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RESEARCH ARTICLE

Assessment on awareness of root knot nematodes (*Meloidogyne* spp.) associated with Tomato production in Mvomero district, Morogoro, Tanzania

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ABSTRACT

Root-knot nematodes (RKN) (*Meloidogyne* spp.) are among the serious biotic constraints to tomato growers in Tanzania but are relatively overlooked. This required a survey of growers in Mvomero District, Morogoro, Tanzania, to assess their RKN expertise. Semi-structured questionnaires were used to collect data from 100 randomly selected respondents in Mlali (33), Doma (33), and Dakawa (34). Socioeconomic status, RKN awareness, tomato varietals, seed sources, and yield were collected. RKN awareness varied significantly among responder categories. 59% were unaware of RKN. Farming experience correlated with tomato yield, RKN awareness, and RKN-resistant tomato varieties. Rio Grande (14%), Cal J (18%), Roma (10%), and Tanya (16%) were popular tomato types, while hybrids included Imara F1 (19%), Assila F1 (15%), Jarrah F1 (2%), Zara F1 (3%), Kipato F1 (2%) and Anna F1 (2%). Seventy-five root and 75 rhizosphere soil samples were taken from tomato plants at the flowering stage demonstrating stunting, chlorosis, and wilting at least 1km apart in Mlali, Doma, and Dakawa Wards. Samples were shovelled 25 cm deep, packed in sterile plastic bags, labelled, and delivered to Tanzania Agricultural Research Institute Kibaha Nematology laboratory. Results revealed the significant prevalence and incidence of RKN. Despite the occurrence and damage caused by RKN in tomato in the study areas, only one percent of respondents recognized RKN as a serious problem. Awareness campaigns on RKN will facilitate farmers' consciousness of their existence and management.

Keywords: *Meloidogyne* spp., Mvomero, prevalence, severity, tomato

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is among important vegetable crops in Tanzania. It is grown on approximately 40 820 ha with a total production of 627 788 tonnes (FAOSTAT, 2019). Morogoro region has the highest annual production of about 155 745 tonnes (URT, 2017). The average tomato yield attained by smallholders in Tanzania varies from 2.2 to 16 t/ha (Msogoya and Mamiro, 2016). The estimated average yield of tomato in Tanzania is 15.4 t/ha (FAOSTAT, 2019), which is significantly lower than the average yield of 20.4 t/ha attained in Kenya and much less than the world average yield of 35.9 t/ha (FAOSTAT, 2019).

Tomato production is constrained by biotic factors including, unavailability of quality seeds, pests and diseases. The abiotic factors include moisture stress, heat, low soil fertility and lack of appropriate cultural practices (Testen et al., 2018; Palilo, 2019). Root-knot nematodes are among the serious biotic factors which cause low tomato productivity in Tanzania (Mamiro et al., 2015). They initiate galls in tomato roots which tend to appear about 25 days post infection (Lu et al., 2020). According to García and Sánchez-Puerta (2012), successful host infection depends on the particular interaction between a specific nematode species and race and a specific plant species and cultivar. Moreover, the level of damage generally depends on factors such as the nematode species, host plant, crop rotation regime, season and soil type (Moens et al., 2009; Olsen, 2011).

Despite the economic loss they cause, they are relatively overlooked because their occurrence is poorly understood by small scale farmers (Janssen et al., 2017). The symptoms of RKN in inflicted tomato plants such as yellowing, stunted growth and wilting may also be attributed to environmental stress or nutrient deficiency (Coyne et al., 2018). Poor awareness and management of RKN have resulted to declining tomato productivity in major tomato producing areas in Tanzania (Missanga and Rubanza, 2018). Furthermore, there is limited information associated with RKN prevalence and how they are perceived by tomato growers in Mvomero District. Therefore, this study focused on assessing the prevalence, incidence, and farmers awareness on RKN affecting tomato in Mlali, Doma and Dakawa wards in Mvomero District.

