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Behaviour of the main okra (*Abelmoschus* spp.) cultivars grown in Côte d'Ivoire to root-knot nematodes (*Meloidogyne incognita* (Kofoid & White, 1919)) under greenhouse conditions

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Abstract: Root-knot nematodes are the main factor limiting okra production in Côte d'Ivoire. Using resistant cultivars appears to be one of the best strategies for managing root-knot nematodes. The aim of this study was to determine the behaviour of the main okra cultivars grown in Côte d'Ivoire against *Meloidogyne incognita*. Seeds of 20 okra cultivars were planted in pots under greenhouse conditions. Fourteen-day-old plants of okra cultivars were inoculated with 500 second-stage juveniles of *M. incognita*. Agronomic and pathological parameters were determined. The Basanti cultivar exhibited the highest gall index (5.0/plant), final population (7938 individuals/plant), and reproductive factor (15.88/plant) of *M. incognita*, whereas the Hiré cultivar showed one of the lowest gall indexes (3.0/plant), final population (912 individuals/plant), and reproductive factor (1.8/plant). Two groups of cultivars were identified based on their susceptibility to *M. incognita* and their agronomic performance. One group consisted of cultivars that were less susceptible to *M. incognita* and had better agronomic performance. Cultivars that were more susceptible to *M. incognita* and had poorer agronomic performance made up the other group. The Hiré cultivar was the least favourable to *M. incognita* development. Based on the current study, the Hiré cultivar may be a promising option for farmers in root-knot nematode-prone environments.

Key words: Côte d'Ivoire, cultivars, galls, nematodes, okra, susceptibility

Odziv glavnih sort jedilnega osleza (*Abelmoschus* spp.) gojenega v Slonokoščeni obali na ogorčico vozlanja korenin (*Meloidogyne incognita* (Kofoid & White, 1919)) v poskusu v rastlinjaku

Izvleček: Ogorčice vozlanja korenin so glavni omejujoči dejavnik pri gojenju jedilnega osleza v Slonokoščeni obali. Uporaba odpornih sort izgleda kot najboljša strategija za uravnavanje teh ogorčic. Namen raziskave je bil določiti odziv poglavitnih sort jedilnega osleza na tega škodljivca v Slonokoščeni obali. Semena 20 sort jedilnega osleza (bamije) so bila posajena v lonce v rastlinjaku. Štirinajst dni stare sejanke so bile inokulirane z juvenilnimi ogorčicani v 500 sekundnem stadiju, kaneje so bili določeni agronomski in patološki parametri. Sorta Basanti je imela največji indeks šišk (5,0/rastlino), največjo velikost končne populacije ogorčic (7938 osebkov/rastlino) in največji reproduktivni faktor (15,88/rastlino), sorta Hiré je imela najmanjši indeks šišk (3,0/rastlino), najmanjšo končno populacijo ogorčic (912 osebkov/rastlino) in najmanjši reproduktivni faktor (1,8/rastlino). Prepoznani sta bili dve skupini sort glede na njihovo občutljivost na ogorčico in agronomske lastnosti. Prva skupina je bila sestavljena iz sort, ki so bile na ogorčico manj občutljive in so imele boljše agronomske lastnosti. Druga skupina sort je bila na ogorčico bolj občutljiva in je imela slabše agronomske lastnosti. Sorta Hiré je bila za razvoj ogorčice *M. incognita* najmanj primerna in bi lahko bila obetajoča izbira za kmete v okoljih okuženih s to ogorčico.

Ključne besede: Slonokoščena obala, sorte, šiške, nematodi, jedilni oslez, občutljivost

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1 INTRODUCTION

Okra is an annual plant of the Malvaceae family (Fondio et al., 2007), native to Ethiopia (Sathish & Eswar, 2013). It is one of the most valuable food crops in tropical and subtropical parts of the world (Oyelade et al., 2003). Mihretu et al. (2014) reported that okra is a plant with many uses due to its fresh leaves, buds, flowers, seeds, and young pods. Indeed, the young leaves of okra are consumed in many African countries because of their richness in vitamins A and C, proteins, calcium, and iron (Ngbede et al., 2014). Oil (Habtanu et al., 2014) and biofuel (Farroq et al., 2010) are produced using okra's mature seeds. Okra leaves and stems are used to make fibre and rope (Jideani & Adetula, 1993). Okra's immature pods are eaten as vegetables. They are used in salads, soups, and stews (Ndunguru & Rajabu, 2004). In addition, consumption of immature pods of okra provides 4,550 kcal kg^{-1} for humans (Edet & Etim, 2010).

