

Chapter

Responses of Tree Tomato (*Solanum betaceum*) Varieties to Root-Knot Nematodes (*Meloidogyne* Spp.)

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Abstract

Tree tomato (*Solanum betaceum* Cav.) is an important fruit in Kenya with growing popularity among farmers and consumers due to potential as an income earner and health benefits. The fruit generate rural income and enhances food and nutritional security. Root-knot nematodes (RKNs) pose a major threat to its production. This study determined responses of six tree tomato varieties (goldmine, ruby red, rothamer and red oratia, red light oratia, and grafted) to RKN infection. Rhizosphere soil and roots from 216 plants were collected. Nematodes were extracted and enumerated from 200 cm³ of soil and 5 grams of roots using modified Baermann tray method. Under greenhouse, seedlings were inoculated with 2000 J2s per pot replicated four times in completely randomized design. Under field, experiments were established in naturally infested field at Kenyatta University and treatments replicated thrice in randomized complete block design. BioNematon-treated plots served as absolute control. Data on plant growth and disease parameters were subjected to analysis of variance using SAS software version 9.1. Means were separated using Tukey's Honestly Significant Difference (HSD) at $P \leq 0.05$. Regression and t-test analysis were done to check for relationships between parameters and significant differences between means, respectively. Based on the nematode reproduction factor rated on 0–5 scale, ruby red, rothamer, and red oratia were moderately resistant both in both tests. Red light oratia and grafted tree tomato were moderately resistant in the greenhouse but tolerant in the field. Moderately resistant and tolerant varieties should be promoted to farmers to manage RKNs in tree tomato.

Keywords: tree tomato, root-knot nematodes, food security, nematode reproduction, plant resistance

1. Introduction

Tree tomato also called tamarillo (*Solanum betaceum* CAV.), is a native fruit to the South American Andes and is currently grown worldwide [1, 2]. Production of tree tomato in Kenya was 5111 and 7433 metric tons for years 2014 and 2016, respectively [3]. Apart from trade, the tree tomato fruit is used as fresh fruit juice and in food processing industries. The fruit is rich in vitamins A, B, C, E, calcium, iron, phosphorus, anthocyanin, and antioxidants [4] and therefore important for nutritional security. Anthocyanins present protect the body against diabetes, aging and neurological disorders [4]. The lycopene present keeps off degenerative diseases, improves heart health, and helps the skin's ability to withstand UV radiation [4]. Lycopene is also associated with decreased incidence of several types of cancers, including breast cancer and prostate cancer [5]. Six main varieties of tree tomatoes are grown in Kenya which include goldmine, rothamer, red oratia, ruby red, red light oratia and tree tomato grafted on *Solanum mauritianum* rootstock.

The major challenge facing tree tomato farming in Kenya is infestation by plant-parasitic nematodes (PPN) [6]. Among the PPNs, root-knot nematodes (*Meloidogyne* spp.) are the most serious crop-damaging pest that are polyphagous and are widely distributed in many farming systems [7, 8]. Root-knot nematodes causes root gall-ing which interferes with water and nutrient uptake [9]. In a study conducted in Colombia, *Meloidogyne*, *Helicotylenchus* and *Pratylenchus* were associated with tree tomato cultivation [1].

Root-knot nematodes in tree tomato have been managed through use of chemical nematicides and crop rotation. However, nematicides are harmful to the environment and human health, lose efficacy after prolonged use and are expensive, hence, increasing the cost of production. The use of resistant tree tomato varieties can be the most effective, economical and ecofriendly method of managing RKNs. This study determined the responses of six tree tomato varieties to RKNs under greenhouse and field conditions.

2. Literature review

2.1 Origin and biology of tree tomato

Tree tomato (*Solanum betaceum* Cav.), also known as “tamarillo,” belongs to the Solanaceae family that originated from the Andean region of Latin America. Tree tomato is also grown throughout sub-tropical and tropical areas in Colombia, Peru, New Zealand, Haiti, Mexico, Malaysia and Uganda [9]. The name tamarillo was coined in New Zealand [1]. According to the Oxfarm Organic report of 2017 (<http://www.oxfarmorganic.com/our-products/tree-tomato/tips-on-how-to-get-over20kgs-tree-from-tree-tomato-farming/>) [10], tree tomatoes were introduced in Kenya by Asians in the late 1800s.

Tree tomato is a perennial plant that grows to a height of about 2–3 m and reaches its maximum yield at 4–5 years [1, 9]. Tree tomatoes produce fruits for up to 10 years [11]. The trees grow between 600 and 3000 m above sea level with optimum growth temperature of 16–20°C, soil pH values of 5.6–7.7, and prefer sandy soils, but the presence of organic matter improves its growth [1]. In developing countries, tree tomato is a subsistence crop cataloged as a marginal species [2], while in Kenya, it is cultivated as a smallholder fruit tree [12].

Tree tomatoes have a very shallow root system that is not very much extensive and grows by forming a single woody trunk at the base and form branches at a height

of about 1.5–2 m [11]. It has large simple leaves and produces fragrant flowers with pink-white corolla in clusters of 10–50 hanging on the branches [11]. Flowers are self-pollinated by wind or insects, while the fruits are oval and about 4–8 cm long and 3–5 cm wide although variations do exist [11]. Tamarillo fruits contain very many seeds while the skin color of fruits ranges between yellow, purple and orange and sometimes with longitudinal stripes [11].

2.2 Tree tomato varieties and their production in Kenya

The main varieties of tree tomato grown in Kenya are the goldmine, Inca red, rothamer, solid gold, red oratia, grafted and ruby red (<https://www.crfg.org/pubs/ff/tamarillo.html>). All varieties of tree tomato are reported to be affected by plant parasitic nematodes but not unequally [13]. In Kenya, tree tomato is mainly grown in highland areas of Kiambu, Nyeri, Embu, Meru, Nyandarua and many Rift valley regions. The fruit is grown alongside other crops like tea, coffee, vegetable crops, and other fruit crops.

There are about eight cultivars known worldwide: Equatorian orange cultivar fruit is medium orange in color with light orange pulp, creamy in texture and less acidic than the ruby red. It is excellent for eating out of hand and suitable for culinary purposes. Red oratia (**Figure 1**) is a large red fruit cultivar that is oval to round in shape with a sharp acidic flavor. Good quality for eating out of hand and excellent for jams and preserves. Goldmine (**Figure 1**) is a superior cultivar originating in New Zealand, and it was recently introduced in Kenya. It is a very large golden-yellow fruit with golden, highly flavored flesh, less bland than solid gold, but not acidic and has superb eating qualities (<https://www.crfg.org/pubs/ff/tamarillo.html>).

