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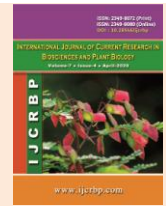

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Influence of root-knot nematodes of the genus *Meloidogyne* spp. on the growth and production of ten cultivars of tomato (*Solanum lycopersicum* L.) in Yamoussoukro in the center of Côte d'Ivoire

Didier Junior KAKOU[1], Kouabenan ABO[2], Ler-N'Ogn Dadé Georges Elisée AMARI[3], Aya Carine N'GUESSAN[4], Brahima CAMARA[5], Gilles Alex PAKORA[6] and Daouda KONE[5]

[1] Doctorant, Unité Pédagogique et de Recherche de Physiologie et Pathologie Végétales, Laboratoire de Biotechnologie, Agriculture et Valorisation des Ressources Biologiques, UFR Biosciences, Université Félix Houphouët-Boigny, 01 BP 7195 Abidjan 01, Côte d'Ivoire

[2] Maître de Conférences, Phytopathologiste, Institut National Polytechnique Félix Houphouët-Boigny, Département de Recherche Agriculture et Ressources Animales (DFR-ARA), Laboratoire de Phythopathologie et de Biologie Végétale, BP 1313 Yamoussoukro, Côte d'Ivoire

[3] Enseignant-Chercheur, Phytopathologiste- Défense des Cultures, Unité Pédagogique et de Recherche de Physiologie et Pathologie Végétales, Laboratoire de Biotechnologie, Agriculture et Valorisation des Ressources Biologiques, UFR Biosciences, Université Félix Houphouët-Boigny, 22 BP 582 Abidjan 22, Côte d'Ivoire

[4] Enseignant-Chercheur, Département de Biologie Végétale, UFR Sciences Biologiques, Université Péleforo Gon Coulibaly, BP 1328 Korhogo

[5] Enseignant-Chercheur, Phytopathologiste- Défense des Cultures, Unité Pédagogique et de Recherche de Physiologie et Pathologie Végétales, Laboratoire de Biotechnologie, Agriculture et Valorisation des Ressources Biologiques, UFR Biosciences, 22 BP 582 Abidjan 22, Côte d'Ivoire

[6] Enseignant-Chercheur, Biochimie Substances Naturelles, Unité Pédagogique et de Recherche de Pharmacologie des Substances Naturelles, Laboratoire de Biologie et Santé, UFR Biosciences, Université Félix Houphouët-Boigny, 22 BP 582 Abidjan 22, Côte d'Ivoire

*Corresponding author; e-mail: kakoudidierjunior@yahoo.fr

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ABSTRACT

Tomato is a widely produced and widely consumed crop in Côte d'Ivoire. However, its production is harmed by many pests such as fungal diseases, bacterial diseases, viral diseases and pests including root-knot nematodes. In order to identify the best varieties against this pest, a study of ten tomato varieties was conducted in the Yamoussoukro region of central Côte d'Ivoire. The device adopted for the test, was complete Fischer blocks in randomization. Observations included tomato development and production parameters, earliness, root-knot nematode population, and yield components. The results of this study showed that of the ten varieties tested, two varieties are distinguished by their yield and their tolerance to root-knot nematodes. These are the F1 Mongal varieties (3437.5 $kg.ha^{-1}$, 4438.75 $kg.ha^{-1}$) and F1 Cobra 26 (2412.5 $kg.ha^{-1}$, 2973 $kg.ha^{-1}$). These results made it possible to select these two varieties for their tolerance to root-knot nematodes and for their productivity. F1 Mongal and F1 Cobra 26 varieties may be recommended for growers in areas with root-knot nematodes.

Introduction

The tomato (*Solanum lycopersicum* L.) is one of the most widely grown field and garden foods among market garden crops in the world (Salunkhe and Kadam, 1998). Tomato production is estimated at over 126 million tons (FAO, 2015). Among these many consumers are African countries, whose needs have become more and more growing as they are used in almost all dishes in the form of salads and sauces (Djidji et al., 2010).

