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Application of agricultural wastes in integration with abamectin reduces root-knot nematode infection and presents a promising avenue for sustainable agriculture

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Abstract

A greenhouse experiment was conducted to assess the efficacy of different agricultural wastes applied singly and in integration with Abamectin (a fermentation product of the bacterium *Streptomyces avermitilis*) against *Meloidogyne incognita* infecting eggplant. Of these, plant residues (rice straw, and cucumber and cabbage leaves), compost (plant and mixed) and vermicompost (solid and liquid). Results demonstrated that utilizing organic residues not only contributes to managing nematode populations but also fosters improved plant health by enriching the soil with essential nutrients. Integrated application of agricultural wastes with Abamectin was found to improve the morphological and physiological traits of eggplant infected with *M.incognita* exhibiting clear synergistic effects on plant growth. The highest increment in plant length was recorded with mixed compost + Abamectin (52.3%), while cucumber leaf residues + Abamectin produced the greatest enhancement in plant fresh weight (161.2%). Combined treatments further enhanced nematode suppression, with mixed compost + Abamectin achieving the highest significant ($P < 0.05$) population reduction (82.0%). Additionally, dried cabbage leaf residues integrated with Abamectin significantly ($P < 0.05$) reduced root galling (81.7%) and number of egg masses (90.2%). The present findings revealed that tested agricultural by-products in integration with abamectin serve as natural amendments, boosting the defense mechanisms of eggplants infected with *M.incognita* and simultaneously promoting key biochemical processes like chlorophyll and carotenoids contents.

Keywords: Abamectin; Agricultural wastes; Plant residues; Compost; Vermicompost; Eggplant

1. Introduction

The southern root- knot nematode, *Meloidogyne incognita* (Kofoid and White) Chitwood is considered an economically widespread plant parasitic nematodes particularly in tropical and subtropical regions, causing substantial losses to vegetable crops. Although chemical nematicides successfully minimize root-knot nematodes (RKNs) infection, their use has greatly declined because of their negative impacts on human health and environment [1]. A growing concern has given to exploit environment-friendly strategies to combat RKNs and promote sustainable agriculture [2], [3].

Egypt is considered one of the countries with significant reliance on chemical fertilizers in agricultural practices. It produces around 2 million metric tons of fertilizers annually, with 68% utilized within the local market [4]. However, the extensive use of these chemical substances poses serious threats to both the environment and public health. Utilizing agricultural wastes in nematode management received a greater interest among scientists. Incorporation of plant residues and industrial wastes into nematode infested soil not only enhance plant growth but also help to suppress root knot nematode population and reproduction [5-7].

Conversion of agricultural wastes to rich organic fertilizer i.e. compost, vermicompost and vermicompost tea appears to be the most ecofriendly, economical, and sustainable strategy for managing wastes. Such materials also have shown

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to be a viable alternative to chemical nematicides and inorganic fertilizers [4], [8], [9]. The use of compost can help in the management of root-knot nematodes, inducing resistance and enhancing plant growth [10], [11]. The materials used for composting are known to release nitrogenous compounds which favor the growth of beneficial microorganisms that antagonize plant parasitic nematodes in the soil [3], [12].

On the other hand, using beneficial microorganisms is also more preferable for nematode management due to their specificity, environmental safety, cost-effectiveness, and non- resistance-inducing nature [13], [14]. The soil bacterium, *Streptomyces avermitilis* has shown nematicidal activity against *Meloidogyne* spp. under controlled, greenhouses and field conditions [12], [15-17] reducing nematode population and reproduction on various crops. Abamectin a commercial fermentation of *S. avermitilis* is particularly effective against root knot nematodes[18-22].

Integrating Abamectin with other control methods, such as biological control, agricultural wastes, organic and inorganic amendments, naturally occurring nematicides and cultural practices makes it a valuable tool in integrated nematode management (INM) strategies reducing the risk of developing resistant pest populations.

Therefore, the main objective of the current study was to explore the efficacy of certain agricultural wastes (plant residues, compost and vermicompost) singly and in integration with Abamectin on growth and chemical constituents of eggplant infected with *M.incognita* as well as nematode reproduction under greenhouse conditions.

2. Materials and Methods

2.1. Nematode inoculum

The *Meloidogyne incognita* inoculum was prepared using cultures propagated on coleus plants (*Coleus blumei*) cultivated under greenhouse conditions at the Nematology Research Unit (NERU), Agricultural Zoology Department, Faculty of Agriculture, Mansoura University, Egypt. Infected roots were carefully rinsed under tap water to eliminate any soil residues. Then sliced into small sections and immersed in a glass container filled with a 1.0% sodium hypochlorite (NaOCl) solution [23]. The container was shaken vigorously for 2 minutes before the solution was filtered through a set of two nested sieves, 200 mesh and 450 mesh. The collected eggs were rinsed with tap water to minimize any residual NaOCl and prevent its deteriorating effects before storing in a fridge.

2.2. Types of Agricultural wastes

2.2.1. Plant residues

Plant residues namely rice (*Oryza sativa*) straw, cabbage (*Brassica oleracea*) leaves, and cucumber (*Cucumis sativus*) leaves were collected from the Experimental Farm, Faculty of Agriculture, Mansoura University, Mansoura, Egypt. Rice straw was cut into 2–3 cm lengths and air-dried for 2 weeks. Whereas, leaves of cabbage and cucumber and peels of potato (*Solanum tuberosum*)and pomegranate (*Punica granatum*) were air dried for 2-3 weeks then milled into powder with a blender. Dried residues were applied to soil, in pots at rate of 10 g/pot.

