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Efficacy of Boron, Silicon, Jojoba and Four Bio-Products on Controlling *Meloidogyne incognita* Infecting Thompson Seedless Grapevines

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Abstract: *In-vitro* test showed that concentrations of 0.5 and 1 g/L of boric acid or sodium metasilicate reduced *Meloidogyne incognita* egg hatching by (90-94.3%) and (89.0-93.3%), after 24 and 48h of exposure, respectively while 2, 5 and 10 ml/L of the chemical nematicide, Nemacur® (Fenamiphos 40%) reduced egg hatching by (80.7-97%) and (74.7-96.7%) after 24 and 48h of incubation, respectively. All concentrations reduced numbers of hatched J_2 after 24 and 48h from exposure to different treatments. The highest reductions (97 and 96.7 %) were achieved by Nemacur® 40% treatment at 10 ml/L after 24 and 48 h of exposure, respectively followed by the other tested treatments. Boric acid and Na-metasilicate increased J_2 mortality to be 10.3-29.6 % at 24 h and 24.2- 53.3% at 48 h of exposure compared with those obtainable in the check treatment (0.9 and 2.5 %) at 24 and 48 h of exposure time, respectively. Field experiments were carried out during 2012 and 2013 growing seasons, under naturally *M. incognita* infested soil, to evaluate the efficacy of boric acid and sodium metasilicate; crushed seeds of jojoba; the four commercial bio-products, Agree®, Halex® Gold® and Temastrol®; and the nematicide, Nemacure®40% and their impact on yield and fruit quality of Thompson seedless grapevines grown at El-Nubaryia, El-Beheira Governorate, Egypt. In both seasons, all treatments significantly reduced number of root galls and egg masses/root system till harvest time. Jojoba and boric acid treatments significantly improved yield; cluster weight and width; weight, size and juice volume of 100 berries as compared with the check treatment, in both seasons. Berry length was increased with Gold, jojoba and boric acid treatments only in the 2nd season. Berry diameter and length/diameter (L/D) ratio were increased with boric acid application when compared with the check treatment, only in the 2nd season. In respect to chemical properties of grapes, treatments of Agree, Halex, Gold and Nemacur® 40% increased TSS% while, acidity was decreased with Agree, Halex, Gold and Temastrol applications as compared with the check treatment. Boric acid and Gold treatments increased total chlorophyll contents in both seasons. However, total chlorophyll was increased, in the 2nd season, with all tested treatments except Halex.

Key words: Grapes · Root-knot nematode · Bioagents · Biocontrol · Nematode control · Boric acid · Na-metasilicate · Nemacur · Fenamiphos

INTRODUCTION

Grape, *Vitis vinifera* L., is one of the most popular fresh fruit in Egypt and in the world. The most important table grape cultivar worldwide is "Thompson seedless" [1]. This crop was reported to be susceptible to several plant-parasitic nematodes of which root-knot nematode *Meloidogyne* spp. occupied the most prominent position [2]. Root-knot nematodes classified as one of the most important pathogens that can cause severe damage to some important crops in Egypt and it was recognized as a major pest causing substantial reductions in the yield of some fruit-trees including grapevines [3]. Controlling of plant-parasitic nematodes has received attention to

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minimize damage to grapevines. The use of nematicides to control root-knot nematodes is well known, but the negative impact of chemical pesticides led researchers to find new bio-products less harmful to the environment. Numerous investigators have focused on non-chemical materials as biocontrol agents or products against plant-parasitic nematodes by using essential plants oils and medicinal plants such as jojoba oil [4, 5, 6]. El-Nagdi *et al.* [4] observed that jojoba oil treatment reduced the population density of nematodes on table grapes and improved yield, physical and chemical characteristics of berries. Also, El-Nagdi and Youssef [7] reported that Abamectin 1.8% increased yield and fruit quality of table grape cv. Bez-Al-Anza under nematode infection. Dugui *et al.* [8] studied the effect of Si concentration, mode and frequency of application in managing *M. incognita* in cucumber cv. Cyclone. They reported that one application of Si at the rate of 200 µg/ml on both leaves and roots significantly reduced number of galls in inoculated plants, while single root application of Si at the rate of 400 µg/ml gave the lowest number of egg masses. Also, application of Si at the rate of 200 µg/ml increased the marketable yield compared to the higher rate of Si (400 µg/ml). Nordalyn [9] investigated the effects of Si (sodium metasilicate) on *M. incognita* and subsequently its effects on plant growth and yield of carrot, celery, tomato and cucumber. The benefits of Si in *M. incognita* reduction and alleviating damage by the nematode specifically in cucumber plants have been shown. This was likely because cucumber plants considered intermediate accumulator of Si and thus, can benefit more from Si amendment. Nevertheless, who concluded that supplemental Si can contribute to *M. incognita* reduction and enhance better yield. Similarly, Vasanthi *et al.* [10] reported that Si is accumulated in plants higher than the essential major nutrients. Application of microorganisms antagonistic to *Meloidogyne* spp., or biocompounds produced by the microbes, could provide additional opportunity for managing the damage caused by root-knot nematodes to grapevines [5, 11, 12]. El-Sheikh *et al.* [11] reported that treated Thompson seedless grapevines with Bionema (A commercial product containing the obligate parasite, *Pasteuria penetrans*) controlled root-knot nematode *M. incognita* and improved physical and chemical properties of Thompson seedless grapevines. El-Nagdi *et al.* [12] found that the commercial formulation "Agerin®" containing an Egyptian isolate of *Bacillus thuringiensis* and "Abamectin" containing *Streptomyces avermitilis* reduced the citrus nematode, *Tylenchulus semipenetrans* and markedly improved nutritional status, yield and fruit quality of mandarin. Therefore, the aim of the present study is to evaluate the efficacy of boron, silicon, jojoba and the four bio-products; Agree, Halex, Gold and Temastrol against root-knot nematode, *Meloidogyne incognita* naturally infecting Thompson seedless grapevines roots and their influence on yield and fruit quality in comparison with the chemical nematicide, Nemacur® (Fenamiphos 40%).