In Côte d'Ivoire, this commodity is a major part of the diet of the population, whose growth is leading to an increase in demand. This large consumption of tomatoes leads to an increase in costs on the local market, especially for off-season production (Soro et al., 2015). On the markets, the average price per kilogram varies between 200 and 1100 F CFA per year. This relatively high selling price trend over the whole year makes tomato a "flagship" crop in the farming environment (Soro et al., 2015).

Unfortunately this crop, like almost all market garden crops, is subject to many biotic constraints such as diseases and pests, especially nematodes, which remain unknown to Ivorian producers. Indeed, ignorance of their presence has often been covered by the term "soil fatigue". Damage caused by nematodes of the genus *Meloidogyne* responsible for galls can lead to the loss of about 70% of production if phytosanitary measures are not taken in time (Nono et al., 2001). For this purpose, chemical control is the most commonly practiced control method after crop rotation by growers (Assih et al., 2018). Although synthetic nematicides have shown their efficacy, they remain expensive, persistent and harmful to the environment and human health (Yéo et al., 2018). In order to overcome this dependency on synthetic nematicides, other more environmentally friendly control strategies through the use of varietal resistance have been developed.

This study aims at evaluating the behaviour of different tomato varieties towards root-knot nematodes of the genus *Meloidogyne* in order to select cultivars tolerant to these pests and having a good productivity potential.

Materials and methods

Study site

The experimental plot was set up in June 2018 in the locality of Djahakro, about 1 km from the Institut National Polytechnique Félix Houphouët-Boigny de Yamoussoukro in central Côte d'Ivoire. It is located between 6°13 north latitude and 5°14 west longitude with an altitude of 206 m in the transition zone between savannah and forest. This zone is characterized by a hot and humid climate. The soils of this region belong to the subclass of medium and low denatured ferralitic soils (Ettien, 2004).

Plant material

The plant material consisted of ten tomato cultivars (*Solanum lycopersicum* L.). These tomato varieties have different agronomic characteristics (Table 1). They were chosen because of their availability on the market and their high use by tomato growers in the production areas.

Nursery and transplanting of tomato plants

The nurseries were carried out during the great rainy season in June 2018 on 3 m^2 beds for each of the ten tomato cultivars under experimentation. The tomato plants remained in growth for 28 days. No phytosanitary treatments were carried out during the nursery.

Transplanting of the plants took place 3 weeks after the beginning of the nursery at the six-leaf stage with 20 plants arranged in double lines on each bed. The plants were transplanted at a distance of 0.5 m between plants, 0.7 m between two consecutive rows and 0.5 m between beds.

Experimental device

The trial was conducted in a randomized complete Fischer block design with 4 replicates. Each replicate covered an area of 100 m^2. The elementary plot consisted of 2 beds of 5 m^2 (5 m x 1 m), which was equivalent to 2 beds for one cultivar. On each bed, a double row of 20 plants was planted. Each tomato variety had 40 plants in each replicate.

Table 1. Agronomic characteristics of the varieties used.

Varieties	Crop cycle length (JAR)	Maturity	Yield (t/ha)	Nematodes sensitivity
Roma VF	70 - 80	Mid-early	40	Me
Rio grande	80	Half late	N/D	N/D
Mongal F1	65	Early	N/D	Tolerant
F1 Cobra 26	65	Early	N/D	N/D
F1 Lindo	65	Early	N/D	N/D
UC82B	70	Early	N/D	N/D
Rodéo 62 F1	70 - 80	Mid-early	N/D	N/D
Petomech	70 - 75	Mid-early	N/D	N/D
Peto 86	65	Early	N/D	N/D
Caraïbo	75	Half-late	N/D	N/D

JAR: Days after transplanting; Me: nematode sensitivity; N/D: not determined.