In Côte d'Ivoire, all people cultivate and consume okra (Fondio et al., 2003). It is typically grown during the main rainy season on small plots near large areas of cereal crops such as rice or maize, as well as yams. It can also be found dispersed throughout these fields (Fondio et al., 2001). Currently, okra is cultivated in the off-season around urban areas, along with other vegetable crops. Two okra species are cultivated in Côte d'Ivoire: *Abelmoschus esculentus* L. and *A. caillei* (A.Chev.) Stevels (Fondio et al., 2007). Plants of *A. esculentus* produce ribbed pods, while those of *A. caillei* produce non-ribbed pods (Fondio et al., 2007). Several cultivars of each okra species are cultivated in Côte d'Ivoire. The Hiré, Kirikou, Emerald, Fatou, Tomi, Adjouablé, and Koto cultivars are popular. They are cultivated for their high yield and financial profitability. Some are local cultivars, while others are the property of European and American seed companies. Some cultivars are imported from neighbouring countries such as Burkina Faso, Mali, Ghana, and Niger. Several okra cultivars are adapted to Côte d'Ivoire's agro-ecological conditions.

However, plant-parasitic nematodes are a limiting factor in okra production. Root-knot nematodes are the most economically destructive (Mukhtar et al., 2013), including *Meloidogyne arenaria* (Neal, 1889), *M. javanica* (Treub, 1885), and *M. incognita* (Kofoid & White, 1919) (Moens et al., 2009). They cause plant wilting and stunting, leaf chlorosis, root gall formation, root reduction, and poor yields if their populations exceed the economic threshold (Sikora & Fernandez, 2005). Root-knot nematodes cause yield losses of 70-90 % (Safiuddin et al., 2011). The estimated economic losses in India due to *M. incognita* on okra are valued at US$ 8.7 million (Jain et al., 2007). Yield losses are the most significant if the root-knot nematode population is high when the crop is planted (Djian-Caporalino et al., 2009). However, if the initial population is low, the plant does not suffer considerable damage in the first year. However, the parasite's multiplication can be so extensive that it results in significant crop losses the following year (Djian-Caporalino et al., 2009).

Various management strategies can help reduce the losses caused by root-knot nematodes on okra (Kumar et al., 2020). Chemical nematicides, although effective, are expensive (Bell, 2000) and are not available to farmers (Alam, 1987). They can be harmful to humans, livestock, and the environment (Kumar et al., 2020). Resistant cultivars are one of the best alternatives to chemical nematicides. In fact, it is economical for farmers to cultivate resistant cultivars in crop rotations. It allows nematode populations to be gradually reduced in infested areas (Kumar et al., 2020). The aim of this study is to determine the behaviour of the main okra cultivars grown in Côte d'Ivoire against root-knot nematodes, specifically *Meloidogyne incognita*.

2 MATERIALS AND METHODS

2.1 CULTIVATION OF OKRA PLANTS

2.1.1 Acquisition of okra seeds

Seeds of 20 okra cultivars were collected from crop seed suppliers (formal structures and retailers) in the District of Abidjan. Seeds of the Clemson Spineless, Emerald, Hiré, Kirikou F1, Koda F1, and Rafiki F1 cultivars were purchased from the Semivoire company. However, seeds of the Caribou F1 cultivar were bought from the Callivoire company, whereas those of Adjouablé and Fatou were acquired from the Akomi company. Seeds of Basanti, Icrisat, Indiana, Koto, Paysan, Perkins, Raci, Tomi, Volta, Yeleen, and Yodana cultivars were obtained from seed retailers in urban markets. Adjouablé, Emerald, and Tomi are cultivars belonging to the *Abelmoschus caillei* species, while the other ones are from the *A. esculentus* species.

2.1.2 Soil preparation and okra planting

A topsoil sample was collected from a fallow plot at the experimental station of NANGUI ABROGOUA University. The soil sample was sterilised twice at 121 °C for 45 minutes and later distributed in perforated polythene bags (1 kg of soil per bag). Seeds of the okra cultivars were planted on the previously sterilised manure. Okra

seedlings were watered at 48-hour intervals for one week. Twenty vigorous seedlings of each okra cultivar were transplanted onto the soil in bags.

2.2 INOCULATION OF OKRA PLANTS

2.2.1 Experimental design

The trial included two factors: okra cultivars (20 okra cultivars) and *M. incognita* inoculation (inoculated plants and non-inoculated plants). There were, therefore, 40 treatments in the trial. Okra plants were arranged in a completely randomised design with 10 plants per treatment. The experiment was conducted for three months (June to August). The plants were exposed to temperatures ranging from 20.9 to 29.5 °C, with relative humidity higher than 85 % and 13 to 14 hours of photoperiod.