2.2.2. Compost

Two types of compost (plant and mixed) were purchased from AGRN-Beni Suef Organic Fertilizers, Egypt. Chemical and organic properties of such composts are shown in Table (1). Compost types were applied to soil, in pots at rate of 15 g/pot.

2.2.3. Vermicompost

Two types of vermicompost were undertaken in the current study, solid vermicompost (VC) and vermicompost tea (VCT).

Solid Vermicompost (VC)

Solid vermicompost consisting of animal and plant wastes was obtained from a private farm located in Mansoura district, and analysed for chemical and organic properties (Table1).

Vermicompost was incorporated into soils in pots at rate of 20 g/pot.

Table 1 Chemical and organic properties of compost and vermicompost

Organic manure properties	Plant Compost	Mixed Compost	Vermicompost
pH 1:5	7.06	6.14	6.63
Moisture %	42.25	48.71	45.09
Organic matter (%)	22.26	31.34	27.52
Organic carbon (%)	14.46	20.41	17.87
Total nitrogen (%)	0.83	1.35	1.28
C/N ratio	17.42	15.11	13.96
Total Phosphorus (%)	0.89	1.12	1.01
Total Potassium (%)	0.67	0.89	0.82
Micronutrients (mg .kg-1)			
Copper	3.42	5.51	4.65
Zinc	7.56	18.66	12.43

Vermicompost tea (VCT)

Vermicompost tea (VCT) was prepared by soaking 250 g of vermicompost in 1 liter of water and stirring thoroughly for 48 hours. The resulting mixture was filtered through muslin cloth and stored in a clean glass flask as the standard solution (S) and each pot received 25 ml of such solution.

2.3. Biopesticide

Abamectin 1.8% EC (Namazoho) a commercial fermentation product of *Streptomyces avermitilis*, was introduced to soil at recommended concentration (1ml/L water).

2.4. Nematicide

The conventional nematicide, Oxamyl (Vydate 24L.) was added at a concentration of 0.3ml/ pot.

2.5. Experimental Design

Plastic pots (14 cm-d) filled with 1800 g steam sterilized silty clay loam (Coarse sand 3.89; Fine sand 22.47; Silt 42.16; Clay 31.48) were separately amended with agricultural wastes such as dried rice straw (10g) as well as cabbage (10g) and cucumber (10g) powdered dried leaves; vermicompost (20g); mixed and plant compost (15g each). Soil amendments were incorporated into soil and irrigated with water. Pots were then covered with polyethylene and left for 10 days to allow proper decomposition. Eggplant (*Solanum melongena* L.) seedlings cv. Black king (40 days old) were separately transplanted. Simultaneously, the conventional nematicide, oxamyl, the biopesticide, Abamectin as well as a standard solution of vermicompost tea (S) were applied to soil. Nematode inocula (4000eggs of *M. incognita*), were then pippeted into soil around the base of plant and irrigated with water. The design was completely randomized, comprising 18 treatments with four repetitions.

Treatments were as follows: 1.Abamectin (0.02ml/pot); 2.Cabbage leaf powder (10g); 3.Cabbage leaf powder (10g) and Abamectin (0.02ml/pot); 4. Rice straw (10g); 5.Rice straw (10g) and Abamectin (0.02ml/pot); 6.Cucumber leaf powder (10g); 7. Cucumber leaf powder (10g) and Abamectin (0.02ml/pot); 8.Plant compost(15g); 9. Plant compost (15g) and Abamectin (0.02ml/pot); 10. Mixed compost (15g); 11 Mixed compost (15g) and Abamectin (0.02ml/pot); 12. Solid Vermicompost (20g); 13. Solid Vermicompost (20g) and Abamectin (0.02ml/pot); 14. Vermicompost tea (S); 15. Vermicompost tea (S); 16. Oxamyl (O); 17. Nematode only (N), and 18. Healthy plants.

Plants were irrigated as required. At the end of the experiment (55 days), plants were carefully uprooted to assess plant growth attributes, including shoot length (cm), root length (cm), fresh shoot weight (g), and fresh root weight (g) as well as shoot dry weight (g). For each treatment, the soil from each pot was thoroughly mixed, and the second juveniles (J2s) in 250g of soil were extracted [24] and recorded. Roots were stained [25] for nematode infestation recording the number of developmental stages, females, galls and egg masses per root system. Gall (GI) and egg mass (EMI) indices were measured.

2.6. Estimation of Chlorophyll and carotenoids contents

The leaf photosynthesis pigments (chlorophyll A, B) were spectrophotometrically measured in dried leaves using Fadeel's method [26]. Chlorophyll concentrations and carotenoid content were estimated in eggplant dried leaves and recorded [27] [28].

2.7. Antioxidant Enzyme activity

Catalase activity (CAT) was estimated in dried leaves of eggplant [29] and represented in protein mg^{-1} units.

2.8. Data analysis

In all experiments, data were subjected to one-way analysis of variance (ANOVA), Means were compared by Duncan's multiple range test at $P \leq 0.05$ probability [30].

3. Results

3.1. Plant growth attributes

Data in Table (2) represent the impact of certain agricultural wastes i.e. compost, vermicompost (VC), vermicompost tea (VCT) and plant residues applied individually or in integration with Abamectin on plant growth attributes of eggplant infected with *M. incognita* under greenhouse conditions. Root-knot nematode infection caused a significant decrement in plant growth parameters with reduction percentage in total plant fresh weight reached 20.5%. Ultimately, all treatments showed a noticeable induction in the morphological characters of eggplant infected with *M. incognita* with different degrees compared to control plants. A significant induction ($P< 0.05$) in shoot weight was recorded with single application of cucumber leaf residues followed by vermicompost and mixed compost with percentage of increase in plant weight amounted to 143.2, 121.8 and 110.2%, respectively.

