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Research Article

Effectiveness of Garlic and Onion Aqueous Extracts on Tomato Root-Knot Nematodes (*Meloidogyne* sp.) in the Autonomous District of Yamoussoukro in Central Côte d'Ivoire

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ABSTRACT

Cultivated for its fruit, tomato is subject to attack by root-knot nematodes which cause huge production losses. This study helps improve tomato production by controlling root-knot nematodes using Alliaceae extracts. To this end, phytosanitary surveys carried out in tomato fields in the Autonomous District of Yamoussoukro made it possible to establish the symptomatology caused by root-knot nematodes on tomatoes and to collect samples. Nematodes were extracted from soil and tomato root samples respectively by the Whitehead tray and Baermann maceration methods, then identified and quantified. The in vitro and in vivo effectiveness of garlic and onion aqueous extracts was assessed on root-knot nematodes. Root galls, chlorosis and reduction of the root system were observed on tomato plants of varieties PADMA and COBRA 26 with prevalence and severity higher than 50%. Meloidogyne sp. *was the main nematode extracted from tomato soils and roots. Garlic extract developed greater nematicidal activity, that is, 55.52% mortality than that of onion extract (29.04%). However, treatments carried out in vivo, with both garlic and onion extracts reduced root gall development and improved tomato plant development. There is therefore an agronomic advantage in combining garlic and onion extracts in the control of Meloidogyne* sp. *infections in tomato.*

Keywords: *Garlic extract, Nematicidal activity, Onion extract, Root-knot nematodes, Tomato.*

INTRODUCTION

Tomato (*Lycopersicum esculentum* Mill) is a plant cultivated in 170 countries under various climates. Global tomato yield in 2018 was over 180 million tons. China is the world leader with a yield of 61.52 million tons, followed by India and the United States with 19.37 and 12.61 million tons, respectively. Egypt is the 1st African producer with a yield of 6.62 million tons. The annual tomato yield, in Côte d'Ivoire, is 40,306 tons over an area of 3 916 hectares (Faostat, 2018). The main tomato production areas in Côte d'Ivoire are the Eastern, Northern and Central zones.

Tomato cultivation is a viable economic activity in those areas for many rural, urban and peri-urban farmers (Didji et al., 2010). Moreover, tomato contains molecules such as lycopene, beta-carotene, flavonoids, vitamin C and derivatives of hydroxy cinnamic acids (Gerszberg et al., 2014). Tomato consumption is associated with the reduction of several types of cancer (prostate, pancreatic, colon and breast cancer, etc.) and cardiovascular diseases (Outis Assia et al., 2016).

Despite its importance, annual tomato yield remains low to meet the national population needs estimated at over 100,000 tons per year (Soro et al., 2007). This low yield is due to several constraints including attacks by plant parasitic nematodes and more especially root-knot nematodes which is the most economically damaging (Korayem et al., 2016). Indeed, nematodes generate huge losses worldwide estimated at US $78 billion (Mokrini et al., 2016). They cause enormous damage directly or indirectly on tomato cultivation in tropical countries (Ibrahim, 2011). They therefore cause about 30% of crop losses (Naika et al., 2005).

Several methods are used by farmers to control plant parasitic nematodes. Chemical nematicides remain the most widely used control method. Although effective, the repeated use of chemical nematicides can have adverse effects on humans and the environment (Bakr et al., 2015). Plant and essential oil extracts are often used in order to reduce the use of synthetic nematicides. Plant-based extracts could help control effectively root-knot nematodes, while preserving the health of farmers and respecting the environment. It is therefore in response to this observation that this work was initiated in order to contribute to tomato yield improvement by controlling *Meloidogyne* sp.

MATERIALS AND METHODS
Agroecological characteristics of the sampling area
Tomato cultivation soil and root samples used in this study were collected from tomato production plots located in the village division of N'Gattakro in the Autonomous District of Yamoussoukro, in Central Côte d'Ivoire. Climate in the area is equatorial transitional, attenuated between Guinean and Sudanese-type climates (N'Guessan, 1990). It is characterized by two rainy seasons (March to June and September to October) and two dry seasons (July to August and November to February) (Bla et al., 2015). Amount of rainfall varies from 1200 to 1600 mm/year (N'Guessan, 1990). Annual average temperature is around 26 °C (Alui et al., 2011). Vegetation consists of mesophilic forest, gallery forests and shrub savannas (Soro et al., 2014). Soils in the area are ferralitic and hydromorphic type. All these agroecological factors make the Autonomous District of Yamoussoukro, the second tomato production area in Côte d'Ivoire, after the one of Abengourou in the East (Agence Ecofin, 2016).

