



Research Article

Organic Amendments Increase the Growth, Resistance and Management of the Root-Knot Nematode, *Meloidogyne arenaria* in *Arachis hypogaea* L.

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Abstract | One of the greatest barriers to the production of peanut crops is plant-parasitic nematodes, which are the most destructive pathogens that affect peanuts globally. A survey of plant-parasitic nematodes (PPNs) in peanuts was conducted in Ismailia, Egypt. The host suitability of four Egyptian peanut cultivars for *Meloidogyne arenaria* cultivation under greenhouse conditions was also examined. Additionally, the effects of fulvic acid, compost, and cattle manure, either alone or in combination, as well as the nematicide Fosthiazate 10% G, on peanut growth, biochemical parameters, and the management of *M. arenaria* were examined. Seven PPN genera were linked to peanut roots according to the results. These genera were *Meloidogyne*. (88%), *Tylenchorhynchus* (25%), *Helicotylenchus* (23%), *Rotylenchulus* and *Xiphinema* (4%, each), in descending order. The findings indicated that peanut cvs. Ismailia-1 and Ismailia-2 were susceptible; however, Giza-5 and Giza-6 were highly susceptible to *M. arenaria*. The growth of peanuts and the formation of nodules were greatly enhanced by organic amendments, either alone or in combination, improving plant tolerance. The organic amendment treatments significantly reduced the number of galls, root egg masses/root and nematode population (J_2 s) in the soil, while fosthiazate resulted in the greatest reduction. All the treatments markedly increased the enzymatic antioxidant enzyme activity in peanuts relative to the control, i.e., peroxidase, catalase, phenylalanine ammonia-lyase, chitinase, β -1,3 glucanase, and total phenolic activities. The integration of several techniques, including fulvic acid, compost, and cattle manure, might have a substantial effect on enhancing peanut development, biochemistry, and the ability to resist and control *M. arenaria*.

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Introduction

Groundnut, or peanut (*Arachis hypogaea* L.), belongs to the family Fabaceae and is grown in more than 82 nations globally. Owing to the high nutritional value of oils, proteins, calories, and vitamins, it is a crop of commercial significance that produces oil seeds. Seeds are an essential source of nourishment for humans and include approximately 25–30% protein, 45–50% oil, 20% carbohydrate, and 5% fiber and slag (Ahmad and Rahim, 2007). Furthermore, peanut cake and green leaves are used as organic manure and animal feed (Shah *et al.*, 2012). Peanut is one of the most widely consumed and exported oil crops in Egypt. According to FAOSTAT (2022) estimates, the cultivated area in Egypt is approximately 170,000 feddans, and the total productivity is 293 thousand tons of peanut pods.

One of the greatest barriers to the production of peanut crops is plant-parasitic nematodes, which are among the most destructive infections affecting peanuts worldwide. Numerous types of pathogenic root-knot nematodes significantly reduce peanut yields every year (Starr *et al.*, 2002). The root-knot nematode *Meloidogyne arenaria* is the most prevalent species affecting peanuts globally (Ballén-Taborda *et al.*, 2019). In heavily infested crops, *M. arenaria* infection resulted in significant yield reductions. The amount of peanut yield loss caused by worm pathogens varies according to the environment, nematode population density, and plant cultivar. It varies from 20 to 90% in Egypt (Mokbel, 2014).

Nematicides are detrimental to the beneficial flora and fauna in the soil, even though they are typically advised for managing nematodes. Furthermore, the application of nematicides has an impact on the environment (Khan *et al.*, 2019). Thus, alternative methods for controlling RKNs, *Meloidogyne* spp., are urgently needed.

Abd-Elgawad (2024) highlighted that stakeholders are seeking more sustainable and efficient alternatives with minimal impact on the environment and human health to address rising food demand, the challenges of climate change, and the harmful use of toxic nematicides. One alternative method of managing nematodes is to introduce soil organic amendments to the soil. Animal manures and biochar are examples of organic amendments for the control of root-knot

nematodes and enhancing plant growth (Edussuriya *et al.*, 2023; Hal *et al.*, 2023). According to Abdel-Monaim *et al.* (2018) an organic amendment promotes plant health by having positive effects on soil nutrition, soil physics, and soil biology, which lower the nematode population. Numerous studies are working on organic amendments against root-knot nematodes, such as animal manures, composts, agricultural wastes, crop residues, and plant derivatives (Peiris *et al.*, 2020). Very high application rates (50–100%) of compost in pots decreased the number of juveniles (J_2 s) in the soil and roots as well as the number of galls of root-knot nematodes, (Mostafa *et al.*, 2022).

According to Stirling (2017), the use of amendments with high phenolic contents could increase plant resistance to nematodes and hence reduce nematode population levels. Amendments can increase nutrient and water availability, which benefits plant health and yield, regardless of their effects on nematodes (Al-Hendy *et al.*, 2021). Compost and manure amendments increased yields by an average of 27% in field research involving potatoes but did not decrease the number of plant-parasitic nematodes (Kimpinski *et al.*, 2003). These examples of enhanced plant tolerance from amendments appear to meet the scenario of high efficiency for host production but inefficiency for nematode control, which was articulated by Melakeberhan (2006) concerning host productivity. The overproduction of reactive oxygen species (ROS), such as superoxide anions (O_2^-) and hydrogen peroxide (H_2O_2), in response to pathogen attack is a primary and prompt response in plants. This leads to a hypersensitive response, which is typified by cell death at the infection site. Systemic acquired resistance (SAR), which ensures long-lasting systemic immunity against both the main pathogen that triggers the response and subsequent infection by other pathogens, typically develops in the challenged plant after a hypersensitive response (Grant and Lamb, 2006). In plant tissues, the synchronization of ROS formation and scavenging is crucial because an excess of ROS can lead to irreversible cellular damage (Halliwell, 2006). Numerous enzymes have been linked to plants developing induced resistance to plant diseases (Ojaghian *et al.*, 2014). These enzymes include peroxidases, catalases, phenylalanine ammonia-lyases, chitinases, and β -1,3-glucanases. β -1,3-glucanase and chitinase can breakdown pathogen cell walls and eggshells of nematodes, releasing chemicals that

function as elicitors in the early phases of phytoalexin and phenolic compound resistance induction (Silva *et al.*, 2004). According to Kurabachew and Wydra (2014), peroxidase is generally essential for the growth and development of plants and is closely linked to defense mechanisms against infections. Additionally, phenolic chemicals play a major role in helping plants withstand a wide range of pests and illnesses. Higher baseline and/or induced levels of phenolic compounds have been found to correlate with nematode resistance across a wide range of plant–nematode combinations (Dhakshinamoorthy *et al.*, 2014). This study aimed to determine the frequency and occurrence of plant-parasitic nematodes associated with peanuts in fields in the Ismailia governorate. In addition to, (1) Determine the frequency and occurrence of plant-parasitic nematodes associated with peanut in Ismailia governorate. (2) Screening different local Egyptian peanut cultivars (Giza 5, Giza 6, Ismailia 1, and Ismailia 2) against the root-knot nematode *M. arenaria* under greenhouse conditions. (3) Examine the ability of certain organic amendments to increase plant resistance and control nematode infection in susceptible cultivar. (4) Investigate some growth and biochemical parameters in treated and untreated plants.

Materials and Methods

Survey study

During the August 2021–August 2022 season, 80 rhizosphere soil samples were collected from four different peanut localities (Abu Suwer, Ismailia, Kasaseen and Tell El-Kebir) in Ismailia governorate, northeastern Egypt. Samples were collected at the early vegetative growth, blooming, and premature stages. The samples were placed in plastic bags, tagged, and brought to our laboratory, where they were kept in a refrigerator at 5 degrees Celsius until processing. Nematode extraction and identification were performed.

The soil samples were well mixed, and a 250 g subsample from each sample was extracted for nematode extraction via the sieving and decanting procedure described by Christie and Perry (1951). Root samples with disease symptoms were chopped into small pieces and incubated for 2–3 days at room temperature in Petri dishes with distilled water to extract any migratory endoparasitic nematodes (Young, 1954). Nematode genera and/or species

were identified on the basis of the morphology of adult and larval forms (Golden, 1971). Adult females of root-knot nematodes (*Meloidogyne* spp.) were removed from the infected roots whenever they were found, and the perennial pattern of these females was removed and prepared for examination as described by Hunt and Handoo (2009). *Meloidogyne* species were identified on the basis of the morphological features of the perennial pattern (Hunt and Handoo, 2009).

Nematode communities were analyzed on the basis of frequency of occurrence (FO %) and population density (PD) (Norton, 1979), where frequency of occurrence (FO %) = number of samples containing a genus/total number of collected samples × 100. Population density (PD) = Total number of individuals of a genus/number of samples containing this genus.

Greenhouse experiments

Screening test: Greenhouse experiments were carried out at Ismailia Agricultural Research Station, Egypt, to assess the response of the growth of four peanut cultivars to the root-knot nematode *Meloidogyne arenaria* during the summer season of 2022.