Maintenance and monitoring of the crop

The cultivation practice adopted is that followed by the majority of small tomato producers in the Yamoussoukro area. The binary insecticide VIPER 46 EC (Indoxacarb and Acetamiprid) was used 15 days after transplanting the plants and then when the pest pressure became important. This insecticide was applied at the rate of 1 $l.ha^{-1}$. The synthetic fungicide MANCO 80 WP (Mancozeb) was applied at the rate of 1 $kg.ha^{-1}$ at the same times as the binary insecticide to control fungal pests of tomato. However, no bactericide or nematicide was used from the beginning to the end of the experiment.

NPK fertilizer formulation 15-15-15 6S 1 B was used at the rate of 150 $kg.ha^{-1}$ 15 days after tomato transplanting. Then urea at 46% N was applied 30 days after transplanting at a rate of 100 $kg.ha^{-1}$. Regular manual weeding and hoeing (four of them on a regular basis) were carried out to avoid weeding the plot and manual watering was carried out morning and evening.

Observations and measures

* Parameters of the plant development cycle

Experimental observations and measurements were made on the height, circumference, yield at harvest of the plants and the length of the growing cycle of each tomato variety.

- The height growth of the plants was measured with a tape measure from the cotyledonary leaves to the "V" formed by the last leaves at the top of the plant.
- The circumference of the plants was measured with an electronic caliper at the collar from 1 cm above the ground.
- The length of the growing cycle is the interval in number of days from transplanting to the day of the first harvest of healthy, mature fruit. This variable is expressed as the JAR number.
- For the determination of the yield the total number of fruits per variety has been recorded for each harvest date. The net yield and potential yield of each variety was calculated using the following formulae (Soro et al., 2015).

Net yield= [Quantity of healthy fruit (kg)] / [Occupied area (ha)]

Potential yield= [Total quantity of fruit (kg)] / [Occupied area (ha)]

* Nematological analysis

The impact of nematodes on the development and production of tomatoes was based on the evaluation of the number of nematodes and the gall index of each variety.

Sampling and extraction of nematodes

Sampling consisted of taking the roots of plants of each cultivar in each block likely to show symptoms due to galls nematode attacks at the end of the crop. The nematodes were then extracted by the centrifugation-flotation method using a composite sample of 10 plants, including 10 g of washed and blender-ground roots of each tomato variety.

Determination of gall index and nematode density

The gall index of the root system of tomato varieties has been evaluated according to the Zeck (1971) scale, which is used to assess damage caused by root-knot nematodes. This scale is based on a notation ranging from 0 to 9 which allows the severity of galls nematode attacks to be estimated.

Nematode identification and enumeration was done microscopically from 2 ml of root extract. The density of *Meloidogyne* individuals in tomato roots was determined by the formula used by Adegbite et al. (2006).

Nematode density =

[(Number of nematodes × Total volume)/10 g of roots)] × 100

Statistical analyses

Data collected on height growth, circumference, crop cycle length and yield components were subjected to an analysis of variance with one classification criterion (ANOVA I). STATISTICA Version 7.1 software was used for this analysis. If there were significant differences between the means, DUNCAN's test at the 5% threshold allowed them to be classified into homogeneous groups.

Results

Growth in height and circumference of tomato varieties

The analysis of variance showed that the variety has a significant effect on plant size. Indeed, the average size of tomato varieties ranged from 46.60 to 62.84 cm. The largest size was recorded for Rodeo 62 F1 (62.84 cm) and the smallest size for Roma (46.60 cm) (Table 2). The analysis of variance carried out on the stem circumference of tomato plants showed a significant difference between varieties. The means ranged from 2.82 and 3.24 cm, respectively, for UC82B and Caraibo varieties. The varieties Petomech, Peto86, F1 Cobra 26 had circumference averages, intermediate of 2.90 cm. The Rio Grande variety recorded an average of 2.95 cm (Table 2).

Table 2. Averages of morphometric parameters and health status according to variety.