Symptomatology of root-knot nematode infections on tomatoes
Description of root galls
A phytosanitary survey was carried out in the tomato production plots. Thus, on each plot, an observation of the phytosanitary status of the tomato plants on the plots made it possible to identify a plan for collecting soil and root samples depending on the cultivated varieties. Thus, an X pattern was defined by selecting, at random, 60 plants on two diagonal rows of each field. On each diagonal, 30 plants at approximately equal distances were selected and uprooted. Careful observation of tomato roots made it possible to describe any possible symptoms, taking into account the type of symptoms, the shape, the distribution and the dimensions.

Assessment of root gall prevalence
Prevalence of tomato root galls was assessed by counting galled plants compared to the 30 plants selected on each diagonal row. Thus, prevalence of root galls per tomato variety was calculated according to the following formula.

$$PM(\%) = \frac{Pt}{N} \times 100$$

PM: gall prevalence,
Pt: number of plants with galls,
N: total number of plants selected

Assessment of root gall severity

Severity of tomato root galls was assessed basing on the Zeck scale (1971). This scale, which corresponds to a rating ranging from 0 to 10, galls observed on the plant root systems, was summarized as follows: 0 (root system completely free from galls), 1 (very few small galls), 2 (numerous small galls), 3 (numerous small galls of which some are grown together), 4 (numerous small and some big galls), 5 (25% of the roots severely galled), 6 (50% of the roots severely galled), 7 (75% of the root severely galled), 8 (no healthy roots but plant is still green), 9 (roots rotting and plant dying) and 10 (plant and roots dead).

Severity scores recorded on tomato plant root systems made it possible to calculate gall severity according to the Mckinney formula (1923).

$$S(\%) = \frac{\sum(ni \times n)}{Nt \times nie} \times 100$$

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

Soil and roots sampling

Soil and root samples from the uprooted plants were taken, making sure to remove the top soil layer. Soil samples, approximately 500 g each, were taken at a depth of approximately 20 cm. Soil and root samples from each plant were put in different labeled plastic bags. All those samples were placed in a polyethylene bag and sent to the laboratory.

Extraction and identification of root-knot nematodes

Soil samples collected per tomato variety in the plot were homogenized so as to constitute a composite sample. Plant parasitic nematodes were extracted from 100 ml of soil samples by the Whitehead tray method (Coyne et al., 2010). Five replicates were made per composite sample.

Nematodes extraction from roots, was done per tomato variety. Roots were washed with running water and cut into approximately 5mm-explants with scissors. Root explants were homogenized in order to constitute a composite sample. Plant parasitic nematodes were extracted from 5 g of tomato root explants by the Baermann maceration method (Coyne et al., 2010). Five replicates were made per composite sample.

Three 5 ml-aliquots of nematode suspensions after extraction were placed on a counting plate and mounted under an optical microscope. Root-knot nematodes were described, identified basing on the Perry et al. key (2009) and quantified.

Quantification of nematodes

To quantify the extracted nematodes, three 5 ml-aliquot were taken per nematode suspension. The number of individuals per 5 ml-aliquot was noted and average numbers of individuals were calculated according to the following formula.

$$AMi = \frac{1}{n} \sum(ni) \times 20$$

ANi: average number of individuals in 100 ml of soil or 5 g of roots
ni: number of individuals in 5 ml-aliquot
n: number of replicates

Contribution to root-knot nematode control by using garlic and onion extracts

Assessment of the *in vitro* effect of garlic and onion aqueous extracts on root-knot

- **Preparation of root-knot nematode aliquots**

Nematode suspensions from tomato root galls were concentrated to an average number of 100 ± 3 individuals of second larval stage per 100 µl of nematode suspension.

- **Preparation of garlic and onion aqueous extracts**

Garlic and onion cloves were stripped of their husks. Then, 100 g of garlic and onion cloves were weighed separately, diced and crushed in 100 ml of distilled water in a household blender. The ground material was collected and filtered twice in a row using hydrophilic cotton. First filtration was done using hydrophilic cotton in a funnel and the second one with a syringe containing densified hydrophilic cotton. Each aqueous extract was used to test its effectiveness on root-knot nematodes, particularly individuals of the 2nd larval stage.