Tested cultivars: The reactions of four peanut cultivars (Giza 5, Giza 6, Ismailia 1, and Ismailia 2) to *M. arenaria* were evaluated under greenhouse conditions. The cultivar seeds were obtained from the Field Crop Research Institute, Agricultural Research Centre, Ministry of Agriculture, Giza, Egypt. The seeds were surface sterilized before being sown into 25 cm-diameter pots filled with steam-sterilized sandy clay soil at a 1:4 ratio. One week after germination, one seedling per pot was thinned. Each seedling (two-weeks old) was inoculated with approximately 3000 newly hatched juveniles (J_2 s) of *M. arenaria* obtained from pure cultures maintained and propagated on tomato cv. 888. Each inoculated cultivar was replicated four times. Treatments in which no nematodes were added serve as controls (check plants). The plants were watered and fertilized with water-soluble N-P-K (20–20–20) as needed. A randomized complete block design was used to arrange the treatments. The experiment was terminated 90 days after inoculation, and plant growth and nematode assessment data were collected.

The shoot, root fresh and dry weights (g), shoot, root lengths (cm), pod weights (g), number of pods per

plant, and number of nodules per root system were recorded.

Nematode assessment: Plants of each cultivar were uprooted, and the roots were washed with a gentle stream of water. The nematode galls were subsequently rated on a 1-9 scale of the gall index (GI), gall size (GS), and percent gall area (GA) according to (Sharma *et al.*, 1994). The damage index (DI) is calculated by dividing the sum of the GI, GS, and GA by 3 (Sharma *et al.*, 1994). On the basis of DI, the host susceptibility (designation of resistance) of each plant cultivar is determined according to the following scheme: plants with DI = 1 are designated highly resistant; DI= 2 to 3, resistant; DI= 4 to 5, moderately resistant; DI = 6 to 7, susceptible; DI = 8 to 9, highly susceptible (Sharma *et al.*, 1994). The number of egg masses/root systems as well as the number of second-stage juveniles in each pot were recorded (Goodey, 1963).

Organic soil amendment treatments

Three organic soil amendments (cattle manure, compost, and fulvic acid) were obtained as pure sterilized dry powders from the local market, and a chemical analysis was performed (Table 1). All the materials were applied alone or in combination for efficacy in managing *M. arenaria* on peanuts. All the tested materials were incorporated uniformly 7 days before being planting into the top of the soil pots. Seeds of the peanut cultivar Giza 6 were sown with three seeds per pot and thinned to one at one week after planting. There were eight treatments in four replicates arranged in a randomized complete block design. The treatments included the following: (1) cattle manure applied at 2 tons/ feddan; (2) compost applied at 2tons/ feddan; (3) fulvic acid applied at 50kg/ feddan; (4) cattle manure + compost; (5) cattle manure + fulvic acid; (6) compost + fulvic acid; (7) fosthiazate (Nemathorin®) 10% G applied at 12.5k/ feddan; and (8) control (nematode only). Each seedling (two-weeks old) was inoculated with

approximately 3000 newly hatched juveniles (J_2 s) of *M. arenaria*. Each treatments replicated four times. The experiment was terminated 90 days after inoculation, and plant growth and nematode assessment data were collected as described previously.

Biochemical determinations

The enzyme extract was prepared according to Urbanek *et al.* (1991) to estimate peroxidase and catalase activity in fresh leaves. The catalase (CAT, EC 1.11.1.6) and peroxidase (POD, EC 1.11.1.7) activities were estimated according to Urbanek *et al.* (1991). The unit of CAT activity was defined as the amount of enzyme that decomposes 1 mM H_2O_2 per mg^{-1} protein.min. POD activity was expressed as the change in absorbance every 0.5 min at 425 nm using a spectrophotometer. Phenylalanine ammonia-lyase (PAL, EC 4.3.1.1) activity was determined spectrophotometrically at an absorbance of 290 nm (Sadasivam and Manickam, 1996). Chitinase (EC 3.2.1.14) and β -1,3-glucanase (EC 3.2.1.39) activities were determined according to the methods of Wirth and Wolf, (1992). The total phenolic content ($mg\ g^{-1}$ FW) was estimated via a modified Folin-Ciocalteu method (Horwitz *et al.*, 1970).

Statistical analysis

All the statistical analyses were carried out via the computer software Statistical Package for Social Science SPSS (IBM-SPSS ver. 29.0) (Knapp, 2017). Data were checked for normality using Shapiro-Wilk and Kolmogorov Smirnov, to check whether data parametric or nonparametric, Accordingly, parametric data analysis were applied. The difference between infected and control plants for were checked statistically. In addition, the difference between tested cultivars was also checked using one way ANOVA. The data are presented as the means and standard deviations, followed by the least significant difference (LSD) test and Duncan's multiple range test (DMRT) at the 0.05 level.

Table 1: Chemical analysis of the cattle manure and compost used in the experiments.

Value	Organic matter (%)	pH*	E.C (dS m^{-1})**	Organic carbon%	Total nitrogen (%)	C/N ratio***	Total phosphorus (%)	Total potassium (%)
Cattle manure	29.00	7.30	4.12	19.00	0.97	19.6:1	0.61	0.58
Compost	25.20	7.10	4.20	18.90	0.91	20.7:1	0.39	0.44

* pH = (Negative logarithm hydrogen ion). **Electrical Conductivity, (ds m^{-1}) (decisiemens per meter) *** C/N ratio = total carbon (%) / total nitrogen (%) (dimensionless).

Results and Discussion

Survey study

The data presented in Figure 1 and Table 2 indicate the presence of seven phytoparasitic nematode genera in the soil samples of the surveyed peanut fields of the Ismailia governorates. Most of the surveyed peanut fields had populations of more than 420 *Meloidogyne* spp., which is the main pest of this crop per 250 g of soil. The percentage of occurrence in the surveyed samples was 88%. The identification of *Meloidogyne* spp. indicated that *M. arenaria* (60%) was the dominant species in all the peanut root samples collected from the samples, followed by *M. javanica* (40%). The second most widely distributed genus was the stunt nematode *Tylenchorhynchus* spp., with a population density of 220 per 250 g of soil and a frequency of occurrence of 25%. The third most common genus in the surveyed samples was spiral nematodes *Helicotylenchus* spp., with an occurrence of 23% and a population density of 80 per 250 g of soil.

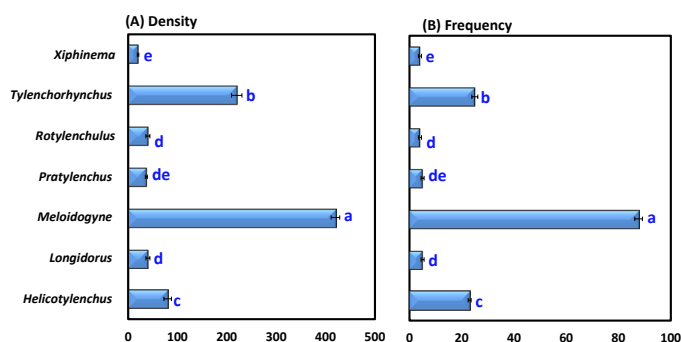


Figure 1: (A) Population density and (B) frequency of occurrence (%) of plant-parasitic nematode genera associated with peanuts in Ismailia Governorate during the 2021-2022 growing seasons. Bars followed by different values are significantly different according to the DMRT.

Susceptibility of the tested cultivars to *M. arenaria*

Based on the damage index (DI) displayed in Table 3, the susceptibility/resistance of four different peanut cultivars to the root-knot nematode *M. arenaria* was categorized. According to the data, the cultivars were divided into two groups: susceptible (Ismailia 1 and Ismailia 2) and highly susceptible (Giza 6 and Giza 5). The cultivar Giza 6 has a damage index (DI) of 8.90, whereas the cultivar Giza 5 has a DI of 8.00. The number of second-stage juveniles (J_2 s) in 250 g of soil and the egg mass index (EI) varied significantly, as revealed by one-way ANOVA ($p \leq 0.05$), between the peanut cultivars. In general, Ismailia 2 presented the lowest egg mass/root and EI, whereas Giza 6

presented the greatest value, followed by Giza 5.

Table 2: Population density (PD) and frequency of occurrence (FO%) of plant-parasitic nematode genera associated with peanuts in Ismailia Governorate during the 2021-2022 growing seasons.

Nematode genera	Population density (PD) ¹	Frequency of occurrence (FO%) ²
<i>Helicotylenchus</i>	80	23
<i>Longidorus</i>	40	5
<i>Meloidogyne</i>	420	88
<i>Pratylenchus</i>	40	5
<i>Rotylenchulus</i>	40	4
<i>Tylenchorhynchus</i>	220	25
<i>Xiphinema</i>	20	4

¹Population density (PD) = number of nematodes per 250 g of soil for a genus and/or species/number of samples containing this genus and/or species. ²Frequency of occurrence (FO %) = (number of samples containing a genus and/or species/total samples collected) $\times$ 100.