Ruby red (**Figure 1**) is a large, brilliant red fruit with a dark red pulp that is tart and flavorful. Fair for eating out of hand, but very good for culinary use. When allowed to ripen for one to three weeks after picking, they become less acidic. Inca gold is a yellow-fruited cultivar that is less acidic than the red types. When cooked, the fruit resembles the apricot in flavor while solid gold is a large, oval-shaped fruit with a golden-orange skin in color. The pulp of solid gold fruit is soft, less acidic in flavor than red oratia and generally very good for eating out of hand, with acceptable culinary qualities.

Rothamer (**Figure 1**) on the other hand is a large fruit with bright red skin. The flesh of the fruit is golden-yellow with a sweet flavor and exotic with dark red seeds. The fruit ripens from December to April. It is delicious, eaten out of hand, and a vigorously heavy-bearing plant.

Grafted tree tomato varieties are also grown in Kenya. Grafting is done to improve production, resist pests and diseases, and enhance early maturity and longer lifespan. Grafting of tree tomato is done with a bug weed (*Muthakwa*) scientifically known as *Solanum mauritianum*, a wild tree that naturally grows in any conditions. *Muthakwa* has tap root system and is resistant to *Ralstonia*. The extensive taproot system makes it ideal for improved nutrient intake and efficient water absorption which makes the plant resist drought [14]. Propagation has also been done using cuttings. However, plants produced from cuttings do not grow tall and tend to be bushy [11].

Tree tomatoes are attacked by PPNs, insect pests such as aphids, greenhouse whitefly, tomato worm, thrips, green vegetable bug, fruit flies, snails, and slugs [11]. Fungal diseases include powdery mildews, tomato leaf spot, root rot, and anthracnose. Bacterial diseases that infect tree tomatoes include bacterial canker, bacterial blast and crown canker. Viruses have also been reported to affect tree tomato. They include tomato mosaic virus, cucumber mosaic virus, alfalfa mosaic virus, tomato spotted wilt virus, arabis mosaic virus, tobacco mosaic virus, and tomato aspermy

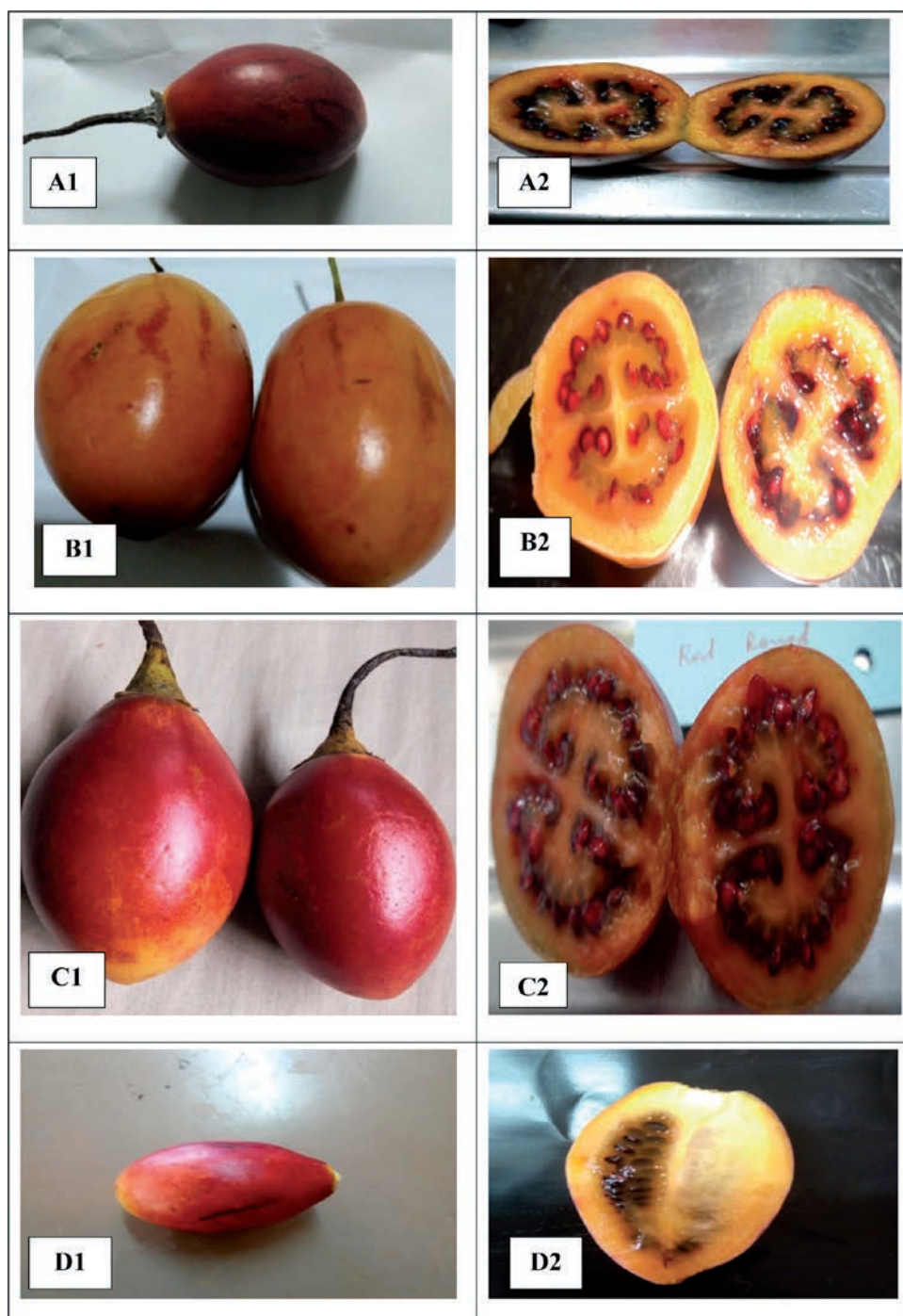


Figure 1.
A1 and A2 = Red oratia whole fruit and transverse section; B1 and B2 = Goldmine whole fruit and transverse section; C1 and C2 = Ruby Red whole fruits and transverse section; D1 and D2 = Rothamer whole fruit and longitudinal section. Source: Own photos from the field in Kiambu and Embu counties, Kenya.

virus [2, 11, 13]. Other production constraints are moisture stress, lack of suitable varieties and certified planting materials, and limited knowledge on appropriate agronomic and post-harvest practices [12].