- **Exposure of individuals to garlic and onion extracts**

Effectiveness of garlic and onion aqueous extracts on root-knot nematodes second larval stage individuals was assessed with three concentrations of aqueous extracts (S, S/2 and S/4). Five replicates were made per concentration. A volume of 100 µl of nematode aliquot containing on average 100 ± 3 individuals was taken with a micropipette and transferred into each Eppendorf tube containing 2 ml of extracts of different concentrations. Control individuals were exposed to 2 ml of sterile distilled water. Eppendorf tubes were slightly shaken and incubated in the container in the laboratory at room temperature (27 ± 2 °C).

- **Determination of nematode immobility and mortality rates**

After 24-hour incubation, individuals were observed under an optical microscope in order to count immobile nematodes. After counting, the nematodes were transferred to sterile distilled water and incubated for 24 hours under the same conditions. Another observation was made to verify whether immobile individuals were dead or recovered by stimulation with a needle. Individual was considered dead in the absence of movement following the injection (Cayrol et al., 1989). Number of dead and recovered individuals were made per concentration. Experiment was repeated three times and the immobility and mortality rates of nematodes concentration were calculated as follows.

$$IR(E) = \frac{NI(E) - NI(C)}{TN(E)} \times 100$$

Ti (E): immobility rate of individuals in the extract
NI (E): number of immobile individuals in the extract
NI (C): number of immobile individuals in the control
TN (E): total number of individuals in the extract

$$MR(E) = \frac{ND(E)}{TN(E)} \times 100$$

ND (E): mortality rate of individuals in the extract
ND (E): number of dead individuals in the extract
TN (E): total number of individuals in the extract

Assessment of the *in vivo* effect of garlic and onion aqueous extracts on root-knot nematodes

- **Acquisition of tomato plants**

Tomato variety F1 seeds were acquired on the market and germinated on moistened blotting paper in the tanks for 7 days. The seedlings were transferred into cavities containing humus-rich soil previously sterilized two times in an autoclave at 121 °C under 1 bar for 30 minutes. Tomato young plants, after 21 days, were transplanted into 30 plastic pots

perforated at the base and containing 500 g of the same sterilized soil. Tomato plants were left in culture for nine days under an insect-proof shelter and were watered at a frequency of 2 days.

- **Preparation of garlic and onion extracts**

Garlic and onion extracts were prepared as previously described with 1 kg of cloves. Concentration of extract with the most important nematicidal activity was selected for the test.

- **Preparation of nematode inoculum**

Root-knot nematodes extracted from tomato roots were used for aqueous extract effectiveness test. They were concentrated in a suspension to an average number of 100 ± 3 second larval stage individuals per 4 ml of aliquot.

- **Inoculation of tomato plants**

Five treatments were performed so as to assess the *in vivo* effectiveness of garlic and onion extracts on root-knot nematodes. These included T0 (inoculated and untreated plants), T1 (uninoculated and untreated plants), NA (plants inoculated and treated with garlic extract), NO (plants inoculated and treated with onion extract) and NAO (plants inoculated and treated with both garlic and onion extracts).

Each plant was inoculated with 4 ml-aliquot containing 100 ± 3 individuals of second larval stage of root-knot nematodes. This aliquot was deposited using a micropipette into four holes of approximately 5 cm deep made around the tomato plant and near the roots. Each treatment was replicated seven times.

- **Assessment of treatment effectiveness**

Treatment effectiveness was assessed, 30 days after, using disease and plant development parameters. Disease development parameters included the number of root-knot nematode individuals in the tomato roots and soil, the number of galls and the nematode reproductive factor. Plant development parameters were size and number of leaves per plant.

Statistical analyses

Data were analyzed using Statistica 7.1 software. Root-knot nematode numbers in soils and roots were transformed log function before being subjected to one-way analysis of variance, including tomato variety or treatment. Likewise, immobility and mortality rates were transformed by angular function before subjecting them to one-way analysis of variance (extract concentrations or type of extract). Homogeneous groups were determined using Fisher's LSD test at 5% level for each analysis.

RESULTS
Phytosanitary status of tomato fields
Symptoms on tomato plants

Three types of symptoms, namely root deformation, aerial organ discoloration and root system reduction were observed on tomato plants. Root deformation, manifested by the presence of rounded excrescence of varying diameter, was characteristic of tomato root galls (Fig. 1A). Aerial organ discoloration is reflected by plant leaf chlorosis (Fig. 1B). Root system reduction was also observed on tomato plants (Fig. 1C).