2.2.2 Preparation of the inoculum

Second-stage juveniles of *M. incognita* were used in this trial. They were maintained on tomato plants, cultivar Cobra 26, at the experimental station of NANGUI ABROGOUA University. The tomato plants were uprooted and washed with tap water. *M. incognita* eggs were collected using the method of Hussey & Barker (1973). The egg suspensions were incubated at 26 °C for 72 hours. Second-stage juveniles from the eggs were concentrated at 500 individuals per ml of aliquot and later inoculated onto two-week-old okra plants.

2.2.3 Inoculation of okra plants

Four holes, approximately 1 cm in diameter and 5 cm deep, were made in the soil around each okra plant. A 1 ml aliquot containing 500 second-stage juveniles of *M. incognita* was distributed in the holes. Control plants were inoculated with distilled water. Four hundred okra plants were used in this trial, with 200 plants inoculated with *M. incognita* and 200 non-inoculated plants. The trial comprised 40 treatments, with 10 plants per treatment. Okra plants were watered at 72-hour intervals with 200 ml of water per plant.

2.3 EVALUATION OF THE EFFECTS OF TREATMENTS

2.3.1 Determination of okra agronomic parameters

The effects of the treatments on okra development were evaluated 60 days after inoculation using agronomic parameters such as plant height, leaf number, leaf area, stem diameter, pre-flowering, pre-emergence time, root, and shoot mass. Plant height was measured with a tape measure from the base of the stem to the apical end. Leaves were counted per okra plant. Root and shoot mass were measured using an electronic balance, whereas the leaf area of plants was measured using the Mesurim2 v1.63 application (Cosentino). The okra leaves were detached from the plants. A photograph of each leaf spread out on a horizontal support was made. The support was marked with a scale bar (1 cm). The photograph of each leaf was imported into the Mesurim2 application (available online), which analysed and determined the surface area of the leaf (cm^2). A slide gauge was used to measure the stem diameter of plants. The pre-emergence time of seeds (time between seed planting and the appearance of the first seedlings) and pre-flowering time (time between seed emergence and the appearance of the first flowers) were measured for each treatment.

2.3.2 Determination of nematode pathological parameters

Pathological parameters, such as gall index, final population, and reproductive factor of *M. incognita*, were used to evaluate the effects of treatments on galls development. Okra plants were uprooted and grouped per treatment. The root systems of the okra plants were rinsed with tap water to remove any remaining soil clods. Root systems were examined to record the severity of the galls using the Bridge & Page (1980) scale.

The gall index was assessed using the method of Zewain (2014). A pair of scissors was used to cut plant roots into explants. *M. incognita* population was extracted from each root system using two methods. The NaOCl method (Hussey and Barker, 1973) was used to collect eggs and swollen individuals. However, second-stage juveniles and adult males were collected from the NaOCl-derived root

shred using the maceration method (Coyne et al., 2010). Whereas, individuals from soil samples of each plant were extracted using the Whitehead tray method (Coyne et al., 2010). Individuals of *M. incognita* were counted per root system. The final population of *M. incognita* for each plant was the sum of all individuals (eggs, second-stage juveniles, adult males, and swollen stages) collected per root system and soil samples after the three methods. The reproductive factor of *M. incognita* was computed using the formula of Rivoal et al. (2001).

2.3.3 Determination of the behaviour of cultivars

The behaviour of okra cultivars against *M. incognita* was determined using gall index and reproductive factor data. The evaluation was based on the Sasser et al. (1984) scale (Table 1).

Table 1: Scale of plant susceptibility to root-knot nematodes (Sasser et al., 1984)

Plant damage (Gall index)	Host efficiency (Reproductive factor)	Degree of resistance
≤ 2	≤ 1	Resistant
≤ 2	≥ 1	Tolerant
≥ 2	≤ 1	Hypersusceptible
≥ 2	≥ 1	Susceptible

2.4 STATISTICAL ANALYSIS

The final population of *M. incognita* and leaf number of okra plants were normalised using the Log10 (x + 1) function. The Shapiro and Wilk test was used to test the normal distribution of the data. The parameters were analysed with Statistica 7.1 software (StatSoft, Inc.) according to both factors and their interactions. If there was a significant difference at the 5 % level, a post-anova test was performed to identify the best cultivars. Multivariate analyses such as Principal Component Analysis (PCA) and Agglomerative Hierarchical Clustering (AHC) were performed to identify groups of okra cultivars based on their level of resistance to *M. incognita*. The data were scaled using the z-score normalization method before applying PCA.