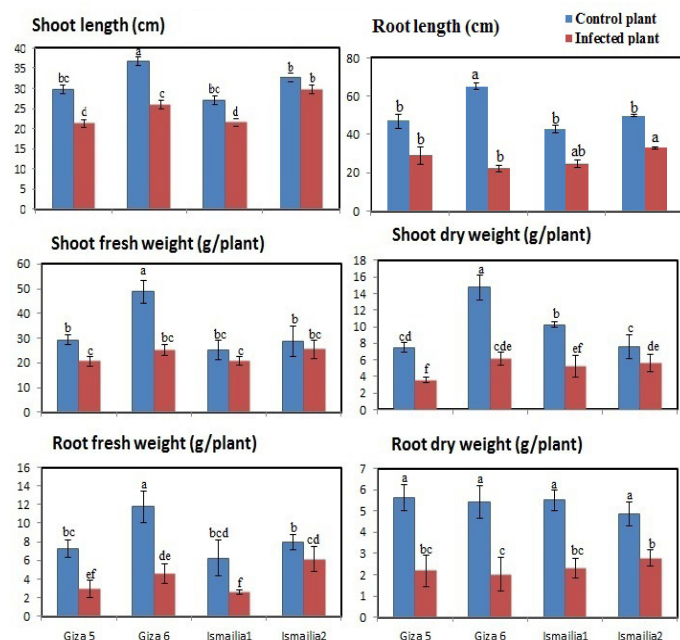


Figure 2: Shoot length, root length, shoot fresh weight, root fresh weight, shoot dry weight and root dry weight of different peanut cultivars (Giza 5, Giza 6, Ismailia 1 and Ismailia 2) infected with *Meloidogyne arenaria*. Bars with different letters are significantly different according to the DMRT.

The growth and yield parameters of the peanut cultivars (Giza-5, Giza-6, Ismailia-1 and Ismailia-2) were severely negatively impacted by the root-knot nematode *M. arenaria* (Figures 2 and 3). Nematode infection caused significant reductions in the fresh shoot weights, fresh root weights, dry shoot weights, dry root weights, shoot and root lengths, as well as the weight and number of pods and the number of

nodules/plant for all cultivars. When the infected peanut cultivars were compared with the control plants, notable significant differences in plant growth and yield parameters were detected, as revealed by one-way ANOVA ($p \leq 0.05$). The shoot length, shoot fresh weight, shoot dry weight, root fresh weight and root dry weight of Giza 6 decreased the most among all the examined cultivars with nematode infection. The percentages of the reduction in shoot length, shoot fresh weight (SFW), shoot dry weight (SDW), shoot fresh weight (RFW), and root dry weight (RDW) were 29.0, 25.0, 58.0, 62.0, and 63.0%, respectively. Furthermore, the greatest decreases in pod weight and the number of pods and nodules per plant also resulted in 49.0%, 32.0%, and 56.0% decreases in Giza 6, respectively. According to the results in Figures 2 and 3, the cultivar Giza 6 was the most damaged, whereas the cultivar least affected was cv. Ismailia 2.

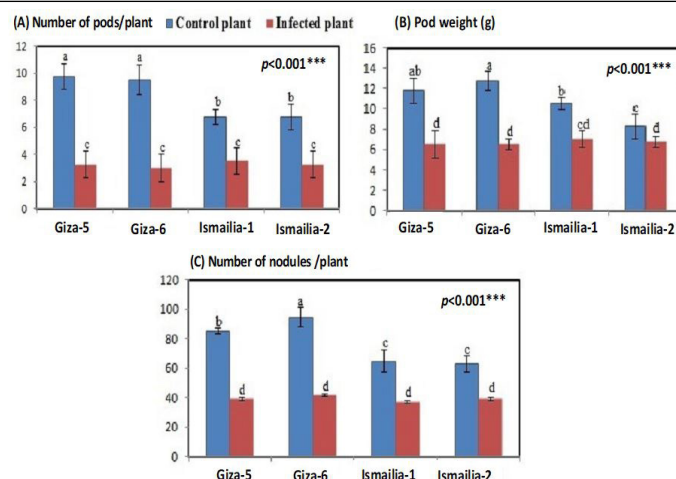


Figure 3: Number of pods per plant, pod weight and number of nodules per plant of different peanut cultivars (Giza 5, Giza 6, Ismailia 1 and Ismailia 2) infected with *Meloidogyne arenaria*. Bars with different letters are significantly different according to the DMRT.

Table 3: Susceptibility of peanut cultivars to root-knot nematode, *Meloidogyne arenaria* infection.

Cultivars	No. of galls/root	Gall index (GI)	Gall size (GS)	Gall area (GA)	Damage index (DI)	Host susceptibility/ Resistance	No. of J_2 /250 g soil	No. of egg masses/root	Egg mass index (EI)
Giza 5	132.50 ^b	9.00 ^a	7.50 ^b	7.50 ^b	8.00 ^b	HS	290.00 ^b	29.00 ^b	5.20 ^b
Giza 6	233.00 ^a	9.00 ^a	8.70 ^a	9.00 ^a	8.90 ^a	HS	460.00 ^a	50.00 ^a	6.20 ^a
Ismailia 1	93.20 ^c	8.00 ^b	7.00 ^{bc}	7.50 ^b	7.40 ^b	S	210.00 ^c	27.70 ^b	5.20 ^b
Ismailia 2	85.00 ^c	8.00 ^b	6.00 ^c	6.50 ^b	6.80 ^c	S	170.00 ^d	19.50 ^c	4.20 ^c
LSD 0.05	14.72		1.23	1.31			34.40	4.62	
p value	0.000*		0.003*	0.012*			0.000*	0.000*	
f-ratio	202.23		8.10	5.67			131.93	73.85	

The data are the average of 4 replicates. Different letters indicate significant differences among treatments within the same column according to Duncan's multiple range test ($P \leq 0.05$). GI and EI indices, 1 = no galls, 2 = 1-5 galls, 3 = 6-10 galls, 4 = 11-20 galls, 5 = 21-30 galls, 6 = 31-50 galls, 7 = 51-70 galls, 8 = 71-100 galls, and 9 = > 100 galls. HS (highly susceptible host), and S (susceptible host).

Table 4: Efficacy of organic soil amendments on root-galling, egg mass and final nematode population of *Meloidogyne arenaria* on peanut plants under greenhouse conditions.

Treatment	No. of galls/ root system	Red. %	No. of egg masses/ root system	Red. %	No. of J_2 /250 g soil	Red. %
Control (Nematode only)	198.00 ^a	-	53.00 ^a	-	456.00 ^a	-
Cattle manure	36.30 ^{de}	81.60	20.00 ^{cd}	62.00	113.00 ^d	75.00
Compost	45.60 ^c	76.90	25.30 ^b	52.00	130.00 ^d	71.40
Fulvic acid	55.00 ^b	72.00	26.00 ^b	51.00	193.00 ^b	57.60
Cattle manure + compost	32.00 ^c	83.80	15.00 ^c	71.60	86.00 ^c	81.00
Cattle manure + fulvic acid	40.60 ^{cd}	79.00	19.00 ^{de}	64.00	133.00 ^d	71.00
Compost + fulvic acid	53.00 ^b	73.00	24.30 ^{bc}	54.00	166.00 ^c	63.00
Fosthiazate 10G	20.00 ^f	90.00	9.00 ^f	83.00	40.00 ^f	91.00
LSD 0.05	6.00		4.40		24.40	
One way ANOVA	p value	0.000*	0.000*		0.000*	
	f-ratio	803.93	75.97		241.14	

The data are the average of 4 replicates. Different letters indicate significant differences among treatments within the same column according to Duncan's multiple range test ($p \leq 0.05$). Red.% = percentage of reduction = $(Cp - Ip / Cp) \times 100$.

Efficacy of organic amendments for the management of *M. arenaria*

The data presented in Table 4 revealed that all the treatments significantly reduced the number of galls, egg masses/roots and final nematode population (J_{2s}) in soil to different degrees. The final nematode population in 250 g of soil and several galls and egg masses/roots are presented in Table 4. The nematicide fosthiazate 10G achieved the greatest reduction in the number of galls (90.0%), number of egg masses (83%), and final nematode population (91.0%). However, the combination of cattle manure with compost induced a reduction in the number of galls (83.8%), the number of egg masses (71.6%), and the final nematode population (J_{2s}) (81.0%). Moreover, a lesser effect was observed with fulvic acid, which caused a reduction in the previous criterion values of 72.0, 51.0, and 57.6% respectively (Figure 4).