Fig. 1: Typical symptoms of plant parasitic nematodes attacks on tomato plants
A: galls on roots; B: leaf chlorosis; C: root system reduction

Root gall prevalence and severity

Tomato plants belonging to varieties PADMA and COBRA 26, showed root galls. Root gall prevalence and severity, however, varied depending on the tomato varieties and exceeded 50% (Table 1). Root gall prevalence was 88.33% in variety PADMA, against 81.67% in variety COBRA 26. Root gall severity was 52% for variety PADMA, while it was 62.19% regarding variety COBRA 26.

Table 1: Average root gall prevalence and severity on tomato roots

Tomato varieties	Root gall prevalence (%)	Root gall severity (%)
PADMA	88.33	52.50
COBRA 26	81.67	62.19

Nematodes extracted from tomato soil and root samples

Individuals of various development stages belonging to *Meloidogyne* genus were identified from tomato soil and root samples. These included eggs, 1st and 2nd larval stages. Adult males and females were extracted, in addition to these different larval stages (Fig. 2).
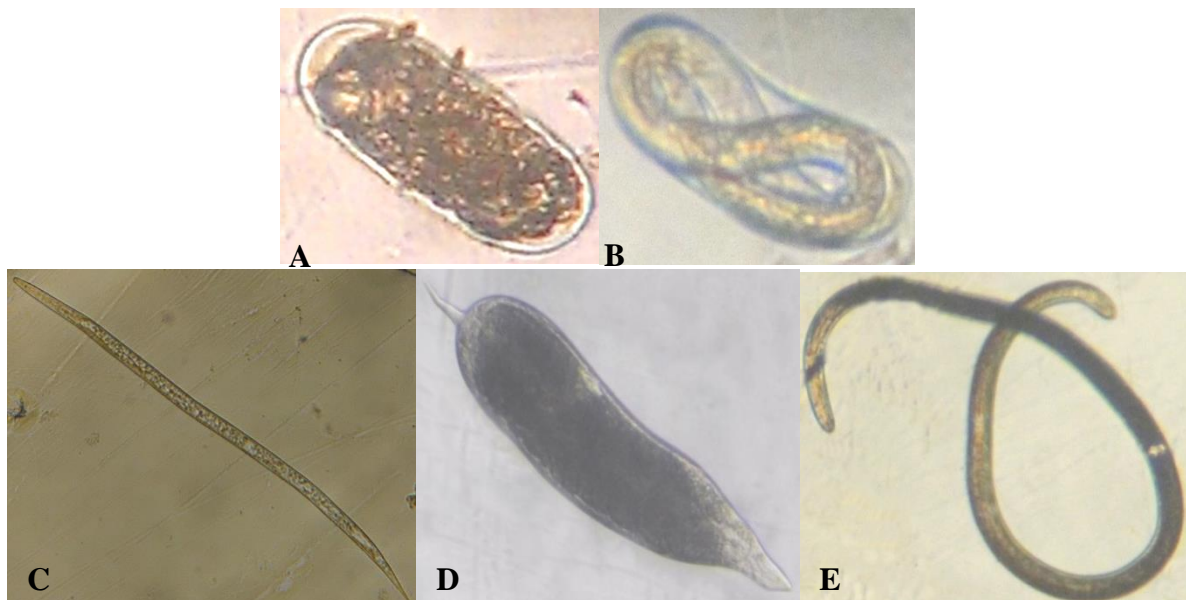

Fig. 2: *Meloidogyne* sp. individuals of various development stages extracted from tomato soil and root samples
A: egg; B: 1st larval stage individual; C: 2nd larval stage individual; D: adult female; E: adult male
Scale bars: A & B: 25 µm; C, D & E: 100 µm

Numbers of *Meloidogyne* sp. individuals in tomato soil and root samples

Average numbers of root-knot nematodes varied in soils and roots depending on the tomato varieties (Table 2). Average numbers of root-knot nematodes were statistically different in soils and roots depending on the tomato varieties. Average numbers of root-knot nematodes were higher in the tomato variety COBRA 26 cultivation soils and roots with 31 and 798 individuals, respectively. Average numbers of root-knot nematodes, whatever the tomato variety, were higher in tomato roots compared to those in soils.

