Efficacy of plant oils and garlic cultivation on controlling *Meloidogyne incognita* infected tomato plants

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Abstract

The efficacy of seven essential plant oils and cultivation of two garlic cultivars: Balady and Sods-40 were evaluated for controlling root-knot nematode, *Meloidogyne incognita* infecting tomato plants under laboratory, greenhouse and field conditions. Treatments with essential oils of arugula, camphor, castor, garlic, nigella, onion and sesame resulted in 48.0-92.7% reduction in numbers of root galls/root under laboratory conditions. Similarly, application of these oils resulted in great reductions of 59.2-92.8% and 47.4-89.6% in numbers of root galls and egg-masses/root when oils applied before and after transplanting of tomato seedlings, respectively. The highest reduction (%) of galls, egg-masses and reproduction of *M. incognita* infecting tomato plants were reached with Nemacure® (95.2-98.8%) and garlic oil was best control among the seven tested essential plant oils with 78.0-98.6% reduction. Moreover, a great reduction of nematode galls, egg-masses and juveniles/250 cc soil (93.6-97.5%) was reached on tomato seedlings, which transplanted in soil previously cultivated with either tested garlic cultivars. In the greenhouse experiment, values of reproductive factor (R_f) decreased as a result of garlic oil to reach (0.07- 0.23 and 0.16-0.34) before and after transplanting of tomato seedlings, respectively. Likewise, R_f values were sharply decreased to reach 0.032-0.041 in soil previously cultivated with garlic plants, in the field experiment. Moreover, applications of the seven tested essential plant oils and cultivation of garlic cultivars enhanced plant growth parameters to reach 34.9-80% increase as compared to the check treatment.

Tomato (*Lycopersicon esculentum* Mill.) is one of the most important vegetable crops grown in Egypt (Ibrahim & El-Sharkawy, 2001). Root-knot nematodes (*Meloidogyne* spp.) are the most widespread nematode pests limiting tomato productivity in Egypt and other parts of the world (Sasser & Carter, 1985; Koenning *et al*., 1999; Akhtar, 2001; Meyer & Roberts, 2002). Most of *Meloidogyne* species are easily diagnosed by farmers by the presence of galls on roots. Galls are formed as a sequence of physiological disturbances in the root tissues caused by the trophic interactions of nematode females (Moens *et al*., 2009). Root-knot nematodes can be managed effectively by chemical nematicides but they are highly toxic to both human health and the environment (Abawi & Widmer, 2000). Most nematicides are being progressively banned or highly restricted for protecting vegetable production (Abd-Elgawad, 2008). Thus the development of an effective integrated pest management derived from plant or plant bio-products which have no adverse effect on plants, beneficial organisms or environment, is urgently needed in order to replace chemical nematicides (Martin, 2003). Essential oils of different plants have been found to possess nematicidal activity against nematodes (Chitwood, 2002; Ibrahim *et al*., 2006; Ibrahim & Traboulsi, 2009; Abo-Elyousr *et al*., 2010). Allelochemicals are plant-produced compounds that affect the behavior of other organisms and thought to be toxins and secondary metabolites, which act as attractants or deterrents (Dodds & Henderson, 1996; Brown & Morra, 1997; Cetintas & Yarba, 2010). Garlic and some other plants have been evaluated for their nematicidal properties and efficacy in the management of root-knot nematodes (Zasada *et al*., 2002; Agbenin *et al*., 2005).

The present work aimed to study (i) the suppressive effect of seven essential oils from arugula, castor, camphor, garlic, onion, nigella and sesame compared with the nematicide, Nemacure®10G on *M. incognita* infected tomato seedlings under laboratory and greenhouse conditions, (ii) nematode multiplication on tomato seedlings transplanted in soil previously cultivated with garlic treated with nematicide Vydate®L 24% under field condition.

Materials and Methods

Laboratory experiment: Ninety five plastic cups, 5 cm dia., filled with 100 cc soil composed of clay: sand (1:3, v:v) were used in this experiment under the laboratory condition. Cups were transplanted with five-wk-old tomato seedlings cv. Viona.