2.3 Economic importance and health benefits of tree tomato

Tree tomato like other horticultural crops plays a critical role in the economy of developing nations [15]. In 2014, the area, production, and value of tree tomato in Kenya were 619 ha, 5111 tons, and KES.156.3 million, respectively [3] while in 2016 it was 873 ha, 7434 tons, and KES.341.7 million, respectively [16]. The fruit is rich in vitamins A, B, C, E, calcium, iron, phosphorus, and antioxidants. They also contain anthocyanin, which protects the body against diabetes, aging and neurological disorders [4]. The lycopene present keeps off degenerative diseases, improves heart health, and helps the skin's ability to withstand UV radiation [4]. Lycopene is also associated with decreased incidence of several types of cancers, including breast cancer and prostate cancer [5].

3. Materials and methods

Four-week-old seedlings of six tree tomato varieties of Goldmine, Ruby Red, Rothamer, Red Oratia, Red Light Oratia and grafted were planted in the greenhouse in pots containing three kilograms of sterilized soil (2:1, sand:soil mixture) and in the field. The populations of RKN inoculum for resistance screening were multiplied on a susceptible tomato variety (Carl-J). Nematode eggs were extracted by cutting the tomato roots into 1 cm pieces and agitating in 0.5% NaOCl for four minutes [17]. The resultant suspension was washed through 106 and 20 μ m sieves with distilled water and incubated. Seedlings in the greenhouse were inoculated with 2000 freshly hatched *Meloidogyne* J2s around the roots seven days after transplanting. Uninoculated plants served as controls. The treatments were labeled and arranged in a completely randomized design with four replicates each at Kenyatta University in the plant sciences greenhouse. The plants were regularly watered as required. In the field, seedlings were planted in a naturally nematode-infested field at Kenyatta University agriculture farm in 3m $\times$ 3m plots. The treatments were replicated thrice in randomized complete block design, making a total of 18 plots of nematode infestation, each having 12 plants, giving a total of 216 tree tomato plants. The same treatments were applied to nematode-infested plots treated with BioNematon nematocide as control. The BioNematon was prepared by diluting 20 ml of the stock suspension containing 1×10^8 spores/ml in 20 L of distilled water and applied at 40 ml per planting hole at planting and at 40 days after planting to check nematode population on control plots. Initial and final nematode populations were determined for each plot before and after the experiments, respectively. After 90 days, the seedlings were uprooted, and plant growth and disease parameters were evaluated as follows:

3.1 Plant growth parameters evaluated

3.1.1 Shoot height

The height of each plant was taken from the first basal node to the shoot apex using a string, transferred onto a ruler and recorded in centimeters.

3.1.2 Dry weight

The plants were gently uprooted and cut at the first basal node to separate the shoots from roots and dried separately in an oven at 60°C to a constant mass and their weights were recorded in grams.

3.2 RKN disease parameters evaluated

3.2.1 Gallings and egg mass indices

Root systems were washed individually and scored for galling indices. Galled roots were stained in phloxine B and scored for egg mass indices. Gallings and egg mass indices were scored on a scale of 0–5 where, 0 = no gall or egg masses, 1 = 1–2 galls or egg masses, 2 = 3–10 galls or egg masses, 3 = 11–30 galls or egg masses, 4 = 31–100 galls or egg masses and 5 = > 100 galls or egg masses per root system [18, 19].

3.2.2 Endoparasitic nematodes in plant tissues

Another 5 g of the root sample per treatment was stained with Acid Fuchsin for viewing endoparasitic nematodes. The roots were cleared in dilute sodium hypochloride (5.25% NaOCl) for 4 minutes using the sodium-hypochlorite acid fuchsin method described by Byrd et al. [20]. The roots were then rinsed in 100 µm sieve to remove traces of the bleach and stained as described by Hooper et al. [21]. The stained nematodes were enumerated under a stereomicroscope at ×100.

3.2.3 Number of J2s in the soil and roots

Root-knot nematodes were extracted from 200 cm³ of soil and 5 g of roots using the modified Bearmann extraction tray method as described by Hooper et al. [21]. The roots were cut to 1 cm and blended in 100 ml of water before extraction.

3.2.4 RKN reproduction factor (Rf)

Resistance and susceptibility of tree tomato varieties was based on nematode reproduction factor (Rf) for each variety calculated as a ratio of pf/pi and rated as Rf ≤ 0 = resistant, Rf > 0 < 1 = moderately resistant, Rf > 1 ≥ 5.0 = tolerant and Rf > 5.0 = susceptible [22].

Data on shoot height, dry weights, J2 populations, gallings and egg mass indices and nematode Rf were subjected to analysis of variance using SAS software version 9.1. Relationship between gallings index (GI) and J2s was determined using regression analysis.

4. Results

4.1 Plant growth parameters in the greenhouse

The shoot heights of inoculated and un-inoculated tree tomato varieties were significantly different ($P \leq 0.05$) from each other, apart from Ruby red. All RKN inoculated varieties recorded lower shoot heights as compared to the control plants (Table 1 and Figure 2).

Treatment	SH(cm)	DSW(g)	DRW(g)
Goldmine+N	38.40 ± 6.64c	6.57 ± 0.93f	2.22 ± 0.99d
Goldmine-N	43.50 ± 5.26a	11.42 ± 1.24d	5.51 ± 2.23b
Ruby red+N	38.68 ± 2.91c	6.49 ± 0.98f	1.47 ± 0.39e
Ruby red-N	38.88 ± 1.53c	7.47 ± 0.80e	1.71 ± 0.65e
Rothamer+N	37.60 ± 2.34d	4.95 ± 1.52 h	1.83 ± 0.70e
Rothamer-N	42.63 ± 4.28b	6.78 ± 0.71f	0.70 ± 0.24f
Red oratia+N	36.75 ± 4.42e	5.71 ± 0.58 g	1.76 ± 0.56e
Red oratia-N	37.45 ± 2.88d	11.02 ± 1.92d	2.19 ± 0.59d
Red L.O + N	33.40 ± 7.51f	16.87 ± 2.41b	12.21 ± 4.89a
Red L.O-N	36.13 ± 3.99e	22.26 ± 2.84a	5.95 ± 1.17b
Grafted+N	28.00 ± 4.02 h	7.56 ± 2.40e	1.82 ± 0.70e
Grafted-N	31.55 ± 2.99 g	12.37 ± 2.49c	3.82 ± 1.58c
P-Value	0.0003	<.0001	0.0025

Means followed by the same letter(s) in the same column are not significantly different ($P \geq 0.05$) according to Tukey's Honestly Significant Difference (HSD). Red L.O = Red light oratia. +N = inoculated with nematodes; -N = un-inoculated treatments.

Table 1.