Table2. Average numbers of root-knot nematodes in soil and roots per tomato variety

Tomato varieties	Substrates	
	Soils	Roots
PADMA	$19 \pm 2b$	$406 \pm 15b$
COBRA 26	$31 \pm 2a$	$798 \pm 61a$
P	*<0.05*	*<0.05*

Values assigned the same letter, in each column, are statistically similar according to Fisher's LSD test at 5% level, P: probability value.

***In vitro* effectiveness of plant extracts on 2nd larval-stage root-knot nematodes**

Immobility and mortality rate depending on the extract concentrations

Average immobility rates of the 2nd larval stage remained relatively constant regardless of garlic and onion aqueous extract concentrations. Average mortality rates of these individuals, in contrast, went up with increasing concentrations of garlic and onion aqueous extracts (Table 3). Average mortality

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rates varied from 43.57 to 72.99% at S/4 and S concentrations of onion extract, respectively. As for garlic extract, average mortality rates switched from 17.69 to 53.56% respectively for the S/4 and S concentrations. Statistical analyses revealed a concentration effect on the average mortality rate of root-knot nematodes ($P \leq 0.05$). Average mortality rates were higher in crude extracts with 72.99% for onion and 53.56% for garlic (Table 3).

Table 3: Average immobility and mortality rates of 2nd larval-stage *Meloidogyne* sp. exposed to garlic and onion extracts depending on their concentrations

Aqueous extract concentrations	Plant extracts			
	Onion		Garlic	
	IR (%)	MR (%)	IR (%)	MR (%)
S	78.59 ± 1.26**a**	72.99 ± 6.87**a**	77.11 ± 2.04**a**	53.56 ± 1.84**a**
S/2	78.89 ± 1.26**a**	50 ± 6.34**b**	77.81 ± 1.44**a**	15.88 ± 2.25**b**
S/4	78.59 ± 1.26**a**	43.57 ± 1.84**b**	75.28 ± 1.39**a**	17.69 ± 3.74**b**
P	*>0.05*	*<0.05*	*>0.05*	*<0.05*

IR: average immobility rates; MR: average mortality rates. Values assigned the same letter, in each column, are statistically equal according to Fisher's LSD test at 5% level. P: probability value

Average immobility and mortality rates depending on the types of extracts

Garlic and onion aqueous extracts caused average immobility rates of 2nd larval stage root-knot nematodes to be higher than 76% (Table 4). No significant difference, however, was noted between the aqueous extracts of

both plants in terms of average immobility rates. In contrast, average mortality rates varied significantly depending on the plant extracts. Statistical analyses showed that onion aqueous extract induced an average mortality rate of 55.52% higher than the one caused by garlic extract (29.04%).

Table 4: Average immobility and mortality rates of 2nd larval stage root-knot nematodes depending on the garlic and onion extracts

Plant extracts	IR (%)	MR (%)
Onion	78.45 ± 0.85**a**	55.52 ± 4.14**a**
Garlic	76.74 ± 0.94**a**	29.04 ± 3.04**b**
P	*>0.05*	*<0.05*

IR: average immobility rates; MR: average mortality rates
Values assigned the same letter, in each column, are statistically equal according to Fisher's LSD test at 5% level. P: probability value

***In vivo* effectiveness of garlic and onion extracts on root gall development**

Effect of treatments on disease development

Number and average reproductive factor of 2nd larval stage root-knot nematodes and the number of root galls varied depending on the treatments (Table 5). Statistical analyses revealed a significant difference between treatments in terms of numbers, reproductive factor and number of root galls. Analyses

showed that average numbers of root-knot nematodes in soils and roots were the highest with 245 individuals in the inoculated and untreated plants. The numbers of nematodes, in contrast, were lower (i.e. two individuals) in the soils and roots of the plants inoculated and treated with both garlic and onion extracts than those of plants inoculated and treated separately with garlic or onion extract.

The reproductive factor of *Meloidogyne* sp. was higher, that is, 2.45 in the inoculated and untreated tomato plants than in the plants inoculated and treated with extracts with a reproductive factor lower than 1. No significant difference was observed in nematode reproduction between tomato plants treated with a single extract and those treated with a combination of both extracts for nematode reproduction.

Number of root galls was lower in plants treated with plant extracts compared to inoculated and untreated plants. However, roots of tomato plants treated with garlic extract did not exhibit root galls. Tomato plants inoculated only with nematodes were more favorable to the development of nematodes and root galls.

