Pak. J. Phytopathol., Vol. 35 (02) 2023. 201-214 DOI:10.33866/phytopathol.035.02.0911

Official publication of Pakistan Phytopathological Society
Pakistan Journal of Phytopathology
ISSN: 1019-763X (Print), 2305-0284 (Online)
http://www.pakps.com

NEMATICIDAL EFFECTS OF THE NUMBER OF DRIED CASTOR LEAF PRODUCT APPLICATIONS ON THE PATHOLOGICAL ACTIVITIES AND POPULATION DYNAMICS OF ROOT-KNOT AND ROOT-LESION NEMATODES ON WATER YAM

Yadom Y. F. R. Kouakou*, Kouamé D. Kra, Hortense A. Diallo

Plant Health Unit, Nangui Abrogoua University, 02 BP 801 Abidjan 02, Côte d'Ivoire.

A B S T R A C T

The current study was designed to investigate the effects of the number of dried castor leaf product applications on the population dynamics and pathological activities of root-knot and root-lesion nematodes on water yam. One application of castor leaf products resulted in an increase in symptom development and nematode numbers three months after yam seed planting. This resurgence of nematodes may be due to the depletion of castor leaf products incorporated into the soil. In view of this concern, it was required to investigate the effects of the number of dried castor leaf product applications on water yam nematodes. Trials were run in the 2015 and 2016 crop seasons in the Autonomous District of Yamoussoukro in Côte d'Ivoire. Castor leaf powder, castor leaf extract, and carbofuran were applied on the tops of mounds before yam seed planting, as well as the 3rd and 6th months following yam seed planting, using a complete random block design with three replicates. The prevalence and severity index of symptoms, nematode numbers, and yam yield were determined depending on the treatments. The harvested yam tubers showed symptoms such as galls, cracks and dry rot upon observation. All products reduced the development of symptoms on tubers after several applications. From one to three applications of the products, the symptom prevalence and severity index decreased from 10.86 to 0% and 9.83 to 0%, respectively. The products reduced the nematode numbers by 22.22% to 96.15% when applied one to three times. Plants cultivated on soils incorporated with castor leaf powder and extract three times showed a yield increase of 4.15 and 1.82 t/ha, respectively. Castor leaf powder, applied three times, is an excellent yam nematode management tool.

Keywords: Castor plant, Formulations, Nematodes, Number of Applications, Population Dynamics, Water Yam.

INTRODUCTION

Plant roots are constantly exposed to many soil microorganisms in the rhizosphere under field conditions (Enagbonma *et al.*, 2023). Among organisms found in the soil, some nematodes are capable of parasitizing plants (Barros *et al.*, 2022). Some plant-parasitic nematodes have the greatest impact on crop productivity when they attack the roots of seedlings immediately after seedling germination (Barros *et al.*, 2022). Plants infected with nematodes show multiple symptoms such as stunting, wilting, chlorosis, and stunted appearance, which ultimately lead to food scarcity, especially in sub-Saharan Africa (Abuzor and Haseeb, 2010).

Nematode infections occur on both yam roots and tubers. Galls, cracks, root necrosis, and dry rot are the major symptoms observed on yam roots and tubers (Kouakou *et al.*, 2016). Several species of nematodes have been associated with yam. Important nematodes are root and tuber endoparasites (Bridge *et al.*, 2005). Those known to cause significant damage by reducing yam yield and commercial quality are yam nematodes (*Scutellonema bradys*), root-lesion nematodes (*Pratylenchus coffeae* and *P. sudanensis*), and root-knot nematodes (Abdulsalam *et al.*, 2021). Yam yield reduction was about 24-80% and 30-100% due to root-knot nematodes and root-lesion nematodes, respectively (Coyne and Affokpon, 2018).

Effective control of plant-parasitic nematodes has relied

Submitted: July 17, 2023
Revised: August 25, 2023
Accepted for Publication: September 21, 2023
* Corresponding Author:
Email: yadomregis@yahoo.fr

on the application of inorganic substances, which are both environmentally insensitive because of their effect on non-target organisms and the high cost of the application (Abd-Elgawad, 2021). Nowadays, another model of pest control is recommended and applied. According to Lale (2006), plant pest management refers to maintaining pest populations through the use of individual strategies or a combination of strategies at a level where they are incapable of reducing crop yield or quality or harming human and animal health. As a result, the use of plant extracts with antimicrobial properties is booming (Hassan *et al.*, 2020; Catani *et al.*, 2023). Thus, neem powders and cocoa pods were used against yam pathogenic nematodes (Osei *et al*., 2013).

In Côte d'Ivoire, dried castor leaf extract and powder were used as tools for yam nematode management (Kouakou *et al*., 2017; Kouakou *et al*., 2023). According to these authors, those products, in a single application, reduced *P. coffeae* and *M. javanica* numbers in soil, yam roots, and tubers. They also limited the symptom development due to the activities of nematodes on yam tubers. These authors, in contrast, noted the increase in the number of individuals of nematodes three months after yam seed planting. The resurgence of nematodes may be due to the depletion of castor leaf products incorporated into the soil. This could pose a threat to developing tubers. Thus, the aim of the study is to evaluate the effect of the number of dried castor leaf product applications on the pathological activities and population dynamics of *P. coffeae* and *M. javanica* on water yam.

MATERIALS AND METHODS

Study Site and Climatic Conditions: The trial location was in the village area of N'Gattakro (N 06°52.950'; W 005°19.992') in the Autonomous District of Yamoussoukro in central Côte d'Ivoire. An equatorial transitional climate covers the area (N'Guessan, 1990), with two rainy seasons (March to June and September to October) and two dry seasons from July to August and November to February (Bla *et al*., 2015). N'Guessan (1990) reported that the yearly rainfall fluctuated between 1200 and 1600 mm. The yearly average temperature is around 26°C (Alui *et al*., 2011). The area's vegetation includes mesophilic and gallery forests and shrubby savannahs (Soro *et al.*, 2014).

Trial set up: Experimental design: A 53 m × 23 m plot was established to evaluate the effect of the number of applications of two dried castor leaf formulations on the yam nematodes. Siam weed (*Chromolaena odorata*), cassava (*Manihot esculenta*), and Guinea grass (*Panicum maximum*) plants dominated the vegetation of the study site. The pre-plant soil of the study site was dominated by *P. coffeae* with 72 to 85 individuals and *M. javanica* with 67 to 79 individuals in 100 ml of soil.

The experiment comprised two factors: the nematicidal products and the number of applications of the nematicidal products. Nematicidal products had three treatment levels (castor leaf powder, castor leaf extract, and carbofuran) and an unincorporated control. The number of applications of the nematicidal products had three treatment levels (one, two, and three applications).

The experimental plot was divided into three blocks of 10 elementary plots, each measuring 5 m by 4 m. Mounds of about 50 cm high were made at a rate of 20 mounds per elementary plot. For this trial, the experimental plot followed a randomized complete block design with three replicates. Implementing the trial started in April (the beginning of the long rainy season in central Côte d'Ivoire) and ended in January (the long dry season where all yam tubers were harvested). The trial was conducted for two consecutive years (2015 and 2016).

Preparation of dried castor leaf products: Castor leaves were collected in the Abidjan Autonomous District's suburbs. The leaves were dried in an airy room and transformed into powder using a household mixer. Two dried castor leaf-based products were prepared. These included the liquid formulation (aqueous extract) and the powder formulation. Caster leaf powder and extract were prepared according to the method of Kouakou *et al*. (2023). Seven hundred twenty (720) batches of 100 g of castor leaf powder and 20 containers of 10-liter leaf extract were used for the two years of the trial.

Supplying of yam seeds: This study used water yam (*Dioscorea alata*, cv. Bètè bètè) tubers with no visible symptoms. Several pieces of peel were collected from all yam tubers to detect the nematodes. Only free-nematode tubers were used to supply yam seeds. Twenty-two yam tubers were cut into seeds weighing around 200 g.