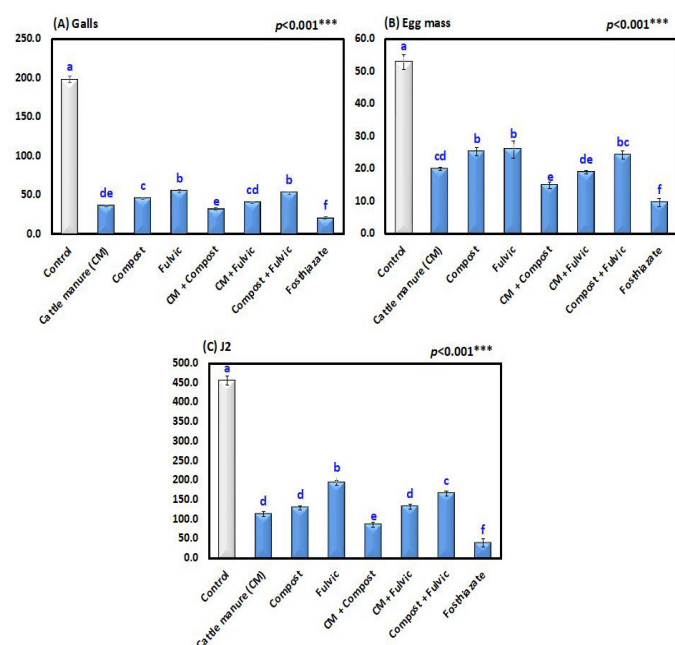


Figure 4: Numbers of galls, egg masses/root system, and final nematode populations (J_{2s}) in different organic amendment treatment groups in peanuts infected with *Meloidogyne arenaria*. Bars with different letters are significantly different according to DMRT.

Effects of organic amendments on several peanut growth parameters

The shoot fresh weight (g/plant) of the plants in the treatment groups was significantly different among the cattle manure, compost, fulvic acid, (cattle manure + compost), (cattle manure + fulvic acid), (compost + fulvic acid), control (nematode only) and nematicide (fosthiazate 10G) groups, as revealed by one-way ANOVA ($p < 0.05$) (Figure 5). The SFW results were

significantly greater in the treatment groups than in the control group, which presented the lowest values. The combination treatment (cattle manure + compost) and fosthiazate 10G resulted in the greatest increase in shoot fresh weight (41.3 and 43.6 g, respectively), followed by the cattle manure treatment (38 g).

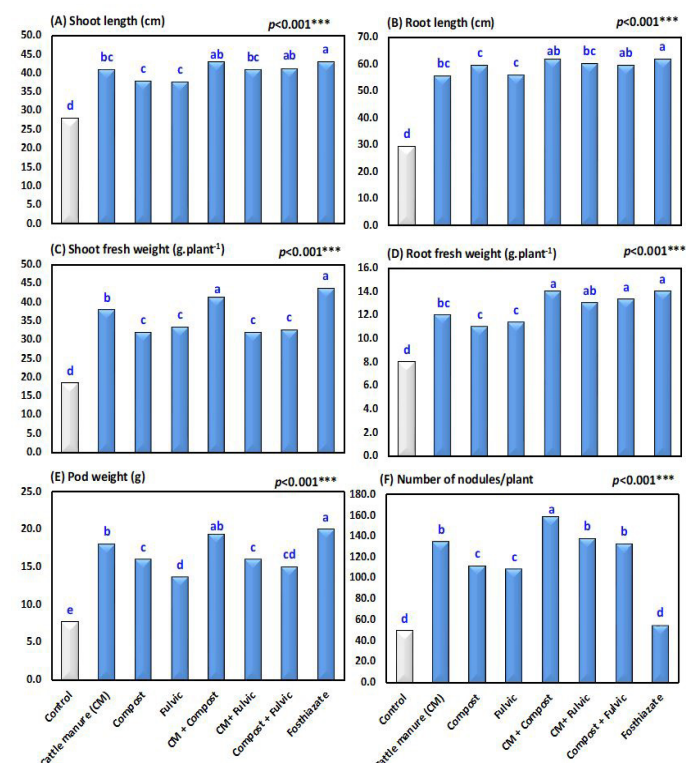


Figure 5: Plant growth parameters of peanuts infected with *Meloidogyne arenaria* in different treatment groups, including cattle manure, compost, fulvic acid, cattle manure + compost, cattle manure + fulvic acid, compost + fulvic acid, control (nematode only) and nematicide (fosthiazate 10G) treatments. Bars with different letters are significantly different according to DMRT.

The root fresh weight (g/plant) was greater in all the groups than in the control group, which presented the lowest values. Compared with the control treatment (8.0 g), the treatments with cattle manure + compost and fosthiazate 10G significantly increased the fresh weight of the roots (14.0 g) (Figure 5).

The average pod weight (g) per plant (Figure 5) significantly differed between the treatment groups. Pod weights were greater in all the groups than in the control group. The maximum pod weight was recorded in the fosthiazate 10G treatment (20 g), followed by the combined treatment (cattle manure + compost) (19.3 g), with a nonsignificant difference compared with the control treatment (7.6 g).

The number of nodules/plant results revealed that the number of nodules significantly increased in the organic amendment groups compared with the control and fosthiazate 10G groups (Figure 5). Compared with the control treatment (49), the combination of cattle manure with compost resulted in the greatest number of nodules (158), followed by the combination of cattle manure with fulvic acid (138) and cattle manure alone (134).

Effects of organic amendments on several peanut biochemical parameters

The levels of the cellular antioxidant enzyme peroxidase (POD) in the cattle manure, compost, fulvic acid, cattle manure + compost, cattle manure + fulvic acid, compost + fulvic acid, control (nematode only) and nematicide (fosthiazate 10G) treatment groups were 1.50 ± 0.05 , 1.44 ± 0.02 , 1.34 ± 0.02 , 1.57 ± 0.02 , 1.53 ± 0.02 , 1.47 ± 0.02 , 0.73 ± 0.15 and 1.38 ± 0.06 , respectively, where the difference between groups was significant, as revealed by one-way ANOVA ($p < 0.05$). Compared with the control, all the treatment groups presented significantly increased peroxidase activity, which presented the lowest values (Figure 6). The highest peroxidase activity was recorded in the cattle manure + compost treatment, with a value that was 115% greater than that of the control, followed by that in the cattle manure + fulvic acid and cattle manure alone, with values of 110 and 105%, respectively.

CAT is an important cellular enzyme; the average ($\pm$ SD) CAT activity in the treatment groups was 12.47 ± 0.15 , 11.94 ± 0.14 , 12.69 ± 0.21 , 14.37 ± 0.14 , 14.40 ± 0.13 , 13.32 ± 0.27 , 8.22 ± 0.07 and 10.59 ± 0.31 , U.min-1.mg.protein-1, respectively, and the difference between the groups was significant (Figure 6). The catalase activity was significantly greater in the organic amendment groups and the fosthiazate group than in the control group. Compared with the control, the cattle manure, compost and fulvic acid treatments increased catalase activity by 1.5 times, while the catalase activity increased by 1.6 times with the compost + fulvic acid treatment and by 1.7 times with the cattle manure + compost and cattle manure + fulvic acid treatment.

The PAL activities in the cattle manure, compost, fulvic acid, cattle manure + compost, cattle manure + fulvic acid, compost + fulvic acid, control (nematode only) and nematicide (fosthiazate) treatment groups presented average values ($\pm$ SD) of 4.73 ± 0.15 ,

4.33 ± 0.14 , 4.73 ± 0.08 , 5.40 ± 0.72 , 5.43 ± 0.12 , 4.86 ± 0.07 , 2.65 ± 0.17 and 3.63 ± 0.22 , U.min-1.mg.protein-1, respectively. The organic amendments significantly improved PAL activity (Figure 6). The maximum values were obtained with cattle manure + compost and cattle manure + fulvic acid.

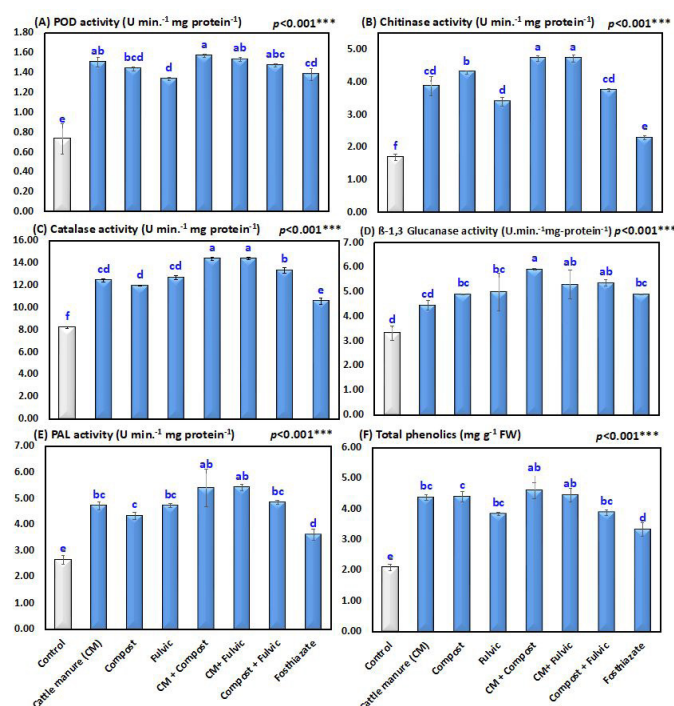


Figure 6: Metabolic enzymes (PPO, CAT, PAL, chitinase and β -1,3 glucanase) and total phenolics in the leaves of peanuts infected with *Meloidogyne arenaria* in different treatment groups. Bars with different letters are significantly different according to the DMRT.