In most treatments, single applications of agricultural wastes, revealed a significant induction ($P< 0.05$) induction in eggplant shoot length with different degrees. The mixed compost demonstrated the highest effectiveness, followed by plant compost then cucumber and cabbage leaf residues with percentage of increase in plant length amounted to 45.4, 37.2, 27.0 and 26.8% respectively (Table 2). Application of the bionematicide Abamectin, presented a significant induction in eggplant shoot length and fresh weight recording percentages of increase in plant length and whole fresh weight counting 16.0 and 57.8%, respectively.

The integration of agricultural wastes with Abamectin demonstrated a synergistic effect on the growth performance of eggplants infected with *M.incognita*. Specifically, the combination of mixed compost with Abamectin resulted in a significant increase in plant length, showing an improvement of 52.3%, compared to 45.4 or 16.0% when mixed compost or Abamectin was used alone. A pronounced synergistic effect was also recorded with the integration of cucumber leaf residues + Abamectin resulting in a percentage of increase in plant length (39.7%), plant fresh weight (161.2%) and shoot dry weight (56.4%) relative to 57.8% in Abamectin single application, even no significant differences ($P < 0.05$) were detected (Table 2). Integration of vermicompost and Abamectin ranked the next resulting in a percentage of increase in such criteria amounted to 37.7, 124.8 and 35.9 %, respectively. It is worth noting that vermicompost tea applied either singly or in integration with Abamectin showed the least effect on plant parameters among screened treatments.

3.2. Nematode parameters

Application of agricultural waste treatments, whether individually or in combination with Abamectin, effectively reduced the total nematode population to varying degrees compared to the control plants (Table 3). Notable, the conventional nematicide oxamyl and the bionematicide Abamectin demonstrated significant efficacy in suppressing soil nematode juveniles, and the number of developmental stages, and females within plant roots. The treatments achieved a reduction in nematode populations by 87.4 and 67.3 %, respectively and reproduction factor equal 0.2 and 0.4, respectively (Fig.1).

Table 2 Impact of certain agricultural wastes applied singly or in integration with Abamectin on plant growth attributes of eggplant infected with *Meloidogyne incognita* under greenhouse conditions

Treatments	Plant Growth Attributes							
	Shoot Length (cm)	Plant Length (cm)	Inc.%	Shoot Weight (g)	Plant Fresh Wt (g)	Inc.%	Shoot Dry Wt (g)	Inc.%
Abamectin	43.3 d-f	83.6	16.0	23.6 d-f	32.5	57.8	5.1 a-c	30.8
Cabbage leaf	49.5 bc	91.4	26.8	31.8 a-c	40.6	97.1	4.8 a-c	23.1
Cabbage leaf + Abamectin	43.5 c-f	95.0	31.8	27.3 b-e	33.6	63.1	4.3 c	10.3
Rice straw	44.5 b-f	87.3	21.1	23.9 d-f	31.4	52.4	4.3 c	10.3
Rice straw + Abamectin	46.0 b-e	97.8	35.6	25.6 c-e	32.2	56.3	4.5 bc	15.4
Cucumber leaf	48.8 b-d	91.6	27.0	37.4 a	50.1	143.2	6.4 a	64.1
Cucumber leaf +Abamectin	48.8 b-d	100.7	39.7	37.4 a	53.8	161.2	6.1 ab	56.4
Plant compost	49.8 b	98.9	37.2	28.5 b-d	40.0	94.2	5.2 a-c	33.3
Plant compost +Abamectin	48.5 b-d	91.8	27.3	26.3 b-e	41.4	101.0	5.2 a-c	33.3
Mixed compost	56.5 a	104.8	45.4	30.1 b-d	43.3	110.2	4.9 a-c	25.6
Mixed compost +Abamectin	57.5 a	109.8	52.3	32.0 a-c	40.7	97.6	5.0 a-c	28.2
Vermicompost	40.5 e-g	82.3	14.1	31.8 a-c	45.7	121.8	4.9 a-c	25.6
Vermicompost +Abamectin	42.0 e-g	99.3	37.7	32.2 ab	46.3	124.8	5.3 a-c	35.9
Vermicompost tea	41.8 e-g	82.1	13.9	16.8 g	23.7	15.0	4.2 c	7.7
Vermicompost tea + Abamectin	40.8 e-g	80.3	11.4	18.2 fg	25.0	21.4	4.6 bc	17.9
Oxamyl	38.8 fg	73.3	1.7	17.4 fg	23.6	14.6	4.1 c	5.1
Nematode only (N)	36.8 g	72.1	-----	15.3 g	20.6	-----	3.9 c	----
Healthy plant	40.0 e-g	79.3	10.0	21.1e-g	25.9	25.7	4.4 bc	12.8
LSD	6.1	17.2	-----	6.6	12.1	-----	1.7	-----

Each value is the mean of four replicates. Means in each column followed the same letter (s) did not differ at P<0.05 according to Duncan's multiple – range test. N=4000 eggs of *M. incognita*. Abamectin 1.8% EC (Namazoho). a commercial product of *S. avermitilis*.

However, concomitant treatment of agricultural wastes with Abamectin proved their effectiveness in mitigating the biotic stress caused by *M. incognita* on eggplants. The most significant reduction in the total nematode population was achieved with mixed compost + Abamectin (82.0%) followed by plant compost + Abamectin (78.8%) and vermicompost + Abamectin (76.2%) as well as cucumber leaf residues +Abamectin (72.4%) (Table 3) with RF= 0.2, 0.3, 0.4, and 0.3, respectively compared to control plants (RF=1.3) (Fig.1).