Application of products and planting of yam seeds: Ten treatments were performed on the study plot, which included:

Control: Unincorporated product soil,

CT1: Soil incorporated once with carbofuran at 0 MAP (10 g/plant),
CT2: Soil incorporated twice with carbofuran at 0 and 3 MAP (10 g/plant),
CT3: Soil incorporated three times with carbofuran at 0, 3, and 6 MAP (10 g/plant),
PT1: Soil incorporated once with castor leaf powder at 0 MAP (100 g/plant),
PT2: Soil incorporated twice with castor leaf powder at 0 and 3 MAP (100 g/plant),
PT3: Soil incorporated three times with castor leaf powder at 0, 3, and 6 MAP (100 g/plant),
ET1: Soil incorporated once with castor leaf extract at 0 MAP (500 ml/plant),
ET2: Soil incorporated twice with castor leaf extract at 0 and 3 MAP (500 ml/plant),
ET3: Soil incorporated three times with castor leaf extract at 0, 3, and 6 MAP (500 ml/plant).

Carbofuran, castor leaf powder, and castor leaf extract were applied and incorporated into the tops of mounds at different periods of the yam crop cycle. There were treatments performed just at planting for each product; others only at planting and 3 MAP; and yet others only at planting, 3, and 6 MAP.

Before inserting the yam seeds, each product was applied and incorporated into the tops of the mounds. In the 3rd and 6th MAPs, depending on the treatments, the roots of the yam plants were exposed by scraping the soil at the tops of mounds. Then products were applied, depending on the treatment, before covering the roots with soil. The mounds of free products were the control treatment.

Conduct of the trials: Yam plants were staked two months after seed planting. Five manual weedings were performed two months apart, starting in the first month. No fertilizer was applied during the trials. The yam tubers were harvested in the 9th month after seed planting.

Sampling: Soil, root, and tuber samples were collected randomly according to the destructive model (uprooting of plants). Soil samples were collected during seed planting and then in the 3rd, 6th, and 9th MAPs. Before product application, soil was sampled from 10 mounds in each elementary plot. Five plants randomly selected from each elementary plot were carefully uprooted in the 3rd, 6th, and 9th MAPs. Each plant's root system and any adherent soil were removed and packaged. Depending on the sampling date, all samples were sent to the laboratory for nematode extraction.

Evaluation of the nematicidal effect of castor leaf formulations: Evaluation of the effect of treatments on symptom development: Yam tubers were harvested nine months after seed planting. Observations were made to identify the characteristic symptoms of plant-parasitic nematode infections on yam tubers (dry rot, cracks, and galls). The prevalence and severity index of symptoms were computed using the methods of Ogara and Bina (2010) and Zewain (2014), based on the products and the number of applications.

Evaluation of the effect of treatments on nematode numbers: Nematodes in soil, yam root, and tuber samples were extracted according to the Whitehead tray and Baermann maceration methods (Coyne *et al*., 2010), respectively. Individuals of *P. coffeae* and *M. javanica* were counted from 100 ml of soil and 5 g of yam roots and tuber peelings using Kouakou *et al*. (2023) formula. The effect of the treatments on nematode populations in the soil, roots, and tubers was evaluated by computing the reduction rate (Rr) of nematode numbers using the Mahdy *et al*. (2014) formula.

Evaluation of the effect of treatments on nematode population dynamics: Individual numbers of *P. coffeae* and *M. javanica* were calculated in 100 ml of soil, 5g of yam roots, and 5g of yam peelings before yam seed planting and 3, 6, and 9 MAPs.

Evaluation of the effect of treatments on yam yield: At tuber harvest, yam plant yield (y) was calculated per treatment using Rodriguez's (2014) formula. The yield was calculated using 10 yam plants per elementary plot and 30 plants per treatment.

STATISTICAL ANALYSIS

Symptom prevalence, severity index, and reduction rate of nematode numbers were transformed by the $\arcsin\sqrt{p/100}$ function (p is the determined rate). Nematode numbers were transformed by the $\log_{10}(x+1)$ function (x is the determined number). Transformed data were subjected to univariate analysis with Statistica 7.1 software to identify the most effective treatments.

RESULTS

Effects of treatments on the development of symptoms: Prevalence and severity index of symptoms depending on the nematicidal products: Galls, cracks, and dry rot were noted on freshly harvested yam tubers regardless of the products. The prevalence of symptoms varied from 2.11 to 26.6% depending on the treatments (Table 1). The prevalence was 26.60% in the control tubers. However, it was 5.13 and 5.94 on tubers from carbofuran and leaf extract treatments, respectively. The prevalence of symptoms was lower (2.11%) on tubers treated with leaf powder. A highly significant difference was noted in the prevalence of symptoms according to the products (*P < 0.001*). The prevalence of symptoms was very low (less than 6%) on tubers from soils incorporated with products compared with control tubers (26.6%).

The severity index of symptoms varied from 2.08 to 29.56% on the tubers, depending on the products. However, the prevalence of symptoms was 29.56% on control tubers and less than 4% on tubers from soils incorporated with products. Statistical analysis showed a highly significant difference in the severity index of symptoms according to the products (*P < 0.001*). Symptoms were less severe on the tubers of plants cultivated on soils incorporated with the different products compared to control tubers.

Prevalence and severity index of symptoms depending on the number of applications of products: The prevalence and severity index of symptoms decreased as the nematicidal products were applied (Figure 1A-B). The prevalence of symptoms was 26.60% when no product was applied. When carbofuran and castor leaf powder were applied one to three times, the prevalence of symptoms decreased from 7.73 to 2.59% and 8.42 to 0%, respectively. However, the prevalence of symptoms varied from 10.86 to 3.19% after one to three applications of castor leaf extract. The prevalence of symptoms was significantly affected by the number of applications of nematicidal products (*P < 0.01*). Thus, the prevalence of symptoms was lowest on yam tubers when the castor leaf powder was applied two to three times.

The severity index of symptoms was 29.56% in the control tubers. However, it fell from 4.38 to 2% on tubers after three applications of carbofuran. It also dropped from 9.29 to 0% after three applications of castor leaf powder. It dropped from 9.83 to 2.71% after three applications of the castor leaf extract. The number of applications of nematicide products had a highly significant effect on the severity index of symptoms (*P < 0.01*). The lowest severity indexes of symptoms were noted after three applications of carbofuran and two to three applications of castor leaf powder and extract.

Table 1. Prevalence and severity index of symptoms according to the castor leaf formulations

Treatments	Symptoms	
	Prevalence (%)	Severity Index (%)
Control	26.60 ± 11.61a	29.56 ± 10.07a
Carbofuran	5.13 ± 2.02b	2.08 ± 1.05b
Leaf Powder	2.11 ± 1.10b	2.31 ± 1.87b
Leaf Extract	5.94 ± 2.20b	3.98 ± 1.38b
F	*9.72*	*19.22*
P	*0.000*	*0.000*

In each column, values with the same letter are statistically identical at the 5% level, according to *Dunnett's test*, *F. Fisher's statistic*, *P. Probability value*. The mean prevalence and severity indexes in this table result from the two years of trials.