Effect of root-knot nematodes on mean shoot height (SH), dry shoot weight (DSW) and dry root weight (DRW) of tree tomato varieties in greenhouse experiment (June–September 2019).

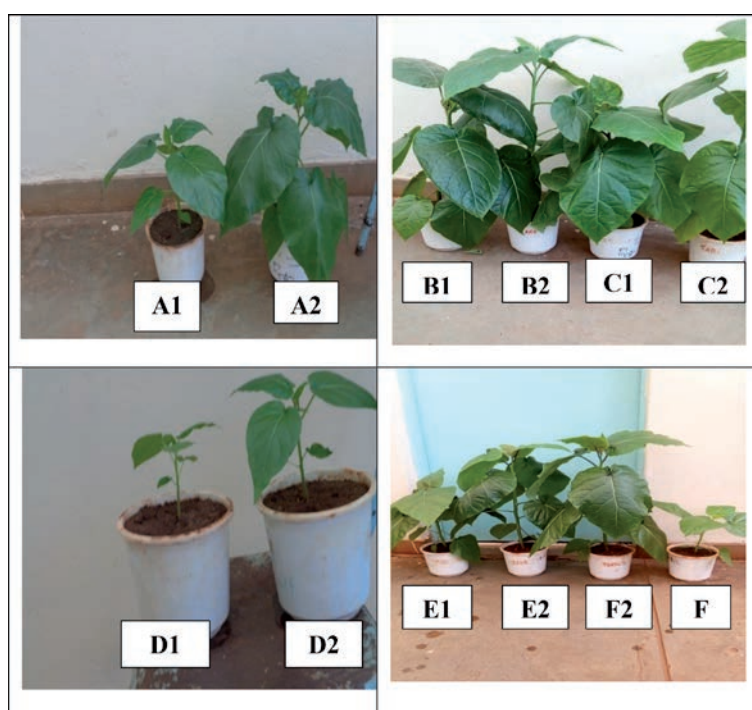


Figure 2.

A1 and A2 = inoculated and un-inoculated red light oratia, B1 and B2 = inoculated and un-inoculated rothamer, C1 and C2 = inoculated and un-inoculated goldmine, D1 and D2 = inoculated and un-inoculated ruby red, E1 and E2 = inoculated and un-inoculated Red oratia and F2 and F1 = uninoculated and inoculated grafted variety in greenhouse experiment. Photos were taken at the end of 90-day period.

The mean dry shoot weight of plants grown on nematode-inoculated soils were lower than that of plants grown on un-inoculated soils for all the tree tomato varieties. There were significant differences ($P \leq 0.05$) between the mean dry shoot weight of plants grown on inoculated and uninoculated soils (**Table 1**).

There were significant differences ($P \leq 0.05$) in the mean dry root weight (DRW) of tree tomato on both inoculated and uninoculated soil. All the tree tomato varieties grown on nematode inoculated soils had their DRW lower than the control treatment except for the cultivar Rothamer and Red light oratia (**Table 1**).

4.2 Root-knot nematode disease parameters in the greenhouse

The mean number of J2s per 5 g of roots was significantly different ($P \leq 0.05$) between varieties except between Ruby red and Red oratia. There were also significant differences ($P \leq 0.05$) in the mean numbers of J2s (pf) per 200 cm³ of soil in all the tree tomato varieties (**Table 2**).

The mean RKN reproduction factor (Rf) was significantly higher ($P \leq 0.05$) for goldmine compared to other varieties (**Table 2**). Based on the Rf rating, goldmine variety was tolerant (Rf = 4.58) while all the other remaining varieties were moderately resistant in the greenhouse (**Table 2**). A regression analysis revealed a positive significant linear relationship between RKN Rf and nematode gall indices in roots of tree tomato varieties in the greenhouse (**Figure 3**).

The mean galling index for cultivar goldmine was significantly higher ($P \leq 0.05$) compared to other varieties. There was significant difference in the GI between varieties as shown by both untransformed and transformed data in parenthesis (**Table 3**). A regression analysis revealed a positive linear relationship between J2 populations in the roots and nematode gall indices in tree tomato varieties in the greenhouse (**Figure 4**).

There were significant differences ($P \leq 0.05$) in the mean egg mass index (EMI) between varieties while Goldmine, Red light oratia and grafted varieties were not significantly different from each other. The ruby red and red oratia EMI means were the same while Rothamer had the least mean of 2.00 (**Table 3**). The means and P-values of transformed data in parenthesis show significant differences between the EMI means of the varieties.

Treatment	J2s/5 g roots	Pi	Pf	Rf	Host status
Goldmine +N	1042.50 ± 582.50a	2000a	9168.75 ± 51.90a	4.58 ± 0.03a	T
Ruby red +N	253.75 ± 76.25ab	2000a	477.5 ± 202.08de	0.24 ± 0.10d	MR
Rothamer +N	141.25 ± 8.75c	2000a	1546.25 ± 531.57c	0.77 ± 0.27b	MR
Red oratia +N	246.25 ± 21.25ab	2000a	363.75 ± 107.38e	0.18 ± 0.05e	MR
Red light oratia +N	88.75 ± 11.25d	2000a	1785 ± 456.13b	0.89 ± 0.23b	MR
Grafted +N	200.00 ± 5.00b	2000a	651 ± 297.55d	0.33 ± 0.15c	MR
P-Value	0.0018		<.0001	<.0001	

Means followed by the same letters within the same column are not significantly different ($P \geq 0.05$) with Tukey's test. +N = inoculated with nematodes, Pi = initial nematode populations and Pf = final nematode populations/200 cc of dry soil. **Host status: susceptible (S) when Rf > 5.0, tolerant (T) if $5.0 \geq Rf > 1$, moderately resistant (MR) if $1 > Rf > 0$, and resistant (R) [22].

Table 2.

Mean number of juveniles in soil and roots, Pi, Pf and RKN reproduction factor (Rf) and Tree tomato variety responses to RKNs under greenhouse conditions (June–September 2019).