Data also cleared that eggplant root galling and number of egg masses were significantly ($P<0.05$) reduced by all treatments of integration compared to control plants and individual agricultural wastes applications (Table 4). Oxamyl and Abamectin significantly reduced root galling and the number of egg masses achieving a percentage of 74.8, 62.1% for root galling and 98.2, 90.5 % for egg masses.

Table 3 Management of *Meloidogyne incognita* infecting eggplant using certain agricultural wastes singly or in integration with Abamectin under greenhouse conditions

Treatments	No. of Galls	Red. %	RGI*	No. of Females/ root system	Red.%	No. of Egg masses	Red. %	EI*	No. of Juveniles/ Pot	Red. %	Total population	Red.%
Abamectin	106.5ef	62.1	4.8a	106.5ef	61.7	9.5e	90.5	2.3f	1584b-d	67.5	1690.5	67.3
Cabbage leaf	184.5de	34.3	5.0a	436.3c	0.0	54.5b-e	45.5	3.8b-d	1580.4b-d	67.6	2029.5	60.7
Cabbage leaf + Abamectin	51.3f	81.7	3.8c	50.8f	81.7	9.8e	90.2	2.3f	1636.2b-d	66.5	1687.5	67.3
Rice straw	287.8cd	0.0	4.8a	455c	0.0	115.8b	0.0	3.8b-d	1130.7c-e	76.8	1596.5	69.1
Rice straw + Abamectin	91.5ef	67.4	4.5ab	86.3ef	69.0	15.0e	85.0	2.8ef	1557b-d	68.1	1648.6	68.1
Cucumber leaf	386.5bc	0.0	5.0a	375c	0.0	89.3b-d	10.7	4.0a-c	1524.6b-e	68.8	1911.1	63.0
Cucumber leaf+ Abamectin	126.3ef	55.1	4.8a	120.5ef	56.7	10.3e	89.7	2.5ef	1297.8c-e	73.4	1424.1	72.4
Plant compost	435.3b	0.0	5.0a	424c	0.0	125.0b	0.0	4.5ab	1701b-d	65.2	2135.8	58.6
Plant compost + Abamectin	142.3ef	49.4	4.5ab	136.5ef	50.9	32.3c-e	67.7	3.3c-e	950.4c-e	80.5	1092.7	78.8
Mixed compost	363bc	0.0	5.0a	561.3b	0.0	99.3b-d	0.7	4.3ab	982.8c-e	79.9	1565.9	69.7
Mixed compost + Abamectin	119.8ef	57.4	5.0a	112.3ef	59.6	27.3de	72.7	3.3c-e	810de	83.4	929.8	82.0
Vermicompost	793.7a	0.0	5.0a	780.3a	0.0	223.3a	0.0	4.8a	1612.7b-d	67.0	2411.2	53.3
Vermicompost + Abamectin	151.8ef	46.0	4.5ab	146.5e	47.3	29.5c-e	70.5	3.0d-f	1076.4c-e	77.9	1228.2	76.2
Vermicompost tea	57.0ef	79.7	3.8c	57.0ef	79.5	14.8e	85.2	2.8ef	2304b	52.8	2361	54.3
Vermicompost tea + Abamectin	52.0f	81.5	4.0bc	52.0f	81.3	11.0e	89.0	2.8ef	1875.6bc	61.6	1927.6	62.7
Oxamyl	70.8ef	74.8	4.0bc	71.0ef	74.5	1.8e	98.2	1.0g	579.6e	88.1	650.6	87.4
Nematode only (N)	281.0cd	-	5.0a	278d	-	100.0b	-	4.5ab	4881.2a	-	5164.7	-
LSD	128.5	-	0.5	91.2	-	72.2	-	1.0	946.1	-	-	-

Each value is the mean of four replicates: Means in each column followed the same letter (s) did not differ at P<0.05 according to Duncan's multiple – range test. N=4000 eggs of *M. incognita*. Abamectin 1.8% EC (Namazoho). a commercial product of *S. avermitilis*. *RF= Reproduction factor = Final population (Pf) /Initial population (Pi)

*Root gall index (RGI) or egg masses index (EI) was determined according to the scale given by Taylor & Sasser (1978) as follows: 0= no galls or egg masses, 1=1-2 galls or egg masses, 2= 2-10 galls or egg masses, 3=11-30 galls or egg masses, 4=31-100 galls or egg masses and 5= more than 100 galls or egg masses.

Among the integration of agricultural wastes and Abamectin the highest percentage of reduction in root galling was sustained with cabbage leaf residues +Abamectin (81.7%) followed by vermicompost tea+Abamectin (81.5%) recording RGI= 3.8 and 4.0, respectively compared to control plants (RGI= 5.0) in single application (Fig.2). Similarly, integration of agricultural wastes +Abamectin revealed remarkable reduction in females maturity showing the highest percentage of reduction in number of egg masses with cabbage leaf residues + Abamectin followed by cucumber leaf + Abamectin and vermicompost tea + Abamectin (90.2 , 89.7 and 89.0 %, respectively) recording EI= 2.3, 2.5 and 2.8, respectively compared to control plants (EI=4.5) (Fig.3 &4). However, no significant ($P<0.05$) differences in root galling and egg masses were observed across the treatments.