MATERIALS AND METHODS

***In vitro* Test:** The effectiveness of boric acid, sodium metasilicate and the nematicide Nemacur® (Fenamiphos 40%) were tested *in vitro* against the root-knot nematode *Meloidogyne incognita*. Two ml of 0.5 and 1.0 g/L of boric acid and sodium metasilicate and 1, 2, 5 and 10 ml/L of Nemacur®40% were transferred to 24 well plate (Corning®), then 50 µl of nematode eggs solution containing about 75 eggs was added to each well and incubated at 29°C. Distilled water was used as a check treatment. Treatments were replicated 4 times. Numbers of hatched juveniles (J_2) of *M. incognita*, alive or dead, were counted and recorded using a compound microscope after 24 and 48 h from the exposure to different concentrations. The percentages of hatched J_2 and mortality % of *M. incognita* were counted and calculated.

Field Experiment: A field experiment was carried out during 2012 and 2013 growing seasons on 9 years old "Thompson seedless" grapevines grown at Al-Yashaa village, El-Nubaryia province, El-Beheira Governorate, Egypt to evaluate the efficacy of boric acid, sodium metasilicate, jojoba and the four bio-products for controlling *Meloidogyne incognita* infecting grapevine and their impact on yield and fruit quality of Thompson seedless grape. Thirty-six grapevines, at approximately the same vigor, naturally infected with *M. incognita* were selected for this study. The vines were planted at 2 × 3 m apart in sandy soil, cane pruned and irrigated by drip irrigation system. The experiment was laid out in randomized complete blocks with four replications. The vines received the following soil drench applications: boric acid and sodium metasilicate from Al-Gomhuria Co., Egypt, 10 g/tree for each; crushed seeds of jojoba (*Simmondsia chinensis*), 30 g/tree; the commercial bio-products, Agree® 50% WG (a biological insecticide contained *Bacillus thuringiensis* subsp. *aizawai* strain GC-91-solids, spores and lepidopteran active toxins 50% and the other ingredients 50%) produced from Certis Company, USA, 10 g/tree; Halex® a bio-fertilizer from

Alsouna Company, 15 g/tree; Gold® (abamectin 1.8% EC) produced from Elhelb Pesticides & Chemicals Co., Egypt, 25 ml/tree; and Temastrol® (a commercial product contains 10% nitrogen, 10% potassium oxide, 0.5% magnesium, 0.5% manganese and 79% natural nematicidal active compounds (ROYAL Company for Agricultural Development, Egypt), 50 ml/tree; and the nematicide Nemacur®40%, 50 ml/tree. From each tree, approximately 250 g soil and 10 g roots were collected before treatment applications at April to represent the 1st sampling collection (P_i). Treatments were applied to each tree then irrigated with 5 L tap water. Four grapevine plants were left untreated to serve as a check treatment. Soil samples were collected and examined to estimate numbers of J_2/kg soil (P_i) then roots were placed in an aqueous solution of phloxin B (0.15 g/l water) for 15 minutes to clarify the nematode egg masses [13]. Number of nematode root galls and egg masses was determined. The 2nd sampling collection was done (in June) after 45 days from the 1st application to estimate the changes in numbers of J_2/250 g soil, numbers of nematode galls and egg masses on the roots, then the 2nd dose of all tested treatments were applied except Gold® and Nemacur®40% which applied once. The 3rd sampling collection, at harvest time (mid-August), was done after two months of the 2nd application to estimate numbers of nematode galls and egg masses/ g root fresh weight. Reductions of nematode parameters were expressed as percentages and calculated at mid grape season and at the end of the experiment using Mulla's formula [14] as follows: % Reduction= $100 - [(C_1 \div T_1) \times (T_2 \div C_2) \times 100]$ where C_1=pre-treatment population density in the check treatment; C_2=post-treatment population density in the check treatment habitat; T_1=pre-treatment population density in treatment; T_2=post-treatment population density in treatment. The same work was repeated in the second growing season. At the harvest date (mid-August) when the berries, in check treatment, reached the maturity stage (TSS =16-17%) according to Tourky *et al.* [15], shoot length, numbers of leaves and total yield were recorded on basis of individual vine and expressed as kg/vine. Samples of 5 clusters from each replicate of treatment were taken to determine the physical and chemical parameters of grapes. Grape cluster weight, length and width; weight, size and juice volume of 100 berries; berry length (L), diameter (D) and averages berry shape index (L/D) were recorded. The percentages of total soluble solids (TSS %) were measured using a hand refractometer (Carl Zeiss Jena 206675). Juice acidity was measured using 0.1N NaOH according to AOAC [16]. TSS/acidity ratio was also estimated. Chlorophyll contents were extracted using N, N-dimethyl formaldehyde and expressed as mg/g fresh tissue according to Moran [17].