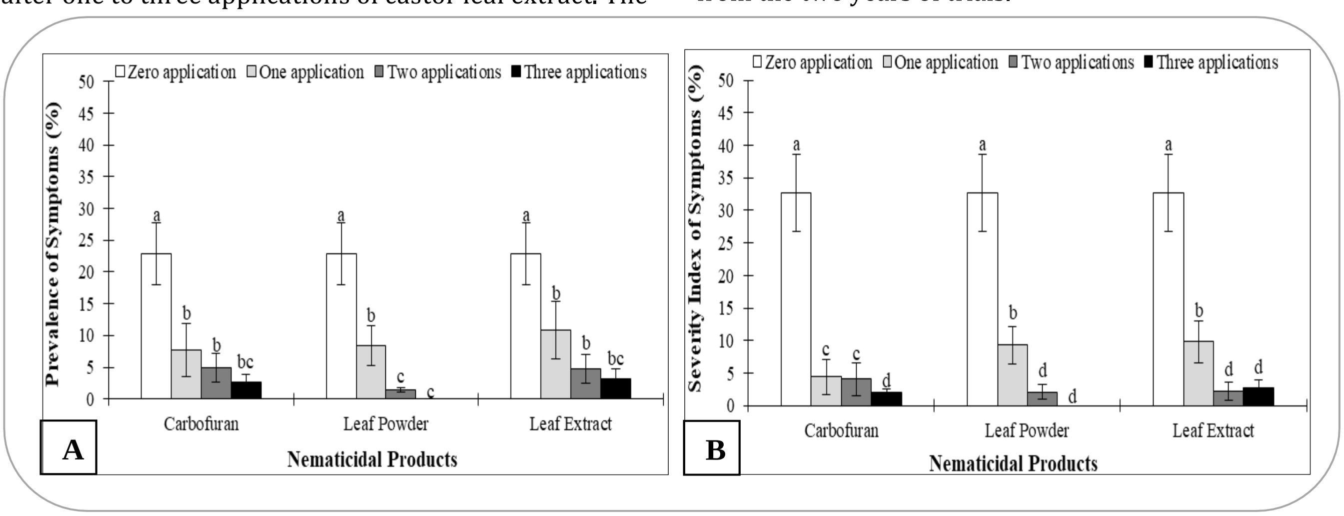

Figure 1. Prevalence (A) and severity index (B) of symptoms depending on the number of applications of castor leaf formulation

For each graph, the histograms with the same letter are statistically identical at the 5% level, according to Fisher's LSD test. The mean prevalence and severity indexes result from the two years of trials.

Effects of treatments on the number of nematodes: Reduction rate of nematode numbers depending on the products: In the soils, reduction rates of M. javanica numbers ranged from 58.82 to 72.55%. However, those of *P. coffeae* oscillated between 72.16 and 88.14% (Table 2). The reduction rates of M. javanica numbers were statistically similar for all products (P > 0.05), unlike *P. coffeae* (P < 0.05). Carbofuran (88.14%) and castor leaf powder (84.02%) reduced *P. coffeae* numbers more than castor leaf extract (72.16%).

In the roots, the reduction rates varied between 46.15 and 94.23% in *M. javanica* and between 75.18 and 78.25% in *P. coffeae* (Table 2). The products applied influenced the reduction rates of *M. javanica* numbers (P > 0.05), unlike those of *P. coffeae* (P < 0.05). Castor leaf powder is the one that reduced *M. javanica* numbers in the roots the most, with a rate of 94.23%.

In the tubers, the reduction rates of *M. javanica* numbers fluctuated between 51.35 and 59.46%, while those of *P. coffeae* increased from 64 to 73.33% (Table 2). However, no significant differences were noted between the products based on the reduction rates of both nematode populations (*P > 0.05*).

Reduction rate of nematodes depending on the number of applications of products: *Meloidogyne javanica* and *P. coffeae* populations decreased in the soil after application of the nematicidal products. This decrease was reflected by the increase in reduction rates (56.86 to 88.24%) of nematode numbers (Figure 2A–B). The number of applications of nematicidal products had a significant effect on the reduction rate of nematode numbers (*P < 0.01*). Then, carbofuran and castor leaf powder decreased the number of *M. javanica* more than castor leaf extract in two applications. After three applications, all products significantly decreased *P. coffeae* populations with over 85%.

Meloidogyne javanica and *P. coffeae* populations in yam roots dropped as nematicidal products were applied. Nematode numbers were reduced by 25 to 96.15% between the first and third applications of the nematicidal products (Figure 3A-B). The number of applications of nematicidal products had a highly significant influence on the reduction rates of nematode numbers in yam roots (*P < 0.01*). Only castor leaf powder decreased *M. javanica* populations by 90% after two treatments. However, the products significantly reduced (85%) *P. coffeae* numbers after three applications.

Meloidogyne javanica and *P. coffeae* numbers were reduced in tubers as the number of nematicide applications increased. Nematode reduction rates ranged from 22.22 to 92% from the first to the third product application (Figure 4A-B). The number of applications of the products significantly influenced the reduction rate of nematode numbers (*P < 0.01*). Carbofuran and castor leaf extract at the second application and castor leaf powder at the third application had the greatest reduction in *M. javanica* numbers (77%). After three applications, all products reduced the number of *P. coffeae* by over 85%.

Table 2. Reduction rate of nematodes numbers according to the castor leaf formulations

Substrates	Castor leaf Formulations	Water Yam Nematodes	
		Meloidogyne javanica	*Pratylenchus coffeae*
Soil	Carbofuran	72.55 ± 11.20a	88.14 ± 1.61a
	Leaf powder	64.71 ± 11.97a	84.02 ± 2.38a
	Leaf extract	58.83 ± 11.74a	72.16 ± 7.28b
	F	*0.14*	*2.93*
	P	*0.970*	*0.040*
Roots	Carbofuran	71.15 ± 09.63b	78.25 ± 7.05a
	Leaf powder	94.23 ± 05.56a	75.18 ± 10.7a
	Leaf extract	46.15 ± 17.63c	77.54 ± 5.89a
	F	*4.25*	*0.47*
	P	*0.010*	*0.760*
Tubers	Carbofuran	59.46 ± 15.23a	72.00 ± 14.01a
	Leaf powder	51.35 ± 13.79a	64.00 ± 13.16a
	Leaf extract	62.16 ± 15.74a	73.33 ± 14.11a
	F	*7.56*	*0.12*
	P	*0.000*	*0.970*

Values with the same letter, in each column, are statistically equal to the 5% level, according to Fisher's LSD test; F. Fisher statistics, P. Probability value. The mean reduction rates in this table result from the two years of trials

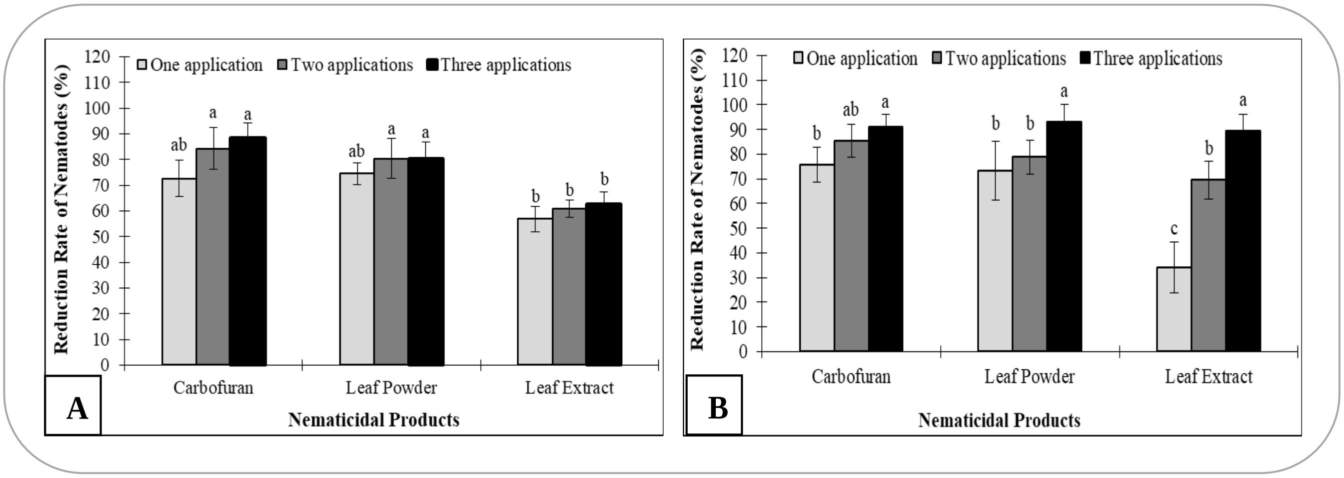

Figure 2. Reduction rate of *Meloidogyne javanica* (A) and *Pratylenchus coffeae* (B) numbers in soils depending on the number of applications of castor leaf formulations

For each graph, the histograms with the same letter are statistically identical at the 5% level, according to Fisher's LSD test. The mean reduction rates of these figures result from the two years of trials.

