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COMPARATIVE EFFICACY OF CHITOSIN, NARINGI AND BIOCHAR POWDERS AGAINST ROOT KNOT NEMATODE (*Meloidogyne* spp.) ON TOMATO (*Solanum lycopersicum* L.) IN MAIDUGURI, BORNO STATE NIGERIA

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***Abstract**: The experiment was carried out during 2024 dry season at the Teaching and Research Farms of the Department Agricultural Technology Ramat Polytechnic Maiduguri, Borno State Nigeria. The aim was to evaluate the effect of chitosin, naringi and biochar powders against root knot nematodes (Meloidogyne spp.) infecting tomato (Solanum lycopersicum L.). The experiment was layout in a Completely Randomized Design (CRD) with three replications using single tomato variety and three (3) treatments. (chitosin, naringin and biochar powders) applied at a dose rate of 50g, 100g, and150g each, and control (0.0g). Nematode population parameters, plant growth and yield Parameters were observed. The result of this study showed that all treatments significantly (P≤0.05%) reduced the population of Meloidogyne spp. while the population increased in the untreated (Control) pots. However, pots treated with chitosan 150g powder were more effective in suppression of nematodes population, as well as significant increased in growth parameters and yield of tomato. It is also observed that application of naringin and biochar powders at a rate of 150g, per stand was found to be reletively effective in suppressing root knot nematode (Meloidogyne spp.), as well as increased in growth parameters and yield of tomato. It is therefore; recommended that farmers should adopt and practice the application of chitosan, 150g per stand in management of Meloigogyne spp. in tomato as these products are less harmful, effective, pollution free, and also available. In the absent of chitosan, naringin and biochar powder should be use at a dose rate of 150g per stand. Further investigation should be carried out at different dose rates*.

Key words: *Solanum lycopersicu, Meloidogyne spp,* chitosin, naringin and biochar

INTRODUCTION

Tomato (*Solanum lycopersicum L.*) belongs to the *Solanaceae* family. This family also includes other well-known species, such as potato, tobacco, peppers and eggplant (Dixie, 2016). Tomato has its origin in the South American Andes (Dixie, 2016). The cultivated tomato was brought to Europe by the Spanish conquistadors in the sixteenth century and later introduced from Europe to southern and eastern Asia, Africa and the Middle East. Common names for the tomato are:

tomate (Spain, France), tomat (Indonesia), faanke'e (China), tomato (Nigeria), tomatl (Nahuatl), jitomate (Mexico), pomodoro (Italy), nyanya (Swahili) (Dixie, 2016).

Tomato is an annual plant, which can reach a height of over two meters (2m).They keep growing after flowering. This feature is called indeterminate. However, under tropical conditions many pests and diseases including, roots knot nematodes, attacks will stop growth. The plants generally have more foliage. This will keep the temperature lower within the crop and the fruits grow in the shade of the leaves. Because they are covered, the sun does not damage the fruits and they ripen more slowly. Slower ripening and a high leaf/fruit ratio improve the taste of the fruits and in particular the sweetness (Aziz, *et. al*., 2015). Tomatoes are a warm-season crop. Tomatoes must be set out in the field as transplants after all danger of frost has passed. Tomatoes do not thrive in extreme cold weather or extreme heat. Tomatoes will produce good yields on a wide range of fertile, well drained soils with pH of 5.5 – 7.5 (Aziz *et. al*., 2015).

In Nigeria, tomato is one of the most important vegetable crops. It is a good condiment in most diets and very cheap source of vitamins A, C and E (Mourvaki, *et. al.,* 2015).

Root-knot nematodes (*Meloidogyne spp.)* are of major importance pest in tomato cultivation (Olson, 2016). Three common types of root-knot nematodes are: *M. incognita*, *M. javanica* and *M. arenaria* (Olson, 2016). The affected plants show symptoms like stunted growth, yellowing of the leaves, wilting, and collapse of individual plants, swelling or gall on the roots. All root knot nematodes damage the vascular tissues of roots and thus interfere with the normal movement of water and nutrient throughout the plants. Nematodes generally are regarded as silent enemies, they cause yield losses of about 30% in tomato in the tropics (Olson, 2016).

Naringin is an indigenous organic compound obtained from plants (Céliz, *et al.,* 2011). A widely abundant citrus flavanone glycoside is typically present in the tissue and seeds of grapefruit, and in the rind of orange and lemon (Citrus). The antibacterial effect of naringin is ascribed to the copious existence of pharmacologically active substances present in the tissue and seeds of grapefruit (Céliz, *et al.,* 2011).