The evaluated plant oils were made by diluting the tested oils using a solvent mixture composed of 3% acetone and 10% ethanol. For each of the tested oil, two concentrations were prepared by adding 75 or 150 µl of each plant oil/10 ml (7.5 and 15 µl/ml) of solvent mixture.

Egg-masses of *Meloidogyne incognita* Kofoid & White (Chitwood), previously identified by the morphological characteristics of the female perineal patterns and reared on tomato plants (*Lycopersicon esculentum* Mill.) cv. Super strain B in a greenhouse (Taylor & Sasser, 1978; Eisenback & Triantaphyllou, 1991). The root-knot nematode eggs were extracted from the infected tomato roots using sodium hypochlorite (NaOCl) solution as described by Hussey & Barker (1973).

Oil of seven plants viz., arugula, camphor, castor, garlic, onion, nigella and sesame were obtained from El-Gomhoria Chemicals Company, Egypt and used in this study (Table 1). Also, two solvents; acetone CH_3COCH_3 (100% analysis grade) and ethanol C_2H_5OH (absolute analysis grade) were used.

Table 1. List of plants.

Common name	Scientific name	Family
Arugula	*Eruca sativa* Mill.	Brassicacaea
Camphor	*Cinnamomum camphora* L.	Lauraceae
Castor	*Ricinus communis* L.	Euphorbiaceae
Garlic	*Allium sativum* L.	Alliaceae
Nigella	*Nigella sativa* L.	Ranunculaceae
Onion	*Allium cepa* L.	Alliaceae
Sesame	*Sesamum indicum* L.	Pedaliaceae

Cups were inoculated with 500 eggs and J_2 of *M. incognita*/cup. Seventy cups were treated with 10 ml of each oil concentration at the same time of tomato transplanting. Five cups were treated with the emulsion nematicide, Nemacure® 10G (Ethyl- 4-methylthio-m- tolylisopropylp hosphoramidate) at the rate of 25 mg/100 cc soil. Five cups were left without oil application to serve as a check treatment. The other check treatments, each of 5 cups, were treated with 10 ml of the used solvent; 3% acetone, 10% ethanol and the mixture of both solvents (3% acetone + 10% ethanol), respectively. Each treatment replicated five times. Cups were arranged in a randomized complete block design. The experiment was terminated 21 days after oil applications. Number of galls/seedling were counted at the end of the experiment.

Greenhouse experiment: One hundred and ninety pots, 25 cm dia., filled with one kg autoclaved soil mixture of clay: sand (1: 3, v: v). All pots were transplanted with five-wk-old tomato seedling cv. Fairouz. Pots were divided into two groups of 95 pots each. Seventy pots of the 1st group were inoculated with 2500 eggs and J_2/kg soil of *M. incognita* and treated, at the same time, with 100 ml of each oil concentration of 7.5 or 15 µl/ml of solvent mixture (100 ml of each oil concentration/pot containing kg soil), 5 days before tomato transplanting. Five pots were treated with Nemacure®10G at the rate of 250 mg /kg soil; five pots treated only with *M. incognita* were served as a check treatment; fifteen pots of 5 pots each were received only 100 ml acetone 3%, 100 ml ethanol 10% and 100 ml solvent mixture, which composed (50 ml acetone 3% + 50 ml ethanol 10%), respectively to serve as the other check treatments. Pots of the 2nd group were received the same treatments but after 5 days from tomato transplanting.

Treatments were replicated five times. Pots were arranged in a randomized complete block design. The experiment was terminated, 60 days after nematode inoculation. Pots were irrigated with tap water every other day.

Numbers of nematode root galls and egg-masses/root, dry weight of root and final nematode population (P_f) were determined. The reproduction factor (R_f) and reduction (%) were calculated (Sasser *et al*., 1984; van Gundy, 1985).