3 RESULTS

3.1 VARIATION SOURCES IN AGRONOMIC AND PATHOLOGICAL PARAMETERS

Both factors (okra cultivar and *M. incognita* inoculation) influenced the agronomic and pathological parameters (Table 2). There was a highly significant difference between okra cultivars in terms of agronomic and pathological parameters ($p < 0.001$). The *M. incognita* inoculation factor did not influence the okra agronomic parameters, except for stem diameter and root mass. As expected, a highly significant difference was noted between inoculated and non-inoculated plants based on the gall index, the final population, and the reproductive

Table 2: Result of analysis of variance of data for agronomic and pathological parameters

		Sources of variations		
Parameters		Cultivar	Inoculation	Cultivar × Inoculation
Agronomic Parameters	Degrees of freedom	19	1	19
	Leaf Number	0.000***	0.791ns	0.323ns
	Pre-emergence Time	0.000***	0.183ns	0.013*
	Pre-flowering Time	0.000***	0.275ns	0.001***
	Stem Diameter	0.000***	0.001***	0.004**
	Plant Height	0.000***	0.104ns	0.129ns
	Leaf Area	0.000***	0.190ns	0.000***
	Shoot Mass	0.000***	0.837ns	0.001***
	Root Mass	0.000***	0.000***	0.000***
Pathological Parameters	Gall Index	0.000***	0.000***	0.000***
	Final population	0.000***	0.000***	0.000***
	Reproductive Factor	0.000***	0.000***	0.000***

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, ns: Not significant probability

factor of *M. incognita* ($p < 0.001$). There was an interaction between both factors on pre-emergence and pre-flowering times, stem diameter, leaf area, shoot and root mass, gall index, final population, and *M. incognita* reproductive factor ($p < 0.001$). In contrast, there was no significant interaction between both factors for leaf number and plant height ($p \geq 0.05$).

3.2 BEHAVIOUR OF OKRA CULTIVARS AGAINST *Meloidogyne incognita*

Each pathological parameter of *M. incognita* varied between okra cultivars (Table 3). The gall index varied from 2.00 to 5.00, depending on the okra cultivar. The final population and the reproductive factor of *M. incognita* varied, respectively, from 912 to 7938 individuals and from 1.82 to 15.88, depending on the okra cultivar. A highly significant difference was noted between okra cultivars based on each studied pathological parameter ($p < 0.001$). The gall index was the highest on the Basanti cultivar, with a value of 5. However, the lowest gall index was recorded for the Rafiki (2.00), Adjouablé (2.67), and Kirikou (2.67) cultivars. The final population of *M. incognita* was higher on the Basanti cultivar (7938 individuals per plant) compared to other cultivars. However, it was lowest on the Hiré cultivar (912 individuals per plant). The reproductive factor of *M. incognita* was higher on the Basanti cultivar (15.88) than on the other cultivars. However, it was the lowest on the Hiré cultivar, with a value of 1.82. In summary, the value of the gall index recorded for all okra cultivars was higher than 1, and the reproductive factor was higher than 2. The main okra cultivars cultivated in Côte d'Ivoire are, therefore, susceptible to *M. incognita*.

Table 3: Values of *M. incognita* pathological parameters between okra cultivars

	Pathological parameters			
Okra Cultivars	Gall index	Final population	Reproductive factor	Degree of Resistance
Adjouablé	2.67 ± 0.36e	2459 ± 149de	4.92 ± 0.30de	Susceptible
Tomi	4.83 ± 0.14ab	1900 ± 65de	3.80 ± 0.13de	Susceptible
Emerald	3.83 ± 0.40c	1606 ± 76de	3.21 ± 0.15de	Susceptible
Fatou	4.17 ± 0.14bc	1831 ± 18de	3.66 ± 0.04de	Susceptible
Koto	3.67 ± 0.36cd	1513 ± 32de	3.03 ± 0.06de	Susceptible
Basanti	5.00 ± 0.12a	7938 ± 297a	15.88 ± 0.59a	Susceptible
Caribou	3.40 ± 0.35cd	2734 ± 107de	5.47 ± 0.21de	Susceptible
Clemson	3.00 ± 0.22de	1964 ± 65de	3.93 ± 0.13de	Susceptible
Hiré	3.00 ± 0.19de	912 ± 53e	1.82 ± 0.11e	Susceptible
Icrisat	4.83 ± 0.14ab	5271 ± 304b	10.54 ± 0.61b	Susceptible
Indiana	4.00 ± 0.22c	1824 ± 64de	3.65 ± 0.1de	Susceptible
Kirikou	2.67 ± 0.28e	4494 ± 368c	8.99 ± 0.7c	Susceptible
Koda	4.83 ± 0.14ab	4527 ± 50c	9.05 ± 0.10c	Susceptible
Paysan	4.17 ± 0.26bc	2544 ± 428de	5.08 ± 0.86de	Susceptible
Perkins	4.00 ± 0.31c	3120 ± 212d	6.24 ± 0.42de	Susceptible
Raci	3.00 ± 0.31de	2218 ± 164de	4.44 ± 0.33de	Susceptible
Rafiki	2.00 ± 0.22e	2527 ± 112de	5.05 ± 0.22de	Susceptible
Yeleen	4.83 ± 0.14ab	4250 ± 94c	8.34 ± 0.10c	Susceptible
Yodana	3.83 ± .014c	4508 ± 172c	9.02 ± 0.7c	Susceptible
Volta	3.00 ± 0.31cd	2537 ± 46de	5.07 ± 0.9de	Susceptible
CV (%)	7.02	4.79	5.77	
p	0.000	0.000	0.000	