The average chitinase activity in the treatment groups was 3.87 ± 0.17 , 4.30 ± 0.03 , 3.41 ± 0.08 , 4.72 ± 0.05 , 4.73 ± 0.07 , 3.75 ± 0.03 , 1.70 ± 0.06 and 2.29 ± 0.03 , U.min-1.mg.protein-1, respectively, and the difference between the groups was significant (Figure 6). Compared with the control and fosthiazate groups, the organic amendment groups presented significantly increased catalase activity.

The average β -1,3 glucanase activity ($\pm$ SD) was 4.45 ± 0.19 , 4.89 ± 0.12 , 4.99 ± 0.36 , 5.90 ± 0.12 , 5.29 ± 0.27 , 5.36 ± 0.13 , 3.33 ± 0.29 and 4.89 ± 0.12 , respectively. Compared with the control, all the treatment groups presented significantly enriched β -1,3 glucanase activity, which presented the lowest values (Figure 6). Compared with the control, the cattle manure + compost treatment increased β -1,3 glucanase activity by 77%.

The total phenolic concentrations in the cattle manure, compost, fulvic acid, cattle manure + compost, cattle manure + fulvic acid, compost + fulvic acid, control (nematode only) and nematicide (fosthiazate) treatment groups were an average ($\pm$ SD) of 4.38 ± 0.08 , 4.40 ± 0.16 , 3.84 ± 0.06 , 4.60 ± 0.26 , 4.46 ± 0.22 , 3.89 ± 0.09 , 2.10 ± 0.10 and 3.33 ± 0.23 , mg/g-FW, respectively. The total phenolic concentration significantly increased in all the treatments compared with the control (Figure 6).

The effects of various independent factors were assessed via the multivariate analysis of variance

(MANOVA) presented in Table 5. Accordingly, the use of a single application of cattle manures and compost had a highly significant ($p < 0.001$) effect on POD, chitinase, glucanase, phenol, catalase (CAT), PAL, shoot length, shoot fresh weight, root length, root fresh weight, number of nodules, pod weight, galls, egg masses and J_2 s. In addition, the use of fulvic acid only had a highly significant ($p < 0.001$) effect on POD, chitinase, glucanase, phenol, CAT, PAL, shoot length, root length, root fresh weight, number of nodules, pod weight, galls, egg masses and J_2 s; however, shoot fresh weight was not significantly affected by fulvic acid.

Table 5: Multivariate analysis of variance (MANOVA) showing the effects of independent factors (different treatments) on various measured dependent variables.

Variable		Corrected model	Cattle manure	Compost	Fulvic acid	Nematicide	Cattle manure * Compost	Cattle manure * Fulvic acid	Compost * Fulvic acid
POD	f-ratio	57.1	89.5	53.4	23.4	165.7	80.3	65.2	64.5
	p value	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***
Chitinase	f-ratio	200.9	293.9	228.9	49.2	29.2	127.5	30.4	212.5
	p value	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***
Glucanase	f-ratio	13.3	18.0	34.8	23.5	28.2	0.1	3.9	8.2
	p value	<.001***	<.001***	<.001***	<.001***	<.001***	0.783	0.066	0.011*
Phenol	f-ratio	74.2	91.6	47.7	4.4	81.4	115.8	74.3	135.9
	p value	<.001***	<.001***	<.001***	0.052	<.001***	<.001***	<.001***	<.001***
CAT	f-ratio	368.1	757.1	373.7	595.4	244.3	72.6	140.3	208.1
	p value	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***
PAL	f-ratio	31.6	63.3	21.7	41.3	17.3	9.3	17.2	21.9
	p value	<.001***	<.001***	<.001***	<.001***	<.001***	0.008**	<.001***	<.001***
Shoot length	f-ratio	66.9	135.4	70.0	41.0	311.5	44.3	64.7	27.8
	p value	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***
Shoot weight	f-ratio	55.9	66.1	18.8	1.0	300.1	25.0	103.1	48.0
	p value	<.001***	<.001***	<.001***	0.338	<.001***	<.001***	<.001***	<.001***
Root length	f-ratio	71.5	52.9	85.2	43.6	322.8	87.1	73.2	107.6
	p value	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***
Root weight	f-ratio	20.7	50.8	34.6	28.6	92.6	1.3	7.0	1.3
	p value	<.001***	<.001***	<.001***	<.001***	<.001***	0.274	0.018*	0.274
Nodule No.	f-ratio	159.2	317.8	142.0	65.0	1.6	38.0	79.6	38.0
	p value	<.001***	<.001***	<.001***	<.001***	0.22	<.001***	<.001***	<.001***
Pod weight	f-ratio	36.5	62.6	24.9	0.0	182.5	29.4	38.4	29.4
	p value	<.001***	<.001***	<.001***	1	<.001***	<.001***	<.001***	<.001***
Galls	f-ratio	803.9	655.8	376.8	198.2	3917.3	1364.3	1352.0	1407.6
	p value	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***
Egg mass	f-ratio	76.0	115.2	42.3	24.2	425.2	58.2	76.5	76.5
	p value	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***
J_2	f-ratio	241.1	252.1	156.5	18.8	1302.1	337.5	301.0	337.5
	p value	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***

*, **, ***, significant at $p < 0.05$, < 0.01 , < 0.001 ; ns, nonsignificant at $p > 0.05$.

The interaction between cattle manures and compost addition had a highly significant ($p < 0.001$) effect on POD, chitinase, phenol, CAT, and PAL activities; shoot length; shoot fresh weight; root length; number of nodules; pod weight; galls; egg masses; and J_2 s; and glucanase and root fresh weight. However, the interaction between cattle manures and fulvic acid had a highly significant ($p < 0.001$) effect on POD, chitinase, phenol, CAT, PAL, shoot length, shoot fresh weight, root length, root fresh weight, number of nodules, pod weight, galls, egg masses and J_2 s; however, glucanase was not significant. Moreover, the interaction between compost and fulvic acid had a highly significant ($p < 0.001$) effect on POD, chitinase, glucanase, phenol, CAT, PAL, shoot length, shoot fresh weight, root length, number of nodules, pod weight, galls, egg masses and J_2 s and non-significantly affected the fresh weight of the roots.

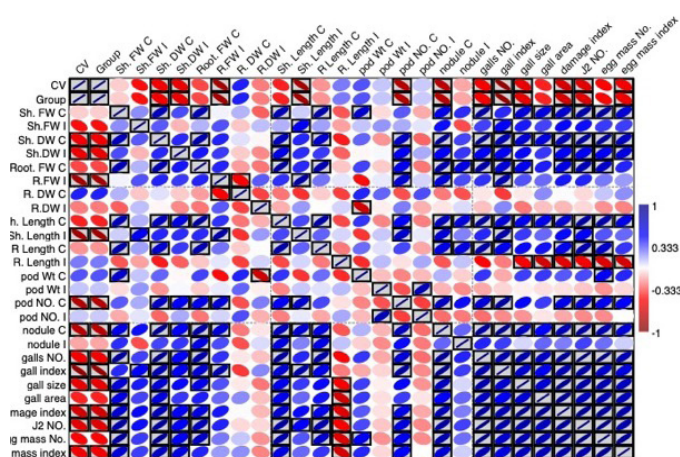


Figure 7: The blue/red heatmaps present the interactions between the studied variables. The blue color indicates a positive direct correlation, the red color indicates a negative inverse correlation, and the white color indicates no correlation. The gray boxed colors indicate significant correlations according to a 2-tailed significance test.

The interactions between the study variables are presented in a blue/red heatmap in Figure 7. The blue color indicates a positive direct correlation, the red color indicates a negative inverse correlation, and the white color indicates no correlation. The gray boxed colors indicate significant correlations according to a 2-tailed significance test. A heatmap was generated via Pearson's correlation test Figure 7.

The harm caused by plant parasitic nematodes is one of the main barriers to the generation of a sufficient food supply in most developing countries. The root-knot nematodes *Meloidogyne* spp. are extremely

important economically in Egypt because they are dangerous diseases of a wide variety of plant crops. Among these species, *M. javanica* and *M. arenaria* (Korayem *et al.*, 2021). In addition to having a significant negative impact on yields, diseased plants also have lower quality, particularly in the case of some crops such as peanuts (El-Nuby *et al.*, 2019). There have been numerous reports of plant parasitic nematodes connected to peanut soil and roots, some of which can severely harm crops. While the survey in this study occurred in Ismailia government, Egypt. Also, this paper evaluates different Egyptian peanut cultivars susceptibility to *M. arenaria*, contributing valuable data on peanut varieties responses to nematode infestation under greenhouse conditions. This provides insights into cultivar-specific resistance, aiding future breeding programs aimed at improving peanut resilience. These findings collectively provide a novel perspective on using sustainable, eco-friendly methods to combat nematode-induced crop loss while improving plant resistance and health.