Biochar, a solid byproduct of biomass pyrolysis, is a soil additive that sequesters carbon. It has been demonstrated to enhance plant performance and decrease the intensity of foliar and soilborne plant diseases (Frenkel, *et al.,* 2017).

Plant Parasitic Nematodes (PPNs) provide a significant challenge in tomato production, as they attack and feed on the roots and subterranean sections of the plant. This can have a detrimental impact on the growth and development of tomatoes (Singh *et al.,* 2015). Root-knot nematode, namely the *Meloidogyne* spp., is a significant pest that affects tomato plants and several other vegetables (Charles, 2018). The unselective application of artificial nematicides to manage plant-parasitic nematodes (PPNs) results in phytotoxicity, environmental contamination, and the development of nematode resistance. Conversely, its improper utilisation can lead to human poisoning, particularly in underdeveloped nations such as Nigeria (Charles, 2018). This study examines the bioactive properties of specific natural compounds derived from plants and animals. It investigates how these compounds, namely chitosan, naringin, and biochar, control *Meloidogyne* spp**.**

MATERIALS AND METHODS

Experimental Site

The trial was carried out in the dry season of 2024 at the Teaching and Research Farm of the Department of Agricultural Technology, Ramat Polytechnic Maiduguri, located within the Sudan

savanna zone of Nigeria. Maiduguri is located at approximately latitude 11°5' and 11.83°' N and longitude 13°09' and 13.50°E. It sits at an elevation of about 350m above sea level. The climate in Maiduguri is predominantly hot and dry, with a rainy season occurring from June to September. The average annual rainfall is around 600 mm, and the temperature ranges from 27 to 45°C. The average relative humidity often fluctuates between 30% and 50%, with the lowest levels occurring in February and March, and the highest levels in August (Nigerian Wiki, 2008).

Treatments and Experimental Design

The experiment consisted of Three (3) treatments, which are Chitosan, Naringin and Biochar powders applied at dose rate of 0.0g, 50g, 100g, and 150g each. Replicated three (3) times each, and was laid out in a Completely Randomized Design (CRD).

Extraction of *Meloidogyne* spp. Eggs from Infected Tomato Roots

The roots of tomato plants, afflicted with nematodes were meticulously uprooted following irrigation. The soil particles were eliminated by the process of rinsing the roots using tap water. The shoots of the crops were detached from the roots with a knife. The galled roots were submerged in a plastic tube filled with water to facilitate the retrieval of egg masses. The pristine (fresh) and uniformly sized egg masses was delicately selected using forceps to minimize any harm to the egg mass. They were then put in a Petri dish filled with distilled water. The egg masses were forcefully agitated with 200ml of a 5.2% solution of sodium hypochlorite (NaOCl) in sealed flasks for 2 minutes, causing the gelatinous matrix of the egg masses to disintegrate (Hussey and Barker, 1973). The eggs were cleansed by washing them with tap water using a 200 mesh (75 pm) sieve. They were then gathered on a 500 mesh (26pm) sieve and placed into distilled water to create an egg suspension. This suspension was then utilized for the experiments conducted (Hussey and Barker, 1973).

Extraction of Second Stage Juveniles of *Meloidogyne* spp.

The collected eggs were kept in an incubator at a temperature of 25±2°C for 7 days to ensure the eggs fully hatched. The freshly hatched J2ssuspension was highly concentrated in such a way that 1ml of the suspension contained 200 J2s individuals. This highly concentrated recently hatched J2s suspension was utilized for the inoculation of the tomatoes in the experiments (Hussey and Barker, 1973).

Preparation of Soil Mixture

A 5% (14ml/L) formaldehyde solution was used to sterilise sandy loam soil. The soil was saturated with a five-liter solution of the treatments and then covered with a sheet for duration of seven days. The sheet was removed, and the soil was aerated for a further seven days until the fumigant scent dissipated entirely (Abhijeet Jogur, 2016). Three (3) kilogramme of sterilised soil were placed in sterilised plastic pots with a diameter of 25 centimetres (The pots were sterilised by being dipped in a solution of 5 percent formaldehyde and left open for three days before filling) were used for the experimentation (Abhijeet Jogur, 2016).