MATERIAL AND METHODS

Description of Study Area

The survey was conducted in October 2019 in farmers' tomato fields in Mlali (06° 57′ 0″ South, 37° 32' 0" East), Doma (7° 14' 0" South, 37°13' 0" East) and Dakawa (6° 26' 0" South, 37° 42' 0" East) wards of Mvomero District (6˚14' 8.2212" South, 38˚ 41' 37.4928" East) in Morogoro Region, Tanzania. These wards are located at an altitude of 358 - 570 m above sea level. Annual rainfall is between 600 mm and 1000 mm. The average temperature ranges from 18 - 30 °C. The dominant soil type in Mlali and Doma is sandy loam (Mbogoni and Ley, 2008), while at Dakawa is sandy clay loam (Mbaga et al., 2017).

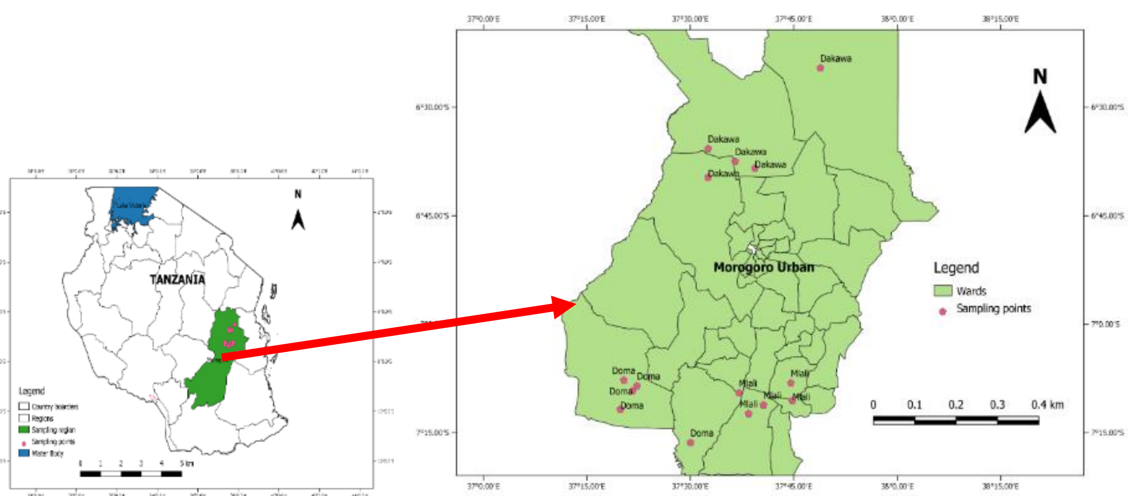

Figure 1. Map of Morogoro region indicating areas where survey and sampling for plant parasitic nematodes were done

Sample Size and Sampling

The sample size for respondents was calculated according to Anderson et al. (2014);

$$n = \frac{p(1-p)Z^2}{E^2} = \frac{0.93(1-0.93)1.92^2}{0.05^2} = 100 \ldots\ldots..(1)$$

Where, n = required sample size, Z = confidence level at 95% (standard value of 1.96), p = estimated proportion of an attribute (average % of tomato farmers in a population of horticultural farmers in the district) and E = margin of error at 5%. Secondary data were obtained from existing sources including journal articles and government reports. The distribution of respondents was as follows; Mlali (33), Doma, (33) and Dakawa (34) making a total number of 100 respondents.

A field survey involving multistage sampling technique was used in selecting respondents (Schreinemachers et al., 2015). Mvomero district was purposively selected as among the major district of Morogoro producing tomatoes. The second stage entailed purposive selection of three wards namely Mlali, Doma and Dakawa based on high tomato production. Five villages (Kipera, Mkuyuni) in Mlali, (Doma B, Kihondo) in Doma and Wami Dakawa in Dakwa wards were purposively selected. The third stage entailed a simple random selection of respondents (Mwatawala et al., 2019). This was done with the assistance from Village Extension Officers. This method is cost-saving and guarantees representativeness of the target population (Anderson et al., 2014).