Statistical Analysis: Data were statistically analyzed using the SAS software [18] and the treatment means were compared with the revised LSD test at the 5% level of probability.

RESULTS

Data presented in Table 1 showed the effect of 0.5 and 1 g/L concentrations of boric acid and sodium metasilicate and 1, 2, 5 and 10 ml/L concentrations of Nemacur®40% on egg hatching and J_2 mortality of *M. incognita*. Both the tested concentrations of boric acid and sodium metasilicate greatly reduced the percentages of egg hatching to be (89.0- 91.0 %) and (89.7-94.3%) reduction at 24 and 48h from incubation, respectively. The chemical nematicide, Nemacur®40% of 2, 5 and 10 ml/L concentrations reduced the percentages of egg hatching to be (80.7-97%) and (74.7-96.7%) reduction after 24 and 48h of incubation, respectively (Table 1). The mortalities % of hatched J_2 were 0.9 and 2.5% at 24 and 48h exposure time in the check treatment (Distilled water). Whereas, the mortalities % of hatched J_2 exposed to boric acid concentrations were (13.3 and 29.6%) and (24.2 and 53.3%) at 24 and 48h of incubation, respectively. Similarly, Na- metasilicate caused mortality % of (10.3 and 11.8 %) and (25.8 and 30%) at 24 and 48h exposure time, respectively. However, Nemacur®40% of 2-10 ml/L caused (18.9-100%) and (32.9-100%) mortalities at 24 and 48h exposure time, respectively. Data in Table 1 also indicated that all concentrations reduced numbers of hatched J_2 after 24 and 48h from exposure to different treatments. The highest reductions (97 and 96.7%) were achieved by Nemacur® treatment at 10 ml/L after 24 and 48h of exposure, respectively followed by the other tested treatments except 1 ml/ L of Nemacur® 40%. Mortalities of hatched J_2 were increased from 3.9 to 6.1 % in 1 ml/L Nemacur® 40% after 24 and 48h of exposure to be 100% with 10 ml/L.

The field experiments established to test the efficacy of different tested treatments against *M. incognita* are presented in Table 2. Results of the extracted J_2 from soil samples, in both seasons, showed few numbers of J_2/250g soil, which were not be able to show any response to the applied treatments. On the other hand, examination of grapevine roots showed recognizable numbers of

Table 1: Effect of boric acid, sodium metasilicate (Na-Si) and Nemacur® on number of hatched J_2 and percentages of egg hatching, reduction and J_2 mortality of *M. incognita* after 24 and 48 h of incubation

	Exposure time (h)							
	24				48			
Treatment & concentration	No. of hatched J_2 (75 eggs)	Hatchability %	Reduction %	Mortality %	No. of hatched J_2	Hatchability %	Reduction %	Mortality %
Check*	57.00 a	76.0	-	0.9	69.5 a	92.7	-	2.5
Boric acid (g/L)								
0.5	7.50 b	10.0	90.0	13.3	8.25 b	11.0	89.0	24.2
1.0	6.75 b	9.0	91.0	29.6	7.5 b	10.0	90.0	53.3
Na-Si (g/L)								
0.5	7.25 b	9.7	90.3	10.3	7.75 b	10.3	89.7	25.8
1.0	4.25 b	5.7	94.3	11.8	5.0 b	6.7	93.3	30.0
Nemacur® (ml/L)								
1.0	45.0 ab	60.0	40.0	3.9	49.25 ab	65.7	34.3	6.1
2.0	14.5 bc	19.3	80.7	18.9	19.0 bc	25.3	74.7	32.9
5.0	11.5 bc	15.3	84.7	95.7	12.75 bc	17.0	83.0	96.1
10.0	2.25 c	3.0	97.0	100	2.5 c	3.3	96.7	100

* = Distilled water. Values are mean of 4 replicates. Hatching % = (No. of hatched J_2 in treatment / total No. of incubated eggs) ×100. Reduction % = 100-Hatching %. Mortality % = (No. of dead J_2 in treatment / total No. of hatched J_2) × 100.

Table 2: Effect of boric acid, sodium metasilicate (Na-Si) and bio-products treatments on numbers of galls (G) and egg masses (EM) and reduction % (R) of *Meloidogyne incognita* infecting grape plants grown in field condition