Variables	Levels	Height plant (cm)	Circumference (cm)
Varieties	Rio Grande	52.91 ± 1.12 a	2.95 ± 0.03 ab
	F1 Lindo	59.51 ± 1.54 b	2.85 ± 0.04 a
	Caraibo	48.66 ± 0.94 c	3.24 ± 0.05 d
	Rodéo 62 F1	62.84 ± 1.30 d	3.01 ± 0.05 bc
	F1 Cobra 26	59.15 ± 1.03 b	2.90 ± 0.04 ab
	UC82B	54.58 ± 0.94 a	2.82 ± 0.03 a
	F1 Mongal	59.34 ± 0.97 b	3.08 ± 0.03 c
	Petomech	54.58 ± 1.10 a	2.90 ± 0.04 ab
	Peto 86	55.50 ± 1.20 a	2.90 ± 0.04 ab
	Roma VF	46.60 ± 0.99 c	2.95 ± 0.04 ab
Average		55.37	2.96
P (%)		0.001	0.004
CV (%)		15.5	10.1

Averages followed by the same letter are not significantly different at the 5% threshold.

Crop cycle length of tomato varieties

The analysis of variance shows that there is a significant difference between varieties. Indeed, the dates of first harvests varied from 60 to 77 JAR. The varieties F1 Lindo, F1 Cobra 26, Peto 86, F1 Mongal and UC82B were the earliest with a mean earliness of 61 JAR. Semi-early tomato varieties were Petomech (67 JAR), Roma VF (68 JAR) and Rodeo 62 F1 (68 JAR). Two varieties had a longer growing cycle length than the others. The Rio Grande and Caraibo varieties were the most precocious, with a peak earliness of 76 JAR. They represent the late varieties (Table 3).

Yield components of tomato varieties

For production parameters such as number of fruits, net yield and potential yield, analysis of variance indicated a significant difference between varieties. For the total number of fruits, the most productive varieties were F1 Mongal with 115 fruits and F1 Cobra 26 with 87 fruits. The varieties Peto 86 (60 fruits) and UC82B (65 fruits) had a low number of fruits compared to the other two varieties. Finally, the varieties Rio Grande (35 fruits), Rodeo 62 F1 (35 fruits) and Petomech (37 fruits) had low fruit production compared to the other varieties (Table 3). In terms of net yield, the averages ranged from 3,437.5 kg.ha^{-1} to 781.25 kg.ha^{-1}. In fact, the 3 varieties Rio Grande, Rodeo 62 F1 and Petomech had the lowest net yields ranging from 781 kg.ha^{-1} to 994 kg.ha^{-1}. The highest net yields were recorded by the F1 Mongal and F1 Cobra 26 varieties with respective averages of 3438 kg.ha^{-1} and 2412 kg.ha^{-1} (Table 3).

With regard to potential yield, the averages ranged from 4438.75 kg. kg.ha^{-1} to 1417 kg.ha^{-1}. The tomato varieties with the highest potential yields were F1 Mongal (4438.75 kg.ha^{-1}), F1 Cobra 26 (2974 kg.ha^{-1}). On the other hand, varieties such as Roma VF (1466 kg.ha^{-1}), Rio Grande (1417 kg.ha^{-1}) and F1 Lindo (1418 kg.ha^{-1}) had the lowest potential yields. The other tomato varieties (Caraibo, Peto 86, UC82B, Petomech, Rodeo 62 F1) behaved intermediate between the first two groups (Table 3).

Table 3. Averages of earliness, yield components and nematode numbers by variety.