Field experiment: To study the usefulness of cultivating cloves of two garlic cultivars; Balady and Sods-40 in highly *M. incognita* infested sandy loam soil, a field experiment was conducted at the end of cultivating garlic cultivars at El-Nobaria, El-Behera governorate. Five-wk-old tomato seedlings of Super strain B cv. was transplanted in the same soil, which cultivated previously with either of the two garlic cultivars. The field plot was 3.5 × 5.0 m for each treatment (5 rows of 3 m long and 85 cm wide with 50 cm gap between rows). All rows were irrigated to full water holding capacity and transplanted at 50-cm distance three days later. Five rows were received the nematicide, Vydate®L 24% Oxamyl [Methyl N'N'-dimethyl-N-[(methyl carbamoyl) oxy]-1-thiooxamimidate] at the rate of 10 ml/seedling. Tomato seedlings transplanted in five rows of *M. incognita* infested sandy loam soil non-cultivated before with garlic cvs., served as a check treatment. Treatments were replicated five times (5 rows) with a completely randomized block design.

Data were collected 60 days after transplanting tomato seedlings. Twenty plants and 15 soil samples from the rhizosphere of tomato plants up to a depth of 20 cm (250 cc soil/sample) from each plot was taken for nematode analysis. Number of nematode, root galls, egg-masses/root, number of J_2/250 cc soil and dry weights of shoot and root were determined. Reproductive factor (R_f) and reduction (%) were calculated for each treatment.

Data obtained were statistically analyzed according to SAS software program (SAS Institute, 1997). Comparison among means was made via the least significant difference (LSD) at 5% level of probability.

Results

Data presented in Table (2) showed that treatment with Nemacure®10G and 15 µl/ml of garlic treatment gave the highest reductions (96 and 92.7%) in number of root galls/root, respectively followed by treatment with the lower concentration of garlic (7.5 µl/ml) which showed 82% reduction. Also, treatments with both concentrations of arugula, castor and sesame oils showed 63.3-72.0% reductions in number of galls/root followed by treatment with both concentrations of camphora, nigella and onion oils, which showed 48.0-62.0% reductions compared to the check treatment. No significant reductions were recorded using acetone 3%, ethanol 10% and the mixture of both solvents as check treatments.

Table 2. Effects of the seven essential plant oils and Nemacure®10G on *M. incognita* (*Mi*) root galls formed on tomato seedlings planted under laboratory condition.

Treatments	No. of galls/root	Reduction (%)
Mi alone*	30.0 a	-
3% Acetone + *Mi*	29.0 a	-
10% Ethanol + *Mi*	28.6 a	-
Solvent mixture + *Mi*	28.4 a	-
Arugula oil + *Mi*		
7.5 µl /ml	9.8 de	67.3
15 µl /ml	8.4 ef	72.0
Camphor oil + *Mi*		
7.5 µl /ml	15.6 b	48.0
15 µl /ml	12.4 bcd	58.7
Castor oil + *Mi*		
7.5 µl /ml	10.6 de	64.7
15 µl /ml	8.4 ef	72.0
Garlic oil + *Mi*		
7.5 µl /ml	5.4 fg	82.0
15 µl /ml	2.2 gh	92.7
Onion oil + *Mi*		
7.5 µl /ml	14.8 bc	50.7
15 µl /ml	11.8 cde	60.7
Nigella oil + *Mi*		
7.5 µl /ml	13.4 bcd	55.3
15 µl /ml	11.4 cde	62.0
Sesame oil + *Mi*		
7.5 µl /ml	11.0 ed	63.3
15 µl /ml	9.8 de	67.3
Nemacure®10G + *Mi*		
25mg/100 cc soil	1.2 h	96.0

Values in column followed by the same letter(s) are not significantly different at p = 0.05.

The application of 250 mg Nemacure ® 10G/kg soil, both oil concentrations of 7.5 and 15 µl/ml of arugula, castor, garlic, nigella, sesame oils and 15 µl/ml of onion oil in soil, before transplanting tomato, caused the highest reductions of 70.2-98.2% followed by the applications of both concentrations of camphore oil and 7.5 µl/ml of onion oil, which showed 59.2-67.6% reductions in number of nematode root galls and egg-masses/root (Table 3).

Table 3. Effects of the seven essential plant oils and Nemacure®10G applied before tomato transplanting on galls, egg-masses and reproduction of *M. incognita* under greenhouse condition.