	Initial (P_i) April		Mid-season June				At harvest (P_f) August			
Treatment	G	EM	G	R	EM	R	G	R	EM	R
					1st season					
Agree®	16.0	5.8	3.0 cd	87.4	1.1 bcd	90.0	4.0 bc	88.5	1.3 bc	92.2
Halex®	15.7	5.4	3.6 bcd	84.6	1.2 bcd	88.1	4.2 bc	87.7	1.3 bc	91.2
Gold®	15.5	3.4	2.1 d	91.0	0.7 d	88.1	1.7 c	95.0	0.4 c	96.1
Temastrol®	19.8	6.7	5.1 bcd	82.9	1.7 bcd	85.7	5.5 bc	87.3	1.9 bc	89.9
Jojoba	16.3	2.4	4.8 bcd	80.3	0.9 cd	78.8	4.8 bc	86.4	1.00 bc	85.3
Boric acid	28.2	10.2	6.6 b	84.4	2.4 b	87.2	7.1 b	88.5	3.0 b	89.6
Na-Si	21.6	7.4	5.7 bc	82.5	2.3 bc	82.9	6.8 b	85.6	3.0 b	85.3
Nemacur®	22.1	5.9	2.0 d	94.0	0.6 d	94.8	2.0 c	95.8	0.6 bc	96.2
Check	10.0	3.5	15.1 a	-	6.3 a	-	21.9 a	-	9.7 a	-
					2nd season					
Agree®	32.5	8.8	5.2 b	89.4	1.6 bc	94.8	7.2 b	89.9	1.8 b	97.3
Halex®	14.4	5.2	4.2 bc	80.4	1.5 bc	91.3	4.5 bc	85.7	1.6 b	95.9
Gold®	17.1	8.2	2.5 bc	90.3	1.3 bc	95.4	4.0 bc	89.1	2.4 b	96.0
Temastrol®	17.0	6.1	4.9 b	80.7	2.3 b	88.9	5.5 b	85.1	2.4 b	94.6
Jojoba	17.1	7.6	5.1 b	80.0	2.4 b	90.8	5.3 b	85.7	2.6 b	95.4
Boric acid	22.1	9.2	4.4 bc	86.7	1.8 bc	94.2	5.3 b	88.9	2.0 b	97.0
Na-Si	14.7	5.2	4.3 bc	80.4	1.8 bc	89.9	5.1 b	83.9	2.1 b	94.6
Nemacur®	14.1	3.6	1.6 c	92.6	0.4 c	96.9	1.8 c	94.2	0.4 b	98.4
Check	9.7	2.2	14.6 a	-	7.4 a	-	21.1 a	-	15.9 a	-

Data are averages of 4 replicates. Values, in each column, followed by the same letter(s) are not significantly different at P = 0.05 of LSD test. (R%) Reduction %= 100 – [($C_1 \times T_2$ / $C_2 \times T_1$)× 100] (Mulla's formula)

nematode root galls and egg masses as a response to the applied treatments. In both season, all treatments significantly ($p \leq 0.05$) reduced number of root galls and egg masses/g root fresh weight along the season till grape harvest time. In the 1st season, the highest reductions of nematode root galls (94 and 91%) and egg masses (94.8 and 88.1%)/g root fresh weight, were achieved by Nemacur® and Gold treatments, respectively at the mid-season, followed by treatment of Agree®, Halex®, Temastrol® and jojoba, which showed 80.3-87.4% reductions in galls and 85.7-90 % reductions in egg masses. Also, treatments with both boric acid and sodium metasilicate (Na-Si) showed 84.4 and 82.5% reductions in number of galls and 87.2 and 82.9% reductions in number of egg masses/g root fresh weight, respectively at the mid-season (June). Similar results were obtained at harvest time. The highest reduction % of galls (95 and 95.8%) and egg masses (96.1 and 96.2%) was obtained with Nemacur and Gold treatments, respectively (Table 2). The other treatments caused reductions of 85.6-88.5% in galls and 85.3-92.2% in egg masses/g root fresh weight. In the 2nd season, similar results were obtained at the mid-season and harvest time (Table 2). All the tested treatments reduced number of root galls and egg masses/g root fresh weight in comparison with the check treatment. However, no significant differences were detected among the applied treatments. The highest reductions % of galls (92.6 and 90.3%) and egg masses (96.9 and 95.4%)/g root fresh weight were achieved with Nemacur and Gold treatments, respectively followed by that of the other treatments. Likewise, at the harvest time, Nemacur, Gold® and Halex® initiated the highest reductions % in number of galls (94.2, 89.1 and 85.7%), respectively. Meanwhile, all applied treatments resulted in 94.6-98.4% reductions of egg masses/g root fresh weight.

Yield, Physical and Chemical Grape Properties: Data presented in Table 3 indicated that treatment applications of Gold, Temastrol, jojoba, boric acid and Na-Si increased grapevine shoot length in both seasons with 28.5-84.7% increase compared with the check treatment. In the 2nd season, the highest increases (84.7 and 75.6%) were recorded with jojoba and Na-Si treatments, respectively followed by those of boric acid (50.5%), Temastrol (42.2%), Nemacur (33%) and Gold (32.3%) treatments. Number of grapevine leaves was significantly increased with applying of Temastrol (60.9%), Halex (54.3%) and Gold (47.3%), in the 1st season (Table 3). Similar results were obtained in the 2nd season with Halex, Temastrol, Na-Si and Nemacur® with 44.1-83.7 % increases. The highest increase (83.7%) was recorded with Nemacur and Na-Si (52.1%) treatment applications. Results, also showed that grapevine yield was increased with Temastrol, jojoba, boric acid, Na-Si and Nemacur® application treatments with (193.3-376.1%) and (51.8-116 %) increases in the 1st and 2nd seasons, respectively compared with the check treatment. The highest increase was achieved with jojoba (367.1%) followed by boric acid, Temastrol and Na-Si treatments with (277.2-212.8%), in the 1st season. Whereas, boric acid achieved the highest increase % (116%) followed treatments of jojoba (79.8%), Temastrol (72.6%), Nemacur (59.1%) and Na-Si (51.8%) treatments, in the 2nd season.