The findings of the present study revealed that *M. arenaria* was the most common species in all surveyed peanut areas, followed by *M. javanica*. The genera *Tylenchorhynchus* and *Helicotylenchus* are frequently found at large population densities. Conversely, *Longidorus*, *Pratylenchus*, *Rotylenchulus* and *Xiphinema* were found at relatively low population densities. These results concurred with those of Mokbel (2014), who reported that *M. arenaria* was the most prevalent nematode in all peanut samples taken from the governorates of Alexandria, El-Behera, and Giza. *Tylenchorhynchus*, *Helicotylenchus*, and *Pratylenchus* were the next most common nematodes. However, Ibrahim and Mokbel (2009) reported that *M. arenaria* was present on peanut plants in the governorates of Alexandria and El-Behera. Additional researchers have documented the presence of *M. arenaria* on peanuts, either by itself or in conjunction with *M. javanica* (Starr *et al.*, 2002).

According to the current data, the studied cultivars of peanuts (Giza 5, Giza 6, Ismailia 1, and Ismailia 2) were susceptible to *M. arenaria* infection under greenhouse conditions. The cultivars were divided into two groups: susceptible (Ismailia 1 and Ismailia 2) and highly susceptible (Giza 5 and Giza 6). These results are consistent with those of Korayem and Bondok (2013) but are not consistent with those of Mokbel (2014), who reported that Giza 5 was susceptible

to *M. arenaria*, whereas Ismailia 1 and Giza 6 were highly susceptible.

Organic materials exemplify a very important manorial resource for improving soil fertility because decomposed materials eventually become plant nutrients and increase crop yields. Furthermore, plants become more tolerant or resistant to nematodes when organic amendments are added (Oka, 2010). In addition, the physical characteristics of the soil may be altered by organic amendments, which could have a negative impact on nematode behaviors such as hatching, mobility, and survival (Oka, 2010). Nematodes and soil antagonists are impacted by several environmental conditions. The breakdown and demands of many populations of soil organisms determine when nutrients such as nitrogen, phosphorous, and potassium are released. In this study, the application of organic soil amendments (cattle manure, compost, and fulvic acid) either individually or in combination improved the shoot length, shoot fresh weight, pod weight, root length, root weight, and number of nodules per plant compared with those in the control treatment. The weights of shoots, pods, and several nodules increased with the combination of cattle manure and compost, followed by a single treatment with cattle manure. Compost is more effective at encouraging plant growth and nodulation processes (Ren *et al.*, 2017). This finding is consistent with Chalwe *et al.* (2019), who reported that increasing the compost dose throughout two seasons significantly increased peanut pod and kernel yields. According to Diab *et al.* (2011), applying farmyard manure to peanut crops improved the number of pods and the pod yield per plant. A range of macro- and micronutrients as well as substantial amounts of organic matter are supplied, the soil structure and porosity are enhanced, heavy soil permeability and infiltration are increased, the water holding capacity is increased, and the cation exchange capacity is increased by organic amendments. Furthermore, compost supplies nutrients that artificial fertilizers cannot, such as humus, vitamins, hormones, and plant enzymes; it also balances the pH of the soil (Evanylo *et al.*, 2008). According to Orisajo *et al.* (2008), enriching soil with organic amendments affects soil organism communities, provides nutrients to crops, and seldom stimulates organisms that are hostile to nematodes or suppressive on plant parasitic nematodes.

The results also clearly show that adding organic soil

amendments, either separately or in combination, can lessen the detrimental impacts of *M. arenaria* on peanut plants, hence increasing crop development and production. The nematode population (J_2s) in the soil and the number of galls and egg masses on the roots were dramatically decreased by all the treatments. These findings are in agreement with Osman *et al.* (2019) those of, who reported that the application of cow or chicken manure to peanuts reduced galls, egg masses, and *M. javanica* J_2s in the soil compared with those in the untreated control group. Amendments may release substances that are harmful to nematodes, such as organic acids or nitrogen compounds, which lead to increased soil fertility and plant development (Oka, 2010; Thoden *et al.*, 2011). A frequent and extensively researched byproduct of the breakdown of organic molecules is ammonia (Rodríguez-Kábana, 1986; Rodríguez-Kabana *et al.*, 1987). Ammonia concentrations released from compost were measured in pot tests and were significantly higher than the threshold required to reduce *Meloidogyne javanica* (Oka and Yermiyahu, 2002). Among the 15 different amendments, McSorley (2011) reported that galling by *Meloidogyne arenaria* decreased as the percentage of N in the amendments increased. Amendments with C:N ratios between 15 and 20 were thought to be the most productive.

According to Jiang *et al.* (2020), organic treatments increase plant tolerance and resistance. As shown by the results, all amendment treatments increased the activity of various defense-related enzymes (peroxidase, catalase, PAL, chitinase, and β -1, 3-glucanase), in addition to the accumulation of phenolic compounds. These results are consistent with Tartoura *et al.* (2014), who reported that the organic amendments enhance the activity of antioxidant enzymes to reduce the accumulation of MDA and H_2O_2 . The induction of disease resistance in plants is largely attributed to organic amendments. This phenomenon has been linked to changes in signaling pathways such as induced systemic resistance (ISR) and systemic acquired resistance (SAR) (De Kesel *et al.*, 2021). ISR is a mechanism that is triggered by infection, whereas SAR is triggered in plants by artificial chemical stimuli or elicitors from virulent or beneficial microbes (Kamle *et al.*, 2020). The resistance generated by organic amendments can be triggered by chemical, biological, or both factors. Organic supplements, such as compost and biochar, might elicit plant defense responses via some chemical

compounds derived from them or by modulating beneficial microbial communities that can induce resistance to systemic diseases (Deng *et al.*, 2020). Organic amendments develop the soil community, which promotes plant growth and tolerance (Jiang *et al.*, 2020). Several enzymes, such as peroxidase, catalase, PAL, chitinase, and β -1,3-glucanase, work together to increase tolerance and resistance in plants. According to Almagro *et al.* (2009), peroxidase plays a role in the synthesis of phytoalexins, the metabolism of ROS and RNS, auxin metabolism, the cross-linking of cell wall components, and the creation of lignin and suberin. Catalase can breakdown H_2O_2 to H_2O and O_2 (Mhamdi *et al.*, 2010). H_2O_2 is a signaling molecule involved in the control of various biological processes, such as interactions between plants and pathogens. The primary enzyme that aids in triggering the synthesis of salicylic acid, which results in systemic resistance in numerous plants, is PAL. In addition, it is essential for the formation of phenolics and phytoalexins (Kim and Hwang, 2014). According to Mandal *et al.* (2010), phenolic compounds can act as plant defense agents in addition to serving as signaling molecules that trigger legume nodulation. Plant chitinases are important defense mechanisms against environmental stressors (Vaghela *et al.*, 2022). Moreover, when a phytopathogen attacks, it hydrolyzes internal 1,4-linkages of chitin, which is a key component of pathogen cell walls and nematode egg shells (Kumar *et al.*, 2018). Plants contain large quantities of β -1,3-glucanases, which are essential for cell division, material trafficking via plasmodesmata, resistance to abiotic stress, flower formation, and seed maturity. Additionally, they protect plants from pathogen attack on their own or in combination with chitinases or other pathogenesis-related proteins (Balasubramanian *et al.*, 2012).

Conclusions and Recommendations

In conclusion, seven PPN genera associated with peanut roots were recorded, namely, *Meloidogyne* (88%), *Tylenchorhynchus* (25%), and *Helicotylenchus*, (23%), *Rotylenchulus* and *Xiphinema*. (4%, each), in descending order. *M. arenaria* (60%) was the dominant species, followed by *M. javanica* (40%). The Egyptian peanut cvs. Ismailia-1 and Ismailia-2 were ranked as susceptible hosts; however, Giza-5 and Giza-6 were ranked as highly susceptible to root-knot nematode, *Meloidogyne arenaria*. The growth of peanuts and the formation of nodules were greatly enhanced by

organic amendments, either alone or in combination, improving plant tolerance. The organic amendment treatments significantly reduced the number of galls, root egg masses and final nematode population (J_2s) in the soil, while nematicide fosthiazate 10G resulted in the greatest reduction. Compared with the control, all the treatments markedly increased the antioxidant enzyme activity in peanuts, i.e., POD, CAT and PAL activities; additionally, chitinase activity; β -1,3 glucanase activity; and total phenolic content. The integration of several techniques, including fulvic acid, compost, and cattle manure, may substantially enhance peanut development, biochemistry, and the ability to resist and control *M. arenaria*.

Farmers can use this information to select the right cultivars for areas prone to nematode infestations, thus minimizing crop loss. In addition, they can adopt these treatments to strengthen the resilience of peanut plants, leading to healthier crops and potentially higher yields. Organic amendments, especially when locally sourced, could be a cost-effective option for farmers.

While this study was conducted under controlled greenhouse conditions, future research should focus on field trials across different agro-climatic regions and evaluate the long-term effects of organic amendments on nematode populations and soil health. This will help validate the effectiveness of organic amendments in real-world farming conditions and assess how environmental factors influence their performance.

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Novelty Statement

This study, conducted in Ismailia, Egypt, assesses the susceptibility of various Egyptian peanut cultivars to

Meloidogyne arenaria under greenhouse conditions. This research contributes to sustainable, eco-friendly approaches to reducing nematode-related crop losses and improving plant health.

Author's Contribution

Eman Abdelrazik: Proposed the research, performed the research and biochemical analyses.