Raising of Tomato Seedlings

Tomato seeds local variety (tantilo) known to be highly susceptible to *Meloidogyne* spp. was sown. Nurseries of these seeds were raised in a sterilized nursery beds at Teaching and Research Farm, Ramat Polytechnic, Maiduguri.

Preparation of Powder Form of Chitosan, Naringin and Biochar

Chitosan: Snail shells and crab-fish were purchased from the market and cleaned to remove all dirts or foreign materials then were ground into a powder form using mortar and pestle. The powder was measured 50g, 100g and 150g used for the experiment.

Naringin: Fresh citrus (sweet orange) peels was collected and dried in shade. After completely shade dried, then pounded into powder form using pestle and mortar, 50g, 100g and 150g was used for the experiment.

Biochar: Fire wood Charcoal was collected cleaned to remove all dirts and ground in to powder form using pestle and mortar, the measured grams (using sensitive electronic weighing balance) 50g, 100g and 150g of the charcoal powder was used for the experiment.

Inoculation of Second Stage Juveniles (J2s) of *Meloidogyne* spp.

After seedlings established well, the plants in each pot were inoculated with 2000 second stage juveniles (J2s) of *Meloidogyne* spp. by pipetting 10ml of the juvenile suspension in to the rhizosphere of each plant (Hussey and Barker, 1973).

Data Collection/Parameters Measured

The experiment was terminated 90 days after transplanting of the tomato and the following data were recorded;

Nematode Population Parameters

Final Nematode Population (P_f) in Soil

The Whitehead and Hemming (1965) technique was used in the extraction of nematodes from the soil samples. A double layer of tissue papers was positioned within a meshed plastic basket, which was evenly disseminated across the surface of the plastic tray. The contaminated soil sample was evenly distributed throughout the surface of the tissue paper. The plastic tray was filled with water in a careful manner until the soil sample reached a state of moisture without being too inundated. Precautions were taken to avoid excessive saturation of the soil. The trays containing damp soil samples were left undisturbed for 24 hours. The motile phase of the nematodes gradually move from the damp soil, descending through the tissue paper, and settle at the bottom of the water-filled tray. The water containing the worms was transferred into a 200ml beaker and left undisturbed for a few hours to allow the nematodes to separate and settle. The surplus water in the beaker was decanted, resulting in approximately 50mls of suspension containing the nematodes. Three aliquots, each measuring 1ml, were pipetted from the suspension following a thorough agitation. Each aliquot was then put individually onto a Doncasters counting Dish. The nematodes were counted in each dish using a stereomicroscope, and the average number of the three samples was recorded.

Reproductive Factor (RF)

Reproductive Factor was calculated by dividing the final population (Pf) by the initial population (Pi) that is;

$$RF = \frac{P_f}{P_i}$$ (Kayani *et al*., 2011).

Changes in Nematode Population

Changes in nematode population was calculated in percentage (%) using the following relationship;

$$\text{Percentage reduction or increase} = \frac{P_f - P_i}{\quad} \times 100$$

P_i (Kayani *et al*., 2011).

Where P_i = initial nematode population per 250cm^3 of soil, P_f = final nematode population per 250cm^3 of soil.

Number of Galls (Gall index in 1-5 scale)

To assess the extent of galling on the tomato roots from each treatment, the plant and the soil were carefully removed in pots at the end of the experiment. The soil was washed out with tap water to obtained intake plant roots. The roots were examined for galls using hand lens. The number of the galls found was counted and indexed according to the indexing scale developed by Ibrahim and Lewis, (1985).

Galling Index Scale

1. 1-2 galls (Completely resistant)
2. 3-10 galls (Moderately resistant)
3. 11-30 galls (Resistant)
4. 31- 100 galls (Slightly resistant)
5. More than 100 galls (Susceptible) (Ibrahim and Lewis, 1985).

Number of Egg Masses

The shoots of the plants were detached from the roots by means of a knife. The galled roots were immersed in a plastic container filled with water to facilitate the extraction of egg masses. The number of egg masses observed were counted and recorded.

Plant Growth and Yield Parameters

Shoot Height (cm): Shoot height (cm) was manually measured using thread then transferred to measuring tape in order to take the measurement of the shoot height and recorded.

Dry Shoot Weight (Kg): fresh shoot was collected after terminated the experiment, the shoot was dried under shade and then weight using electronic weighing scale then recorded.