In the 1st season, data of grapevine clusters showed that cluster weights were increased (41.3- 97.3%) with Agree, jojoba, boric acid and Na-Si treatments and with Agree, Temastrol, jojoba, boric acid, Na-Si and Nemacur® in the 2nd season with 41.3- 97.3% increases, in the 1st season and with 62.8-148.6 % increases, in the 2nd season (Table 3). The highest increase was achieved by jojoba and boric acid treatments (79.3 and 68.4%) and (120.6 and 148.6%), in the 1st and 2nd seasons, respectively. Similar results were obtained with grape cluster length, which increased with Agree (24.9%), boric acid (29.1%) and Na-Si (24.3%) treatments, in the 1st season and with boric acid, Na-Si and Nemacur with (29.7-21.9%) increase, in the 2nd season. Also, the grape cluster width was increased (25.4-44%) with Agree, Temastrol and jojoba, in the 1st season and with Agree, jojoba and boric acid in the 2nd season. Results of the effectiveness of the tested treatments on weight, size, juice volume of 100 grape berries and length (L), diameter (D) and L/D of grape berries are presented in Table 4. Jojoba and boric acid treatments increased the weight of 100 berries in the 1st season by 17.5-23.6 % compared with the check treatment. However, in the 2nd season, Agree, jojoba and boric acid treatments increased the weight of 100 berries by 22-27.7% compared with the check treatment. The size and juice volume of 100 grape berries were significantly increased with jojoba (25.6 and 30.4%), boric acid (27.8 and 38.5%) and Na-Si (15.4 and 18.3%), in the 1st season, respectively and with Agree (29.3 and 15.8%), jojoba (34.5 and 20.2%) and boric acid (37.9 and 35%), respectively, in the 2nd season (Table 4). Also, treatments of Gold and Temastrol increased the size of 100 berries by 15.5 and 19.8%, respectively, in the 2nd season. Characteristics of grape berries (Length, diameter and L/D) were not affected by any application treatments in the 1st season (Table 4). However, in the 2nd season, Gold, jojoba and boric acid increased the berry length by 8.4, 6.1 and 12%, respectively. Grape berry diameter and L/D were only increased with boric acid treatment with 7.8 and 4.8% increase compared with the check treatment.

Chemical properties of grapes (TSS%, acidity, TSS/acidity and chlorophyll contents) are presented in Table 5. Data indicated that only Halex treatment increased TSS by 9.8% in the 1st season. However, Agree, Halex, Gold and Nemacur treatments increased TSS in the 2nd season by 7.7-12.6% compared with the check treatment. The acidity of grape juice was decreased by 10.6-20.4% with Agree, Halex, Gold and Temastrol treatments compared with the check treatment, only in the 1st season. Results in Table 5 showed that Agree, Halex and Temastrol increased TSS/acidity by 18.7, 23.4 and

Table 3: Effect of boric acid, Na-metasilicate (Na-Si), jojoba and bio-products treatments on shoot length, Number of leaves, yield and clusters of grape plants and increase % (I) grown in *M. incognita* infested field condition

							Cluster					
Treatment	Shoot length (cm)	I	No. of leaves	I	Yield (kg/tree)	I	Weight (g)	I	Length (cm)	I	Width (cm)	I
						1st season						
Agree®	53.0 bc	-	20.5 c	-	2.75 d	-	376.0 bc	56.6	21.6 a	24.9	12.3 ab	29.5
Halex®	65.6 ab	-	28.4 a	54.3	2.70 d	-	189.9 e	-	16.9 c	-	10.9 bc	-
Gold®	73.0 a	37.7	27.1 ab	47.3	2.59 d	-	301.6 cd	-	19.7abc	-	9.8 c	-
Temastrol®	72.1 a	36.0	29.6 a	60.9	6.11 bc	239.4	233.7 de	-	17.5 bc	-	12.3 ab	29.5
Jojoba	68.1 a	28.5	22.4 bc	-	8.57 a	376.1	473.8 a	97.3	20.3 ab	-	13.3 a	40.0
Boric acid	70.0 a	32.1	20.8 c	-	6.79 b	277.2	404.4 ab	68.4	22.3 a	29.1	10.3 bc	-
Na-Si	68.1 a	28.5	21.0 c	-	5.63 bc	212.8	339.4 bc	41.3	21.5 a	24.3	10.3 bc	-
Nemacur®	48.8 c	-	20.8 c	-	5.28 c	193.3	303.1 cd	-	20.3 ab	-	10.7 bc	-
Check	53.0 bc	-	18.4 c	-	1.80 d	-	240.2 de	-	17.3 bc	-	9.5 c	-
						2nd season						
Agree®	82.4 cd	-	37.5abc	-	6.2 c	-	531.2 bc	101	24.0 bc	-	15. 7 b	25.4
Halex®	80.6 cd	-	39.6 ab	50.6	5.7 c	-	330.5 ef	-	22.3 c	-	13.3 c	-
Gold®	83.1 c	32.3	35.8 bc	-	5.1 c	-	343.9 def	-	23.7 bc	-	10.5 d	-
Temastrol®	89.3 c	42.2	37.9 ab	44.1	8.9 b	72.6	450.0 cd	70.2	23.8 bc	-	14.3 bc	-
Jojoba	116.0 a	84.7	35.9 bc	-	9.2 b	79.8	583.1 ab	120.6	23.3 bc	-	18.0 a	44.0
Boric acid	94.5 bc	50.5	33.8 bc	-	11.1 a	116	657.2 a	148.6	27. 7 a	29.7	15.7 b	25.4
Na-Si	110.3 ab	75.6	40.0 ab	52.1	7.8 b	51.8	430.3 cde	62.8	26.0 ab	21.9	13.3 c	-
Nemacur®	83.5 c	33.0	48.3 a	83.7	8.2 b	59.1	490.8 bc	85.7	26.0 ab	21.9	13.7 bc	-
Check	62.8 d	-	26.3 c	-	5.1 c	-	264.3 f	-	21.3 c	-	12.5 cd	-