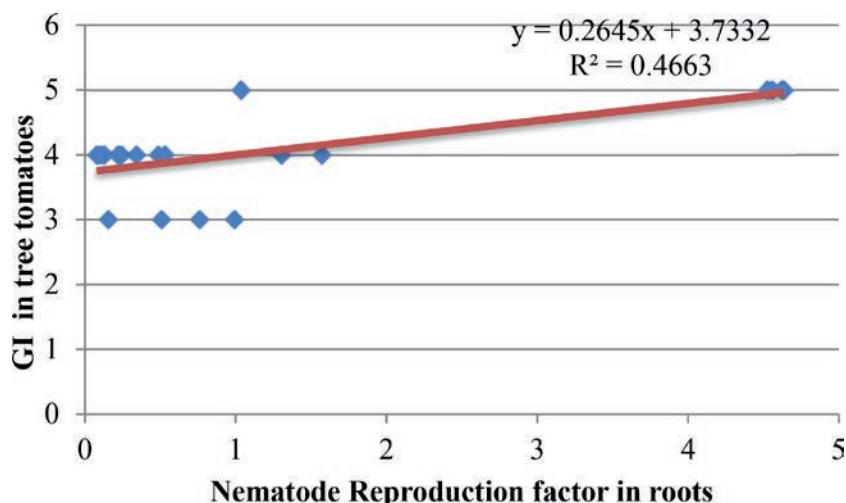


Figure 3.
Relationship between root-knot nematodes reproduction factor and galling index in roots of tree tomatoes in the greenhouse.

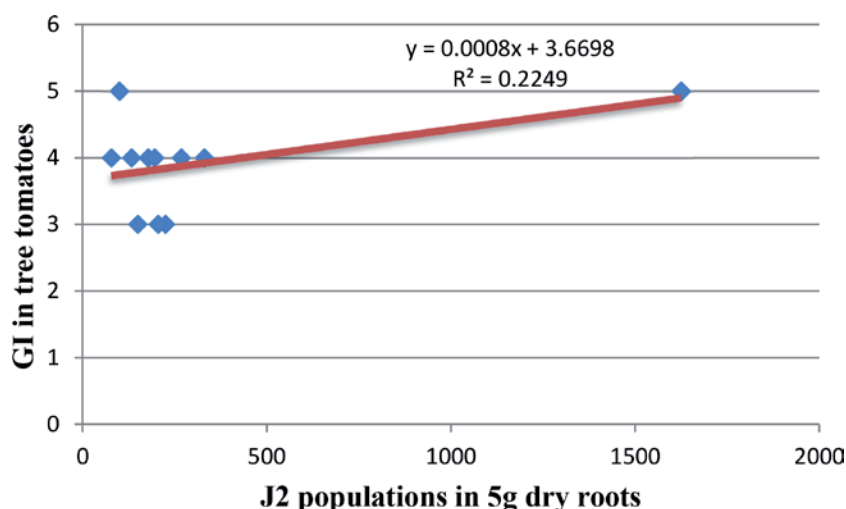


Figure 4.
Relationship between RKN J2 populations and GI in roots of tree tomatoes in the greenhouse.

4.3 Plant growth parameters in the field

The shoot heights were significantly different among the varieties. Goldmine recorded a higher mean shoot height of 29.11 cm in plants grown in nematode-infested soils without BioNematon treatment, followed by Red oratia. Ruby red, Rothamer and Red light oratia had mean heights not significantly different ($P \geq 0.05$) from each other. The Grafted variety grown on nematode-infested plots had the lowest mean height of 21.06 cm (**Table 4**). However, the shoot heights of all tree tomato varieties grown on nematode-infested plots were lower shoot height compared to those on control plots (**Table 4**).

Treatment	GI	EMI
Goldmine+N	5.00 ± 0.00a(0.69a)	4.00 ± 0.00a (0.60a)
Ruby red+N	4.00 ± 0.00ab(0.60ab)	2.50 ± 0.50ab (0.39ab)
Rothamer+N	3.75 ± 0.25b(0.57b)	2.00 ± 0.00b (0.30b)
Red oratia+N	3.75 ± 0.25b(0.57b)	2.50 ± 0.50ab (0.39ab)
Red light oratia+N	4.00 ± 0.41ab(0.59ab)	4.00 ± 0.00a (0.60a)
Grafted+N	3.75 ± 0.25b(0.57b)	4.00 ± 0.00a (0.60a)
P-Value	<.0001(0.0397)	<.0001 (0.0161)

Means followed by the same letters within the same column are not significantly different ($P \geq 0.05$) with Tukey's Honestly Significant Difference (HSD). +N = inoculated with nematodes. GI or EMI on a scale of 0–5, where 0 = no galls or egg masses; 1 = 1–2 galls or egg masses; 2 = 3–10 galls or egg masses; 3 = 11–30 galls or egg masses; 4 = 31–100 galls or egg masses and 5 = > 100 galls or egg masses per root system [18]. Values in parenthesis are for transformed data.

Table 3.

Mean galling index (GI) and egg mass index (EMI) on Tree tomato varieties under greenhouse conditions (June to September 2019).

Treatment	SH (cm)	DSW (g)	DRW (g)
Goldmine+N	29.11 ± 1.27f	13.07 ± 2.73d	2.89 ± 0.60e
Goldmine+N + BN	44.50 ± 1.43a	20.90 ± 1.41a	5.49 ± 0.45b
Ruby red+N	22.41 ± 1.26 h	7.40 ± 1.72 h	1.92 ± 0.29f
Ruby red+N + BN	30.31 ± 1.21e	8.32 ± 1.49 g	2.44 ± 0.23e
Rothamer+N	22.58 ± 1.33 h	9.44 ± 2.17f	2.14 ± 0.64e
Rothamer+N + BN	32.57 ± 1.00d	13.07 ± 1.80d	3.18 ± 0.52d
Red oratia+N	26.06 ± 1.12 g	16.20 ± 4.01b	4.60 ± 1.25c
Red oratia +N + BN	39.38 ± 1.10b	20.66 ± 2.84a	6.23 ± 1.37a
Red light oratia+N	22.13 ± 1.15 h	9.82 ± 2.26f	2.55 ± 0.56e
Red light oratia+N + BN	37.09 ± 0.95c	14.57 ± 0.92c	4.36 ± 0.75c
Grafted+N	21.06 ± 0.72i	9.01 ± 1.19f	3.02 ± 0.52d
Grafte +N + BN	29.64 ± 0.96f	12.32 ± 0.89e	3.43 ± 0.62d
P-Value	<.0001	<.0001	0.0004

+N = nematode-infested soil; BN = BioNematon (nematicide). Means followed by the same letters within the same column are not significantly different ($P \geq 0.05$) according to Tukey's Honestly Significant Difference (HSD).

Table 4.

Effect of root-knot nematodes on mean shoot height (SH), dry shoot weight (DSW) and dry root weight (DRW) of tree tomato varieties in field experiment (June to August 2019).

The dry shoot weights of all the varieties on nematode-infested plots were significantly different ($P \leq 0.05$) as compared to those on control plots. The dry shoot weights of plants on control plots were higher than those on nematode-infested plots without BioNematon treatment. Red oratia variety recorded a mean dry shoot weight of 16.20 g followed by Goldmine and Red light oratia on nematode-infested plots. Ruby red recorded the lowest mean dry shoot weight of 7.40 g (**Table 4**).

