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New Chemical and Biological Agents for Controlling Root-Knot Nematode *Meloidogyne arenaria* on Cucumber under Greenhouse Conditions

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ABSTRACT

Results of pre and post - planting application of different control agents showed their significant effect in reducing infection criteria of cucumber compared to uncontrolled plants. No infection was found after pre - planting application of Velum prime nematicide, where decreasing in all infection criteria was 100% to be the best pesticide and application method for controlling *Meloidogyne arenaria* on cucumber under greenhouse conditions with significant differences compared to other treatments, followed by application the same pesticide at post - planting application. The effect of pre - planting application of Abamectin biopesticide and Trichoderma bio - control agent was very close to each other in number of galls to be similar in root - knot index, but they differed significantly in nematode population density, whereas the lowest effective was found by post - application of goat manure, where the highest number of galls (365 galls/root system),nematode population density (1142.3 J2s/pot) and root - knot index (8/ root system) were recorded, but it didn't differ significantly with the aqueous extract of tobacco leaves by the same application method. The highest increasing in cucumber growth criteria was reported after pre-planting application of Velum prime nematicide, except the dry weight of roots, where the highest value of root system length (41.7 cm), length (99.3 cm) and dry weight (15.5 g) of shoot system and chlorophyll content (37.2 SPAD) was recorded, with significant differences compared to the most control agents at both application methods The lowest improvement in growth criteria was found after post - application of the aqueous extract of tobacco leaves, as the values reached (23.5 cm, 51.3 cm and 10.1 g) for each of root system length, length and dry weight of shoot system respectively. The lowest increase in chlorophyll content (22.1 SPAD) by percentage (20.76 %) was reported by post - application of goat manure with no significant difference to its content (22.2 SPAD) after post - planting application of the aqueous extract of tobacco leaves by percentage (21.31 %).

1. Introduction

Cucumber (Cucumis sativus L., Cucurbitaceae) is one of the most popular vegetables. It is a commonly cultivated plant and is ranked as an important vegetable globally (MAO et al., 2016, Sebastian et al.,2010). Root – knot nematodes (RKNs) *Meloidogyne* spp., are economically the most important plant parasitic nematodes distributed in the world (Jones et al., 2013), causing significant damage and production loss in many cultivated plants, particularly vegetable crops (Feyisa, 2021). They have ability to affect approximately 5,500 species of plants (Akyazi et al., 2012). The most well - known and

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important species of RKNs are *M. javanica, M. arenaria, M. incognita* and *M. hapla* that cause high economic damages to numerous crops (Khalil, 2013). It has been reported that *Meloidogyne* spp. is one of the most destructive pathogens in cucumber crops which causes damage and reduces growth and yield loss (Muther, 2020).

2. Literature review

During a survey of greenhouses cultivated by cucumber in Duhok province / Kurdistan Region – Iraq, the highest disease incidence within the studied areas reached 80.5% (Ami & Shingaly, 2018). In another survey of greenhouses cultivated by vegetables in provinces of Erbil, Duhok and Sulaymaniyah, the highest disease incidence of RKNs was in cucumber (58%) (Hamad & Mennan, 2022). In a field survey of cucumbers planted under greenhouses in the growing seasons of 2020 and 2021 in Duhok province in eight locations, the highest disease incidence reached 53.9%, and M. javanica was the most widespread species followed by M. incognita then *M. arenaria* (Taher, 2023). The main objective for controlling Meloidogyne spp. is to prevent the crops from its infection and reducing their vulnerability to secondary infection and achieve maximum crop yield at a low cost (Norshie et al., 2011). Many methods have been applied to control RKNs, such as nematicides (Zasada et al., 2010), plant extracts (Hassan et al., 2015, Montasser et al., 2012), organic fertilizers (Sarkar et al., 2021), biological control (Kumar and Singh, 2006, Bent et al., 2008), biopesticides (Myers et al., 2017, d'Errico et al., 2023). This study aimed to evaluate different biological methods for controlling RKN *M. arenaria* in cucumber, including plant extracts, BM Root Pan (containing various bacterial species), Trichoderma as a biocontrol agent, biopesticides (Nimbecidine EC and Abamectin), organic fertilizer (goat manure), and chemical control (Velum Prime).