Table 4: Effect of boric acid, Na-metasilicate (Na-Si), jojoba and bio-products treatments on weight, size and juice volume of 100 berries and length (L), width (D), L/D of berries and increase % (I) of grape plants grown in *M. incognita* infested field

	100 berries						Berry					
Treatment	Weight (g)	I	Size (ml)	I	Juice volume (ml)	I	Length (mm)	I	Diameter (mm)	I	L/D	I
						1st season						
Agree®	182.1 c	-	167.0 bc	-	104.9 bcd	-	17.4 ab	-	13.6 b	-	1.28 a	-
Halex®	189.8 c	-	170.8 bc	-	98.0 c	-	17.2 ab	-	13.7 ab	-	1.25 a	-
Gold®	190.7 c	-	173.3 bc	-	103.9 bcd	-	17.1 ab	-	13.5 b	-	1.27 a	-
Temastrol®	185.8 c	-	169.0 bc	-	99.1 cd	-	16.3 b	-	13.9 ab	-	1.18 a	-
Jojoba	212.8 ab	17.6	203.3 a	25.6	118.0 a	30.4	18.0 a	-	14.2 a	-	1.27 a	-
Boric acid	223.8 a	23.6	206.7 a	27.8	125.3 a	38.5	17.0 ab	-	14.0 ab	-	1.22 a	-
Na-Si	200.2 bc	-	186.7 ab	15.4	107.1 bc	18.3	17.6 ab	-	13.7 b	-	1.29 a	-
Nemacur®	182.5 c	-	173.3 bc	-	105.3 bcd	-	16.6 ab	-	13.6 b	-	1.22 a	-
Check	181.0 c	-	161.8 c	-	90.5 d	-	17.8 ab	-	13.9 ab	-	1.28 a	-
						2nd season						
Agree®	263.6 ab	22.0	250.0 abc	29.3	141.3 bc	15.8	17.6 d	-	14.3 b	-	1.23 c	-
Halex®	216.3 c	-	203.3 def	-	120 def	-	18.1 cd	-	14.2 b	-	1.28 abc	-
Gold®	239.6 bc	-	223.3 cde	15.5	130 cde	-	19.0 ab	8.4	14.8 ab	-	1.29 abc	-
Temastrol®	235.8 bc	-	231.6 bcd	19.8	131.5 cd	-	17.5 d	-	14.0 b	-	1.25 abc	-
Jojoba	274.7 a	27.1	260.00 ab	34.5	146.7 b	20.2	18.6 bc	6.1	14.7 ab	-	1.27 abc	-
Boric acid	276.0 a	27.7	266.67 a	37.9	164.7 a	35.0	19.6 a	12	15.2 a	7.8	1.30 a	4.8
Na-Si	206.1 c	-	193.33 f	-	115.8 f	-	18.0 cd	-	14.1 b	-	1.28 abc	-
Nemacur®	209.7 c	-	196.67 ef	-	118.0 ef	-	18.0 cd	-	13.9 b	-	1.29 ab	-
Check	216.1 c	-	193.33 f	-	122 def	-	17.5 d	-	14.1 b	-	1.24 bc	-

Table 5: Effect of boric acid, Na-metasilicate (Na-Si), jojoba and bio-products treatments on TSS %, acidity (A), TSS/A, chlorophyll (Chl) contents (mg/g fresh weight) and change % of grape plants grown in *M. incognita* infested field condition

Treatment	TSS %	Increase %	A	Reduction %	TSS/A	Increase %	Chl (mg/g)	Increase %
				1st season				
Agree®	17.27 c	-	0.580 c	12.5	29.9 ab	18.7	46.04 ab	-
Halex®	18.33 a	9.8	0.593 bc	10.6	31.1 a	23.4	34.08 b	-
Gold®	16.36 c	-	0.583 bc	12.1	28.2 abc	-	48.06 a	35.4
Temastrol	16.33 c	-	0.528 c	20.4	31.3 a	24.2	34.86 b	-
Jojoba	16.67 bc	-	0.633 ab	-	27.0 bc	-	41.98 ab	-
Boric acid	17.05 bc	-	0.633 ab	-	26.9 bc	-	52.6 a	48.2
Na-Si	16.70 bc	-	0.675 a	-	24.8 c	-	44.4 ab	-
Nemacur®	16.83 bc	-	0.633 ab	-	26.9 bc	-	44.6 ab	-
Check	16.7 bc	-	0.663 a	-	25.2 c	-	35.5 b	-
				2nd season				
Agree®	19.33 a	12.6	0.750 a	-	26.41 a	12.3	76.17 ab	49.6
Halex®	18.67 ab	8.7	0.760 a	-	24.75 abcd	-	59.13 cd	-
Gold®	18.50 ab	7.7	0.720 a	-	25.72 ab	9.4	73.07 abc	43.6
Temastrol	17.17 c	-	0.740 a	-	23.23 d	-	67.72 bc	33.0
Jojoba	17.17 c	-	0.720 a	-	23.74 cd	-	72.36 abc	42.2
Boric acid	18.17 abc	-	0.750 a	-	24.21 bcd	-	85.54 a	68.1
Na-Si	17.50 bc	-	0.710 a	-	24.82 abcd	-	67.39 bc	32.4
Nemacur®	18.50 ab	7.7	0.730 a	-	25.34 abc	-	65.98 bc	29.6
Check	17.17 c	-	0.730 a	-	23.51 cd	-	50.9 d	-

24.2 %, respectively, in the 1st season and with Agree and Gold in the 2nd season by 12.3 and 9.4 %, respectively compared with the check treatment. Leaf chlorophyll contents were increased, in the 1st season, with treatments of Gold and boric acid by 35.4 and 48.2%, respectively. However, all the tested treatments except Halex increased chlorophyll contents, in the 2nd season, by 29.6-68.1% compared with the check treatment. The highest increase was recorded with boric acid (68.1%), Agree (49.6%), Gold (43.6%) and jojoba (42.2%) application treatments.