The mean dry root weight of the tree tomato varieties differed significantly ($P \leq 0.05$) from each other between plants on nematode-infested plots as compared

to those on control plots, except the grafted variety. The dry root weight of plants on nematode-infested plots without BioNematon were lower than that of the controls (**Table 4**). Red oratia recorded the highest mean of 4.60 g followed by Grafted and Goldmine varieties (3.02 g and 2.89 g, respectively) on nematode-infested plots. Ruby red had the lowest mean dry root weight of 1.92 g (**Table 4**).

4.4 Root-knot nematode disease parameters in the field

The number of J2s in 5 g of roots was significantly different ($P \leq 0.05$) between tree tomato varieties. The grafted variety and red light oratia had the highest mean number of J2 populations in the roots with 388.33 J2s/5 g and 294.20 J2s/5 g of roots, respectively. Red oratia had the lowest mean number of J2s for plants grown on nematode-infested plots without BioNematon treatment (**Table 5**). The number of J2s in 5 g of roots for plants grown on control plots had a lower number of nematodes as compared to those on untreated plots.

There were significant differences ($P \leq 0.05$) between the mean numbers of J2s in the rhizosphere soils of the tree tomato varieties. The Grafted variety recorded a mean of 80.00 J2s (pf), followed by Goldmine variety with a mean of 61.67 J2s and Red light oratia with a mean of 46.67 J2s per 200 cm³ of soil (**Table 5**).

The mean RKN Rf was significantly different ($P \leq 0.05$) among the varieties with goldmine having the highest mean Rf of 5.78. The Grafted variety had a mean Rf of 4.26 followed by Red light oratia with 4.07 (**Table 5**). Plants on nematode-infested plots without BioNematon treatment were rated for susceptibility or resistance to RKNs [22]. Goldmine (Rf = 5.78) was rated as susceptible (S),

Treatment	J2s/5 g dry roots	Pi	Pf	Rf	Host status
Goldmine + N	53.30 ± 35.83c	10.00 ± 2.88 h	61.67 ± 22.19b	5.78 ± 1.30a	S
Goldmine + N + BN	7.00 ± 0.14 g	9.17 ± 2.22i	8.09 ± 2.00 g	0.62 ± 0.04e	—
Ruby red+N	21.70 ± 4.17d	18.33 ± 8.82d	17.50 ± 5.77f	1.60 ± 0.96c	MR
Ruby red + N + BN	6.89 ± 0.20 g	16.17 ± 4.67e	10.00 ± 1.90 g	0.44 ± 0.07e	—
Rothamer + N	15.83 ± 0.83e	19.17 ± 4.64c	19.17 ± 2.21e	1.10 ± 0.21d	MR
Rothamer + N + BN	6.23 ± 0.10 g	18.50 ± 1.76d	10.12 ± 3.03 g	0.35 ± 0.50e	—
Red oratia + N	12.50 ± 1.44f	6.67 ± 3.01j	25.83 ± 7.12d	1.50 ± 0.14c	MR
Red oratia +N + BN	7.50 ± 1.1 g	18.17 ± 1.88d	10.94 ± 2.97 g	0.47 ± 0.06e	—
Red L.O + N	294.20 ± 187.14b	13.33 ± 2.21f	46.67 ± 15.43c	4.07 ± 1.73b	T
Red L.O + N + BN	6.86 ± 1.00 g	43.67 ± 33.21a	11.82 ± 3.40 g	0.21 ± 0.09e	—
Grafted + N	388.33 ± 87.61a	27.5 ± 15.00b	80 ± 11.27a	4.26 ± 1.24b	T
Grafted +N + BN	6.39 ± 0.10 g	12.73 ± 2.39 g	8.42 ± 1.05 g	0.48 ± 0.08e	—
P-Value	0.0007	0.0041	<.0001	<.0001	

Means followed by the same letters along the same column are not significantly different ($P \geq 0.05$) according to Tukey's Honestly Significant Difference (HSD). +N = nematode infested plots; +BN=Plots treated with BioNematon (nematicide); Red L.O = Red light oratia. Pi = initial nematode population per 200 cm³ of soil, Pf = final nematode population per 200 cm³ of soil. Rf is based on Pf/Pi rated on a scale of 0–5. Host status (susceptible or resistant); susceptible when $Rf > 5.0$, tolerant if $5.0 \geq Rf > 1$, moderately resistant if $1 > Rf > 0$, and resistant when $Rf \leq 0$ [22].

Table 5.
Mean number of juveniles in soil and roots and RKN reproduction factor (Rf) on tree tomato varieties under field conditions.

Treatment	GI	EMI
Goldmine+N	3.38 ± 0.20a (0.58a)	4.67 ± 0.33a (0.67a)
Goldmine+ N + BN	0.32 ± 0.15e (0.20e)	0.90 ± 2.17e (0.07e)
Ruby red+N	0.75 ± 0.15c (0.05c)	1.33 ± 0.33d (0.10d)
Ruby red+ N + BN	0.30 ± 0.18e (0.01e)	0.44 ± 0.09e (0.03e)
Rothamer+N	0.38 ± 0.16d (0.03d)	1.33 ± 0.33d (0.10d)
Rothamer+ N + BN	0.33 ± 0.10 e(0.19e)	0.50 ± 0.07e (0.03e)
Red oratia+N	0.79 ± 0.20c (0.06c)	2.33 ± 0.33c (0.36c)
Red oratia+ N + BN	0.29 ± 0.14e (0.13e)	0.21 ± 0.69e (0.02e)
Red light oratia+N	2.00 ± 0.26b (0.27b)	3.00 ± 0.58b (0.46b)
Red L.O+ N + BN	0.25 ± 0.11e (0.15e)	0.75 ± 0.07e (0.04e)
Grafted+N	3.79 ± 0.19a (0.56a)	4.67 ± 0.33a (0.67a)
Grafted+ N + BN	0.31 ± 0.21e (0.26e)	1.02 ± 3.00e (0.08e)
P-Value	<.0001 (<.0001)	<.0001(<0.0001)

Means followed by the same letter(s) along the same column are not significantly different ($P \geq 0.05$) according to Tukey's Honestly Significant Difference (HSD) test. Means in parenthesis are for log-transformed data. +N = nematode infested plots; +BN=Plots-treated with BioNematon (nematicide); Red L.O = Red light oratia. GI or EMI on a scale of 0–5, where 0 = no galls or egg masses; 1 = 1–2 galls or egg masses; 2 = 3–10 galls or egg masses; 3 = 11–30 galls or egg masses; 4 = 31–100 galls or egg masses and 5 = > 100 galls or egg masses per root system [18]. Values in parenthesis are for transformed data.