Sahar H. Abdel-Baset: Proposed the research, performed the research and biochemical analyses, wrote and re-vised the manuscript.

Abdelghafar M. Abu-Elsaoud: Analyzed data statistically.

Shimaa M.A. Mohamed: Proposed the research, performed the research and revised the manuscript.

Author's Contribution

EA, SHA, and SMAM, proposed the research, performed the research and biochemical analyses, EA, and SHA wrote and revised the manuscript, AMA analyzed data statistically.

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Conflict of interest

The authors have declared no conflict of interest.

References

- Abd-Elgawad, M.M.M., 2024. Upgrading strategies for managing nematode pests on profitable crops. *Plants*, 13: 1558. <https://doi.org/10.3390/plants13111558>
- Abdel-Monaim, M., Abdel-Bast, S. and Wahdan, R., 2018. Effectiveness of some organic fertilizers and bio-control agents for controlling root-knot nematodes *Meloidogyne* spp. in cowpea forage (*Vigna unguiculata*) in New Valley, Egypt. *Egypt. J. Phytopathol.*, 46: 143–164. <https://doi.org/10.21608/ejp.2018.87777>
- Ahmad, N. and Rahim, M., 2007. Performance of promising groundnut, *Arachis hypogaea* L. varieties for yield and other characters. *J. Agric. Res. (Lahore)*, 45: 185–189.
- Al-Hendy, M., Bakr, R., Mahdy, M. and Mousa, E.S., 2021. Ecofriendly management of root-knot nematodes on Eggplant using compost. *Egypt. J. Crop Prot.*, 16: 1–19. <https://doi.org/10.21608/ejcp.2021.205588>
- Almagro, L., Gómez Ros, L.V., Belchi-Navarro, S., Bru, R., Ros Barceló, A. and Pedreño, M.A., 2009. Class III peroxidases in plant defence reactions. *J. Exp. Bot.*, 60: 377–390. <https://doi.org/10.1093/jxb/ern277>
- Balasubramanian, V., Vashisht, D., Cletus, J. and Sakthivel, N., 2012. Plant β -1,3-glucanases: Their biological functions and transgenic expression against phytopathogenic fungi. *Biotechnol. Lett.*, 34: 1983–1990. <https://doi.org/10.1007/s10529-012-1012-6>
- Ballén-Taborda, C., Y. Chu, P. Ozias-Akins, P. Timper, C.C. Holbrook, S.A. Jackson, D.J. Bertoli and S.C.M. Leal-Bertoli. 2019. A new source of root-knot nematode resistance from *Arachis stenosperma* incorporated into allotetraploid peanut (*Arachis hypogaea*). *Sci. Rep.*, 9: 17702. <https://doi.org/10.1038/s41598-019-54183-1>
- Chalwe, H.M., O.I. Lungu, A.M. Mweetwa, E. Phiri, S.M.C. Njoroge, R.L. Brandenburg and D.L. Jordan. 2019. Effects of compost manure on soil microbial respiration, plant-available-water, peanut (*Arachis hypogaea* L.) yield and pre-harvest aflatoxin contamination. *Peanut Sci.*, 46: 42–49. <https://doi.org/10.3146/PS18-6.1>
- Christie, J. and Perry, V.G., 1951. Removing nematodes from soil. *Proceedings of the Helminthological Society, Washington.*, 18: 106–108.
- De Kesel, J., Conrath, U., Flors, V., Luna, E., Mageroy, M.H., Mauch-Mani, B., Pastor, V., Pozo, M.J., Pieterse, C.M.J., Ton, J. and Kyndt, T., 2021. The induced resistance lexicon: Do's and Don'ts. *Trends Plant Sci.*, 26: 685–691. <https://doi.org/10.1016/j.tplants.2021.01.001>
- Deng, X., Zhang, N., Shen, Z., Zhu, C., Li, R., Salles, J.F. and Shen, Q., 2020. Rhizosphere bacteria assembly derived from fumigation and organic amendment triggers the direct and indirect suppression of tomato bacterial wilt disease. *Appl. Soil Ecol.*, 147: 103364. <https://doi.org/10.1016/j.apsoil.2019.103364>
- Dhakshinamoorthy, S., Mariama, K., Elsen, A. and De Waele, D., 2014. Phenols and lignin are involved in the defence response of banana (*Musa*) plants to *Radopholus similis* infection. *Nematology*, 16: 565–576. <https://doi.org/10.1163/15685411-00002788>

- Diab, M., Zaid, M.S. and Akila, M.A., 2011. Effect of phosphorus fertilization and farmyard manure application on growth and yield of peanut. *J. Soil Sci. Agric. Eng.*, 2: 1327–1342. <https://doi.org/10.21608/jssae.2011.56467>
- Edussuriya, R., Rajapaksha, A.U., Jayasinghe, C., Pathirana, C. and Vithanage, M., 2023. Influence of biochar on growth performances, yield of root and tuber crops and controlling plant-parasitic nematodes. *Biochar*, 5: 68. <https://doi.org/10.1007/s42773-023-00261-7>
- El-Nuby, A., Montasser, S. and Khadrawy, I., 2019. Diversity of plant parasitic nematodes associated with some vegetables in Sinai peninsula, Egypt. *Egypt. J. Desert Res.*, 69: 77–100. <https://doi.org/10.21608/ejdr.2021.16271.1032>
- Evanylo, G., Sherony, C., Spargo, J., Starner, D., Brosius M. and Haering K., 2008. Soil and water environmental effects of fertilizer, manure, and compost-based fertility practices in an organic vegetable cropping system. *Agric. Ecosyst. Environ.*, 127: 50–58. <https://doi.org/10.1016/j.agee.2008.02.014>
- FAOSTAT, 2022. Food and agriculture organization of the United Nations. <http://faostat3.fao.org/home/E>.
- Golden, A.M., 1971. Classification of the genera and higher categories of the order Tylenchida (Nematoda). *Plant parasitic nematodes*. Vol. 1. Morphology, anatomy, taxonomy, and ecology. Academic Press, Inc., New York, USA. pp. 191–232. <https://doi.org/10.1016/B978-0-12-782201-3.50014-9>
- Goodey, J.B., 1963. Laboratory methods for work with plant and soil nematodes, 4th edit., Technical Bulletin. Ministry of Agriculture, Fisheries and Food. London, London.
- Grant, M. and C. Lamb. 2006. Systemic immunity. *Curr. Opin. Plant Biol.*, 9: 414–420. <https://doi.org/10.1016/j.pbi.2006.05.013>
- Hal, H.A., Mostafa, F.A.M. and Khairy, D., 2023. Alleviating biotic stress induced by *Meloidogyne incognita* in eggplant using dried plant residues and compost. *Egypt. J. Agronematol.*, 22: 91–107. <https://doi.org/10.21608/ejaj.2023.333149>
- Halliwell, B., 2006. Reactive species and antioxidants. Redox biology is a fundamental theme of aerobic life. *Plant Physiol.*, 141: 312–322. <https://doi.org/10.1104/pp.106.077073>
- Horwitz, W., Chichilo, P. and Reynolds, H., 1970. Official methods of analysis of the Association of Official Analytical Chemists. Washington, DC, USA: Association of Official Analytical Chemists.
- Hunt, D.J. and Handoo, Z.A., 2009. Taxonomy, identification and principal species. In: (eds. R.N. Perry, M. Moens, and J.L. Starr), *Root-knot nematodes*. CABI, UK. pp. 55–97. <https://doi.org/10.1079/9781845934927.0055>
- Ibrahim, I.K.A. and Mokbel, A.A., 2009. Occurrence and distribution of the root-knot nematodes *Meloidogyne* spp. and their host plants in northern Egypt. *Egypt. Soc. Exp. Biol.*, 5: 125–129.
- Jiang, L., Bonkowski, M., Luo, L., Kardol, P., Zhang, Y., Chen, X., Li, D., Xiao, Z., Hu, F. and Liu, M., 2020. Combined addition of chemical and organic amendments enhances plant resistance to aboveground herbivores through increasing microbial abundance and diversity. *Biol. Fertil. Soils*, 56: 1007–1022. <https://doi.org/10.1007/s00374-020-01473-w>
- Kamle, M., Borah, R., Bora, H., Jaiswal, A.K., Singh, R.K. and Kumar, P., 2020. Systemic acquired resistance (SAR) and induced systemic resistance (ISR): Role and mechanism of action against phytopathogens. In: (eds. A.E.L. Hesham, R.S. Upadhyay, G.D. Sharma, C. Manoharachary and V.K. Gupta), *fungi biotechnology and bioengineering*. Springer International Publishing, Cham. pp. 457–470. https://doi.org/10.1007/978-3-030-41870-0_20
- Khan, F., Asif, M., Khan, A., Tariq, M., Ansari, T., Shariq, M. and Siddiqui, M.A., 2019. Evaluation of the nematicidal potential of some botanicals against root-knot nematode, *Meloidogyne incognita* infected carrot: In vitro and greenhouse study. *Curr. Plant Biol.*, 20: 100115. <https://doi.org/10.1016/j.cpb.2019.100115>
- Kim, D.S. and Hwang, B.K., 2014. An important role of the pepper phenylalanine ammonia-lyase gene (PAL1) in salicylic acid-dependent signalling of the defence response to microbial pathogens. *J. Exp. Bot.*, 65: 2295–2306. <https://doi.org/10.1093/jxb/eru109>
- Kimpinski, J., Gallant, C.E., Henry, R., Macleod, J.A., Sanderson, J.B. and Sturz, A.V., 2003. Effect of compost and manure soil amendments on nematodes and on yields of potato and barley: A 7-year study. *J. Nematol.*, 35: 289–293.