Table 5: Parameters of root gall development on tomato plants per treatment

Treatments	Average numbers of nematodes	Average reproductive factor	Average numbers of root galls
T0	0**c**	0**c**	0**c**
T1	246 ± 1**a**	2.45 ± 0.25**a**	11 ± 9.01**a**
NA	5 ± 0.04**b**	0.02 ± 0.00**b**	0**c**
NO	5 ± 0.04**b**	0.5 ± 0.01**b**	3 ± 0.93**b**
NAO	2 ± 0.06**c**	0.4 ± 0.01**b**	1 ± 0.69**b**
P	*<0.05*	*<0.05*	*<0.05*

T0: uninoculated and untreated plants; T1: inoculated and untreated plants; NA: plants inoculated and treated with garlic extract; NO: plants inoculated and treated with onion extract; NAO: plants inoculated and treated with both garlic and onion extracts.

Averages assigned the same letter, in each column, are statistically similar according to Fisher's LSD test at 5% level. P: probability value.

Effect of treatments on tomato plant development

Tomato plants reacted differently in their development (Fig. 3). Indeed, the size and average number of tomato leaves per plant varied depending on the treatments (Table 6). Statistical analyses showed a treatment effect on the tomato plant development. Tomato plants inoculated and treated with both garlic and onion extracts showed a higher average height (22.63 cm) and a higher average leaf count per plant (36 leaves) than the plants that were subjected to other treatments.

Fig. 3: State of tomato plants 30 days after treatment with garlic and onion aqueous extracts
A: uninoculated and untreated plants; B: inoculated and untreated plants; C: plants inoculated and treated with garlic and onion extracts; D: plants inoculated and treated with garlic extract; E: plants inoculated and treated with onion extract

Table 6: Plant sizes and leaves numbers of tomato plants per treatment

Treatments	Plant sizes (cm)	Leave numbers per plant
T0	18.44 ± 2.51**b**	31 ± 4.08**b**
T1	16.82 ± 2.46**c**	28 ± 8.87**c**
NA	17.44 ± 1.46**b**	29 ± 4.86**b**
NO	16.17 ± 1.87**c**	29 ± 3.6**b**
NAO	22.63 ± 1.79**a**	36 ± 4.13**a**
P	*<0.05*	*<0.05*

T0: uninoculated and untreated plants; T1: inoculated and untreated plants; NA: plants inoculated and treated with garlic extract; NO: plants inoculated and treated with onion extract; NAO: plants inoculated and treated with both garlic and onion extracts.
Averages with the same letter, in each column, are statistically similar according to Fisher's LSD test at 5% level. P: probability value

DISCUSSION

The characteristic symptoms of root-knot nematode infection were observed on tomato plants during phytosanitary surveys carried out in tomato fields. These included root galls, root system reduction and plant leaf chlorosis among others. Root-knot nematodes, particularly individuals of the 2nd larval stage, once in the central cylinder of the root thanks to their salivary secretions, induce the formation of permanent nourishing sites made up of hypertrophied cells (Djian-Caporalino et al., 2018). Giant cells therefore divert nutrients in favor of nematodes in order to complete their development cycle. The increase in the volume of corrupt plant cells therefore leads to the formation of gall, characteristic of root-knot nematode infection. The permanent diversion of nutrients in favor of nematodes leads to leaf discoloration resulting in chlorosis, followed by plant wilting. Root galls, chlorosis, tomato plant root system reduction have previously been observed by Mokrini et al. (2016) in a survey of tomato farms in Morocco.

Furthermore, the phytosanitary surveys carried out in the tomato fields showed that the plants of all tomato varieties PADMA and COBRA 26 showed the characteristic symptoms of root-knot nematode infection. Prevalence and severity of these symptoms was over 50% regardless of the variety of tomato. This strong presence of the characteristic symptoms of root-knot nematode infection on tomato plants could be explained by the fact that these tomato varieties are sensitive to this category of nematodes. These varieties are best known for their resistance and tolerance to fungal, bacterial and viral infections. But it is clear that they are sensitive to root-knot nematode infection, even though they are one of the main varieties of tomato grown in the area of Yamoussoukro. Mokrini et al. (2016) showed that root-knot nematodes have a strong preference for Solanaceae and legumes. Thus, tomato yield in the area, already subject to numerous phytosanitary constraints, is strongly and negatively impacted by root-knot nematodes.