Table 6.

Mean galling index (GI) and egg mass index (EMI) on tree tomato varieties under field conditions.

Grafted ($R_f = 4.26$) and Red light oratia ($R_f = 4.07$) were tolerant (T). Ruby red, Rothamer and Red oratia ($R_f = 1.60, 1.10$ and 1.50 , respectively) were moderately resistant (MR) (Table 5).

The mean galling indices differed significantly ($P \leq 0.05$) between the varieties (Table 6). The grafted and goldmine varieties had the highest GI followed by red light oratia. All the plants on nematode-infested plots without BioNematon treatments had significantly higher mean number of GI as compared to those on control plots (Table 6).

The mean EMI indices differed significantly ($P \leq 0.05$) among the varieties except between ruby red and rothamer on nematode-infested plots without BioNematon treatment (Table 6). Goldmine and grafted varieties had the highest mean EMI (Table 6).

5. Discussion

There were significant differences in the responses of tree tomato varieties to RKNs in the greenhouse test and also in the field. The shoot heights of all tree tomato varieties differed significantly both in the greenhouse and in the field. However, plants in the greenhouse had higher shoot heights than those in the field. A conducive and ambient environment in the greenhouse could be the reason for this observation. This could also be due to harsh environmental conditions and the interaction of the tree tomato with mixed nematode populations in the field. The dry shoot weight and dry root weight of tree tomato varieties varied significantly in both greenhouse and

field tests. Tree tomatoes on RKN-infested soils were lighter and shorter compared to the control in both experiments. This could be due to nematode damage to the root system, which interferes with water and mineral uptake.

The variety response to RKNs ranged between tolerant for goldmine and moderately resistant for ruby red, rothamer, red oratia, red light oratia and grafted varieties in the greenhouse. Ruby red, rothamer and red oratia were consistently moderately resistant in both greenhouse and field tests. Red light oratia and grafted varieties were both moderately resistant in the greenhouse and tolerant in the field. Goldmine was tolerant in the greenhouse and susceptible in the field. Change of responses from tolerant to susceptible for goldmine could be due to mixed nematode populations, varied nematode pathotypes and variations in population density in the greenhouse and field. These could have also been the reasons for loss of moderate resistance to tolerance in red light oratia and grafted varieties between greenhouse and field tests. Maleita [23] reported that moderately resistant and tolerant varieties can become susceptible when the RKN population and environmental conditions vary. The Goldmine variety was found to harbor comparatively high numbers of J2s, high egg mass and gall indices in both greenhouse and field tests. In addition, red light oratia and grafted varieties recorded high galling and egg mass indices. However, the moderately resistant varieties had comparatively lower nematode reproduction factors. These varieties could have resistant genes [24].

The moderately resistant varieties should be promoted to farmers through extension programs so as to avoid losses that come as a result of planting susceptible varieties. These varieties can also be used in breeding and seed certification programs for quality production of tree tomato yields through improved phytosanitation of planting materials.

Moderately resistant varieties can be used in integrated pest management strategies since they could have a resistant gene (Mi gene). Resistance to RKN invasion may trigger the plant to form necrotic cells at the point of infection to stop J2 development. However, very high genetic variability of RKNs has brought about the occurrence of virulent races that can reproduce in plants carrying the resistant genes. These are pathotypes that break resistance [24–26]. The information on tree tomato variety responses to RKNs can be helpful to farmers in selecting the varieties to plant on RKN-infested farms.

The plants in the Solanaceae family are susceptible to RKN infection and other PPNs, hence, supporting higher nematode populations [27, 28]. The root-knot nematodes were found to be associated with all six screened tree tomato varieties in both tests. Studies on indigenous leafy vegetables by Nchore et al. [29] and Wangai et al. [28] on coffee germplasms reported variations in responses to RKN similar to these findings. Another study on sweet potatoes reported that susceptibility to RKN could be due to the presence of unfavorable alleles that reduce resistance [30]. Failure of the infective J2s to penetrate, form feeding sites, mature and reproduce in the plant roots may have been the cause of the observed moderate resistance [29–31]. The observed differences in responses of tree tomato varieties to RKNs could also be due to genetic variations between themselves, and this explains the differences in galling index, egg mass index and nematode reproduction factor [24].

All tree tomato varieties on nematode-inoculated/infested soils had lower plant growth parameters. The stunting and yellowing of leaves observed on susceptible plants was due to RKN damage on the roots that interfered with water and mineral uptake. Stunting is caused by the redirection of manufactured food to nematode feeding sites [32–34].

6. Conclusion

Ruby red, rothamer and red oratia varieties were moderately resistant while red light oratia and grafted varieties were tolerant and goldmine was susceptible to RKNs.

7. Recommendations

- i. The identified moderately resistant varieties (ruby red, rothamer and red oratia) and tolerant varieties (red light oratia and grafted) should be promoted to farmers to manage RKNs in tree tomato through rotational programs.
- ii. Moderately resistant and tolerant varieties should be incorporated into breeding programs to manage RKNs in tree tomato.
- iii. Further research is needed to characterize the RKN species infecting tree tomato.