3. Materials and methods

Chemical and Biocontrol agents used for controlling RKN *M. arenaria* on cucumber under greenhouse conditions

Plastic pots with a diameter of 21 cm and depth of 20 cm were filled with a sandy loam soil (15 clay, 20.2 silt and 64.8% sand) sterilized by formalin with a rate of 4.5kg of soil/pot after mixing it with the peat moss in a ratio of 6:1. Two seeds of cucumber hybrid cv. Roni F1, which was the most widely cultivated hybrid cv. in Erbil province / Kurdistan Region – Iraq. were planted in each pot, then thinned following germination to keep one plant / pot. Pots were plunged randomly in the trenches prepared previously in the soil of the greenhouse considering that each trench (block) contains all treatments. Soil of all pots were infested with cucumber roots severely infected by *M. arenaria* (after being diagnosing) brought from one of the greenhouses, where infected roots were cleaned carefully with a tap water to remove debris and soil, then cut into small pieces (3-5 cm) and kept in a large beaker containing 1% NaOCl for approximately 1min to prevent any fungal or bacterial infection. Infected roots were transferred to another beaker containing D.W. for 2-3 mins to remove residual of sodium hypochlorite. Soil in pots was infested with nematode inoculum by 12g of infected roots / pot. Pots were divided into two groups: In the first group selected biological agents and chemical pesticides were applied to the soil one-week pre – planting cucumber seeds, while in the second group, cucumber seeds were planted directly after soil infestation by nematode inoculum then after 20 days selected control agents were applied to the soil (post - planting) (Fig.1).

Figure 1. The greenhouse in which the experiment of nematode control was conducted

Source: Authors, own research

Seven control agents were selected to control *M. arenaria* on cucumber under greenhouse conditions included: BM – Root Pan as bio – control agent, which contains races of bacteria (Bacillus megaterium, P*antoea agglomerans, Paenibacillus polymexa,* and *Bacillus subtilis*), Biocont-T, ingredient *Trichoderma harzianum* contains more than 19×10^7 spores /1g. used as source of Bio - control *T. harzianum* , Bio - pesticide Vertemic (Abamectin) (Abamectin 1.8% EC) Chemical nematicide Velum Prime (Fluopyram 400g / L.SC), Bio - pesticide chemical compound Nimbecidine (Azadirachtin 0.3g / L.EC) (Table appendix A), Bio fertilizer (Goat manure) and aqueous extract of tobacco leaves.

Thus, this experiment consisted of the following treatments:

1- Aqueous extract of tobacco leaves (10 ml plant extract + 10 ml D.W.) (20ml/pot).
2- Bio - control agent *Trichoderma* at a rate of 10 g / 1 kg of soil.
3- Bio - control agent BM- Root Pan:1 ml / L of D.W. (100 ml / pot).
4- Chemical nematicide Velum Prime: 1 ml / L of D.W. (50 ml / pot).
5- Bio - pesticide Vertemic (Abamectin): 11.11 ml / L of D.W. (50 ml / pot).
6- Bio - pesticide chemical compound Nimbeciden: 5ml/L of D.W. (50 ml/pot).
7- Goat manure at the rate of 10 g/1 kg of soil.

Each treatment was applied at two times: pre – planting and post - planting of cucumber seeds except for

Trichoderma (Only at pre - planting) and BM Root Pan (Only at post - planting), and after their application, pot soil was covered with a thin layer of sterilized soil.

8. Control treatment (1) non-infested soil.
9. Control treatment (2) soil infested by cucumber roots severely infected by *M. arenaria.*

Pots were watered as needed, and 60 days after infesting soil with nematode inoculum, plants were carefully pulled up and taken to the lab for the purpose of determining the following infection criteria:

A - Number of root galls /root system.