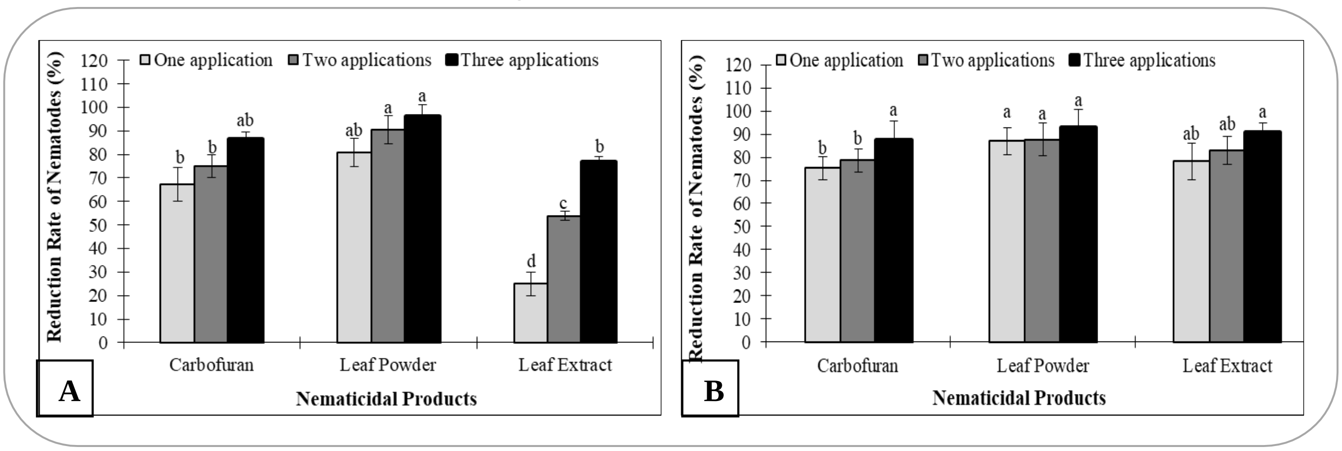

Figure 3. Reduction rate of *Meloidogyne javanica* (A) and *Pratylenchus coffeae* (B) numbers in yam roots depending on the number of applications of castor leaf formulations

For each graph, the histograms with the same letter are statistically identical at the 5% level, according to Fisher's LSD test. The mean reduction rates of these figures result from the two years of trials.

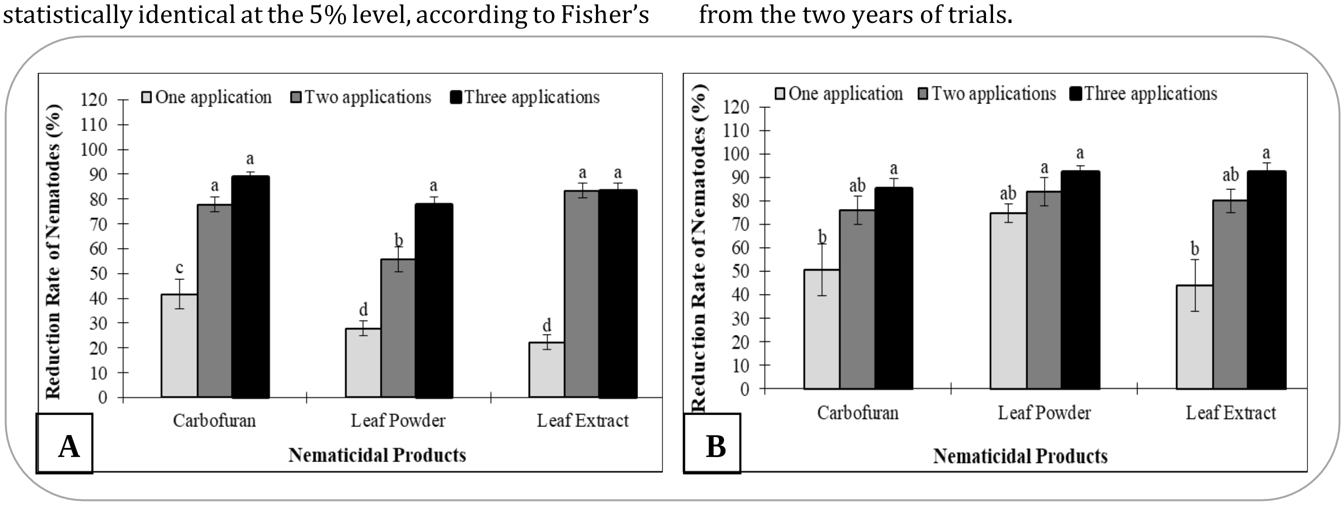

Figure 4. Reduction rate of *Meloidogyne javanica* (A) and *Pratylenchus coffeae* (B) numbers in yam tubers depending on the number of applications of castor leaf formulations

For each graph, the histograms with the same letter are statistically identical at the 5% level, according to Fisher's LSD test. The mean reduction rates of these figures result from the two years of trials.

Effects of the number of applications of products on yam yield: Yam yield increased with the number of applications of each nematicidal product (Figure 5). The number of applications of nematicidal products significantly influenced the yam yield ($P < 0.05$). Thus, when carbofuran was applied one to three times, the yield increased from 8.61 to 12.1 t/ha. There was, therefore, an increase in yield ranging from 0.94 to 4.43 t/ha compared to that of the control plants (7.67 t/ha). When castor leaf powder was applied up to three times, yam yield increased from 8.91 to 11.82 t/ha, an increase of 1.24 to 4.15 t/ha. A yield increase ranging from 0.34 to 1.82 t/ha was noted in yam plants after one to three applications of castor leaf extract. Thus, the highest yields were noted in yam plants cultivated on soils incorporated with carbofuran and castor leaf powder in three applications.

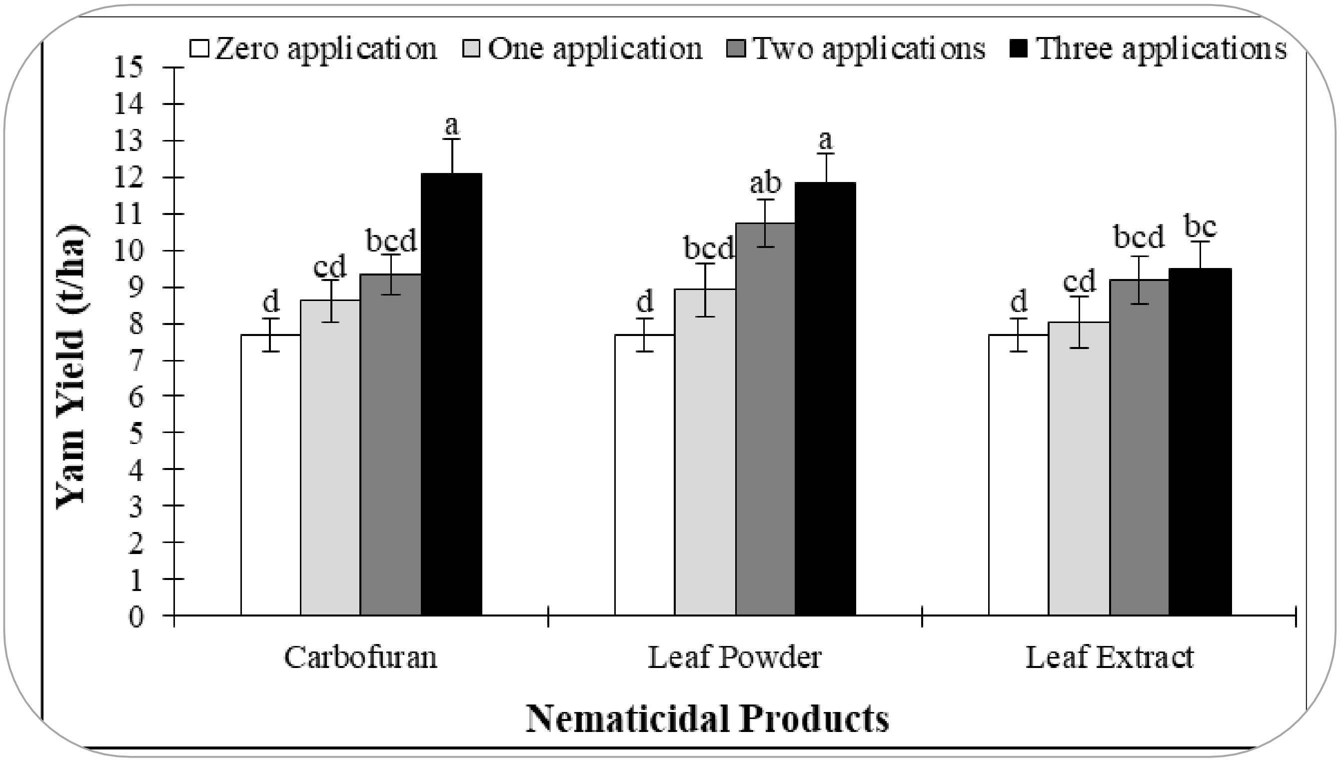

Figure 5. Yam yield depending on the number of applications of castor leaf formulations