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References

- [1] Ramirez F, Grijalra R, Navarrete X, Guerrero R. Phytoparasitic Nematodes Associated with Tree Tomato (*Solanum betaceum* Cav.) in the Provinces of Imbura, Pichincha and Tungurahua, Ecuador. Interoceanic Km 14 1/2. Tumbaco, Ecuador: The MAGAP Farm; 2015
- [2] Ramírez-Gil JG, Gil-Aguirre A, Morales-Osorio JG. Etiología de enfermedades del cultivo de tomate de árbol (*Solanum betaceum* CAV.). Revista de Protección Vegetal. 2017;32(1):33-51
- [3] United States Agency on International Development, Agriculture Fisheries and Food Authority of Kenya. Horticulture Validated Report. 2014. pp. 51-52. Available from: www.agricultureauthority.go.ke/Horticulture-Validated-Report.2014
- [4] Reddy PP. Impact of climate change on insect pests, pathogens and nematodes. Pest Management sin Horticultural Ecosystems. 2013;19(2):225-233
- [5] Agarwal S, Rao AV. Tomato lycopene and its role in human health and chronic diseases. CMAJ: Canadian Medical Association Journal = Journal de l'Association medicale canadienne. 2000;163(6):739-744
- [6] Waswa SJ, Waceke JW, Nchore SB. Occurrence and abundance of phytonematodes in tree tomato (*Solanum betaceum* Cav.) farming systems in Kenya. Journal of Agriculture. 2020;7(7):1-10. Available from: <http://www.researchjournali.com/pdf.5605.pdf>
- [7] Coyne DL, Cortada L, Dalzell JJ, Claudius-Cole AO, Haukeland S, Luambano N, et al. Plant-parasitic nematodes and food security in sub-Saharan Africa. Annual Review of Phytopathology. 2018;56:381-403
- [8] Jones JT, Haegeman A, Danchin EGJ, Gaur HS, Helder J, Jones MGK, et al. Top 10 plant-parasitic nematodes in molecular plant pathology. Molecular Plant Pathology. 2013;14:946-961
- [9] Vásquez PU, Soria CA. Nematodos parásitos asociados con tomate de árbol (*Solanum betaceum* Cav.) en la sierra del Ecuador. Revista Ecuatoriana de Medicina y Ciencias Biológicas. 2017;38(2):107-118
- [10] Oxfarm. 2017. Available from: <http://www.oxfarmorganic.com/our-products/tree-tomato/tips-on-how-to-get-over-20kgs-tree-from-tree-tomato-farming/>
- [11] Prohens J, Nuez F. The Tamarillo (*Cyphomandra betacea*) a review of a promising small fruit crop. Small Fruits Review. 2001;1(2):43-68
- [12] Muriithi C, Matiri F, Kihanda F, Maina D, Kasungu F. Evaluation of potential of tree tomato production and marketing in Eastern Kenya for improved nutrition and food security. In: Joint Proceedings of the 27th Soil Science Society of East Africa and the 6th African Soil Science Society Conference; 20-25 October 2023
- [13] Korayem AM, Youssef MMA, Mohamed MMM, Lashein AMS. A survey of plant parasitic nematodes associated with different plants in North Sinai. Middle East J Agriculture Research. 2014;3(3):522-529
- [14] Oxfarm. 2019. Available from: www.oxfarm.com/our-products/tree-tomato/tree-tomato-farming-made-easy-in-Kenya

- [15] Rahman SSA, Zain SM, Mat MB, Sidam AK, Othman RY, Mohamed Z. Population distribution of plant-parasitic nematodes of bananas in peninsular Malaysia. *Sains Malaysiana*. 2014;**43**(2):175-183
- [16] Agriculture and Food Authority, Government of Kenya and Kenya National Bureau of Statistics. 2015-2016. p. 41. Available from: www.agricultureauthority.go.ke/Horticulture-Validated-Report.2015-2016
- [17] Hussey RS, Barker KR. A comparison of methods of collecting inocula of *Meloidogyne* species including a new technique. *Plant Disease Report*. 1973;**57**:1025e1028
- [18] Quesenberry KH, Baltensperger DD, Dunn RA, Wilcox CJ, Hardy SR. Selection for tolerance to root-knot nematodes in red clover. *Crop Science*. 1989;**29**:62-66
- [19] Taylor AL, Sasser JN. Biology, Identification and Control of Root-Knot Nematodes (*Meloidogyne* Species). North Carolina State University Graphics; 1978. pp. 1-111
- [20] Byrd DW, Kirkpatrick T, Baker R. An improved technique for clearing and staining plant tissue for detection of nematodes. *Journal of Nematology*. 1983;**15**:142-143
- [21] Hooper DJ, Hallmann J, Subbotin SA. Methods for extraction, processing and detection of and soil nematodes. In: Luc M, Sikora R, Bridge A, editors. *Plant Parasitic Nematodes in Subtropical and Tropical Agriculture*. 2nd ed. Wallingford, UK: CAB International; 2005. pp. 53-86. Available from: <https://www.crfp.org/pubs/ff/tamarillo.html>
- [22] Zhang F, Schmitt DP. Host status of 32 plant species to *Meloidogyne konaensis*. *Journal of Nematology*. 1994;**26**(4S):744
- [23] Maleta CM. Biology and Ecology of the Root-Knot Nematodes *Meloidogyne Hispanica*: A Species of Emerging Importance [PhD thesis]. Portugal: University of Coimbra; 2011
- [24] Singh SK, Khurma UR. Susceptibility of six tomato cultivars to the root-knot nematode, *Meloidogyne incognita*. *The South Pacific Journal of Natural and Applied Sciences*. 2007;**25**(1):73-77
- [25] Castagnone-Sereno P. Genetic variability and adaptive evolution in parthenogenetic root-knot nematodes. *Heredity*. 2006;**96**(4):282
- [26] Jacquet M, Bongiovanni M, Martinez M, Verschave P, Wajnberg E, Castagnone-Sereno P. Variation in resistance to the root-knot nematode *Meloidogyne incognita* in tomato genotypes bearing the mi gene. *Plant Pathology*. 2005;**54**(2):93-99
- [27] Nchore SB. Incidence, Prevalence and Management of Root-Knot Nematodes (*Meloidogyne* Spp.) on Selected Indigenous Leafy Vegetables in Kisii and Trans-Mara Counties, Kenya [Msc thesis]. Nairobi, Kenya: Kenyatta University; 2012
- [28] Wangai KJ, Nzesya MJ, Maina MW, Peter WM, Elijah GK. Reaction of selected coffee germplasm to root-knot nematodes in Kenya. *Journal of Natural Sciences Research*. 2014;**4**(3):68-75
- [29] Nchore SB, Waceke JW, Kariuki GM. Efficacy of selected agroindustrial wastes in managing root-knot nematodes on black nightshade in Kenya. *ISRN Agronomy*. 2012:2012
- [30] Karuri HW, Olago D, Neilson R, Mararo E, Villinger J. A survey of root knot nematodes and resistance to *Meloidogyne incognita* in sweet potato

varieties from Kenyan fields. *Crop Protection*. 2017;**92**:114-121

[31] Sujatha R, Vethamoni PI, Manivannan N, Sivakumar M. Screening of tomato genotypes for root knot nematode (*Meloidogyne incognita* Kofoid and white chit wood). *International Journal of Current Microbiology and Applied Sciences*. 2017;**6**(3):1525-1533

[32] Hunt DJ, Palomares-Rius JE, Manzanilla-López RH. Identification, morphology and biology of plant parasitic nematodes. *Plant Parasitic Nematodes in Subtropical and Tropical Agriculture*. 2018;**20**:20-61

[33] Wallace HR. Interactions between nematodes and other factors on plants. *Journal of Nematology*. 1983;**15**(2):221

[34] Jaiteh F. Screening tomato (*Solanum lycopersicum* L.) genotypes for resistance to root-knot nematodes (*Meloidogyne* species) [M.sc thesis]. Kumasi, Ghana: Kwame Nkrumah University of Science and Technology; 2010