B - Root gall index: It was calculated according to galling index (GI) measure which consisted of 0-8 scales and as follows: 0 = 0 gall, 1 = 1 - 10 galls, 2 = 11-20 galls, 3 = 21 - 50 galls, 4 = 51 - 100 galls, 5 = 101 - 150 galls .6 = 151 - 200 galls, 7 = 201 - 300 galls and 8 = More than 300 galls.
C - Number of J2s in the soil / pot by tray method as described by Coyne et al. (2007)
D - Reduction percentage in infection criteria = [(A-B)/A] ×100,
where A = Value of infection criterion in infested soil.
B = Value of infection criterion after application of control methods.
The following plant growth criteria were also measured:
A - Chlorophyll (SPAD) meaning Soil Plant Analysis Development: It was measured by chlorophyll meter (SPAD502 / Konica Minolta Sensing, INC. Japan).
B - Shoot and root length (cm / plant).
C - Dry weight of shoot and roots system (g/plant. D- Alterations in growth criteria:
1 - Improvement percentage in growth criteria=[(a-b)/b] × 100
where: a = Value of growth criterion after application of control methods.
b = Value of growth criterion in infested soil.
2 - Reduction percentage in dry root weight = [(c-d)/c] × 100
Where: c = Value of dry root weight in infested soil.
d = Value of dry root weight after application of control methods.

4. Results and discussion

4.1. Infection criteria on cucumber plants as affected by pre and post - planting application of different control agents used for controlling root – knot nematode *M. arenaria* under greenhouse conditions

Results of applying various materials to control RKN *M. arenaria* at pre - and post - planting cucumber plants under greenhouse conditions indicated their significant effect ($p \leq 0.05$) in reducing infection criteria of cucumber compared to uncontrolled plants (Table 1).

Table 1. Infection criteria as affected by different pesticides and bio- control agents used for controlling RKN *M. arenaria* on cucumber at pre and post-planting

Control materials		Infection criteria *		
		No. of galls/ root system	Nematode population density/pot	Root-knot index/ root system
Goat manure	Pre - Planting	197 d	1513 g	5.7 cd
	Post - Planting	365 b	1142.3 i	8 a
Velum prime	Pre – Planting	0 h	0 l	0 h
	Post – Planting	34 g	356 k	2.7 g
Abamectin	Pre-Planting	96.7 f	1017 j	3.3 fg
	Post-Planting	150 e	1637 f	4.3 ef
Nimbecidine	Pre-Planting	118.3 f	1298 h	4.3 ef
	Post-Planting	143.3 e	4226 d	4.7 de
Aqueous extracts of tobacco leaves	Pre-Planting	214.7 d	3831 e	6.3 bc
	Post-Planting	366 b	5233 c	7.3 ab

Control materials		Infection criteria *		
		No. of galls/ root system	Nematode population density/pot	Root-knot index/ root system
Bio - control agent	Pre-Planting (*Trichoderma*)	86.7 f	5121 c	3.3 fg
	Post-Planting BM Root Pan	271 c	6855 b	6.7 bc
Infested soil	Pre-Planting	1221 a	19563 a	8 a
	Post-Planting	1221 a	19563 a	8 a
Non-infested soil	Pre-Planting	0.0 h	0.0 l	0.0 h
	Post-Planting	0.0 h	0.0 l	0.0 h

*Source: Authors, own research *Each number is a mean of 3 replications. *The means followed by different letter (s) in each column significantly differ according to the Duncan's Multiple Range Test (p ≤ 0.05).*

Regardless of application method, the lowest number of galls (17galls / root system), nematode population density (178 J2s/pot) and root - knot index (1.35 / root system) were recorded by Velum prime pesticide with significant distinctions compared to the other materials utilized, followed by *Trichoderma* bio - control agent in number of galls and root - knot index, then by using of biopesticide Abamectin in nematode population density, while the highest number of the aforementioned infection criteria were reported by the aqueous extract of tobacco leaves, BM Root Pan and goat manure in term of number of galls (290.35 galls/root system), nematode population density (6855 J2) and root – knot index (6.85 / root system), respectively (Table 2).

Table 2. Infection criteria as affected by chemical and bio – control agents used for controlling RKN *M. arenaria* on cucumber, regardless of application method under greenhouse conditions.