DISCUSSION

Data of both tested concentrations (0.5 and 1 g/L) of boric acid and sodium metasilicate (Na-Si), greatly reduced the percentage of egg hatching and increased mortality % of *M. incognita* similar to that achieved by Nemacur 40%. The highest reductions were achieved by Nemacur® treatment followed by the other tested treatments. The efficacy of some organic acids on survival and hatching of some plant-parasitic nematodes has been studied by many researchers. Cox [19] and Saad *et al.*[20] stated that boric acid and its salts are active ingredients of pesticide products used against insects, spiders, mites, algae, molds, fungi and weeds. Al-Sayed *et al*. [21] found that the egg hatching and larval emergence from egg masses of *M. incognita* and *Rotylenchulus reniformis* were obviously influenced by concentrations of some organic acids. They found that the values of egg hatchability of both nematode species of the lowest concentrations of boric acid did not differ from that in distilled water. Likewise, silicon (Si) has been reported to be effectively managed some pests and diseases of plants. Qin and Tian [22] reported that exogenous application of Si in the form of sodium metasilicate reduced disease development caused by *Penicillium expansum* and *Monilinia fructicola* in sweet cherry fruit and the inhibition of fruit decay was correlated closely with Si concentrations. Miller and Faske [23] found that 364.4 µg/ml Si (26.6% SiO_2) applied as a root dipping reduced nematode reproduction compared to applying Si near roots in soil. Data regarding the extracted J_2 from soil samples, in both seasons, showed a few J_2 numbers. For this reason, we ignored its numbers. On the other hand, examination of grapevine roots showed recognizable numbers of nematode root galls and egg masses as a response to the applied treatments. This may be attributed to high susceptibility of Thompson seedless grapes to the root-knot nematode species existing in the soil (*M. incognita*) and suitable environmental conditions, which were fit nematode multiplication inside the root. Therefore, a small numbers of egg sacs were existed outside the roots.

Our results indicated that in both seasons all treatments significantly reduced number of root galls and egg masses/g root fresh weight along the season till grape harvest time. The highest reduction of nematode root galls was achieved by Nemacur® and Gold treatments followed by that of the other treatments. Boric acid and Na-Si showed 82.5- 87.2% reductions in numbers of galls and egg masses. Similar results were obtained by El-Nagdi *et al*. [4], who observed that jojoba oil treatment reduced the population density of nematodes on table grapes and improved yield, physical and chemical characteristics of berries. Mervat *et al.* [5] found that jojoba oil was effective treatment in reducing total population and build up rate of *M. incognita* in both soil and roots up to the harvesting time. El-Nagdi and Youssef [7] reported that Abamectin 1.8% caused nematode reduction in the number of J_2 in soil and roots and in the number of galls. Dugui *et al.* [4] found that application of Si at the rate 200 µg/ml significantly reduced number of galls in inoculated plants. However, root application of Si at the rate of 400 µg/ ml gave the lowest number of egg masses. El-Nagdi *et al*. [12] found that Agerin®, which containing *B. thuringiensis* and Abamectin®, containing *S. avermitilis* reduced the citrus nematode and markedly improved nutritional status, yield and fruit quality of mandarin. The positive action of "Agerin®" and Bionema® products in enhancing growth and vine nutritional status could reflect in increasing the quality of the berries [24, 25].

Studies aiming at searching for appropriate biocontrol agents found high levels of Bt toxicity against nematodes [26]. The mechanism of Cry toxins action in nematodes is similar to that on insects, correlating with damage to the intestine. Symptoms of nematode poisoning include lethargy, reduced size, pale coloration and contraction, vacuolation and degeneration of the intestine [27]. It has been shown that *B. thuringiensis* subspecies *aizawai* produces chitinases that are used against phytopathogenic fungi, which attack their cell wall and, thus, inhibit growth of the fungus. Chitinolytic enzymes of *B. thuringiensis* have been selected and characterized; hence, it is concluded that the synergistic action between the chitinases and the Cry proteins can be used in biological control of plant pathogens. Shawky *et al.* [28] reported that orange oil could provide abundant sources of secondary metabolites and enhance biological activities against the target nematode. Treatment applications of Gold, Temastrol, jojoba, boric acid and Na-Si increased grapevine shoot length, numbers of grapevine leaves in both seasons compared with the check treatment. The highest increase was recorded with jojoba and Na-Si treatments followed by that of boric acid, Temastrol, Nemacur and Gold treatments.