Variables		Crop cycle length (days)	Number of fruits	Net yield (kg.ha^{-1})	Potential yield (kg.ha^{-1})
Variety	Rio Grande	76.25 ± 1.75 c	34.75 ± 2.46 a	975.00 ± 118.58 a	1417.50 ± 153.21 a
	F1 Lindo	60.50 ± 0.64 a	53.00 ± 5.74 a	1187.50 ± 201.16 ab	1418.75 ± 180.96 a
	Caraibo	76.75 ± 1.97 c	54.00 ± 5.74 a	1412.50 ± 151.15 ab	2046.25 ± 213.92 ab
	Rodéo 62 F1	68.25 ± 1.65 b	34.75 ± 4.66 a	993.75 ± 207.09 a	2006.25 ± 340.15 ab
	F1 Cobra 26	60.50 ± 0.64 a	87.00 ± 5.67 bc	2412.50 ± 310.66 bc	2973.75 ± 313.73 b
	UC82B	63.00 ± 1.29 a	64.75 ± 11.10 ab	1395.00 ± 165.27 ab	1852.50 ± 302.91 ab
	F1 Mongal	62.25 ± 1.31 a	115.25 ± 25.89 c	3437.50 ± 1086.78 c	4438.75 ± 1125.22 c
	Petomech	67.00 ± 2.44 b	36.75 ± 3.96 a	781.25 ± 73.50 a	1992.50 ± 300.95 ab
	Peto 86	61.75 ± 1.54 a	60.50 ± 5.63 ab	1273.75 ± 219.25 ab	1878.75 ± 192.15 ab
	Roma VF	68.25 ± 2.01 b	49.75 ± 7.56 a	1070.00 ± 249.51 a	1466.25 ± 332.73 a
Average		66.45	59.15	1493.88	2149.13
P (%)		0.001	0.0072	0.1206	0.0691
CV (%)		9.8	51.3	69.8	54.6

Averages followed by the same letter are not significantly different at the 5% threshold.

Root gall index of tomato varieties

The analysis of variance carried out on the root gall index of tomato plants showed a significant difference between varieties. The root gall index of tomato plant roots varied from 1.50 to 4.10.

The variety Petomech had the highest root gall index 4.10 and the variety Mongal had the lowest root gall index 1.57. Petomech appears to be the tomato variety most susceptible to infestations of *Meloidogyne* nematodes (Table 4).

Number of *Meloidogyne* spp. in the roots of tomato varieties

Analysis of variance showed that there is a significant difference between tomato varieties for the number of nematodes in the roots. The number of *Meloidogyne* spp. between tomato varieties ranged from 27563 to 177492 individuals per 100 grams of roots. Variety F1 Mongal had the lowest average number of individuals at 27,563 with a gall index of 1.57, a circumference of 3.08 cm and a plant height of 59.34 cm respectively. The highest population of nematodes of the genus *Meloidogyne* (177,492 individuals) was recorded with the variety Petomech. These results showed that this variety obtained a mean height of 54.58 cm, a gall index of 4.10 and a circumferential mean of 2.90 cm (Table 2). Also, F1 Cobra 26 and UC82B had a mean number of nematodes of 31,392 and 50,579 individuals respectively. The varieties Rio Grande, F1 Lindo, Caraibo, Rodeo 62 F1, Roma VF and Peto 86 recorded mean numbers of intermediate nematodes between 68,697 and 14,9021 individuals (Table 4).

Table 4. Averages of nematological parameters on the different tomato varieties at the end of cultivation.

Variables		Gall index	Number of Meloidogyne (nematodes / 100 g of roots)
Variety	Rio Grande	2.82 ± 0.17 a	68 697.25 ± 16773.43 ab
	F1 Lindo	2.45 ± 0.19 a	72 021.50 ± 9642.95 ab
	Caraibo	2.75 ± 0.20 a	76 695.25 ± 7545.62 ab
	Rodéo 62 F1	3.45 ± 0.21 b	112 039.50 ± 27495.69 ab
	F1 Cobra 26	1.67 ± 0.12 cd	31 392.25 ± 744.30 a
	UC82B	2.17 ± 0.17 de	50 579.50 ± 17839.49 a
	F1 Mongal	1.57 ± 0.12 c	27 563.25 ± 6407.71 a
	Petomech	4.10 ± 0.24 e	177 492.00 ± 77885.57 b
	Peto 86	3.45 ± 0.20 b	149 021.25 ± 75208.76 ab
	Roma VF	3.65 ± 0.23 e	134 342.50 ± 33848.87 ab
Average		2.81	89 984.9
P (%)		0.001	0.5112
CV (%)		51.9	91.9

Averages followed by the same letter are not significantly different at the 5% threshold.