Average ± Standard deviation; Values with the same letter in each column are statistically identical at the 5% level; CV (%): Coefficient of variation; Fisher's statistic value, *p*: Probability value

3.3 GROUPS OF OKRA CULTIVARS

Principal component analysis of all parameters revealed two principal components accounting for 67.51 % of the variability in okra cultivars. Principal component 1 (PC1) explained 48.30 % of the total variability. PC1 was positively correlated (≥ 0.6) with all okra agronomic parameters (Table 4). The contributions of the parameters varied according to the principal components (Table 4). The parameters with the highest contribution to PC1 were shoot mass (16.92 %), plant height (13.33 %), leaf area (16.70 %), stem diameter (12.01%), and pre-emergence time (12.51 %). Therefore, PC1 was defined as the axis of okra cultivars resistant to *M. incognita*.

However, principal component 2 (PC2) represented 19.21 % of the total variability. It was positively correlated with pathological parameters (gall index and reproductive factor of *M. incognita*) and root mass (≥ 0.67) (Table 4). The contributions of the parameters varied according to the principal components (Table 4). The parameters

Table 4: Coefficient of correlation and contribution of parameters to principal components

	Coefficients of correlation		Contributions (%)	
Parameters	PC1 (48.30 %)	PC2 (19.21 %)	PC1 (48.30 %)	PC2 (19.21 %)
Shoot mass	0.90*	0.12	16.924*	0.718
Leaf number	0.60*	-0.31	7.077	5.007
Plant height	0.80*	0.05	13.328*	0.106
Leaf area	0.90*	0.15	16.702*	1.110
Stem diameter	0.77*	-0.01	12.101*	0.002
Pre-emergence time	0.78*	-0.21	12.514*	2.296
Pre-flowering time	0.60*	-0.12	7.346	0.776
Root mass	0.68*	0.70*	9.529	25.401*
Gall index	-0.02	0.89*	0.006	41.532*
Reproductive factor	-0.45	0.67*	4.473	23.051*

* = Parameters with the greatest contribution to the formation of Principal component 1 (PC1) and Principal component 2 (PC2)