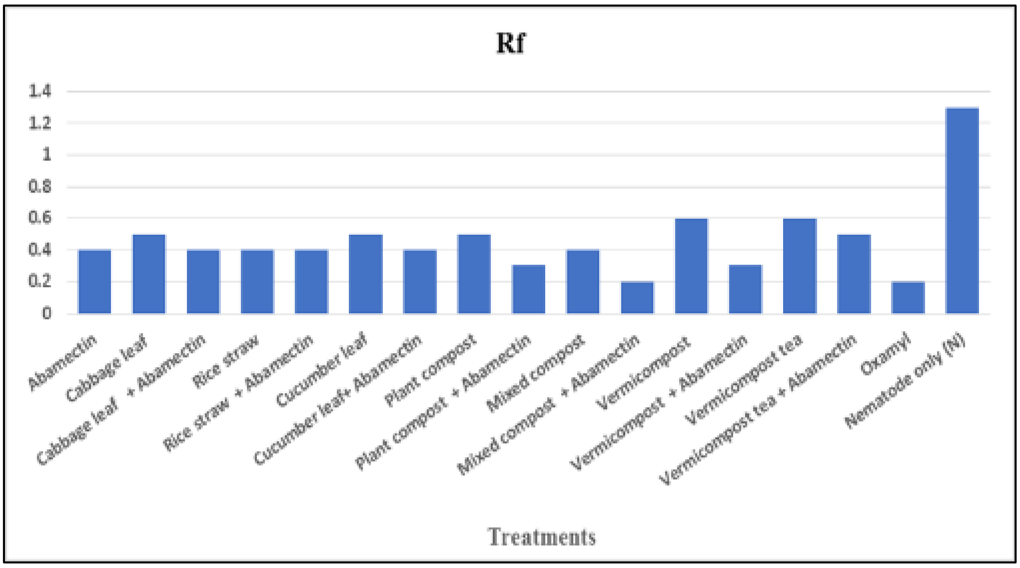

Figure 1 Reproduction factor of *Meloidogyne incognita* on eggplant as affected by the addition of certain agricultural wastes singly or in integration with Abamectin.

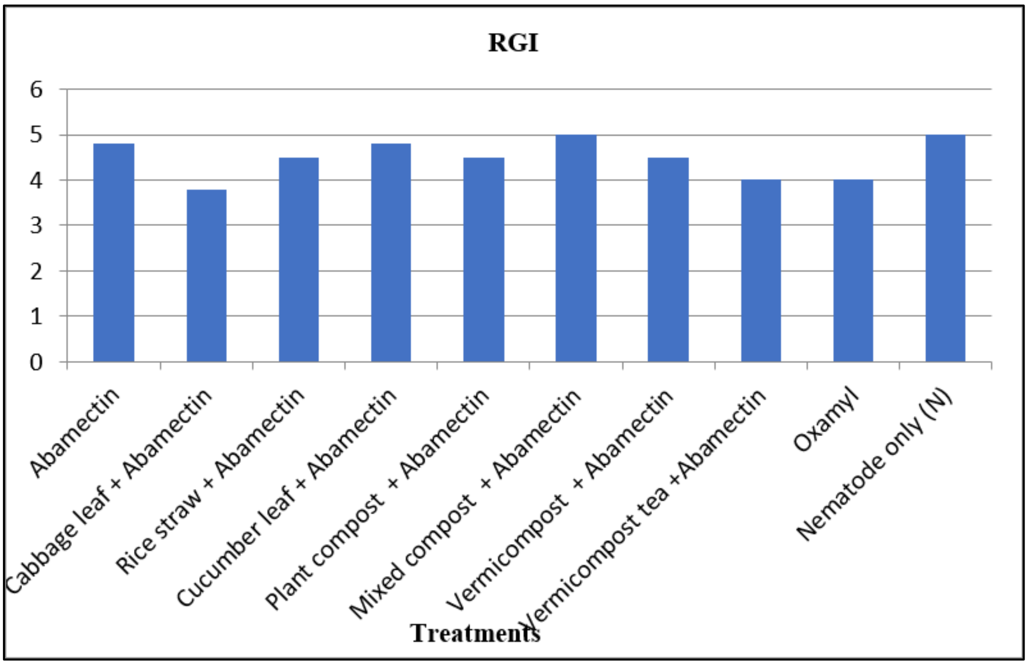

Figure 2 Root gall index of *Meloidogyne incognita* on eggplant as affected by the integration of certain agricultural wastes with Abamectin.

3.3. Chlorophyll and carotenoids Content

A significant decrement in photosynthetic pigments, chlorophyll and carotenoids as a result of *M. incognita* infestation (Table 4). However, a significant improvement in such criteria levels was observed in the dried leaves of eggplant when agricultural wastes were combined with Abamectin. The most pronounced increase in chlorophyll A+B and carotenoids occurred with the application of Vermicompost + Abamectin (28.4 and 30.7%), followed by Mixed Compost + Abamectin (26.8 and 29.2%) and Plant Compost + Abamectin (25.1% and 27.2%), respectively.