Discussion

Overall, the vegetative and nematode behaviour of the genus *Meloidogyne* in tomatoes varies from one variety to another. Indeed, gall indices differ between tomato varieties. The varieties Petomech, Peto 86 and Roma VF were the most susceptible to nematodes with the highest gall indices. This high gall index, which reflects the formation of numerous galls and the presence of a large population of nematodes in the root system, is responsible for the stunting and lack of vigour of plants at an advanced stage of the tomato crop cycle (Buisson et al., 2011). These symptoms are among the main markers of the presence of these pests (Ogou et al., 2018). Indeed, as the genus *Meloidogyne* is a sedentary endoparasite group, it diverts nutrients from the plant to its benefit, creating a physiological dysfunction that leads to the above-mentioned damage and symptoms (Castagnone-Sereno and Djian-Caporalino, 2011; Cadet, 1990).

As regards the length of the growing cycle, it made it possible to distinguish three groups of varieties, of which the one made up of the earliest varieties was composed of F1 Lindo, F1 Cobra 26, Peto 86, F1 Mongal and UC82B. The other two groups of tomato varieties, depending on the time of first harvesting of the fruit, were the semi-early and the late ones. According to Djidji et al. (2010), the difference between first harvest dates is the self-expression of the intrinsic genetic trait of the varieties that shows it. With regard to production, varieties such as F1 Mongal and F1 Cobra 26 were observed to perform well because their net yield and yield potential were better compared to other varieties. Indeed, these varieties recorded very low galls nematode populations which would explain their better production yields.

Some varieties such as Petomech, Peto 86, Roma VF and Rodeo 62 F1 had better nematode multiplication abilities than the F1 Mongal and F1 Cobra 26 varieties. Varieties with high gall indexes also recorded the highest nematode numbers. This fact shows that these varieties are potential hosts for *Meloidogyne* spp. (Dropkin, 1969; Fatiha et al., 2018).

Considering their behaviour in natural nematode infestation environments and the high number of *Meloidogyne* spp. observed, the varieties Petomech, Rio Grande, Roma VF and Rodéo 62 F1 have been shown to be susceptible to gall nematodes which confirms their high susceptibility to pests and parasites as reported by Soro et al. (2007). However, F1 Mongal and F1 Cobra 26 varieties which showed better yields and low nematode infestation were not very susceptible and therefore tolerant to the genus *Meloidogyne* (Soro et al., 2015). In addition, in their work, Chesneau, and Roux-Cuvelier, (2012) claimed that F1 Mongal would be tolerant to root-knot nematodes. Indeed, the tolerance of F1 Mongal could be explained by the fact that it seems to carry a major resistance gene (Mi) to the three predominant species of root-knot nematodes, *Meloidogyne arenaria, Meloidogyne incognita and Meloidogyne javanica* (Castagnone-Sereno.et, Djian-Caporalino, 2011).

Conclusion

This study highlights the important presence of root-knot nematodes in the market gardening area of central Côte d'Ivoire. Net yields and yield potential of the tested tomato varieties were relatively low under conditions of heavy soil infestations of nematodes of the genus *Meloidogyne*. However, the F1 Mongal and F1 Cobra 26 varieties revealed fairly convincing results with interesting intrinsic abilities as they showed a high level of tolerance to root-knot nematodes with good earliness and productivity. The best adapted varieties for the Yamoussoukro market gardening zone are F1 Mongal and F1 Cobra 26.

Conflict of interest statement

Authors declare that they have no conflict of interest.

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