Baermann's maceration method, used for nematode extraction, revealed the presence of individuals of several developmental stages of root knot nematode belonging to the genus *Meloidogyne*. Their presence in the roots might be due to their plant-parasitic way of life. Indeed, plant parasitic nematodes are obligate biotrophic organisms that only live dependent on a host plant (Dinh et al., 2014). Part of their life cycle takes place in the roots of host plants. Thus, water and mineral salts extracted and sugars synthesized by plants are diverted by plant parasitic nematodes for their development (Bleve-Zacheo et al., 2007).

Number of nematodes, in addition, was found to be higher in the roots than in the soil. This might be due to the fact that nutrients (minerals absorbed) are found in roots for nematode development and reproduction. Jia et al. (2012) showed that root exudates (sugar, salts, enzymes) from plants

sensitive to nematodes favor nematode egg hatching, which would explain their high proportion in roots.

On the basis of the foregoing, the *in vitro* effectiveness tests carried out with crude aqueous extracts of garlic (*Allium sativum*) and onion (*Allium cepa*) showed that they have nematicidal activity. This nematicidal activity might be due to the presence of sulfur compounds such as dimethyl-dipropyl and dimethyl-disulfide in Alliaceae extracts (Djian-Caporalino et al., 2018). Indeed, these compounds could act on nematode development and reproduction so as to modify their physiology, by affecting ion absorption, by modifying membrane permeability, enzymatic activity, cell division and electron transportation, thus leading to their paralysis and then their death (Anaya et al., 2006). Studies carried out by Youssef et al. (2016), showed the nematicidal effectiveness of garlic and acetyl salicylic acid on root-knot nematodes. These authors have shown, through their study, that the extracts significantly reduced, either by watering or by foliar spraying, the development parameters of diseases caused by nematodes. This reduction therefore improved the growth and development of the plants. Bakr (2018) also demonstrated that the highest concentrations of garlic and onion aqueous extracts were more effective in reducing the numbers of *Meloidogyne* sp. infecting tomatoes. Onion aqueous extract, in this study, has a stronger nematicidal activity than that of garlic extract. Bakr (2018), in the same perspective, showed the larvicidal potential of onion extract, through the reduction in the number of individuals of the 2nd larval stage of *Meloidogyne incognita*. Joshi et al. (2013), in addition, reported the ovicidal and larvicidal potential of onion extract on 2nd larval stage *Meloidogyne* incognita. In view of the significant *in vitro* nematicidal activity of onion and garlic aqueous extracts, their nematicidal potential has been verified *in vivo*.

Under semi-controlled conditions, all treatments carried out with garlic and onion aqueous extracts reduced nematode reproductive factor and root gall development in tomatoes compared to other treatments. However, garlic extract reduced root gall development more than that of onion. El-Saedy et al. (2014), showed that garlic oil helped control effectively *Meloidogyne incognita* in tomatoes. Likewise, the work carried out by Abd Elgawad et al. (2009) showed that treating the soil with a product containing garlic extract reduced root gall index. In contrast, the combination of garlic and onion extracts in root-knot nematode control has helped improve the development of tomato plants. This improvement might be due to a synergy of activity of phytochemicals with nematicidal activity present in plant extracts. According to El-Nagdi et al. (2010), turmeric and ginger-based aqueous extract treatment improves the availability of nutrients, which could be explained by a high absorption of these nutrients by the roots.

CONCLUSION

Root galls, leaf chlorosis and root system reduction, characteristic of root-knot nematode infection, are found on the plants of different varieties of tomato grown in the area of the Autonomous District of Yamoussoukro. These symptoms are not only preponderant, but also severe on the plants regardless of the variety of tomato. *Meloidogyne* sp., only, found at different development stages was associated with tomato root galls, leaf chlorosis and root system reduction with an important presence in soils and roots of variety COBRA 26. Crude garlic and onion aqueous extracts used against root-knot nematode developed an important nematicidal activity under controlled and semi-controlled conditions. Treatment carried out with both garlic and onion extracts reduces root gall development and improves tomato plant development. There is therefore an interest in combining garlic and onion aqueous extracts in an integrated tomato pests and disease management program. An inclusion of Alliaceae crops in an association or rotation with host crops, particularly tomato, could be made in order to study the impact on nematode development and tomato yield.

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