Root Length (cm): Root length (cm) was measured using thread, and then thread was transferred to measuring tape in order to take the measurement of the root length and recorded.

Dry Root Weight (g): After the termination of the experiment, the plant root was cut up using knife and dried under room temperature, was then weighted and recorded using electronic weighing scale.

Fruit Yield (Weight) per Plant (kg): Fresh fruit weights were measured using a weighting scale and recorded immediately after harvest in screen house. Collection of fruit starts from beginning of fruits bearing to the end of the experiment (Taylor and Sasser, 1978).

Statistical Analysis

All data collected were subjected to analysis of variance (ANOVA) appropriate to Completely Randomized Design (CRD) in Factorial and means were compared using Turkey's (HSD) at 0.05 level of significance using Statistix version 8.0 Software.

RESULTS AND DISCUSSION

Results

Table 1: Effect of Chitosan, Naringin and Biochar Powers on Root Knot Nematodes (*Meloidogyne* spp.) Population infecting Tomato

Treatments (g)	Initial population (Pi)	Final population (Pf)	Change-in population (%)	Reproductive Factor (Pf/Pi)
Elicitors (E)				
Chitosan	2000	864.39^{c}	-56.78	0.43
Naringin	2000	888.83^{b}	-55.56	0.44
Biochar	2000	930.78^{a}	-53.46	0.47
SE±		1.55		
Levels (L)				
0	2000	3137.6^{a}	56.88	1.57
50	2000	188.1^{b}	-90.60	0.09
100	2000	140.0^{c}	-93.00	0.07
150	2000	113.0^{d}	-94.35	0.06
SE±		1.81		
Interactions				
E × L		***		

Values are means of three replications. Values in the same column accompanied by the same letter are considered statistically not significant different based on the Tukey HSD test at a significance level of 0.05. **+** indicates increase in nematodes population, while **–** indicates decrease in nematode population. E= Elicitors L= Level, ***= highly significant.

The result of effect of different treatments on root knot nematodes (*Meloidogyne* spp.) population is presented in Table 1. The results showed that, there were significant (P≤0.05) differences between eclicitors (chitosan, naringin and biochar) (**Table 1**). However, the highest root knot nematodes (*Meloidogyne* spp.) population was obtained in pots treated with biochar with 930.78 followed by the Naringin with 888.83.while the least root knot nematodes (*Meloidogyne* spp.) population was recorded in pot treated with chitosan with 864.39 (Table1). The results also revealed that there were significant differences (P≤0.05) among application levels. However, pots treated with 150g were significantly higher in nematodes reduction than other levels of application. While untreated (0.0g) had the *Meloidogyne* spp population (3137.6) (Table1).

Table 2: Effect of Chitosan, Naringin and Biochar Powers on Shoot height, Dry shoot weight, Root length and Dry root weight of Tomato Grown in Soil Infected with *Meloidogyne* spp.

Treatments (g)	Shoot height (cm)	Dry shoot weight (kg)	Root length (cm)	Dry root weight (g)
Elicitors (E)				
Chitosan	37.47[a]	0.81[a]	11.00[a]	126.72[a]
Naringin	35.33[b]	0.75[b]	10.44[b]	117.25[b]
Biochar	33.00[c]	0.66[c]	9.58[c]	108.39[c]
SE±	0.27	0.01	0.11	0.51
Levels (L)				
0	28.89[d]	0.42[d]	6.222[d]	81.89[d]
50	33.56[c]	0.69[c]	9.111[c]	99.78[c]
100	36.21[b]	0.82[b]	12.148[b]	127.52[b]
150	42.33[a]	1.16[a]	13.889[a]	160.63[a]
SE±	0.31	0.01	0.13	0.69
Interactions				
E × L	***	***	***	***

Values are means of three replications. Values in the same column accompanied by the same letter are considered statistically not significant different based on the Tukey HSD test at a significance level of 0.05. E= Elicitors L= Level, ***= highly significant.

The result of effect of different treatments with elicitors on shoot height, dry shoot weight, root length and dry root weight is presented in Table 2. The results showed that, there were significant (P≤0.05) differences among the treatments. However, the highest shoot height was obtained in pot treated with chitosan with 37.47cm followed by the Naringin with 35.33cm.while the least shoot height was recorded in pot treated with biochar with 37.47cm. The results also indicated statistically significant (P≤0.05) variations among application levels. However, pots treated with 150g were significantly higher than other levels of application.