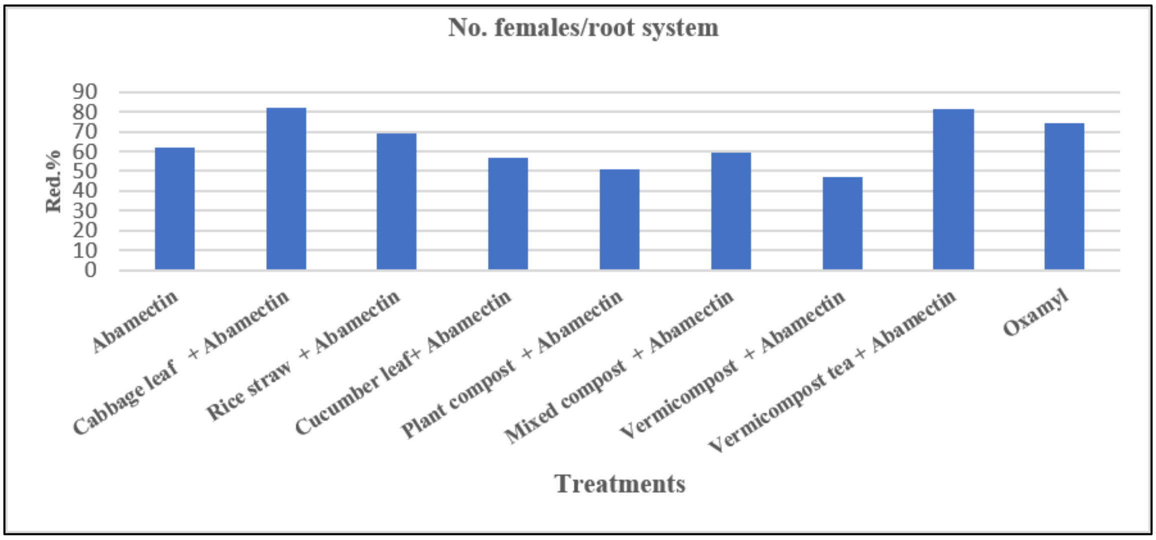

Figure 3 Percentage of reduction in *Meloidogyne incognita* females as affected by the integration of certain agricultural wastes with Abamectin under greenhouse conditions.

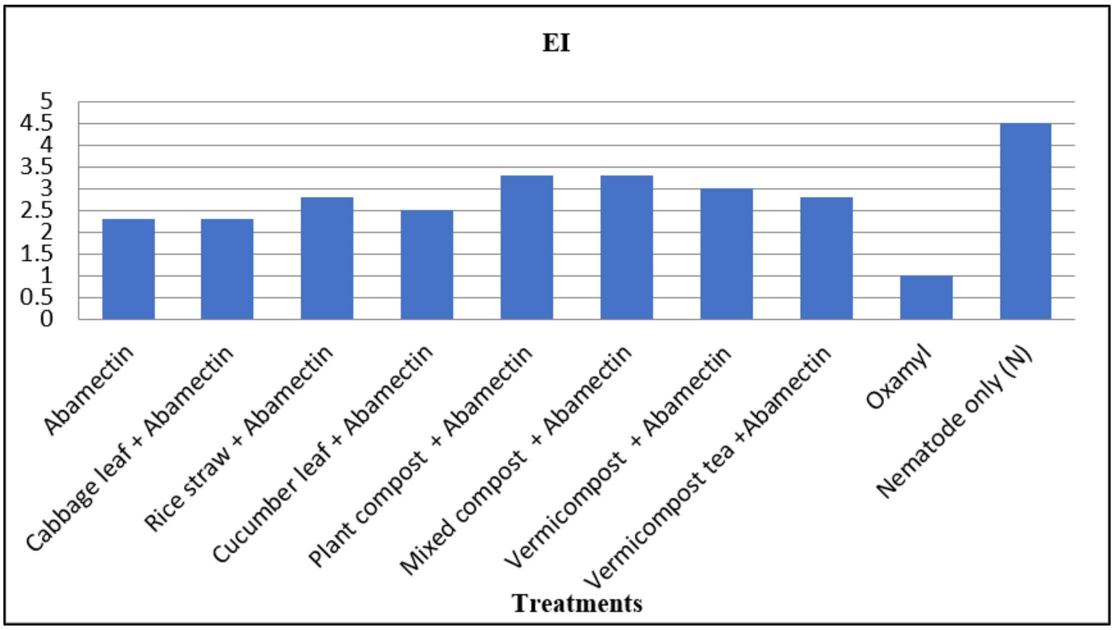

Figure 4 Egg mass index of *Meloidogyne incognita* on eggplant as affected by the integration of certain agricultural wastes with Abamectin.

3.4. Catalase activity

Significant differences in catalase (CAT) activity ($P<0.05$) was recorded across all treatments compared to control plants (Table 5). As a reaction of *M. incognita* infestation eggplant showed higher CAT activity ($P<0.05$) scoring a value of 0.337 compared to healthy plants (0.233). However, CAT activity was significantly lowered by Vermicompost + Abamectin (39.2%) followed by Mixed compost + Abamectin (35.3%) and Plant compost + Abamectin (32.6%).

Table 4 Impact of certain agricultural wastes applied singly or in integration with Abamectin on chemical constituents of dried leaves of eggplant infected with *Meloidogyne incognita* under greenhouse conditions