Respondents were interviewed using semi-structured questionnaire. Personal interview was done because it enables real-time response and clarification of questions. Tomato growers who had harvested tomatoes or with some reasons such as crop rotation did not have tomatoes in their fields were also involved in the interview to capture their awareness on RKN.

Data Collection

Farmers awareness on RKN

Baseline data were collected in October 2019 through face-to-face interviews and filled in pre-tested semi-structured questionnaires. This interview was done as it allows real time clarification of questions. Coloured pictures of RKN infested tomato plants showing root galling symptoms were used to confirm farmers' awareness (Lutuf et al., 2018).

Occurrence of RKN

A total of 75 samples containing soil and roots were collected from fifteen fields of about 0.1 ha each in Kipera (2), Mkuyuni (3), Doma B (3), Kihondo (2) and Wami Dakawa (5) villages. Tomato fields with plants at flowering/fruiting stage located at least 1 km apart were selected for assessment. Tomato plants which indicated symptoms such as chlorotic leaves, wilting and stunted growth were marked. Thereafter, five symptomatic tomato plants per field were carefully uprooted to a depth of approximately 25 cm using a hand shovel (Coyne et al., 2014). Collected root and rhizosphere soil samples obtained from a single sampling point were loaded in sterile plastic bags and labelled to make a sample. Labelled samples were packed in a cool box and transported to Tanzania Agricultural Research Institute (TARI) - Kibaha Nematology Laboratory. In the laboratory, the roots samples were gently cleaned of embedded soil in running tape water. Cleaned roots were visually observed for presence of galls and scored for galls using RKNs galling scale of 1 (no galling) to 5 (severe galling) (Coyne et al., 2018). The frequency of occurrence (prevalence) and incidence of nematode were determined according to Khan and Ahamad (2020) as follows;

$$\text{Prevalence} = \frac{\text{Number of fields with RKN infestation in one location}}{\text{Total number of field surveyed in the same location}} \times 100..(2)$$

$$\text{Nematode incidence} = \frac{\text{Number of plants galled in one field}}{\text{Total number of plants sampled in the same field}} \times 100..(3)$$

Surveyed fields were geo-referenced using the Global Positioning System (GPS) (Garmin-etrex 10, Taiwan).

Extraction and quantification of RKNs from field samples

Root samples from each point were separated from soil, cleaned and thereafter the extraction of RKNs from soil and roots was done separately. Each sampled roots were individually chopped in 1 cm pieces using a pair of scissors, and individual sub samples of 5 g from chopped roots were weighed on a digital weighing scale (Wagtech, ADG 600L, Wagtech International Ltd, UK). Weighed roots were macerated by using laboratory blender (Waring Commercial, HGB2WTS3, Torrington, CT, USA) at 18 000 revolutions per minute for about 5 seconds. Similarly, soil sub samples of 100 cm^3 were measured in beaker per sample for extraction of RKNs. All roots and soil subsamples were individually subjected to the modified Baermann technique as described by Coyne et al. (2014). Nematode's identification and counting were done separately for soil and root samples whereby 2 ml aliquots from each sample was counted three times with the aid of a tally counter and stereo microscope (Leica DM 2500, Leica Microsystems, US) at 10× magnification. The means of the counted nematodes were used to estimate root and soil populations of RKN. Morphological identification to genus level was done parallel with counting using identification key and descriptors illustrated by Mai and Lyon (1975).

Data Analysis

Quantitative and qualitative data from completed questionnaires were coded before subjected to statistical analysis using Statistical Package for Social Sciences software (IBM SPSS Statistics version 25). The descriptive statistics analysed included frequencies and percentages. To make statistical inferences, contingency chi-square tests were computed at $p \leq 0.05$ levels of significance across categories. Pearson's correlation coefficients were calculated to determine linear relationships amongst variables.