The results showed that there were significant (P≤0.05) differences among treatments on dry shoot (**Table 2**). However, the highest dry shoot weight was obtained in pot treated with chitosan with 0.90kg, followed by the naringin with 0.75kg, while the least dry shoot weight was recorded in pot treated with biochar with 0.66kg. The results also indicated statistically significant (P≤0.05) variations among application levels. However, pots treated with 150g were significantly higher than other levels of application (Table 2).

The results indicated the presence of statistically significant (P≤0.05) variations among treatments on root length (**Table 2**). However, the highest root length was obtained in pot treated with chitosan with 11.00cm, followed by the Naringin with 10.44 cm, while the least root length was recorded in pot treated with biochar with 9.58 cm. The results also indicated statistically

significant (P≤0.05) variations among application levels. However, pots treated with 150g powder were significantly higher than other levels of application (Table 2).

The results also indicated the presence of statistically significant (P≤0.05) variations among treatments on dry root weight (**Table 2**). However, the highest dry root weight was obtained in pot treated with chitosan with 126.72g, followed by the Naringin with 117.25g, while the least dry root weight was recorded in pot treated with biochar with 108.39g. The results also indicated statistically significant (P≤0.05) variations among application levels. However, pots treated with 150g were significantly higher (160.63g) than other levels of application (Table 2).

Table 3: Effect of Chitosan, Naringin and Biochar Powers on Number of galls, Number of egg masses, and Yield weight of Tomato Grown in Soil Infected with *Meloidogyne* spp

Treatments (g)	Number of galls	Number of egg masses	Yield weight (Kg)
Elicitors (E)			
Chitosan	42.39^{c}	31.11^{c}	7.39^{a}
Naringin	44.83^{b}	33.92^{b}	6.78^{b}
Biochar	49.03^{a}	43.61^{a}	6.17^{c}
SE±	0.28	0.34	0.09
Levels (L)			
0	137.56^{a}	59.56^{a}	2.89^{d}
50	18.81^{b}	35.21^{b}	6.33^{c}
100	14.00^{c}	29.11^{c}	8.17^{b}
150	11.30^{d}	20.89^{d}	9.72^{a}
SE±	0.33	0.31	0.11
Interactions			
E × L	***	***	***

Values are means of three replications. Values in the same column accompanied by the same letter are considered statistically not significant different based on the Tukey HSD test at a significance level of 0.05. E= Elicitors L= Level, ***= highly significant.

The result of effect of different treatments chitosan, naringin and biochar powers on number of galls, number of egg masses, and yield weight of tomato is presented on the Table 3. The results indicated the presence of statistically significant (P≤0.05) variations among treatments on number of galls (**Table 3**). However, the highest number of galls was obtained in pot treated with biochar with 49.03 galls, followed by the Naringin with 44.83 galls, while the least number of galls was recorded in pot treated with chitosan with 42.39 galls. The results also indicated statistically significant (P≤0.05) variations among application levels. However, pots treated with 150g were significantly higher in galls reduction (11.30) than other levels of application. Control (0.0g) had the highest number of galls (137.56) (Table 3).

The results further indicated the presence of statistically significant (P≤0.05) variations among treatments on number of egg masses (**Table 3**). However, the highest number of egg masses was

obtained in pot treated with biochar with 43.61 egg masses, followed by the Naringin with 33.92 egg masses, while the least number of egg masses was recorded in pot treated with chitosan with 31.11 egg masses. The results also indicated statistically significant (P≤0.05) variations among application levels. However, pots treated with 150g were significantly higher in egg masses reduction (20.89) than other levels of application. Control (0.0g) had the highest number of egg masses 59.56) (**Table 3**).

The results indicated statistically significant (P≤0.05) variations among treatments on yield weight. However, the highest yield weight was obtained in pot treated with chitosan with 7.39kg, followed by the Naringin with 6.78kg, while the least yield weight was recorded in pot treated with biochar with 6.17kg. The results also indicated statistically significant (P≤0.05) variations on yield weight among application levels. However, pots treated with 150g were significantly higher on yield weight (9.72kg) than other levels of (Table 3).