Treatments	No. of galls/plant	Reduction (%)	No. of EM/plant	Reduction %	R_f	Reduction (%)
Mi alone*	1003.4 a	-	990.5 a	-	5.09 a	-
3% Acetone + *Mi*	991.9 a	-	982.6 a	-	4.93 a	-
10% Ethanol+*Mi*	989.8 a	-	982.7 a	-	4.83 a	-
Mixture + *Mi*	1002.7 a	-	988.6 a	-	4.83 a	-
Arugula oil + *Mi*						
7.5 µl /ml	274.9 e	72.6	264.3 e	73.3	1.24 bc	75.6
15 µl /ml	211.3 fg	78.9	202.9 fg	79.5	1.07 cde	79.0
Camphor oil + *Mi*						
7.5 µl /ml	408.9 b	59.2	398.7 b	59.7	1.17 bc	77.0
15 µl /ml	376.0 bc	62.5	362.8 bc	63.4	1.30 bc	74.5
Castor oil + *Mi*						
7.5 µl /ml	220.5 fg	78.0	212.1 fg	78.6	0.84 def	83.5
15 µl /ml	146.0 hi	85.4	139.9 hi	85.9	0.76 f	85.1
Garlic oil + *Mi*						
7.5 µl /ml	122.9 ij	87.8	115.5 ij	88.3	0.23 g	95.5
15 µl /ml	81.3 j	91.9	71.6 j	92.8	0.07 g	98.6
Onion oil + *Mi*						
7.5 µl /ml	332.1 cd	66.9	321.1 cd	67.6	1.23 bc	75.8
15 µl /ml	276.6 e	72.4	272.3 de	72.5	1.36 b	73.3
Nigella oil + *Mi*						
7.5 µl /ml	299.0 de	70.2	288.2 de	70.9	1.13 bcd	77.8
15 µl /ml	205.4 g	79.5	197.5 g	80.1	1.05cdef	79.4
Sesame oil + *Mi*						
7.5 µl /ml	264.5 ef	73.6	253.2 ef	74.4	1.01 cdef	80.2
15 µl /ml	194.8 gh	80.6	184.7 gh	81.3	0.78 ef	84.7
Nemacure® + *Mi*						
250 mg /kg soil	22.1 k	97.8	17.8 k	98.2	0.06 g	98.8

Values in each column followed by the same letter(s) are not significantly different at $p = 0.05$.

In oil treatments applied after tomato transplanting, results indicated that the application of Nemacure® 10G at the rate of 250 mg/kg soil reduced number of nematode root galls and egg-masses/root up to 95.9%, followed by application of both oil concentrations of garlic, which showed reductions of 78.0-89.6%.

Application of both oil concentrations of arugula, castor, nigella, sesame oils and 15 µl/ml of onion oil resulted in reductions of 62.0-76.6 % in number of nematode root galls and egg-masses/root, followed by the applications of the same concentrations of camphor oil and 7.5 µl/ml of onion oil, which showed 47.4-59.6 % reduction (Table 4).

Values of nematode reproductive factor (R_f) were significantly reduced as a result of Nemacure®10G application and 15 µl/ml of garlic oil to reach (0.05-0.16), followed by the application of 7.5 µl/ml of garlic oil, which reached 0.23-0.34. Values of R_f showed 0.76-0.93 after the application of 7.5 µl and 15 µl/ml of castor oil and 15 µl/ml of sesame oil and 1.01-1.67 after the application of 7.5 µl and 15 µl/ml of arugula, camphor, onion, nigella oils and 7.5 µl/ml of sesame oil in comparison with that of the check application in both before and after tomato planting treatments (Table 3 and 4).

After transplantation treatments with 250 mg/kg soil of Nemacure®10G and both concentrations (7.5 µl and 15 µl/ml) of arugula, castor, garlic, onion, nigella, sesame oils and (15 µl/ml) of camphor resulted (54.8- 80.0%) increase in dry weight of root followed by treatment with (7.5 µl/ml) of camphor oil which showed 34.9-51.4% increase in after and before transplant treatment (Table 5).