Grapevine yield; cluster weight and length; weight, size and juice volume of 100 grape berries were increased with Agree, Temastrol, jojoba, boric acid, Na-Si and Nemacur® application treatments compared with the check treatment. The highest increase was achieved with jojoba and boric acid treatments. Also, Gold, jojoba and boric acid increased the berry length. Grape berry diameter and L/D were only increased with boric acid treatment, in the 1st season. These findings are in line with those reported by Nijjar [29], who stated that boron plays an important role in movement of natural hormones and encouragement of both cell division and cell enlargement. The enhancement of growth by boric acid may be attributed to possible effects in stimulating the biosynthesis of organic materials, especially carbohydrates and proteins and enhancement of the formation and movement of natural hormones, which are vital to improved cell division, especially in the meristematic tissues. Ahmed and Abd El-Hameed [30] found that boric acid caused considerable increases in cluster weight and physical parameters of "Red Roomy" vines. Marschner *et al.*[31] observed that an improvement of plant growth by addition of Si may be occur for higher mechanical stability of stems and leaf blades and thus better light interception. Wojcik *et al.* [32] explained the increase in yield of apple to increase in fruit size and fruit number through soil application and foliar spray of Si, respectively.

El-Nagdi *et al.* [4], El-Nagdi and Youssef [7] and El-Nagdi *et al.* [12] found that Abamectin and jojoba oil improved growth of grape and citrus under nematode condition attributed to faster absorption of water and nutrients via roots. El-Nagdi *et al.* [4] found that jojoba oil applied as combined (foliar spraying + soil drench) increased grapevine yield, cluster weight and dimensions as compared to the check plants in both seasons for Superior, Flame and Crimson seedless grapes. Dugui *et al.* [8] found that leaf and root application of Si significantly increased fresh top weight of inoculated and non-inoculated plants. They found that application of Si at the rate 200 µg/ml increased the marketable yield compared to the higher rate of Si (400µg/ml). Kamilogu [33] concluded that adopting some cultural practices along with application of boron increased yield, cluster weight as well as berries per cluster of table grape cv. Horozkarasi. El-Sayed *et al.* [34] reported that boric acid caused an increase in cluster length and juice percent of "Ruby seedless" grape. Mervat *et al.* [5] found that jojoba oil was effective treatment in increasing cluster weight, number of clusters, yield per vine as well as enhancing the physical characteristics of berries, TSS %, TSS/acidity ratio whereas, acidity was decreased in berry juice and improved vegetative growth parameters and increased the total surface area/vine, wood ripening coefficient, total chlorophyll and percentages of total nitrogen, phosphorus and potassium of leaves. Ganie *et al.* [35] observed that boron fertilization regardless of application increases fruit yield and quality of temperate fruits. Vasanthi *et al.* [10] reported that Si is accumulated in plants higher than the essential major nutrients. Although it is not considered as an essential element it is accepted as an agronomically beneficial element as it confers rigidity and strength, resistance against pests and diseases, improves water economy by reducing transpiration rate, alleviates the ill effects of abiotic stresses and enhances crop yield.

Our results also indicated that Agree, Halex, Gold and Nemacur treatments increased TSS. However, acidity of grape juice was decreased with Agree, Halex, Gold and Temastrol treatments compared with the check treatment. Agree, Halex and Temastrol increased TSS/acidity, in the 1st season and with Agree and Gold, in the 2nd season. Similar results were obtained by Mervat *et al.* [5], El-Sheikh *et al.* [11], El-Nagdi *et al.* [12], Lang [36], Spayed *et al.* [37], Martine *et al.* [38], Stino *et al.* [39], Abd El-Razek *et al.* [40] and Khalil [41]. Lang [36] Spayed *et al.* [37], Martine *et al.* [38] and Abd El-Razek *et al.* [40] reported that high potassium fertilization resulted in an increase of total soluble solids and decrease of acid concentration in grape and interact with tartaric acid to form potassium bitartrate which has limited solubility. Due to this, potassium is the most abundant cation, which contributes to change balance and may be involved in sugar transport. El-Sheikh *et al.* [11] and Ahmed *et al.* [24] found that bionema reduced acidity in Thompson seedless cultivar. On the other hand, El-Sayed *et al.* [34] found that acidity of Ruby seedless cultivar was not affected by boric acid and sodium metasilicate applications. El-Nagdi *et al.* [12] found that "Agerin" containing an isolate of *B. thuringiensis* increased TSS% of mandarin. Khalil [41] reported that biofertilizer namely Halex significantly increased TSS% of "Flame seedless grapevines". The benefit of using bio-fertilizer namely Halex is due to the activation of *Azospirillum* and *Azotobacter* to fix N_2 gas from soil atmosphere to become ammonium N. Abd El-Razek *et al.* [40] found that increasing N supply improved vegetative growth of Crimson seedless cultivar. Therefore, increase in leaf content of nitrogen leads to increase photosynthesis of carbohydrates in the leaves [39].

Leaf chlorophyll contents were increased, with Gold and boric acid treatments, in the 1st season. However, all the tested treatments except Halex increased chlorophyll contents, in the 2nd season. The highest increase was recorded with boric acid, Agree, Gold and jojoba application treatments. Similarly, Mervat *et al.* [5] found that jojoba oil was effective treatment in increasing cluster weight, number of clusters, yield per vine as well as enhancing the physical characteristics of berries, TSS %, TSS/acidity ratio whereas, acidity was decreased in berry juice and improved vegetative growth parameters and increased the total surface area/vine, wood ripening coefficient, total chlorophyll and percentages of total nitrogen, phosphorus and potassium of leaves. Thuroz *et al.* [42] observed an increase in the photosynthetic pigment contents like chlorophylls and carotenoids by foliar application of boron in sweet cherry at full bloom. Due to this, the increase in the rate of photosynthesis is expected.

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