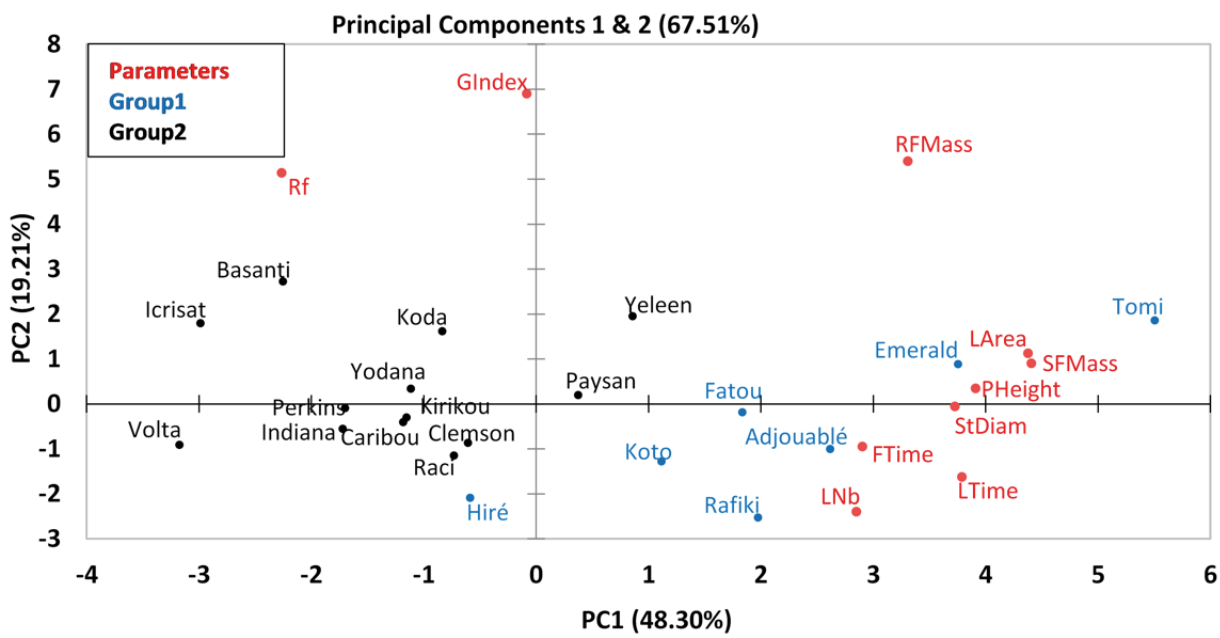

Figure 1: Factorial plan with groups of okra cultivars against *Meloidogyne incognita*
PC1: Principal component 1, PC2: Principal component 2, SFMass: Shoot mass, LNb: Leaf number, PHeight: Plant height, LArea: Leaf area, StDiam: Stem diameter, LTime: Pre-emergence time, FTime: Pre-flowering time, RFMass: Root mass, GIndex: Gall index, Rf: Reproductive factor

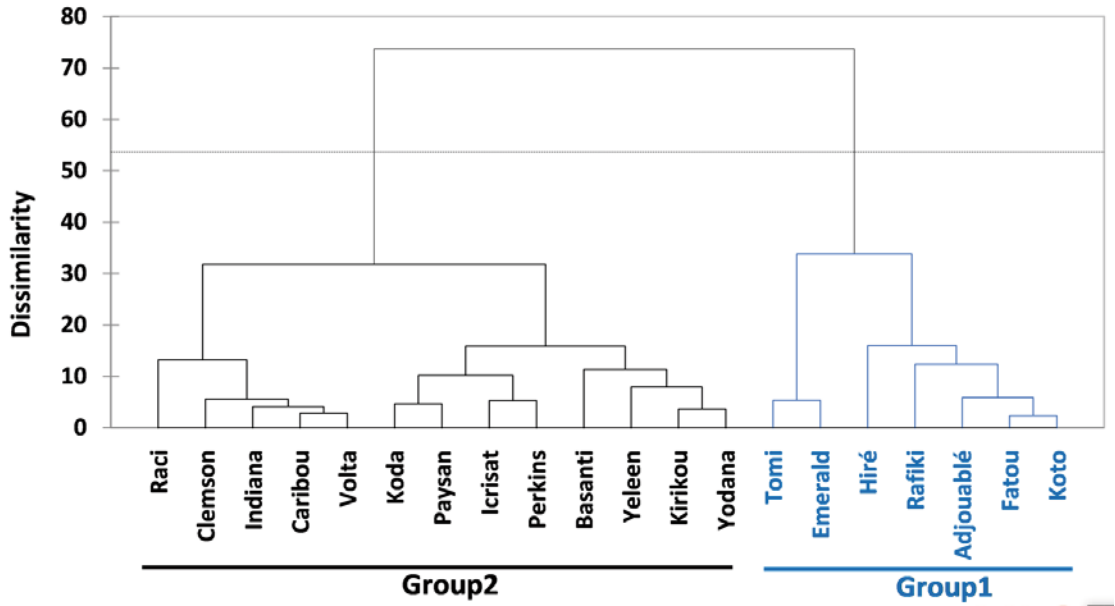

Figure 2: Similarity dendrogram of okra cultivar susceptibility to *Meloidogyne incognita*

with the highest contribution to PC2 were gall index (41.53 %), reproductive factor (25.05 %), and root mass (25.40 %) (Table 6). Thus, PC2 was defined as the axis of cultivars susceptible to *M. incognita*.

Projection of the parameters and individuals onto the plan defined by both principal components revealed two groups (Group 1 and Group 2) within the okra cultivars planted in Côte d'Ivoire against *M. incognita* (Figure 1). Agglomerative hierarchical classification (with a dissimilarity of 53) also confirmed both groups of okra cultivars (Figure 2).

3.4 CHARACTERISTICS OF GROUPS OF OKRA CULTIVARS

Group 1 comprised 35 % of the studied okra cultivars. It comprised three cultivars of *A. caillei* (Adjouablé, Tomi, and Emerald) and four cultivars of *A. esculentus* (Fatou, Hiré, Koto, and Rafiki). Group 1 cultivars were the least susceptible to *M. incognita* (Table 5). These cultivars had the lowest gall index (3.45 per plant) and reproductive factor of *M. incognita* (3.64 per plant). However, these cultivars showed the best agronomic performance. Their plants were the tallest (30.08 cm/plant), with the highest leaf number (6.31 leaves/plant) and leaf area (56.52 cm^2/plant). Shoot mass (13.07 g/plant) and root mass (3.73 g/plant) were the highest. Pre-emergence time (5.45 days/plant) and pre-flowering time (74.76 days/plant) were the longest.