Histograms with the same letter are statistically identical at the 5% level, according to Fisher's LSD test. The average yields in this figure result from the two years of trials.

Effects of the number of applications of products on the dynamics of nematode populations: Nematode numbers were considerably higher in the unincorporated soils than in the product-incorporated soils (Figure 6). When each treatment was performed, the number of individuals of each nematode species dropped considerably. Thus, after two to three applications, the *M. javanica* numbers stood at less than 40 individuals from 3 MAP, regardless of the product applied. *P. coffeae*, after three treatments, had less than 50, 30, and 20 individuals at the third, sixth, and ninth MAP, respectively.

Nematode numbers increased over time in the roots of yam plants despite the nematicidal products applied (Figure 7). However, once the products were incorporated, they decreased. Thus, *M. javanica* numbers increased from less than 13 individuals in the third MAP to 28 individuals in the sixth MAP following three applications of the products. Those of *P. coffeae* increased from less than 8 individuals in the third MAP to over 55 individuals in the sixth MAP after three applications of the products.

In the tubers, nematode numbers of the control plants were higher than those in the tubers of the plants on the soils incorporated with the products (Figure 8). Despite the products' applications, nematode numbers increased in yam tubers during the season. However, their numbers were reduced as the products were applied. *M. javanica* and *P. coffeae* numbers stood at less than 30 individuals throughout the yam crop cycle after three applications of the products.

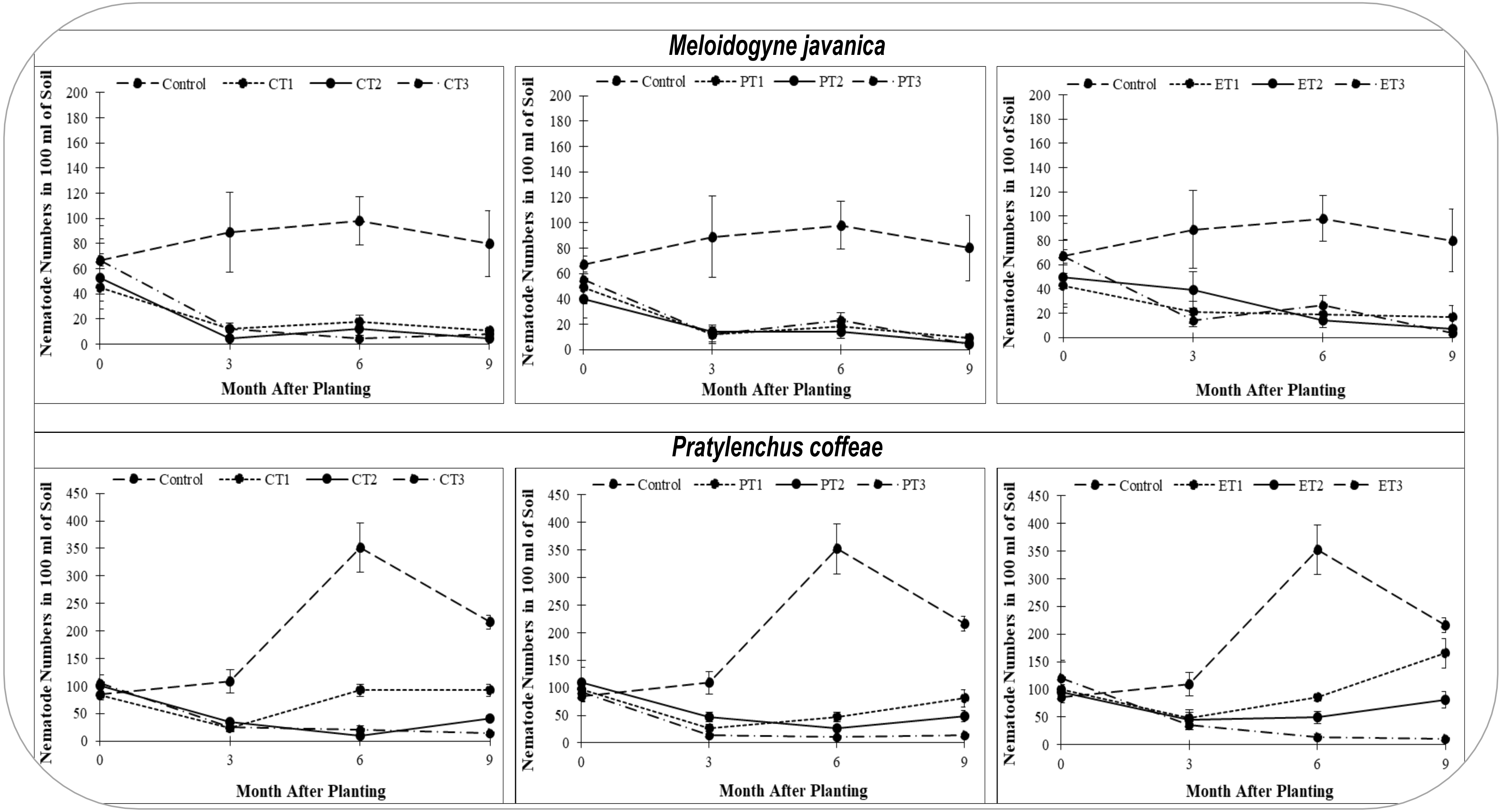

Figure 6. Fluctuations in nematode numbers in yam cultivation soils depending on the number of applications of castor leaf formulations

Control: Unincorporated product soil; Soils incorporated one (CT1), two (CT2), or three times (CT3) with carbofuran (10 g/plant); Soils incorporated one (PT1), two (PT2), or three times (PT3) with castor leaf powder (100 g/plant); Soils incorporated one (ET1), two (ET2), or three times (ET3) with castor leaf extract (500 ml/plant). The average numbers in this figure result from the two years of trials.