Table 4. Effects of the seven essential plant oils and Nemacure®10G applied after tomato transplanting on galls, egg-masses (EM) and reproduction of *M. incognita* under greenhouse condition.

Treatments	No. of galls/plant	Reduction (%)	No. of EM/plant	Reduction (%)	R_f	Reduction (%)
Mi alone*	907.5 a	-	855.4 a	-	4.27 a	-
3% Acetone+*Mi*	886.2 a	-	844.0 a	-	4.25 a	-
10% Ethanol+*Mi*	905.9 a	-	854.4 a	-	4.15 a	-
Mixture + *Mi*	907.0 a	-	849.8 a	-	4.26 a	-
Arugula oil + *Mi*						
7.5 µl /ml	338.3 cde	62.7	324.8 cde	62.0	1.42 bcd	66.7
15 µl /ml	263.5 efg	71.0	246.7 fgh	71.2	1.14 def	73.3
Camphor oil + *Mi*						
7.5 µl /ml	460.2 b	49.3	449.6 b	47.4	1.67 b	60.9
15 µl /ml	393.8 bc	56.6	382.4 bc	55.3	1.46 bc	65.8
Castor oil + *Mi*						
7.5 µl /ml	293.9 def	67.6	282.2 def	67.0	0.89 fg	79.2
15 µl /ml	212.3 g	76.6	205.3 gh	76.0	0.81 g	81.0
Garlic oil + *Mi*						
7.5 µl /ml	199.6 g	78.0	173.4 h	79.7	0.34 h	92.0
15 µl /ml	105.1 h	88.4	89.3 i	89.6	0.16 h	96.3
Onion oil + *Mi*						
7.5 µl /ml	366.6 cd	59.6	353.2 cd	58.7	1.53 bc	64.2
15 µl /ml	322.4 cde	64.5	300.6 def	64.9	1.39 cd	67.4
Nigella oil + *Mi*						
7.5 µl /ml	346.2 cd	61.9	330.6 cde	61.4	1.25 cde	70.7
15 µl /ml	308.4 de	66.0	303.8 def	64.5	1.15 def	73.1
Sesame oil + *Mi*						
7.5 µl /ml	298.5 de	67.1	276.3 efg	67.7	1.09 efg	74.5
15 µl /ml	218.0 fg	76.0	207.6 gh	75.7	0.93 fg	78.2
Nemacure®10G + *Mi*						
250 mg/kg soil	43.6 h	95.2	34.9 i	95.9	0.05 h	98.8

Values in each column followed by the same letter(s) are not significantly different at p = 0.05.

Results of Table (6) revealed that the highest reduction up to 99.4% in number of nematode root galls, egg-masses/root and number of J_2/250 cc soil was achieved by two treatments; the application of Vydate® L 24% and the 2nd was after transplanted treatment of tomato seedlings in the same rows, which cultivated first with either garlic cultivars. Also, R_f values reach 0.007-0.04 in the previous treatments compared to 1.277 for the check treatment. Moreover, previous treatments resulted in 62.4-72.2% increase in root and shoot dry weight compared to the check treatment (Table 7).

Table 5. Effects of the seven essential plant oils and Nemacure®10G applied before and after transplanting on growth parameters of tomato plants infected with *M. incognita* under greenhouse condition.