Treatments	Biochemical Constituents									
	Catalase Activity unit mg^{-1} $protein^{-1}$	Dec. %	Carotenoid mg/g	Inc. %	Chlorophyll (mg/g)					
					Chl. A	Inc. %	Chl. B	Inc.%	Chl. A+B	Inc.%
Abamectin	0.322c	4.5	0.248f	22.8	0.648f	18.2	0.360f	24.6	1.008f	20.4
Cabbage leaf	0.301f	10.7	0.215o	6.4	0.575o	4.9	0.309o	6.9	0.884o	5.6
Cabbage leaf + Abamectin	0.278i	17.5	0.225l	11.4	0.601l	9.7	0.327l	13.1	0.928l	10.9
Rice straw	0.309e	8.30	0.212p	5.0	0.567p	3.5	0.305p	5.5	0.872p	4.2
Rice straw + Abamectin	0.288h	14.5	0.222m	10.0	0.592m	8.0	0.322 m	11.4	0.914 m	9.2
Cucumber leaf	0.294g	12.8	0.22n	8.9	0.585n	6.8	0.316n	9.3	0.901n	7.6
Cucumber leaf + Abamectin	0.269j	20.2	0.229k	13.4	0.607k	10.8	0.331k	14.5	0.938k	12.1
Plant compost	0.263k	22.0	0.231j	14.4	0.615j	12.2	0.338j	17.0	0.953j	13.9
Plant compost + Abamectin	0.227p	32.6	0.257c	27.2	0.668c	21.9	0.379c	31.1	1.047c	25.1
Mixed compost	0.255l	24.3	0.236i	16.8 3	0.621i	13.3	0.343i	18.7	0.964i	15.2
Mixed compost + Abamectin	0.218q	35.3	0.261b	29.2	0.675b	23.2	0.386b	33.6	1.061b	26.8
Vermicompost	0.249m	26.1	0.24h	18.8	0.63h	15,0	0.347h	20.1	0.977h	16.7
Vermicompost + Abamectin	0.205r	39.2	0.264a	30.7	0.684a	24.8	0.391a	35.3	1.075a	28.4
Vermicompost tea	0.315d	6.5	0.208q	3.0	0.561q	2.4	0.296q	2.4	0.857q	2.4
Vermicompost tea +Abamectin	0.242n	28.2	0.243g	20.3	0.637g	16.2	0.353g	22.1	0.99g	18.3
Oxamyl	0.331b	1.8	0.254d	25.7	0.662d	20.8	0.373d	29.1	1.035d	23.7
Nematode only (N)	0.337a	-	0.202r	-	0.548r		0.289r		0.837r	
Healthy plant	0.233o	30.9	0.25e	23.8	0.654e	19.3	0.365e	26.3	1.019e	21.7
LSD	0.002	-	0.002	-	0.001	-	0.002	-	0.003	-

Each value is the mean of four replicates: Means in each column followed the same letter (s) did not differ at P<0.05 according to Duncan's multiple –range test. N= 4000 eggs of *M. incognita*. Abamectin = (Namazoho) 1.8% EC. a commercial product of *S. avermitilis*.

4. Discussion

The root-knot nematode, *M. incognita* is a significant endoparasitic nematode that causes substantial economic losses to solanaceous crops worldwide. Organic soil amendments such as plant residues, decomposed materials (compost and vermicompost), animal and green manure, are considered sustainable to the environment, safe alternatives for inorganic fertilizers as they have many beneficial effects on soil properties, and crop productivity [31], [32]. Furthermore, they are suggested as a promising tool for the management of plant-parasitic nematodes [33], [34].

The effectiveness of agricultural wastes such as dried plant residues in the suppression of root-knot nematodes, *Meloidogyne* spp., and enhancement of plant growth attributes is well documented [7], [35]. Dried plant residues are an essential source of carbon [36] and also provide valuable nutrients like nitrogen, playing a crucial role in replenishing soil organic matter and supporting cultivation [37]. Vermicompost is as an organic fertilizer created through the non-thermophilic breakdown of organic materials, facilitated by the combined activity of earthworms and microorganisms [38]. The use of vermicompost as an organic fertilizer, rich in NPK and micronutrients, has been shown to effectively reduce the impact of plant-parasitic nematodes and as an excellent promoter and protector for crop plants [7], [20]. However, its effectiveness is influenced by several factors such as the quality and type of vermicompost, the application rate, and the composition of parasitic nematode communities in the soil and the nematode density [39]. In the current study a significant induction ($P< 0.05$) in eggplant shoot weight was recorded with single application of cucumber leaf residues (143.2%) followed by vermicompost (121.8%) and mixed compost (110.2%). These results are in agreement with a number of researchers [7], [10], [11] [39] [40], who reported the effectiveness of composted agricultural wastes in the suppression of root-knot nematodes and improvement of plant growth parameters.

Generally, the effectiveness of organic amendments depends directly on nitrogen content and inversely on C/N ratio. Our study revealed a narrower C/N ratio in plant (medicinal and aromatic plants) and mixed compost (rice straw + animal manure) as well as vermicompost scoring 17.42, 15.11, and 13.96, respectively. Fertilizers with C/N ratio of 15-20 is considered the most effective and optimal to soil microorganisms [41], [42].

On the other hand, the introduction of beneficial microorganisms are also more preferable for nematode management due to their specificity, environmental safety, cost-effectiveness, and non-resistance-inducing nature [13], [14]. The soil bacterium, *S. avermitilis* has shown nematicidal activity against *Meloidogyne* spp. under controlled, greenhouses and field conditions [15-17] reducing nematode population and reproduction on various crops and commercially utilized as biocontrol agents against certain plant-parasitic nematodes [18- 21].

Abamectin, a fermentation product of the bacterium *Streptomyces avermitilis,* has found widespread use in agriculture due to its broad-spectrum activity against a variety of pests. It is particularly effective against root knot nematodes [17], [22], [43]. Abamectin exerts its insecticidal, acaricidal and nematicidal effects by targeting the nervous system of pests. The disruption in the normal functioning of the nervous system renders the pests paralyzed and ultimately leads to their demise. In the current study, Abamectin showed a moderate improvement in eggplant growth parameters and a significant ($P< 0.05$) reduction in nematode population. Similar results with other plants were reported [17], [19].