The remaining 65 % of the studied cultivars formed Group 2. These were 13 cultivars of *A. esculentus*. Group 2 cultivars were the most susceptible to *M. incognita* (Table 5). Their plants showed the highest gall index (5.89 per plant) and reproductive factor (7.36 per plant). These cultivars had the poorest agronomic performance. Plant height was the lowest (25.53 cm/plant), as were leaf number (5.54 leaves/plant) and leaf area (32.37 cm^2/plant). Shoot mass (8.07 g/plant) and root mass (3.01 g/plant) were the lowest. Pre-emergence time (3.58 days/plant) and pre-flowering time (69.44 days/plant) were the shortest.

3.5 CORRELATION BETWEEN PARAMETERS

Coefficients of correlation ranging from -0.44 to 0.88 were noted between the okra agronomic parameters (Table 6). Okra plant height increased significantly with leaf area, stem diameter, shoot mass, and root mass ($0.47 \leq r \leq 0.82$; $p < 0.05$). Strong positive correlations existed between the leaf area and shoot mass ($r = 0.88$; $p < 0.001$) and between the leaf area and root mass ($r = 0.71$; $p < 0.001$). Root mass increased with shoot mass ($r = 0.64$; $p < 0.01$). The gall index increased significantly with root mass and the reproductive factor of *M. incognita* ($0.46 \leq r \leq 0.61$; $p < 0.05$).

Table 5: Characteristics of groups of okra cultivars in the presence of *Meloidogyne incognita*

	Cultivar groups			
Parameters	Group 1 (7 cultivars)	Group 2 (13 cultivars)	CV (%)	p
Shoot mass(g)	13.07 ± 2.02a	8.07 ± 0.78b	12.56	0.010
Leaf number	6.31 ± 0.21a	5.54 ± 0.11b	2.66	0.002
Plant height (cm)	30.08 ± 2.29a	25.53 ± 3.65b	10.95	0.020
Leaf area (cm^2)	56.52 ± 9.33a	32.37 ± 2.23b	11.70	0.004
Stem diameter (mm)	5.78 ± 0.24a	4.66 ± 0.18b	4.01	0.002
Pre-emergence time (day)	5.45 ± 0.36a	3.58 ± 0.24b	6.65	0.000
Pre-flowering time (day)	74.76 ± 0.67a	69.44 ± 0.99b	1.16	0.002
Root mass (g)	3.73 ± 0.59a	3.01 ± 0.25a	12.06	0.200
Gall index	3.45 ± 0.36b	5.89 ± 0.23a	7.17	0.020
Reproductive factor	3.64 ± 0.42b	7.36 ± 0.95a	12.22	0.010

Mean ± standard deviation; *p*: Probability value; CV (%): Coefficients of variation. In each line, values with the same letter are statistically identical at the 5 % level

Table 6: Matrix of correlations between okra agronomic and nematode pathological parameters

Parameter	PHeight	LNb	Larea	StDiam	LTime	FTime	SFMass	RFMass	GIndex	Rf
Pheight	1									
LNb	0.36ns	1								
Larea	0.82***	0.44ns	1							
StDiam	0.47*	0.33ns	0.52*	1						
Ltime	0.54*	0.59**	0.58**	0.59**	1					
Ftime	0.11ns	0.41ns	0.64**	0.64**	0.37ns	1				
SFMass	0.76***	0.36ns	0.88***	0.66**	0.54*	0.53*	1			
RFMass	0.59**	0.19ns	0.71***	0.47*	0.41ns	0.28ns	0.64**	1		
Gindex	-0.07ns	-0.44ns	0.00ns	-0.18ns	-0.1ns	-0.09ns	0.04ns	0.61**	1	
Rf	-0.41ns	-0.31ns	-0.28ns	-0.28ns	-0.50*	-0.23ns	-0.36ns	0.11ns	0.46*	1

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, ns: Not significant probability; SFMass: Shoot mass, LNb: Leaf number, PHeight: Plant height, LArea: Leaf area, StDiam: Stem diameter, LTime: Pre-emergence time, FTime: Pre-flowering time, RFMass: Root mass, GIndex: Gall index, Rf: Reproductive factor; Values in bold are the most significant correlations ($|r| \geq 0.46$)

4 DISCUSSION

Agronomic parameters, such as plant height, leaf number, and pre-flowering time, and pathological parameters, such as gall index and reproductive factor, varied according to the okra cultivar. This agronomic variation may be attributable to differences in the genetic make-up of the okra cultivar genotypes (Jacquet et al., 2005). The collection of okra cultivars in Côte d'Ivoire includes two species of okra: *A. esculentus* and *A. caillei*. The difference in species could justify the agronomic variation between okra cultivars. In addition, some cultivars, such as Hiré, native to Côte d'Ivoire (Technisem, 2017a), seem to be adapted to the country's agroecological constraints. Adegbite (2011) found that maize cultivars varied in their agronomic performance in the presence of *M. incognita*.