- Knapp, H., 2017. Introductory statistics using SPSS, Second edition. SAGE, Los Angeles. <https://doi.org/10.4135/9781071878910>
- Korayem, A.M. and Bondok, M., 2013. Damage threshold of root-knot nematode, *Meloidogyne arenaria* on peanut in relation to date of planting and irrigation system. Can. J. Plant Prot., 1: 117–124.
- Korayem, A.M., Mohamed, M.M.M. and El-Ashry, S.M., 2021. Estimation of yield losses in broad bean due to *Meloidogyne arenaria* in Egypt. Pak. J. Nematol., 39: 135.
- Kumar, M., Brar, A., Yadav, M., Chawade, A., Vivekanand, V. and Pareek, N., 2018. Chitinases potential candidates for enhanced plant resistance towards fungal pathogens. Agriculture, 8: 88. <https://doi.org/10.3390/agriculture8070088>
- Kurabachew, H. and Wydra, K., 2014. Induction of systemic resistance and defense-related enzymes after elicitation of resistance by rhizobacteria and silicon application against *Ralstonia solanacearum* in tomato (*Solanum lycopersicum*). Crop Prot., 57: 1–7.
- Mandal, S.M., Chakraborty, D. and Dey, S., 2010. Phenolic acids act as signaling molecules in plant-microbe symbioses. Plant Signal. Behav., 5: 359–368. <https://doi.org/10.4161/psb.5.4.10871>
- McSorley, R., 2011. Overview of organic amendments for management of plant-parasitic nematodes, with case studies from Florida. J. Nematol., 43: 69–81.
- Melakeberhan, H., 2006. Fertiliser use efficiency of soybean cultivars infected with *Meloidogyne incognita* and *Pratylenchus penetrans*. Nematology, 8: 129–137. <https://doi.org/10.1163/156854106776179908>
- Mhamdi, A., Queval, G., Chaouch, S., Vanderauwera, S., Van Breusegem, F. and Noctor, G., 2010. Catalase function in plants: A focus on Arabidopsis mutants as stress-mimic models. J. Exp. Bot., 61: 4197–4220. <https://doi.org/10.1093/jxb/erq282>
- Mokbel, A.A., 2014. Effect of *Pasteuria penetrans* against *Meloidogyne* spp., on peanut cultivars. Pak. J. Nematol., 32: 137–147.
- Mostafa, E.S., El-Ashry, R. and Ali, A., 2022. Suppress root-knot nematode infested vegetable fields via enhancing rhizobacteria inoculated in composted chicken manure. Egypt. Acad. J. Biol. Sci. B. Zool., 14: 169–191. <https://doi.org/10.21608/eajbsz.2022.229451>
- Norton, D.C., 1979. Ecology of plant-parasitic nematodes. 1978. Soil Sci., 127: 63. <https://doi.org/10.1097/00010694-197901000-00012>
- Ojaghian, M.R., Chen, Y., Chen, S., Cui, Z.Q., Xie, G.L. and Zhang, J., 2014. Antifungal and enzymatic evaluation of plant crude extracts derived from cinnamon and rosemary against *Sclerotinia* carrot rot. Ann. Appl. Biol., 164: 415–429. <https://doi.org/10.1111/aab.12111>
- Oka, Y., 2010. Mechanisms of nematode suppression by organic soil amendments. A review. Appl. Soil Ecol., 44: 101–115. <https://doi.org/10.1016/j.apsoil.2009.11.003>
- Oka, Y. and Yermiyahu, U., 2002. Suppressive effects of composts against the root-knot nematode *Meloidogyne javanica* on tomato. Nematology, 4: 891–898. <https://doi.org/10.1163/156854102321122502>
- Orisajo, S.B., Afolami, S.O., Fademi, O. and Atungwu, J.J., 2008. Effects of poultry litter and carbofuran soil amendments on *Meloidogyne incognita* attacks on cacao. J. Appl. Biosci., 7: 214–221.
- Osman, H.A., Ameen, H.H., Mohamed, M., Elshahawy, I.E. and Elkelany, U.S., 2019. Comparative effects of some natural eco-friendly biofertilizers with the nematicide oxamyl on suppression of root knot-root rot complex diseases infecting peanut plants under field conditions. Middle East J. Agric. Res., 8: 371–381.
- Peiris, P.U.S., Li, Y., Brown, P. and Xu, C., 2020. Efficacy of organic amendments to control *Meloidogyne* spp. in crops: A systematic review and meta-analysis. J. Soils Sediments, 20: 1584–1598. <https://doi.org/10.1007/s11368-019-02498-x>
- Ren, H., Hu, J., Hu, Y., Yang, G. and Zhang, Y., 2017. Divergence of compost extract and bio-organic manure effects on lucerne plant and soil. PeerJ, 5: e3775. <https://doi.org/10.7717/peerj.3775>
- Rodríguez-Kábana, R., 1986. Organic and inorganic nitrogen amendments to soil as nematode suppressants. J. Nematol., 18: 129–134.
- Rodriguez-Kabana, R., G. Morgan-Jones and I. Chet. 1987. Biological control of nematodes: Soil amendments and microbial antagonists. Plant Soil, 100: 237–247. <https://doi.org/10.1007/BF02370211>

- [org/10.1007/978-94-009-3627-0_17](https://doi.org/10.1007/978-94-009-3627-0_17)
- Sadasivam, S. and Manickam, A., 1996. Biochemical methods. New age international.
- Shah, H., Khan, M.A., Azeem, T., Majid, A. and Mehmood, A., 2012. The impact of gypsum application on groundnut yield in rainfed Pothwar: An economic perspective. Lahore J. Econ., 17: 83–100. <https://doi.org/10.35536/lje.2012.v17.i1.a5>
- Sharma, S.B., Mohiuddin, M., Jain, K.C. and Remanandan, P., 1994. Reaction of pigeonpea cultivars and germplasm accessions to the root-knot nematode, *Meloidogyne javanica*. J. Nematol., 26: 644–652.
- Silva, H.S.A., Romeiro, R.D.S., Macagnan, D., Halfeld-Vieira, B.D.A., Pereira, M.C.B. and Mounter, A., 2004. Rhizobacterial induction of systemic resistance in tomato plants: Non-specific protection and increase in enzyme activities. Biol. Contr., 29: 288–295. [https://doi.org/10.1016/S1049-9644\(03\)00163-4](https://doi.org/10.1016/S1049-9644(03)00163-4)
- Starr, J.L., Morgan, E.R. and Simpson, C.E., 2002. Management of the peanut root-knot nematode, *Meloidogyne arenaria*, with host resistance. Plant Health Progress, 3: 13. <https://doi.org/10.1094/PHP-2002-1121-01-HM>
- Stirling, G.R., 2017. Biological control of plant-parasitic nematodes. Diseases of nematodes. CRC Press. pp. 103–150. <https://doi.org/10.1201/9781351071468-9>
- Tartoura, K.A.H., Youssef, S.A. and Tartoura, E.S.A.A., 2014. Compost alleviates the negative effects of salinity via up-regulation of antioxidants in *Solanum lycopersicum* L. plants. Plant Growth Regul., 74: 299–310. <https://doi.org/10.1007/s10725-014-9923-y>
- Thoden, T.C., Korthals, G.W. and Termorshuizen, A.J., 2011. Organic amendments and their influences on plant-parasitic and free-living nematodes: A promising method for nematode management? Nematol., 13: 133–153. <https://doi.org/10.1163/138855410X541834>
- Urbanek, H., Kuźniak-Gębarowska, E. and Herka, K., 1991. Elicitation of defence responses in bean leaves by *Botrytis cinerea* polygalacturonase. Acta Physiol. Plant., pp. 43–50.
- Vaghela, B., Vashi, R., Rajput, K. and Joshi, R., 2022. Plant chitinases and their role in plant defense: A comprehensive review. Enzyme Microbial Technol., 159: 110055. <https://doi.org/10.1016/j.enzmictec.2022.110055>
- Wirth, S.J. and Wolf, G.A., 1992. Micro-plate colourimetric assay for Endo-acting cellulase, xylanase, chitinase, 1,3-β-glucanase and amylase extracted from forest soil horizons. Soil Biol. Biochem., 24: 511–519. [https://doi.org/10.1016/0038-0717\(92\)90074-8](https://doi.org/10.1016/0038-0717(92)90074-8)
- Young, T.W., 1954. An incubation method for collecting migratory endo-parasitic nematodes. Plant Dis. Rep., 38: 794–795.