Control methods	Infection criteria *		
	No. of galls / root system	Nematode population density / pot	Root-knot index / root system
Goat manure	281 bc	1327.65 f	6.85 b
Velum prime	17 f	178 g	1.35 e
Abamectin	123.35 d	1327 f	3.8 cd
Nimbeidine	130.8 f	2762 e	4.5 c
Aqueous extract of tobacco leaves	290.35 b	4532 d	6.8 b
(*Trichoderma*)/Pre-planting	86.7 e	5121 c	3.3 d
BM Root Pan/Post-planting	271 c	6855 b	6.7 b
Infested soil	1221 a	19563 a	8 a
Non-infested soil	0.0 g	0.0 h	0.0 f

Source: Authors, own research Each number is a mean of 6 values (2 application dates x 3 replications). *The means followed by different letter in each column significantly differ according to the Duncan's Multiple Range Test (p ≤ 0.05).*

Methods of application also showed their significant effect on infection criteria, where the lowest number of galls (276.34 galls/root system), nematode population density (4620.43 J2) and root - knot index (4.41 /root system) were observed by pre - planting application, regardless of material types (Table 3).

Table 3. Infection criteria as affected by pre and post - planting application of materials used for controlling RKN *M. arenaria* on cucumber

Application method	Infection criteria*		
	No. of galls/root system	Nematode population density	Root-knot index/root system
Pre - Planting	276.34 b	4620.43 b	4.41 b
Post – Planting	364.33 a	5573.2 a	5.96 a

*Source: Authors, own research *Each number is a mean of 21 values (7 control methods x 3 replications). *The means followed by different letter in each column significantly differ according to the Duncan's Multiple Range Test (p ≤ 0.05).*

In general, no infection was found in pre - planting application of Velum pesticide, meaning that the decrease percentage in all infection criteria is 100% (Table 4) with significant difference compared to other materials at both application methods, followed by application of the same pesticide at post - planting application.

Table 4. Reduction percentage of infection criteria achieved by application of different materials for controlling RKN *M. arenaria* on cucumber

Control materials		Reduction percentage of infection criteria (%)		
		No. of galls/ root system	Nematode population density/pot	Root-knot index/ root system
Goat manure	Pre - Planting	83.86	92.27	28.75
	Post - Planting	70.84	41.61	0.0
Velum prime	Pre - Planting	100	100	100
	Post - Planting	97.21	98.18	66.25
Abamectin	Pre - Planting	92.08	94.80	58.75
	Post - Planting	87.71	91.63	46.25
Nimbeidine	Pre-Planting	90.31	93.36	46.25
	Post-Planting	88.26	78.4	41.25
Aqueous extracts of tobacco leaves	Pre-Planting	82.42	80.42	21.25
	Post-Planting	70.02	73.25	8.75
Bio - control agent	(*Trichoderma*) Pre-Planting	92.9	73.82	58.75
	BM Root Pan Post-Planting	77.8	64.96	16.25

Source: Authors, own research

The effect of Pre - planting application of Abamectin biopesticide and *Trichoderma* bio - control agent was very close to each other in number of galls and similar in root - knot index, but they differ significantly in nematode population density, whereas the lowest effective was found by post – application of goat manure, where the highest number of galls (365 galls/root system), nematode population density (1142.3 J2) and root - knot index (8/ root system) were recorded (Table 1), meaning that the decrease percentage in infection criteria is (70.84 , 41.61 and 0.0%), respectively (Table 4) but it didn't differ significantly with the aqueous extract of tobacco leaves by the same application method.

4.2. Growth criteria of cucumber plants as affected by pre and post - planting application of different control agents used for controlling root – knot nematode *M. arenaria* under greenhouse conditions

Results of cucumber infection by RKN *M. arenaria* showed significant reduction ($p \leq 0.05$) in growth criteria, except for dry root weight which revealed significant increase compared to uncontrolled cucumber plants (Table 5).

Table 5. Effect of different pesticides and bio – control agents used for controlling RKN *M. arenaria* on cucumber at pre and post – planting application on some growth criteria of cucumber

