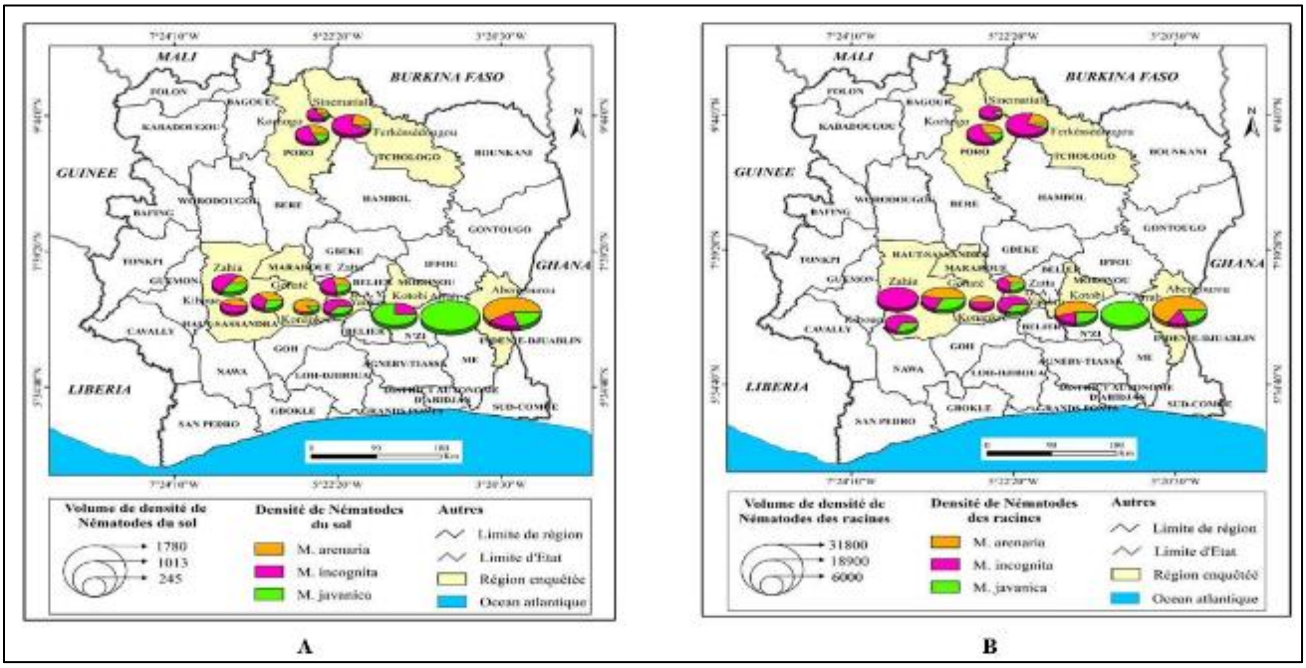

Figure 9 Geographical distribution of nematode species isolated from tomato soil (A) and roots (B)

4. Discussion

4.1. Symptoms observed on tomato plants

The symptoms observed on tomato plants range from wilting and dwarfing of the plants, chlorosis and leaf reduction to the appearance of root galls. These symptoms could be explained by the presence of root-knot nematodes in the soil. Stage 2 (infesting) juveniles penetrate the roots of the host plant via the areas of intense metabolic activity, i.e. the apices. These parasitic attacks cause galls to form on the roots, hindering the proper circulation of nutrients such as water and mineral salts. This parasitism also causes dwarfing of the plants and chlorosis of the leaves. Our results corroborate those of [14] who stated that root galls, plant dwarfing and leaf chlorosis are characteristic of *Meloidogyne* attacks. These authors maintain that galls damage the root system by reducing and destroying the plant's roots and rootlets, leading to extreme tuberisation of the root cortex and abnormal rootlet proliferation. Branches develop upstream and the roots become bushy, while the root hair disappears, leading to wilting, chlorosis, dwarfing and reduction of the leaves, which end up curling up like a spoon, as reported by [15].

4.2. Nematode species identified

The extraction of nematodes from crop soil and roots showing galls enabled three species of nematodes to be identified: *Meloidogyne arenaria*, *Meloidogyne incognita* and *Meloidogyne javanica*. These sedentary plant-parasitic nematodes are the most dreaded bio-aggressors, causing numerous yield losses in vegetable crops, in this case tomatoes. Some species can cause significant damage to crops, leading to a significant reduction in the quality and quantity of agricultural production. Our results are in agreement with those of [16] who argued that the damage caused by the *Meloidogyne* genus alone represents around 5% of world agricultural production each year, equivalent to tens of billions of dollars per year. Furthermore, the M. incognita species alone is responsible for the loss of more than 10% of harvests for most of its hosts and around 30% of yield losses for the species most susceptible to infection, such as tomato, melon and aubergine, according to the work of [17].

Moreover, these nematodes represent a major risk for vegetable crops, being responsible for more than 14% of yield losses in vegetable crops worldwide. [18]. In Côte d'Ivoire, as in most countries with a tropical climate, vegetable crops are experiencing a significant drop in yields due to parasitic pressure. This pressure is exerted mainly by root-knot nematodes, to which little attention is paid. Our work is in line with that of [19] who stated that plant-parasitic nematodes significantly compromise tomato and pepper production in Niger.