Treatments	Before transplanting		After transplanting	
	Root dry weight (g)	Increase (%)	Root dry weight (g)	Increase (%)
Mi alone*	3.6 i	-	2.8 i	-
3% Acetone + *Mi*	3.7 i	-	2.9 i	-
10% Ethanol + *Mi*	3.6 i	-	3.0 i	-
Mixture + *Mi*	3.8 i	-	2.8 i	-
Arugula oil + *Mi*				
7.5 µl /ml	10.4 defg	65.4	9.3 cde	69.9
15 µl /ml	11.7 de	69.2	11.5 bc	75.6
Camphor oil + *Mi*				
7.5 µl /ml	7.4 h	51.4	4.3 hi	34.9
15 µl /ml	10.4 defg	65.4	6.3 fgh	55.6
Castor oil + *Mi*				
7.5 µl /ml	11.3 def	68.1	6.9 fg	59.4
15 µl /ml	12.1 cd	70.2	12.0 ab	76.7
Garlic oil + *Mi*				
7.5 µl /ml	13.9 bc	74.1	12.5 ab	77.6
15 µl /ml	14.3 b	74.8	14.0 a	80.0
Onion oil + *Mi*				
7.5 µl /ml	10.1 efg	64.4	7.3 efg	61.6
15 µl /ml	10.8 def	66.7	8.5 def	67.1
Nigella oil + *Mi*				
7.5 µl /ml	8.6 gh	58.1	6.2 gh	54.8
15 µl /ml	11.7 de	69.2	7.8 defg	64.1
Sesame oil + *Mi*				
7.5 µl /ml	9.7 fg	62.9	7.5 efg	62.7
15 µl /ml	10.9 def	67.0	9.8 cd	71.4
Nemacure®10G+ *Mi*				
250 mg /kg soil	17.4 a	79.3	13.9 a	79.9

Values in each column followed by the same letter(s) are not significantly different at p = 0.05.

Table 6. Effect of previous cultivation of two garlic cultivars and Vydate® L 24% on galls, egg-masses and reproduction of *M. incognita* infected tomato plants grown in field condition.

Treatments	No. of galls/ root	Reduction (%)	No. of EM/root	Reduction (%)	J_2/250 cc soil	Reduction (%)	R_f	Reduction (%)
Check*	185.6 a	0.0	178.4 a	0.0	2408.0 a	0.0	1.277 a	0.0
Infested soil previously cultivated with garlic cv:								
Balady	11.3 b	93.9	8.1 b	95.5	59.4 b	97.5	0.032 b	97.5
Sods-40	11.9 b	93.6	8.8 b	95.1	77.4 b	96.8	0.041 b	96.8
Infested soil treated with Vydate L 24%:								
10ml/seedling	8.6 b	95.4	4.2 b	97.6	13.6 b	99.4	0.007 b	99.5

Values in each column followed by the same letters are not significantly different at p = 0.05.

Table 7. Effect of cultivation of two garlic cultivars and Vydate® L 24% on *M. incognita* infested tomato fields (growth parameters).

Treatments	Root dry weight (g)	Increase (%)	Shoot dry weight (g)	Increase (%)
Check*	10.6 b	0.0	13.2 b	0.0
Infested soil previously cultivated with garlic cv:				
Balady	28.2 a	62.4	46.2 a	71.4
Sods-40	29.1 a	63.6	45.2 a	70.8
Infested soil treated with Vydate L 24%:				
10 ml/seedling	30.1 a	64.8	47.5 a	72.2

Values in each column followed by the same letter(s) are not significantly different at p = 0.05.

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Discussion

Laboratory, greenhouse and field experiments showed that treatment with both systemic chemical nematicides, Nemacure®10G and Vydate® L 24% caused the highest reductions of *M. incognita* reproduction on tomato plants and findings are agreed (Ploeg & Phillips, 2001; Gugino *et al*., 2006). As nematicides, the organophosphates (Nemacur®) and carbamates (Vydate®) act as acetylcholine-esterase inhibitors, that offer systemic and contact activity and inhibits the enzyme cholinesterase and interferes with root-knot nematodes nervous system. Both nematicides, inhibited root-knot nematodes invasion and lessened pest activity that supposedly leads to the deprivation of plant nutrients, their functions as a crop protection agent by preventing the feeding of nematodes and by disrupting the life cycle findings suggested by Ploeg & Phillips (2001). Gugino *et al*., (2006) reported that Vydate® L 24% was effective in reducing root-galling severity in commercial carrot fields and increased carrot yield.