Discussion

The finding of this study showed that all treated pots showed a lower nematode population when compared to the control. This suggests that treatments used in this experiment had significantly reduced the population of the *Meloidogyne* spp. that was inoculated in experimental pots. The results indicated that all the treatments have significant impact on the *Meloidogyne* spp. population in all levels. The results showed that, statistically significant variations (P≤0.05) were observed among the treatments. All the treatments significantly reduced the population of soil nematodes while their population increased in the untreated pots (control). However, Pot treated with Chitosan applied at 150g was more effective in suppression of *Meloidogyne* spp. population by making the plant more resistant, which suppressed the *Meloidogyne* spp. population by 99.34% followed by the pot treated with naringin applied at 150g with reduction of nematodes population by 96.67%. The least reduction in nematodes population was recorded in pots treated with Biochar 50g with 85.67% of reduction in *Meloidogyne* spp. population. While highest increase in *Meloidogyne* spp. population was recorded in control. This discovery aligns with the research conducted by Kuchitsu *et al,.* (1997), which indicated that both chitin and chitosan possess the capability to augment the plant's defensive mechanism against infections.

The reproductive factor (RF) which portrays the relationship between the final population (Pf) and initial population (Pi) revealed that pot treated with chitosan applied at 150g exhibited the least reproductive factor with 0.007, followed by pots treated with chitosan applied at 100g 0.028. However, the highest Reproductive Factor (RF) was recorded under control (0.0g) 1.56.

The observed decrease in nematode population in this study may have resulted directly from the application of the treatments (chitosan, naringin, and biochar). This is in conformity with observation made by Kuchitsu *et al*., (1997). In a similar research who reported that both chitin and chitosan have demonstrated ability to enhance plant defense system against pathogens.The responses mentioned are lignification, variations in ion flux, cytoplasmic acidification, membrane depolarization, protein phosphorylation, activation of chitinase and glucanase, biosynthesis of phytoalexin, generation of reactive oxygen species, biosynthesis of jasmonic acid, and expression

of unique early responsive and defense-related genes (Kuchitsu *et al.,* 1997).In addition, chitosan has been documented to stimulate the production of callose, proteinase inhibitors, and phytoalexins in several dicotyledonous plant species.The results of this study align with the findings of Angioni *et al.,* (1998). Garcion *et al.,* (2007) discovered that grapefruit extract (naringin), when applied as a spray on crops, functions as an inducer of immunity. It induces systemic acquired resistance by means of 7-geranoxycoumarin, a compound found in the extract. Host plant predispositions to develop physical barriers, together with other biochemical pathways, play a crucial role in resistance. The impregnation of cell walls with different compounds, such as waxes in the epidermis, suberin in cork, and lignin in woody cells, and creates barriers that prevent entry of pathogens. Additional forms of passive resistance are obstacles that hinder the mobility of an external agent, whether it is a living organism or a non-living factor.. The discovery also aligns with the observation made by Frenkel, *et al.,* (2017) which said that the suppression of illnesses caused by pathogens, as a result of biochar amendment, is obviously facilitated by induced systemic resistance. This is due to the fact that biochar is physically remote from the location of pathogen assault. The result of effect of the treatments on shoot height showed that, there were significant differences between the treatments and the controls. The results showed that the highest shoot height was obtained in treated pots (chitosan, naringin and biochar) while the lowest shoot height was observed in untreated plots (control). This might have been due to the ability of the treatments to suppress nematode population, hence increased the plant growth. This aligns with the findings of Abd El-Monem et al. (2016), who observed that plants treated with resistance elicitors had a significantly greater effect on plant height (23.66 cm) compared to untreated plants (11.55 cm). Furthermore, the treatments led to notable enhancements in the height of plants infected with nematodes.

The result on the effect of the treatments on dry shoot weight (DSW) of tomato, showed that, there were significant difference among the all the treatments compared to control (untreated pots) The pot treated with chitosan, naringinrin and biochar had the highest dry shoot weight when compared with untreated pots (control). This is in the conformity of with the work of Hadis *et al.,*(2014)who reported that dry shoot weight of infected plants with nematodes and treated with resistance elicitors were increased compared with infected plants without treatment.

Root length results revealed that, significant difference on root length was observed in all treatments compared to control. However, the longest root length was recorded in treated plants with natural resistance elicitors while the shortest roots length was observed in untreated pots. The longest root produced by the treated plants might have been due to effect of the treatments which led to reduction in nematodes and improved root growth, while the short root length produced by the untreated (control) plants might be due to huge nematodes infection of the plant root which resulted to retarded root growth. This finding is similar with the observation made by Abd El-Monem*et al*., (2016) who reported that root's length of tomato plants were decreased significantly in response to the infection with nematode.