Control materials		Growth criteria *				
		Root system		Shoot system		
		Length (cm / plant)	Dry weight (g / Plant)	Length (cm / plant)	Dry weight (g / plant)	Chl. (SPAD)
Goat manure	1	30 h	1.40 bcd	67.7 g	12.3 cd	25.1 ef
	2	37 cd	1.54 bc	55.6 h	13.9 bc	22.1 g
Velum prime	1	41.7 b	0.71 e	99.3 b	15.5 b	37.2 b
	2	38.3 cd	0.81 e	88.4 d	14.3 bc	33.0 c
Abamectin	1	40.2 bc	1.2 d	94.1 c	14.2 bc	35.5 bc
	2	36.2 de	1.32 cd	83.2 e	13.6 bc	30.2 d
Nimbecidine	1	35.4 def	1.33 cd	91.2 cd	12.4 cd	30.3 d
	2	31.4 gh	1.37 bcd	82.4 e	12.7 bcd	26.1 ef
Plant extract of tobacco leaves	1	32 fg h	1.41 bcd	64.2 g	11. 7 cd	25.3 ef
	2	23.5 i	1.55 b	51.3 h	10.1 d	22.2 g
Bio - control agent	1	39.2 bc	1.24 d	88.7 d	12.4 cd	27.9 de
	2	33.7 efg	1.38 bcd	71.7 f	12.1 cd	23.3 fg
Infested soil	1	16.2 j	1.88 a	34.2 i	4.5 e	18.3 h
	2	16.2 j	1.88 a	34.2 i	4.5 e	18.3 h
Non -infested soil	1	44.7 a	0.78 e	117.2 a	21.4 a	42.5 a
	2	44.7 a	0.78 e	117.2 a	21.4 a	42.5 a

*Source: Authors, own research; 1=Pre – Planting. 2=Post-Planting; Chl=Chlorophyll - Each number is the mean of 3 replications. *The means followed by different letter (s) in each column significantly differ according to the Duncan's Multiple Range Test ($p \leq 0.05$).*

Regardless of application method, and comparing with infested soil the highest increase of growth criteria were recorded by Velum prime in each of root system length (40 cm), length (93.85 cm) and dry (14.9 g) weight of shoot system, then chlorophyll content (35.65 SPAD), to be the most effective material used for nematode control, followed by application of Abamectin, where the differences were not significant, except in shoot system length, whilst the lowest improving in root system length, length and dry weight of shoot system was noted after application of the aqueous extract of tobacco leaves where they reached (27.75 cm, 57.75 cm and 10.9 g) respectively. The lowest content of chlorophyll (24.1 SPAD) was reported by goat manure application with no significant difference compared to that of aqueous extract of tobacco leaves application (Table 6).

Table 6. Growth criteria as affected by chemical and bio - control agents used for controlling RKN *M. arenaria* on cucumber, regardless of application method under greenhouse conditions

Control methods	Growth criteria*				
	Root system		Shoot system		
	Length (cm/plant)	Dry weight (g/Plant)	Length (cm/plant)	Dry weight (g/plant)	**Chl (SPAD)**
Goat manure	33.5 d	1.47 a	61.65 e	13.1 cd	24.1 d
Velum prime	40 b	0.76 c	93.85 b	14.9 b	35.65 b
Abamectin	38.2 bc	1.26 bc	88.65 c	13.9 bc	33.35 b
Nimbecidine	33.4 d	1.35 b	86.8 c	12.55 cd	29.2 c
Aqueous extracts of tobacco leaves	27.75 e	1.48 a	57.75 f	10.9 e	24.3 d
Bio-control agent	36.45 c	1.31 b	80.2 d	12.25 de	26.15 d
Infested soil	16 f	1.88 a	34.2 g	4.5 f	18.3 e
Non -infested soil	44.3 a	0.78 c	117.2 a	21.4 a	42.5 a

*Source: Authors, own research *Each number is the mean of 6 values (2 application dates x 3 replications), Chl =Chlorophyll. *The means followed by different letter in each column significantly differ according to the Duncan's Multiple Range Test ($p \le 0.05$).*

Regardless of material types pre - planting application proved its effect in increasing (improvement) growth criteria over post- planting, except dry weight of root system, where the highest length of root system (34.85 cm), length of shoot (82.06 cm) and dry weight of shoot (13.05 g), then chlorophyll content (30.26 SPAD) were recorded (Table 7).