The present data showed that treatments with seven essential oils from arugula, camphora, castor, garlic, nigella, onion and sesame on *M. incognita* infected tomato plants resulted in a significant reduction in nematode reproduction and supported (Oka *et al*., 2000; Sharma & Tripathi, 2006; Ibrahim *et al*., 2006; Melakeberhan *et al*., 2006; Abbas *et al*., 2009; Ibrahim & Traboulsi, 2009; Adomako, 2010). Knoblock *et al*., (1989) reported that the nematicidal effect of the many plant extracts may possibly be attributed to their high contents of certain oxygenated compounds which are characterized by their lipophilic properties that enable them to dissolve the cytoplasmic membrane of nematode cells and their functional groups interfering with the enzyme protein structure. The mechanisms of plant extracts action may include denaturing and degrading of proteins, inhibition of enzymes and interfering with the electron flow in respiratory chain or with ADP phosphorylation (Konstantopoulou *et al*., 1994). Moreover, several of these oils immobilized root-knot nematodes J_2 and some also reduced egg hatching (Ibrahim *et al*., 2006).

It was recorded that garlic essential oil also posses nematicidal activity on root-knot nematodes (Agbenin *et al*., 2005; Park *et al*., 2005; Ibrahim & Traboulsi, 2009). The volatile antimicrobial substance allicin produced in garlic is active against several plant pathogenic bacteria and fungi and suppressed different plant parasitic nematodes (Sukul, 1992; Zasada *et al*., 2002; Gupta & Sharma, 1993; Curtis *et al*., 2004; Agbenin *et al*., 2005). The immobility of J_2 after 24 hrs of exposure may reach 100% immobility of *M. incognita* J_2 after 24 h of exposure induced by the active bulb extract of *Allium sativum* which contain component allicin (Gupta & Sharma, 1993; Korayem & Hasabo, 1994; Curtis *et al*., 2004). An environmentally benign garlic derived polysulfide product is approved for use in the European Union and the UK as a nematicides (Anwar *et al*., 2009). Sharma & Tripathi (2006) reported that essential oils of castor bean and black cumin showed nematicidal efficacy against *M. incognita* and *Rotylenchulus reniformis* on tomato.

Eruca sativa considered to be one of the antagonistic plants which reduce nematode numbers (Alam *et al*., 1990). Many brassica plants, including arugula, possess biofumigant and trap crop qualities and thus have been gaining popularity as potential alternatives to methyl bromide. Melakeberhan *et al*., (2006) showed that arugula interferes with development and reproduction of populations and thus has potential as a trap crop to control *M. hapla*. Avato *et al*., (2013) focused on the role of the glucosinolates, which contain sulfur, as bionematicides. Also, reported the efficacy of these phytochemicals against the most common phytoparasitic nematodes affecting crops of agriculture importance such as tomato, potato and grapevine. Abbas *et al*., (2009) reported that the black seed, *Nigella sativa* oil also contain about 0.5-1.5% volatile oil, including nigellone and thymochinone which are resposible for the anti-histamine, anti-oxidant and anti-infective effect.

The present work revealed that the used essential oils provided significant increase in the dry weight of shoot and root compared to check treatment and these findings are agreed (Zasada *et al*., 2002; Oduor-Owino, 2003; Adomako, 2010). Meanwhile, the check treatment provided the expected results and the tomato plants weighed significantly less than all the other treatments. These results imply that check plants were readily attacked by *M. incognita* as they exhibited stunted growth, in support of Gowen *et al*., (2005) and Guerena (2006).

Among seven tested essential oils, garlic found highly promising in controlling *M. incognita* on tomato under laboratory and greenhouse conditions. Moreover, transplanting tomato seedlings in the same rows which previously cultivated with either of the two tested garlic cultivars provided the highest reduction in nematode reproduction and increased root and shoot dry weights, which is almost the same results when treated tomato plants with Vydate L 24% compared to the check treatment and results supported (Anwer *et al*., 2009; Abo-Elyousr *et al*., 2010; El-Nagdi *et al*., 2013).

In conclusion, the used plant essential oils were able to control *M. incognita*, though the most effective was garlic oil. Therefore, they have the potentials to replace the hazardous and environmental unfriendly nematicides. In addition, considering safety to the environment, human health hazards and cost of nematode management, the non chemical means especially botanical nematicides will be much safer and highly practicable. It can easily fit into the integrated nematode management.

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