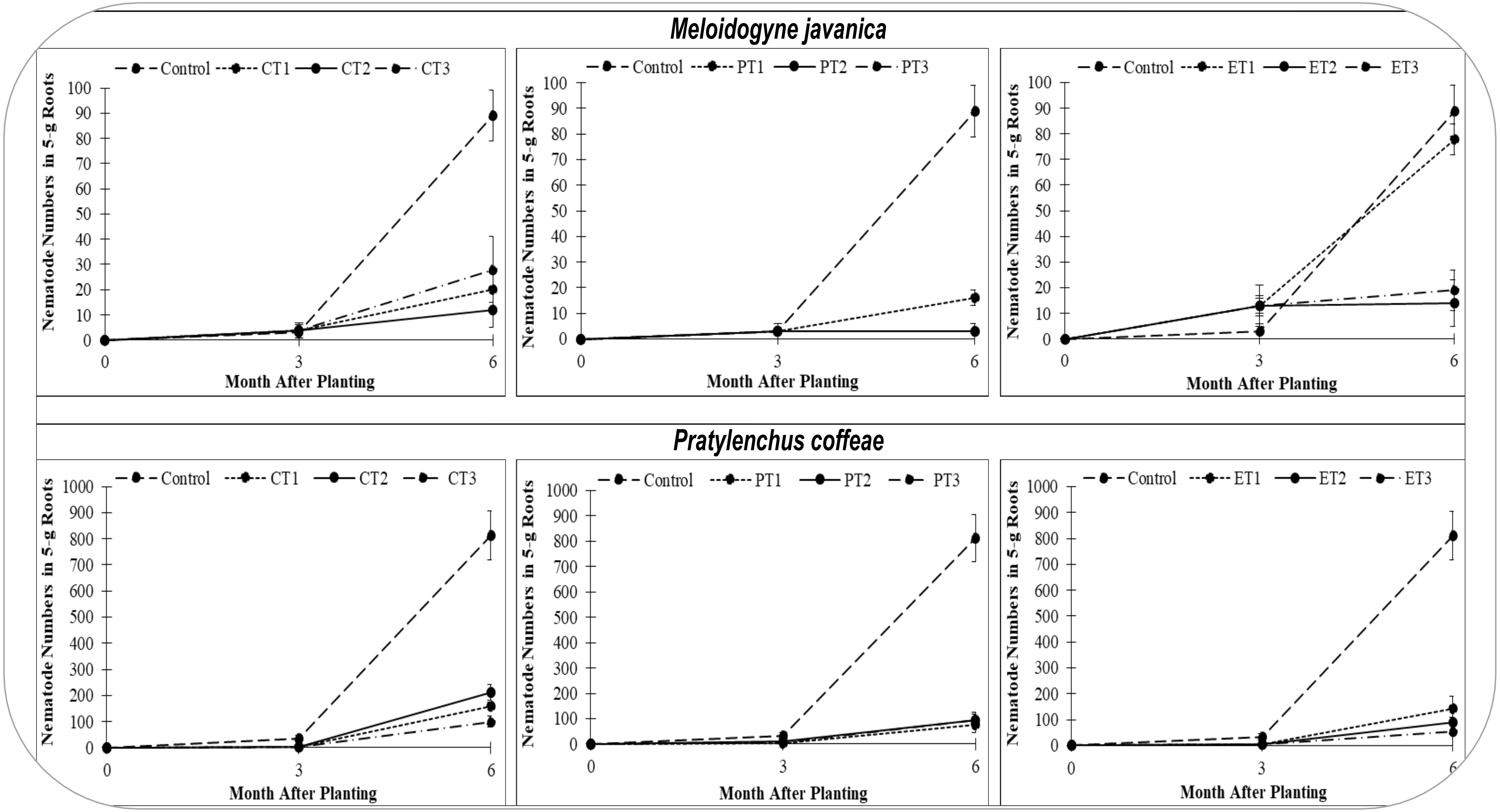

Figure 7. Fluctuations in nematode numbers in the roots of yam plants depending on the number of applications of castor leaf formulations

Control: Unincorporated product soil; Soils incorporated one (CT1), two (CT2), or three times (CT3) with carbofuran (10 g/plant); Soils incorporated one (PT1), two (PT2), or three times (PT3) with castor leaf powder (100 g/plant); Soils incorporated one (ET1), two (ET2), or three times (ET3) with castor leaf extract (500 ml/plant). The average numbers in this figure result from the two years of trials.

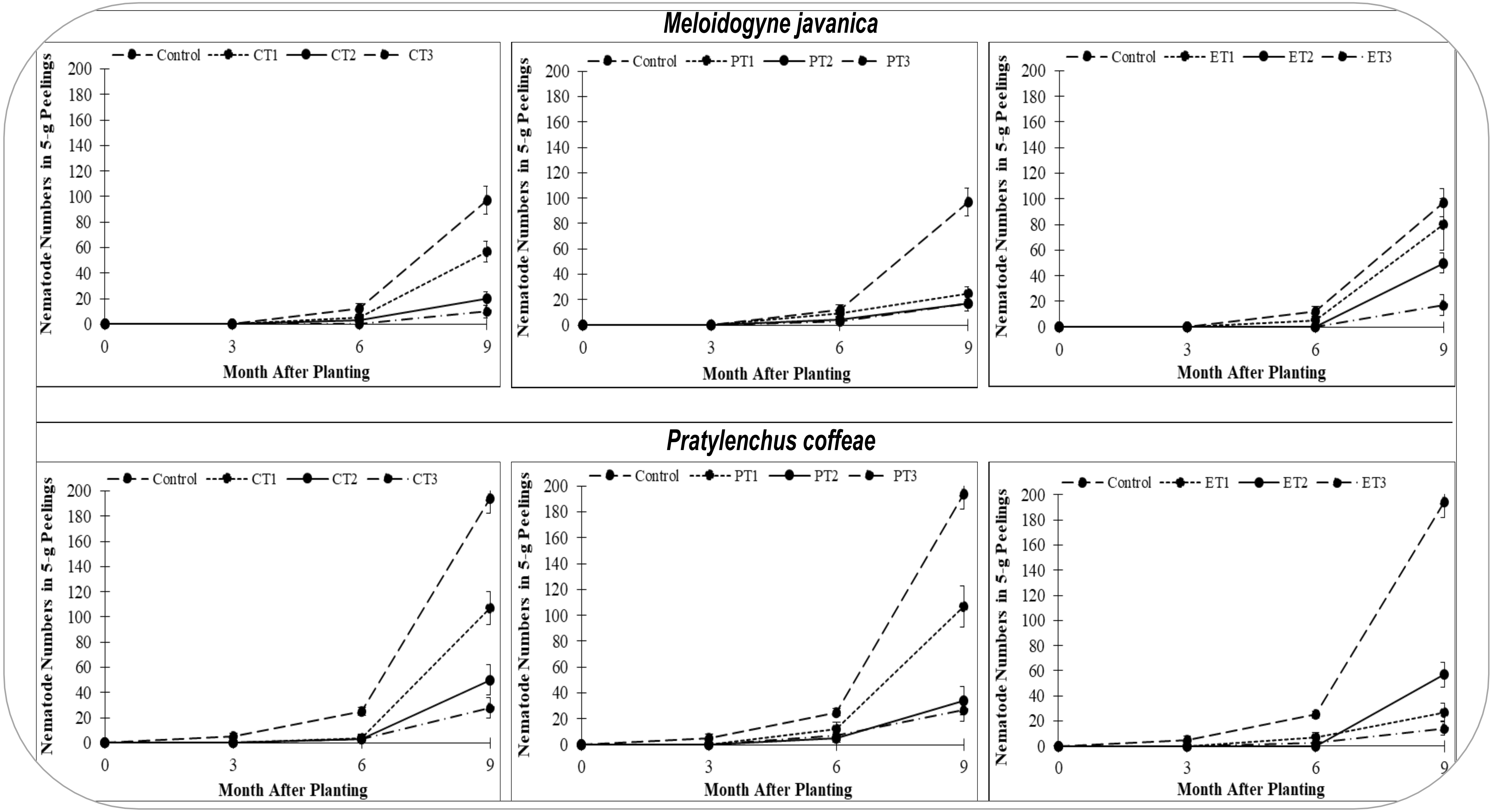

Figure 8. Fluctuations in nematode numbers in yam tubers depending on the number of applications of castor leaf formulations

Control: Unincorporated product soil; Soils incorporated one (CT1), two (CT2), or three times (CT3) with carbofuran (10 g/plant); Soils incorporated one (PT1), two (PT2), or three times (PT3) with castor leaf powder (100 g/plant); Soils incorporated one (ET1), two (ET2), or three times (ET3) with castor leaf extract (500 ml/plant). The average numbers in this figure result from the two years of trials.