Table 7. Growth criteria as affected by pre and post - planting application of materials used for controlling RKN *M. arenaria* on cucumber

Application date	Growth criteria*				
	Root system		Shoot system		
	Length (cm)	Dry weight (g)	Length (cm)	Dry weight (g)	Chl (SPAD)
Pre – Planting	34.85 a	1.24 a	82.06 a	13.05 a	30.26 a
Post – Planting	32.55 b	1.33 a	73 b	12.825 a	27.21 b

*Source: Authors, own research, *Each number is a mean of 21 values (7 control methods x 3 replications). *The means followed by different letter in each column significantly differ according to the Duncan's Multiple Range Test ($p \le 0.05$).*

In general, the highest increasing in growth criteria was reported after pre - planting application of Velum prime pesticide, except dry weight of root system, where the highest value of root system length (41.7 cm), length (99.3 cm) and dry weight (15.5 g) of shoot system and chlorophyll content (37.2 SPAD) was recorded (Table. 5), with significant differences compared to the most materials at both application methods, meaning that the percentage of increasing in the for mentioned growth criteria is 157.41, 190.35, 244.44 and 103.28 % respectively (Table. 8), followed by Pre – planting application of Abamectin in all growth criteria except dry weight of shoot system, where the difference was not significant. The lowest improvement in growth criteria was found after post- application of the aqueous extract of tobacco leaves, as the values reached 23.5 cm, 51.3 cm and 10.1 g for each of root system length, length and dry weight of shoot system (Table 5), meaning that the percentage of improvement is 45.06, 50 and 124.44 % respectively (Table 8). The lowest increasing in chlorophyll content (22.1 SPAD) (Table 5) by percentage 20.76 % was reported by post - application of goat manure with no significant difference to its content (22.2 SPAD) (Table 5) by percentage 21.31 % after post-planting application of the aqueous extract of tobacco leaves (Table 8).

Table 8. Alteration percentage of growth criteria achieved by application of different materials used for controlling RKN *M. arenaria* on cucumber

Control materials		Alteration percentage in growth criteria (%)				
		Root system		Shoot system		
		Length (+)	Dry weight (–)	Length (+)	Dry weight (+)	Chlorophyll (+)
Goat manure	1	85.18	25.53	97.95	173.33	37.16
	2	128.39	18.08	62.57	208.89	20.76
Velum prime	1	157.41	62.23	190.35	244.44	103.28
	2	136.42	56.91	158.48	217.78	80.33
Abamectin	1	148.15	26.17	175.15	215.55	93.99
	2	123.46	29.79	143.27	202.22	65.03
Nimbecidine	1	118.52	29.25	166.67	175.55	65.57
	2	93.83	27.13	140.93	182.22	42.62
Aqueous extract of tobacco leaves	1	97.53	25	87.72	160	38.25
	2	45.06	17.55	50	124.44	21.31
Bio - control agent	1	141.97	34.04	159.36	175.55	52.46
	2	108.02	26.59	109.65	168.89	27.32

Source: Authors, own research, 1= Pre – Planting, 2 = post-planting.

According to the results, cucumber hybrid cultivar Roni F1 appears as high susceptible host to RKN *M. arenaria*, owing to its severe infection by this nematode species, and this is mainly due to its genetic characteristics which

allow huge numbers of J2s to penetrate its roots and complete their development and reproduction. After application of chemical and bio - control agents, the infection criteria on cucumber decreased clearly with different proportions, according to the type of control agent used. Velum Prime nematicide was the most effective control agent due to its systemic properties. This finding aligns with previous research on its efficacy in controlling plant-parasitic nematodes (Al-Hayali, 2021; Guri, 2023).

Velum prime contains fluopyram as active ingredient and its mode of action includes inhibition of succinate dehydrogenase (SDHI) at protein complex II in the mitochondrial respiration chain of nematodes (Abad-Feunteset*al.,* 2015) which cannot generate energy due to cessation production of the compound adenosine triphosphate, hence nematode become immobile and eventually die (https://www.cropscience.bayer.in/Products-H/Brands/Crop-Protection/Insecticide- Velum-Prime).