4.3. Incidence and severity of symptoms observed

Symptoms observed in tomato crops had the highest incidence in the Centre zone. The North and East regions showed the lowest incidences. The severity of foliar symptoms was also higher in the Centre region than in the other regions. Our results show that tomato plants in the Centre region are more affected by root-knot nematode attacks and have a high susceptibility to attacks by these bioaggressors. These results could be explained by the abundance of root-knot nematodes in the cultivation soil in this area. The abundance of nematodes in the cultivated soil in the central zone could be attributed to the cultivation technique used in this zone. Farmers in this zone opt for monoculture systems. Our results corroborate those of [20] and [21], who stated that the impact of these pests is greater in monoculture systems, as is the case for most vegetable crops in West Africa. In addition, the high incidence and severity observed in the central region could be explained by the unavailability of land for tomato cultivation. Indeed, the unavailability of cultivated land prevents fallowing or considerably limits its duration. Consequently, the nematofauna present in the soil does not disappear before the next crop is grown on the plot in question. Our results corroborate those of [22] who stated that the age of the fallow has a direct influence on the vegetation and therefore has an indirect effect on the nematological population. The reduction in the number of nematodes in the crop soil corresponds to the cessation of the physiological activity of the host plant, which has completed its vegetative cycle. The roots are therefore no longer conducive to nematode multiplication. In addition, our results showed that the absence of fallow, which consists of temporarily interrupting cultivation on a plot, prevented the nematodes from separating from their host plant. The absence of fallow on cultivated plots would have favoured the proliferation of nematodes and the increase in their damage to crops. Our results are in line with those of [23] who asserted that the introduction of non-host plants into a crop plot can interrupt the life cycle of a pathogen. The incidence and severity of symptoms observed in the central zone could also be explained by the lack of appropriate cropping practices such as crop rotation. This cultivation technique, based on alternating different plant families on the same plot over the seasons, improves soil health and prevents the development of specific pathogens. Our results are in line with those of [24] and [25], who have demonstrated the influence of rotation on nematode control in numerous previous studies. Also, [26] showed that sorghum grown in a rotation with a legume was less infected by nematodes. In fact, rotation with a legume mobilises more nitrogen for the following crop, and this nitrogen increases root protection against nematodes. In a study, [27] argued that the use of leguminous plants would have nematicidal properties and therefore constitute an alternative to the use of synthetic agrochemicals against nematodes. These authors showed that the use of two leguminous plants (*Mucuna pruriens* L. and *Tithonia divesifolia* Hemsl) reduced the populations of *Meloidogyne spp*. and Pratylenchus bruchyurus in the roots by 86 to 95% compared with the control crop.

In addition, the excessive use of chemical pesticides to control nematodes has led to resistance by these pathogens to these synthetic inputs. This nematode resistance would increase their population in crop soils. Our studies are supported by those of [28] cited by [29] who stated that plant-parasitic nematodes increase with the treatment of soils with chemical pesticides. In addition, studies on the effects of pesticides on the enzymatic and respiratory activity of microorganisms have shown that chemical pesticides have a negative impact on soil fauna [30]. The biological activity of a soil, like its physical and chemical properties, is a determining factor in its productivity [31].

4.4. Prevalence, severity of galls and nematode density

The frequencies of root galls in tomato crops in the Centre and Centre-West regions were significantly higher than those in tomato crops in the North and East regions. In addition, the crop soil in the Centre zone showed a higher density of nematodes per gram of soil than that in the North, East and Centre-West. Also, nematodes showed a higher concentration per gram of fresh matter in the Central and Central-West regions than in the Northern and Eastern regions.

The high densities of nematodes per gram of soil and the high prevalence observed in the Centre and Centre-West regions can be explained by the influence of certain abiotic factors such as water, temperature, pH, soil structure and texture on the nematofauna. The central region has a transitional climate marked by two maximum rainfall periods, one in June and the other in September-October. As for the Centre-West region, its rainy season falls between April and September. These rainy periods coincide with the planting of tomato crops. Soil moisture during this period would favour the proliferation of nematodes. Our work is in agreement with that of [32] who demonstrated that the water content of a soil has a significant effect on the nematofauna. The low nematode densities observed in the eastern zone can be explained by the period when crops are planted. In fact, crops in this zone are not planted during periods of heavy rainfall because farmers are busy planting cash crops. In the northern zone, this low density could be explained by the scarcity of rainfall. The scarcity of rain would lead nematodes to begin the process of acquiring various forms of resistance. As a result, their average number in the soil decreases. It is possible that some individuals do not manage to acquire this state in time and die.

However, our results do not corroborate those of [33] who showed that low temperatures and soil moisture cause a considerable delay in the development of *Meloidogyne*. This author also maintains that root-knot nematode activity is regulated by humidity. According to the author, humidity limits the penetration of larvae into the host plant and inhibits egg hatching. Excess moisture can also cause the juveniles to suffocate. In addition, the significantly high number of juveniles in crop soils in the middle and middle- West regions could be explained by the pH value of these soils. These soils have a pH of between 5.2 and 6.5 [34]. This acid pH would favor the proliferation of nematodes in the crop soil. Our results are in the line with those of [35] who stated that *Meloidogyne* incognita larvae hacth most rapidly at pH =6.5.

Furthemore [36] showed that neutral or more or less acidic soils favour the hatching of root-knot nematode eggs, but below pH 5.2, hatching is inhibited. On the other hand, [34] and [37] maintain respectively that *Meloidogyne* infestation is less severe in acid soils than in neutral or alkaline soils and that root-knot nematodes survive, hatch and reproduce at variable pH levels between 4 and 8.

In addition, the high number of nematodes in soils cultivated in the Centre and their low density in soils cultivated in the North would be due to the texture and structure of the soils in these different regions. The loosely compacted, sandy-clay-textured, well-aired soils of the Centre would facilitate the development, movement and infestation of tomato plants. Our results corroborate those of [34] who maintained that sandy-textured soils are favourable to nematode growth. In addition, [38] showed that the very high compactness of soils with a more clayey texture and a lack of aeration, such as northern soils, is a limiting factor in the distribution of nematodes.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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