DISCUSSION

Nematode numbers were lower in soils, roots, and tubers of yam plants cultivated on soils incorporated with dried castor leaf products compared to unincorporated soils. It is evident that castor leaf products have phytochemicals with a lethal effect on water yam nematodes. Nematode suppression by castor leaf extract might be due to the presence of phytochemicals in the extract that possess nematicidal properties. The nematicidal phytochemicals include alkaloids, phenols, diterpenes, fatty acids, tannins, and steroids (Sithole, 2021). Several processes and solvents, including aqueous extraction, can be used to extract such phytochemicals. In fact, maceration of dried castor leaf powder in water yielded this extract, which was incorporated into the soil. Phytochemicals are known for their nematicidal properties. However, their mode of action on plant-parasitic nematodes is still unknown. Das *et al.* (2015) extracted such phytochemicals from castor leaves using the aqueous method. In Ghana, Adomako *et al.* (2013) used crude castor seed extract against *Meloidogyne* spp. in potted tomato plants. El-Nagdi and Youssef (2013) reduced *M. incognita* numbers in tomato soil and roots by 15-21% using castor seed extract in Egypt.

As for castor leaf powder, its antiparasitic activity might be due to the toxicity of decomposing plant material against soil nematodes. Indeed, the soil is enriched in phenolic products, ammoniacal nitrogen, and hydrogen ions thanks to the decomposition of organic matter. However, these substances are very active against plant-parasitic nematodes (Kerkeni *et al*., 2007). In addition, the organic amendment of the soil increases the activity of predatory and parasitic microorganisms in nematodes. This situation stimulates the microbial community, which decomposes specific proteins and substances found in the nematode cuticle (Farahat *et al*., 2010). These results support those of Radwan *et al.* (2012), although the plant material used is different from that used in the current study. These authors found over an 80% reduction in *M. incognita* numbers after application of castor seed powder at a dose of 5 g/kg of tomato soil in Egypt. Hayat *et al.* (2012) concluded that the castor cake used as a soil amendment was effective in reducing the infestation of *M. incognita* on potatoes.

Nematode reduction by carbofuran might be due to its anticholinesterase activity. In fact, carbofuran in contact with nematodes might inhibit the activity of acetylcholinesterase. This is a cholinergic enzyme that prevents the hydrolysis of acetylcholine (Colovic *et al.*, 2013). This inhibition leads to a disruption of the transmission of nerve impulses, thus creating perceptual disturbances, muscle paralysis, or even the death of nematodes (Daramola *et al.*, 2013). Carbofuran is a broad-spectrum carbamate that is used in farm practices to increase crop productivity. Carbofuran is also used as an insecticide, nematicide, and acaricide due to its broad-spectrum action (Gupta *et al.*, 2016). Zafar *et al.* (2022) controlled nematodes associated with *Malus pumila* using carbofuran. Nowadays, carbofuran is banned in several countries due to its high toxicity to humans, invertebrates, fish, and birds. Carbofuran is accumulated in the fat depots and exerts adverse effects on vital organs such as the brain, liver, skeletal muscles, and heart (Gupta *et al.*, 2016). However, carbofuran is still present on the black market in several developing countries.

The nematicidal effects of the phytochemicals were enhanced after several applications of castor leaf products. The increase in nematode reduction rate with the number of applications of castor leaf products reflected this result. Thus, the lowest nematode numbers were noted after three applications of castor leaf products. Several applications of castor leaf products resulted in nematode numbers remaining below their thresholds, where damage to yam plants is negligible. According to Coyne *et al*. (2010), the damage threshold depends on the biology of the pathogen, the host plant, and environmental factors. Thus, castor leaf powder, castor leaf extract, and carbofuran applied several times significantly disrupted the development cycles of *M. javanica* and *P. coffeae*. This situation affected the nematode's reproduction, hence their low numbers in soils and yam plants. In Brazil, Almeida *et al*. (2011) noted that *Meloidogyne enterolobii* numbers were reduced in the roots of guava trees and soils after six organic soil amendments.

After one application of castor leaf products, nematode numbers showed an upward trend throughout the yam crop cycle. However, this trend stagnated after several applications of the products. This means that several generations of *M. javanica* and *P. coffeae* individuals were suppressed. As a result, the pathological activity of nematodes was kept at a lower level. As a result, yam tubers were less infected, and yields were higher in plants grown on soils incorporated with products than in control soils. The increased yield of plants grown on soils incorporated with dried castor leaf powder is due to the improved physico-chemical properties of the soil following the decomposition of the organic matter. In fact, organic treatment enhanced soil pH and organic C, the most frequently reported characteristics and essential indicators of soil quality and agricultural sustainability (Nobile *et al.*, 2020). The yam pants would have drawn important nutrients necessary for their growth and development, resulting in a good yield. According to Severino *et al.* (2021), castor meal is predominantly used as organic fertilizer because of its high N content and rapid mineralization. Furthermore, yam yield increased as the products were applied. When each product was applied once, the yam yield reached at least 8 t/ha. It was higher than the average yam yield (7.1 t/ha) in central Côte d'Ivoire but lower than the national average yield (9.4 t/ha) for the years 2013 and 2014 (ENSEA, 2014).

CONCLUSION

Dried castor leaves, in aqueous extract (500 ml/plant) and powder (100 g/plant) forms, reduced the number of yam nematodes. Only dried castor leaf powder limited the development of symptoms to a very negligible level. It induced the best yam yields at the same level as carbofuran. Dried castor leaf powder at 100 g/plant is an excellent means for yam nematode management. Its application must be made three times: when planting the seeds and in the third and sixth months of yam cultivation. It could be used as a replacement for chemical nematicides in yam nematode management.

ACKNOWLEDGEMENTS

The Interprofessional Fund for Agricultural Research and Advisory (FIRCA) and the West Africa Agricultural Productivity Program (WAAPP) provided technical and financial assistance for this effort.

REFERENCES

Abd-Elgawad, M. M. M. 2021. Optimizing safe approaches to manage plant-parasitic nematodes. Plants, 10(9): 1-20,

Abdulsalam, S., H. Peng, Y. Yao, L. Fan, R. Jiang, H. Shao, Y. Zhang, W. Huang, L. Kong and D. Peng. 2021. Prevalence and molecular diversity of plant-parasitic nematodes of yam (*Dioscorea* spp.) in China, with focus on *Merlinius* spp. Biology, 10(12): 1-17.

Abduzor, S and A. Haseeb. 2010. Plant growth and plant parasitic nematode in response to soil amendments with plant growth promoting rhizobacteria and inorganic fertilizer in Pigeon pea, *Cajanus cajan* L. World Applied Science Journal, 8(4): 411-413.

Adomako, J. and C. K. Kwoseh. 2013. Effect of castor bean (*Ricinus communis* L.) aqueous extracts on the performance of root-knot nematodes (*Meloidogyne* spp.) on tomato (*Solanum lycopersicum* L.). Journal of Science and Technology, 33: 1-11.

Almeida, A. M., R. M. Souza, V. M. Gomes and G. B. Miranda. 2011. Greenhouse and field assessment of different organic compounds against guava-parasitic *Meloidogyne enterolobii.* Bragantia Campinas, 71(1): 67-74.

Alui, K. A., A. Yao-Kouamé, K. C. Ballo, K. P. Kouadio, K. A. N'guessan and K. Y. Nangah. 2011. Comportement de deux morphotypes de *Lippia multiflora* (Verbenaceae) sur ferralsols de la région de Yamoussoukro. Journal of Applied Biosciences, 38: 2592-2601.

Barros, F. M. R., A. Pedrinho, L. W. Mendes, C. C. G. Freitas and F. D. Andreote. 2022. Interactions between soil bacterial diversity and plant-parasitic nematodes in soybean plants. Applied and Environmental Microbiology, 88(7): 1-14.

Bla, K. B., J. N. D. Trébissou, A. P. Bidié, Y. J. Assi, N. Zirihi-Guédé and A. J. Djaman. 2015. Étude ethnopharmacologique des plantes antipaludiques utilisées chez les Baoulé- N'Gban de Toumodi dans le Centre de la Côte d'Ivoire. Journal of Applied Biosciences, 85: 7775-7783.

Catani, L., B. Manachini, E. Grassi, L. Guidi and F. Semprucci. 2023. Essential oils as nematicides in plant protection. Plants, 12(6): 1-21.