Trichderma as bio - control agent also expressed its competence, and this was confirmed by the results of previous studies on its the effectiveness in nematode control (Al-Hayali, 2021, Guri, 2023). The fungus *Trichoderma* has an important potential, by directly parasitize on both nematode eggs and juveniles and causing their death. It has ability to decrease the damage caused by plant-parasitic nematodes directly through parasitism, paralysis, antibiosis, and by formation of lytic enzymes. However, they also reduce the harm caused by space and resource competition by increasing water and nutrient intake in the plant or by changing root morphology and/or rhizosphere interactions, which provides an advantage for plant growth, besides its capacity to induce resistance against nematodes by activating hormone-mediated (salicylic and jasmonic acid, strigolactones among others) plant-defense mechanisms. in addition, changing of transport of chemical defense components through the plant or the creation of plant secondary metabolites and various enzymes can also be involved in improving plant defenses (Povida et al., 2020). The influence of the aqueous extract of tobacco leaves in suppression infection criteria is in consistent with the previous studies, which emphasized that tobacco extract is one of the most toxic extract against the nematodes (Wiratno et al*.* 2009) and significantly suppressed infection criteria induced by *Meloidogyne* spp. in tomato (Olabiyi et al., 2011), but its nematocidal activity was low compared to the other materials, perhaps because of its low concentration and its poor mobility in the soil. Regarding its mechanism effect on nematodes, it is mainly attributed to its active ingredients which are a large number of alkaloids, and nicotine is known as the primary alkaloid of this plant to which its actual nematocidal activity is attributed (Nouri *et al.,* 2016) and it may have the same effect as some nematicides, which include acetylcholinesterase inhibiting effects, leading to paralysis of the J2s and then their death. This is what Nguyen *et al*. (2000) indicated. As for the nematocidal activity of the goat manure, the results was in agreement with the results of previous studies on the effectiveness of goat manure in suppressing infection criteria induced by RKN *M. incognita* infecting sweet potato (Osunlola & Fawole, 2015) and cucurbit plants (El-Deeb et al.,2018).Three major biological processes are involved in the mechanism action of organic amendment including animal manures against nematodes (Oka, 2010):

1-They enhance soil's ability to retain water and nutrients, which boosts plant vigor and increases its tolerance to nematodes.
2- They emit substances that could have nematocidal properties.
3- They also encourage microbial activities in the soil (including nematode antagonists), and indirectly, they promote nematode predators and parasites that rely on microbial activities.
The low effectiveness of goat manure is attributed to the soil situation and might be to low activity soil microorganisms responsible for decomposition of goat manure.