The results of effect of the treatments on dry root weight (DRW) indicated that, all the treatments had significant impact on the dry root weight of tomato. The results furthermore revealed that,

there were significant variations among the treatments compared to control, in both locations. The treated Plants recorded the highest dry root weight of tomato, while the control pots had the lowest dry root weights in both locations. These findings align with the research conducted by Bigeard et al. (2015), which demonstrated that the use of a elicitor resulted in a considerable increase in average root weights across all treatments compared to the control group. The treated plants had a significantly higher maximum mean root weight of 40.6 gm compared to the control plants, which had a mean root weight of 15.8 gm.

The findings on the impact of treatments on tomato yield weight indicate a substantial increase in yield for all treatments in comparison to the untreated pots (control). Nevertheless, the outcome indicated those pots treated had the greatest fruit weight. This might be attributed to the capacity of the resistant elicitors to inhibit the nematodes by means of the presence of phytochemicals and enhanced soil fertility, leading to an increase in fruit weight. The control group had the lowest fruit weight, most likely because nematodes were active in the root zone. This activity negatively impacted root performance, resulting in a poor yield for the control plant. This is consistent with the results of Abou-Aly et al., (2015), who observed that soil infestation with root-knot nematodes led to a substantial reduction in the growth characteristics and fruit output of tomatoes compared to the control treatment. The production of tomatoes showed a considerable increase when plants were treated with bio-agents, as compared to the infected treatment.

The findings of the study on the impact of treatments on root galls in tomato plants indicate that all the treatments effectively reduced the occurrence of galls in tomato roots. The greatest decrease in the number of galls per root system was observed in pots treated with chitosan, naringin, and biochar, whereas the largest number of root galls was recorded in the control. The absence of an effective deterrent on the roots of the untreated (control) crops allowed nematodes to infiltrate, feed on, and multiply within the roots, resulting in the formation of enlarged cells or root knot diseases. These findings align with the results of Hadis et al.,(2014) who found that the application of resistance elicitors as soil drench and leaf spray led to a substantial reduction in gall diameter by 28% and 32%, and a decrease in the number of galls per plant by 40% and 44% compared to the control group (plants infected with nematodes only).

The results on effect of treatments on number of egg masses on tomato roots revealed that all the treatments significantly suppressed egg masses in tomato roots. The greatest decrease in the number of egg masses per root system was observed in pots treated, whereas the maximum number of egg masses was observed in the control group. The reduction in egg masses might be due to the effect exhibited by the treatments on nematodes. While increased in egg masses were due to absence of a deterrent on the roots of the untreated (control) crops allowed nematodes to infiltrate, feed on, and breed on them. This findings is in line with the observation made by Hadis *et al.,* (2014) who reported that use of resistance elicitors as soil drench and leaf spray significantly reduced number of egg masses per plant by 45% and 49% andnumber of eggs per individual egg mass by 53% and 55% compared to control(inoculated with nematode only).In a similar vein, Abd El-Monem et al. (2016) found that when natural resistance elicitors were applied

either simultaneously or one week after inoculating M. incognita, there was a reduction of 88% and 60% respectively in the number of egg masses. Applying the treatment one week prior to the inoculation of *M.incognita* resulted in an 80% decrease in the quantity of egg masses.

Conclusion

The result of this study showed that all treatments significantly (P≤0.05%) reduced the population of *Meloigogyne* spp. while the population increased in the untreated (Control) pots. However, pots treated with chitosan 150g powder was more effective in suppression of nematodes population, as well as significant increase in growth parameters and yield of tomato.

Recommendations

- Based on the findings of this research, it is observed that application of chitosan, naringin and biochar at rates 150g per stand was found to be effective in suppressing *Meloidogyne* spp. population, as well as increased in growth parameters and yield of tomato. Consequently; it is recommended for farmers to embrace and implement the use of chitosan, powder at 150g per stand in management of *Meloigogyne* spp. as well as increased in yield of tomato which was the most effective among others, as these products are less harmful, effective, pollution free, and also available.
- It is recommended to carry out further investigation on application methods and rates of the tested materials (chitosan, naringin and biochar) in controlling *Meloigogyne* spp.
- It is also recommended to carry out further research to investigate the effect of the treatments (chitosan, naringin and biochar) on other crops.

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