The pathological difference between cultivars in the presence of *M. incognita* would be because of the specificity of the host-parasite interaction. Nematodes interact with their hosts in various ways (Jones et al., 2013). Host-parasite interaction depends on factors such as the nutritional and immune status of the host, the virulence and reproductive factors of the parasite, and edaphic factors (Castillo and Vovlas, 2007). For a successful host infection, the nematode must overcome the host's defence strategies (Kyndt et al., 2012). These strategies include the localised production of toxins such as phytoalexins

(Wuyts et al., 2006). The presence of such toxins results in an unfavourable environment for some nematodes. However, some nematodes can produce compounds such as glutathione-S-transferase that neutralize these toxins (Dubreuil et al., 2011). This suggests that *M. incognita* has a unique relationship with each okra cultivar.

Okra plants inoculated with *M. incognita* showed similar agronomic characteristics to non-inoculated plants. This similarity in agronomic characteristics is because of the low density of the inoculum, which corresponds to 500 individuals per kg of soil or 1 individual per gramme of soil. Under favourable conditions, root-knot nematodes can complete one development cycle per month (Khan et al., 2009). They would therefore need more time to invade and damage the root system, which would have a negative impact on okra development. According to Djian-Caporalino et al. (2009), the plant does not suffer any damage in the first year if the density of root-knot nematodes is low initially. However, the parasite's multiplication can be so extensive that it results in significant crop losses the following year if conditions are favourable.

Despite variations in pathological parameters, all okra cultivars were susceptible to *M. incognita* based on the Sasser et al. (1980) scale. This result reveals the high pathogenicity of *M. incognita* on okra cultivars. To achieve this, the second-stage juveniles of *M. incognita* overcame the physical and biochemical barriers of the okra plants. The differences in gall index and reproductive factor between cultivars could be because of the differences in genetic make-up between okra genotypes (Jacquet et al., 2005). These results contradict those of Sujatha et al. (2017), who found different responses in tomato cultivars to *M. incognita*. The difference in findings may be due to the use of different evaluation methods. Sujatha et al. (2017) used the percentage of galled roots and the gall index, while the current study used the gall index and reproductive factor according to the Sasser et al. (1984) scale.

Two groups of okra cultivars were identified using multivariate analyses. One group comprised 13 cultivars (Basanti 447, Caribou F1, Clemson Spineless, Icrisat, Indiana, Kirikou F1, Koda F1, Paysan, Perkins, Raci, Volta, Yeleen, and Yodana F1) that are more susceptible to *M. incognita*. The Kirikou F1 cultivar, which belongs to this group, is one of the most widely planted okra cultivars in Côte d'Ivoire. It is planted in season or off-season in several agroecological zones. So, its precocity of 40 to 45 days (Technisem, 2017b) and its susceptibility to *M. incognita* could help to increase and perpetuate the *M. incognita* population on farms. According to Mukhtar and Kayani (2020), *M. incognita* and *M. javanica* are the most destructive root-knot nematode species. This could justify the near-impossibility of planting okra in the country for the previous two years.

In addition, the second group of seven cultivars least susceptible to *M. incognita* was identified. It comprised three cultivars (Adjouablé, Tomi, and Emerald) of *A. caillei* and four cultivars (Fatou, Hiré, Koto, and Rafiki F1) of *A. esculentus*. This group of cultivars had the lowest values for gall index and reproductive factor. The Hiré cultivar had the lowest reproductive factor of *M. incognita* in this group. The Hiré cultivar is one of the most popular and widely planted okra cultivars in Côte d'Ivoire. It is native to Côte d'Ivoire (Technisem, 2017a) and appears to be adapted to the country's agro-ecological constraints. Indeed, the Hiré cultivar is very productive in tropical conditions (Technisem, 2017a). Thus, the implementation of a cropping system with several okra cultivars would make it possible to increase the level of resistance of this cultivar to *M. incognita*. Indeed, Bridge (1996) suggested that nematode control could be achieved by enhancing the biodiversity inherent in traditional multi-crop or multi-cultivar cropping systems to increase nematode resistance or tolerance.

5 CONCLUSIONS

The current study showed that *M. incognita* infects the main okra cultivars planted in Côte d'Ivoire. All okra cultivars are susceptible to *M. incognita*. However, the Hiré, Koto, Fatou, Adjouablé, Tomi, Emerald, and Rafiki cultivars showed potential for tolerance to *M. incognita*. Among these, the Hiré cultivar could be a promising cultivar in an environment prone to root-knot nematodes. Its tolerance to *M. incognita* and favourable agronomic performance make it a potential solution for reducing yield losses caused by the nematode. Further research and field trials should be conducted to validate these findings and determine the best management strategies for incorporating the Hiré cultivar into okra production.

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