The mechanism of *S. avermitilis* has been suggested by many scientists [18], [44] as it acts as antagonistic or stimulatory to GABA (y-aminobutyric acid) released from avermectins. *Streptomyces* spp. produce exoenzymes including chitinolytic enzymes, and various toxic substances that effectively combat plant parasitic nematodes [45]. A significant ($P< 0.05$) induction in total chlorophyll and carotenoids was also recorded with Abamectin which agreed with a previous study [46] in which the treatment of *Streptomyces* (strain ST15) was the most effective and significantly increased photosynthetic pigments (total chlorophyll, and carotenoids), compared to control plants and other strains.

Agricultural wastes viz. plant residues (cucumber leaf, cabbage leaf and rice straw), compost (plant or mixed), solid vermicompost, vemicompost tea in concomitant with Abamectin had the greatest synergistic impact on suppressing *M.incognita* damage and boosting eggplant growth attributes. The persistence and mobility of Abamectin in soil may be affected by the addition of agricultural wastes. They were significantly increased by chemical fertilizer i.e. ammonium sulfate, which could extend and enhance its ability promote to control root- knot nematode, *M.incognita* [47].

Integration of Abamectin with agricultural wastes namely cucumber leaf residues and vermicompost surpassed other treatments in improving plant fresh weight of eggplant infected with *M.incognita*. Photosynthetic pigments (chlorophyll, carotenoids) were significantly increased by all treatments, being concomitant application the superior. The highest percentage of increase in chlorophyll A+B and carotenoids was recorded with the concomitant application, vermicompost + Abamectin (28.4%) followed by mixed compost + Abamectin (26.8%) and plant compost + Abamectin (25.1%). These findings align with a previous study that demonstrated the enhancement of plant growth characteristics and the increment of macronutrients as well as photosynthetic pigments in dried leaves of tomato infected with *M .incognita* following vermicompost and Abamectin application [20]. Incorporating vermicompost with biopesticides offers significant benefits for organic farming by addressing soil nutrient deficiencies and suppressing harmful nematode pests [48], [49].

Catalase (CAT) functions as an antioxidant enzyme. A significant differences in catalase (CAT) activity ($P<0.05$) were recorded by all treatments of agricultural wastes singly and in integration with Abamectin compared to control. As a reaction of *M. incognita* infestation eggplant showed higher CAT activity ($P<0.05$) compared to treated plants. CAT activity was significantly retarded by vermicompost + Abamectin (39.16%) followed by mixed compost + Abamectin (35.31%) and plant compost + Abamectin (32.64%). The present result agreed with a study documented that CAT activity showed an upwards trend in pomegranate cultivars infected with *M. incognita* [50]. However, it contradicts with a previous study indicated that enzyme activity of CAT, was shown to be reduced after nematode exposure but enhanced after treatment with vermicompost at different dilutions [51].

All treatments significantly (P< 0.5) succeeded to suppress nematode population as compared to control. Notably, no significant differences were indicated within some treatments. It was evident that all individual treatments significantly (P< 0.5) succeeded to suppress nematode population as compared to control. Among selected agricultural wastes, the highest percentages of reduction in nematode population in soil and root was recorded with vermicompost tea followed by and cabbage leaf residues compared to control plants. Brassicas are known to contain glucosinolates (GSL) [52]. When cells are damaged, glucosinolates (GSL) are released into the cytoplasm and transformed into toxic isothiocyanates (ITC) through enzymatic hydrolysis by myrosinase. These ITCs are known to be harmful to root-knot nematodes (RKNs) and other soil-borne diseases [53]. Agricultural wastes in integration with Abamectin demonstrated a synergistic effect, further reducing total nematode population, root galling and egg masses numbers. The highest reduction in nematode population was recorded by the integration of compost (mixed or plant) + Abamectin, followed by vermicompost + Abamectin then cucumber leaves + Abamectin, These results are in accordance with previous study [54] that documented the nematicidal activity of the combination of arugula vermicompost+ bacteria species+ chitosan against *M. javanica* on tomato.

Several pharmacological activities including the antioxidant, antiwrinkle, antimicrobial, etc. potentials have been reported with cucumber plant [55]. Notably root galling and egg masses numbers were significantly decreased by cabbage or cucumber leaves + Abamectin. Cucumber leaves were found to possess several bioactive compounds, of these cucurbitacins (group of triterpenoid substances) which are well-known for their bitterness and toxicity, anti-cancer, biological and antimicrobial activities [56]. Another study has reported the presence of flavonoids i.e flavone C-glycosides, C-glycosyl flavonoid phytoalexins and acylated flavones in cucumber leaves [56].

The present investigation, revealed that screened agricultural wastes in concomitant with Abamectin had the greatest synergistic impact on suppressing nematode damage and boosting growth attributes. The efficacy of agricultural wastes combined with bionematicide Abamectin could be due to different secondary metabolites released during decomposition which can improve soil health and indirectly help plants resist nematode damage [57] and the ability of Abamectin to disrupt the nematode nervous system, leading to paralysis and death [45].

5. Conclusion

Ultimately, integrated nematode management (INM) is a sustainable approach for managing plant-parasitic nematodes. The current study displayed a green approach to mitigate the biotic stress induced by *M. incognita* using plant residues or converted agricultural wastes such as compost and vermicompost in concomitant with Abamectin (a fermentation product of *S. avermitilis*), improve plant health as well as increase the plant defense and soil quality. Composting materials would be an efficient and suitable solution of discarding plant residues and polluting from by-products of agro-industry and appear as promising ecological alternative to conventional inorganic fertilizers. However, further studies are needed under greenhouse and field conditions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest exists among the authors.

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