Results of nematocidal activity of Abeamctin as biopesticide are consistent with those of earlier studies, which proved the effectiveness of this biopesticide in controlling plant parasitic nematodes (Qiaoet*al.,*2012 and El- Marzoky*etal.,* 2022), and its strong activity against a wide variety of plant parasitic nematodes (Cao *et al.,* 2015). The mechanism influence of Abamectin as a member of Avermectin family, includes that Avermectins block γ-amino butyric acid-stimulated chloride channels (Jansson and Dybas,1998) and bind to the glutamate - gated chloride channels that are found in invertebrate nerve and muscle cells, causing hyperpolarization of these cells resulting in paralysis and death (Wolstenholmeet*al.,*2006). It is worth noting that hyperpolarization inhibits the neuron from firing an impulse, causing an ion imbalance in the nematode nervous system, leading to paralysis and then death. Results of Nematocidal activity of Nimbicidine (a.i. Azadirachtin) agreed with those of the previous studies, that confirmed the effectiveness of Azadirachtin in reducing infection criteria caused by RKN *M. javanica* (Javed *et al.,* 2007) and *M. incognita* (D‟Addabbo et al.,2008 and d‟Errico *et al.,* 2023). The mode of action of azadirachtin on nematodes is not elucidated, but according to the previous studies, this pesticide is widely used as a biological nematicide and insecticide because of shared physiological functions such as molting between nematodes and insects (Waisen et al.,2021). The modes of action of azadirachtin on insects, include an alteration of insect feeding and growth, furthermore it delayed their molts and sterility, due to the direct action of azadirachtin on neuroendocrine cells and tissues (Mordue, 2004). This was confirmed also by Rembold et al., (2009), that the main mechanism of this compound is by interfering with molting hormone pools of insect species. The effect of azadirachtin product on nematodes was also emphasized by Javed *et al.* (2007), that it significantly reduced the penetration and delayed development of *M. incognita*. Results of the effectiveness of BM Root Pan which contains bacterial species *Bacillus megaterium*, *Pantoea agglomerans, Paenibacillus polymexa* and *B. subtilis* on *M. arenaria* by reducing infection criteria on cucumber were in agreement with those of previous studies, especially that regard to *Bacillus* spp. and their effectiveness in reducing infection criteria induced by RKNs (Anastasiadia et al., 2008 and Wani, 2015), as well as with the nematocidal activity of *Paenibacillus, Bacillus* and other bacterial genera and their lethal effect on plant parasitic nematodes (Hashem and Abo- Elyousr, 2011). There are several process involved in the mechanism effect of bacterial species on nematodes, through ability of many bacterial organisms involved in the formation of these biopesticides to secrete plant hormones, and antibiotics, which are often toxic to many pathogens, including nematodes, causing paralysis and death of nematode J2s before they can infect the plant, in addition to the capacity of some bacterial species to stimulate defense resistance in the plant and induce the plant to precipitate lignin and thicken the root cells and increase their resistant against plant pathogens, so they fail to penetrate the roots and cause infection (Siddiqui *et al.,* 2006). Some bacterial species also enhance the plant growth by producing natural growth regulators and providing the necessary elements (Hashem & Abo-Elyousr, 2011) by decomposition of soil organic matter (Anwar-Ul-Haq et al., 2011). Certain substances used in this study may have an impact on the development and physiology of nematodes by altering ion absorption, membrane permeability, enzyme anticaptivity, cell division, and electron transport. This could cause paralysis and ultimately nematode death (Anaya *et al.,* 2006). The results also revealed that the infection criteria that appear after pre - planting application of control materials were significantly less than their post -planting application. This is attributed to direct contact between the control materials and nematodes, as they caused their death and inhibit their egg hatching before emerging J2s from them. It seems also that one week was sufficient for the control agents to implement their lethal effect in nematode stages in the absence of the host plant, whereas the least effect of the control materials when applied at post - planting is due to penetration of huge numbers of nematode J2s into the cucumber roots before being applied control materials to the soil, though most of the control materials were able to implement their impact in nematode stages inside plant but one time application might be not enough to severely suppress nematode infection. Results observed that nematode infection resulted in a considerable drop in all growth criteria of cucumber, except root dry weight because of severe infection and formation of large galls that increased dry weight of the infected roots. The main reason of decreasing growth criteria in infected plants is by a negative effects caused by nematode species to infected plants, where RKN reduce growth criterion by consuming food and energy required for regular plant growth, nematodes disrupt root vascular cylinder and retard transfer of water and nutrients to other parts of the host plant (Hajera *et al.*, 2009), nematode infection also hindered growth roots of cucumber and lowered the uptake of water and nutrients (Anwar and Din, 1986 and Karssen and Moens, 2006) causing stunting of the plants. Also, RKNs destroyed root tissues during penetration toward vascular cylinder, where the females settled and formed giant cells, the vascular cylinder then deformed the vascular cylinder then deformed, followed by impeding transfer of elements and water to shoot system, resulting in a reduction in plant growth criteria. The waste and harmful enzymes secreted by nematodes in the roots had a negative effect on plant growth (Ami & Shingaly, 2020). Nematode feeding activities interfere with plant physiological functions such as photosynthesis causing a decrease in growth criteria (Carneiro et al., 2002).

The application of control materials resulted in a significant increasing in the growth criteria of cucumber in different percentage depending on the type of the control material, and this is due to their nematocidal activity which reduced nematode infection then improved cucumber growth. The increasing of growth criteria can reasonably be attributed to improved plant nutrition, resulted from the reduced nematode pressure on the root system, in addition to that the control agents act as inducers for increasing of the systemic acquired resistance (SAR) of the infected cucumber as demonstrated by increasing of the biochemical substance including activity of peroxidase, Polyphenol oxidase and amount of the total phenols that act as indicator of increasing SAR of the infected cucumber plant.

5. Conclusions

All selected control agents expressed their nematocidal activity against *M. arenaria* on cucumber under greenhouse conditions at pre or post - planting application in term of reducing infection and increasing cucumber growth, and it was found that Velum prime nematicide was the most effective agent at both application methods, whereas goat manure and the aqueous extract of tobacco leaves was found to be the lowest effective control agent at post - planting application.

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