Colovic, M. B., D. Z. Krsti, T. D. Lazarevic-Pasti, A. M. Bondzic and V. M. Vasic. 2013. Acetylcholinesterase Inhibitors: Pharmacology and Toxicology. Current Neuropharmacology, 11(3): 315-335.

Coyne, D. L. and A. Affokpon. 2018. Nematode parasites of tropical root and tuber crops (excluding potatoes) in Plant parasitic nematodes in subtropical and tropical agriculture; Luc, M., R. A. Sikora, J. Bridge, Eds.; CABI: Wallingford, UK. pp. 258–272.

Coyne, D. L., J. M. Nicol and B. Claudius-Cole. 2010. Plant nematodes: A practical guide to field and laboratory techniques. Cotonou, International Institute of Tropical Agriculture (IITA), Cotonou, Benin.

Daramola, F. Y., S. O. Afolami, A. A. Idowu and I. S. Odeyemi. 2013. Effects of poultry manure and carbofuran soil amendments on soil nematode population and yield of pineapple. International Journal of AgriScience, 3(4): 298-307.

Das, S., S. Jamal, M. Dutta, S. Rej and S. Chatterjee. 2015.

Comparative phytochemical analysis and antimicrobial activity of four medicinal plants. European Journal of Medicinal Plants, 6(4): 191-199.

El-Nagdi, W. M. A. E. and M. M. A. Youssef. 2013. Comparative efficacy of garlic clove and castor seed aqueous extracts against the root-knot nematode, *Meloidogyne incognita* infecting tomato plants, Journal of Plant Protection Research, 53(3): 285-288.

Enagbonma, B. J., A. E. Fadiji, A. S. Ayangbenro and O. O. Babalola. 2023. Communication between Plants and Rhizosphere Microbiome: Exploring the Root Microbiome for Sustainable Agriculture. Microorganisms, 11(8): 1-15,

ENSEA. 2014. Situation de référence sur la banane plantain et autres produits du WAAPP. Rapport d'analyse des données, FIRCA, p. 190.

Farahat, A. A., A. A. Al-Sayed and N. A. Mahfoud. 2010. Compost and other organic and inorganic fertilizers in the scope of the root-knot nematode reproduction and control of *Meloidogyne incognita* infecting to tomato. Egyptian Journal of Agronematology, 9(1): 18-29.

Gupta, V. K., A. Pathak, N. J. Siddiqi and B. Sharma. 2016. Carbofuran modulating functions of Acetylcholinesterase from rat brain *in vitro*. Advances in Biology, 1-7.

Hassan, A. H., M. M. Ihab, I. Sherin, M. D. Turki, H. A. Jwaher, S. M. Ayman, A. K. Saleh, A. A. Roua, M. T. Azza and A. M. Sherif. 2020. Antimicrobial effect of different herbal plant extracts against different microbial population. Saudi Journal of Biological Sciences, 27(12): 3221-3227.

Hayat, A., N. Javed, S. A. Khan, A. S. Gondal and H. U. Khan. 2012. Effect of organic amendments on nematode galling index and egg masses production in potato inoculated with root knot nematode. Pakistan Journal of Phytopathology, 24(1): 1-5.

Kerkeni, A., N. Horrigue-Raouani and M. B. Khedher. 2007. Effet suppressif de cinq extraits de compost vis-à-vis du nématode à galles, *Meloidogyne incognita*. Nematologia Mediterranea, 35(1): 15-21.

Kouakou, Y. Y. F. R., K. D. Kra and D. H. Atta. 2016. Plant parasitic nematodes associated with deformation and degradation symptoms of yam tubers (*Dioscorea* spp.) in Côte d'Ivoire. International Journal of Agriculture Sciences, 8(54): 2906-2911.

Kouakou, Y. Y. F. R., K. D. Kra and D. H. Atta. 2023. Effects of two-dried castor leaf formulations on the population dynamics and pathological activities of root-lesion and root-knot nematodes on water yam. International Journal of Plant & Soil Science, 35(14): 33-41.

Kouakou, Y. Y. F. R., K. D. Kra, K. P. Assiri and H. Atta. 2017. Nematicidal effectiveness of products stemming from dried leaves of castor-oil plant (*Ricinus communis*) on *Meloidogyne* and *Pratylenchus*, yam pathogenic nematodes in Côte d'Ivoire. International Journal of Agronomy and Agricultural Research, 11(5): 57-68.

Lale, N. E. S. 2006. Dictionary of Entomology and Acarology. Mole Publications (Nig.) Ltd. Second Edition, pp. 198.

Mahdy, M. E., E. M. Mousa, E. Sanaa and A. E. Abeer. 2014. Effect of fresh and dry neem leaves applications on root-knot nematode *Meloidogyne javanica* on tomato plants. Egyptian Journal of Plant Protection, 9(1): 12-20.

N'guessan, K. E. 1990. Etude de l'évolution de la végétation du « V Baoulé » (contact forêt/savane en Côte d'Ivoire) par télédétection. Télédétection Sécheresse, Ed. AUPELF-UREF, pp.181-196.

Nobile, C. M., M. N. Bravin, T. Becquer and J. M.Paillat. 2020. Phosphorus sorption and availability in an andosol after a decade of organic or mineral fertilizer applications: Importance of pH and organic carbon modifications in soil as compared to phosphorus accumulation. Chemosphere, 239: 1-10.

Ogara, I. M. and R. N. D. Bina. 2010. Prevalence and persistence of galls and the galling nematodes *Meloidogyne* spp on yams in Nasarawa state, Nigeria. Acta SATECH, 3(2): 10-13.

Osei, K., E. Otoo, Y. Danso, J. Adomako, A. Agyeman and J. S. Asante. 2013. Organic soil amendments in nematode management in yam production. Nematropica*,* 43: 78-82.

Radwan, M. A., S. A. A.Farrag, M. M. Abu-ELamayem and N. S. Ahmed. 2012. Efficacy of dried seed powder of some plant species as soil amendment against *Meloidogyne incognita* on tomato. Archives of Phytopathology and Plant Protection, 45(10): 1246-1251.

Rodriguez, M. 2014. Calcul du rendement, https://agriculture.vic.gov.au/crops-and-horticulture/grains-pulses-and-cereals/crop-production/general-agronomy/a-brief-guide-to-estimating-crop-yields, Accessed on 23/03/2016.

Severino, L. S., B. S. D. S. Mendes, R. D. C. C. Saboya, L. A. Barros and D. R. D. F. Marinho. 2021. Nutrient content of solvent-extracted castor meal separated in granulometric fractions by dry sieving and applied as organic fertilizer. Industrial Crops and Products, 161: 1-7.

Sithole, N. T., M. G. Kulkarni, J. F. Finnie and J. V. Staden. 2021. Potential nematicidal properties of plant extracts against *Meloidogyne incognita.* South African Journal of Botany, 139: 409-417.

Soro, G., E. K. Ahoussi, E. K. Kouadio, T. D. Soro, S. Oulare, M. B. Saley, N. Soro and J. Biemi. 2014. Apport de la télédétection à la cartographie de l'évolution spatio-temporelle de la dynamique de l'occupation du sol dans la région des Lacs (Centre de la Côte d'Ivoire). Afrique Science, 10(3): 146-160.

Zafar, M. I., A. Khalid, S. Kali, F. Khan, M. Tahir, M. Ali and A. Siddiqa. 2022. Organic amendments as an ecofriendly substitute of carbofuran for the suppression of nematodes associated with *Malus pumila*. South African Journal of Botany, 14: 187-193.

Zewain, Q. K. 2014. Evaluation of some chemical nematicides and organic formulations in management of root knot nematode *Meloidogyne* on eggplant. Journal of Tikrit University for Agricultural Sciences, Third Scientific Conference for Plant Production, Tikrit, Iraq: 8-14.

Contribution of Authors:

Yadom Y. F. R. Kouakou	:	Designed the study, conducted the field trials, performed the statistical analysis and wrote the manuscript.
Kouamé D. Kra	:	Assisted to conduct the field trials and reviewed the manuscript.
Hortense A. Diallo	:	Supervised the study and reviewed the manuscript.