Nematode population counts for roots and soil were normalised by transforming them to $\log_{10}(x+1)$ before they were subjected to analysis of variance (ANOVA). Each nematode count was assessed separately from roots and soil sample. Means were compared by Least Significant Difference (LSD) at $p \leq 0.05$ using GenStat for Windows 20th Edition (VSN International, Hemel Hempstead, UK).

RESULTS

Social economic background of respondents

There was no significant difference (χ^2 = 0.86; p = 0.911) across surveyed wards on the gender of respondents (Table 1). However, it was observed that males dominated females in tomato production across the study areas. Majority of respondents (89%) were males while (11%) were females. The age of tomato growers differed significantly (χ2 = 9.503; p = 0.05) across categories of the surveyed wards. Forty-one percent of respondents interviewed were aged between 18 and 35 years while 39% ranged between the age of 36 - 45 years and the rest (20%) were more than 45 years old. Also, there was no significant variation (χ^2 = 3.205; p = 0.527) in education level of respondents was observed across categories of the surveyed wards (Table 2). The majority of tomato growers (77%) had primary school education whilst 33.0% had secondary school education. Moreover, there was significant difference (χ^2 = 13.638; p = 0.009) across categories of surveyed wards in farm size of tomato growers (Table 1). Majority of tomato growers (63%) had farm size in the range of 0.4 – 0.8 ha whilst 24% had farm size less than 0.4 ha and the rest (13%) had farm size bigger than 0.8 ha. Furthermore, the farming experience of respondents across categories of the surveyed wards varied significantly (χ^2 = 15.388; p = 0.04). Majority of tomato growers (50%) had farming experience ranging from 2 – 5 years while (46%) had farming experience of more than 5 years and the rest (4%) had farming experience of less than 2 years (Table 1).

Table 1. Social - economic background of respondents (n = 100)

Social - economic characteristics	Ward Mlali (n = 33)	Doma (n = 33)	Dakawa (n = 34)	Mean (%)	df	χ^2	p-value
Sex							
Male	87.9	90.9	88.2	89	2	0.186	0.911
Female	12.1	9.1	11.8	11			
Age							
18 – 35	48.5	36.4	38.2	41.0			
36 – 45	39.4	27.2	50.0	39.0	4	9.503	0.05
> 45	12.1	36.4	11.8	20.0			
Education level							
Primary school	78.8	81.8	70.6	77.0	2	15.388	0.527
Secondary school	21.2	18.2	29.4	33.0			
Farm size							
< 0.4 ha	42.4	12.1	17.6	24.0			
0.4 – 0.8 ha	54.5	63.6	70.6	63.0	4	13.638	0.009
> 0.8 ha	3.0	24.2	11.8	13.0			
Farming experience							
< 2 years	6.1	0	5.9	4.0			

2 - 5 years	24.2	69.7	55.9	50.0	4	15.388	0.004
> 5 years	69.7	30.3	38.2	46.0			

*df = degree of freedom, χ2 = Chi-Square test, p ≤ 0.05 shows significant difference

Tomato seed sources

Seed sources varied significantly (χ^2 = 10.615; p = 0.031) across the surveyed wards. However, the majority (81%) of growers were sourcing tomato seeds from agro-inputs dealers (Table 2). Other tomato growers were using their own saved seeds (6%) whereas others were using both own saved seeds and those from agro-inputs dealers (13%).

Table 2. Sources of tomato seeds across the wards (n = 100)

Sources of seeds	Wards						
	Mlali (n =33)	Doma (n =33)	Dakawa (n =34)	Mean (%)	df	χ2	p-value
Own saved	0.0	0.1	8.8	6.0			
Agro dealers	97.0	66.7	79.4	81.0	4	10.615	0.031
Agro dealer+own saved	3.0	24.2	11.8	13.0			

*df = degree of freedom, χ2 = Chi-Square test, p ≤ 0.05 shows significant difference,

Cropping patterns

There was no significant difference (χ^2 = 1.982); p = 0.421) in cropping patterns across the surveyed wards. However, the survey revealed that most tomato growers (68.9%) were practicing crop rotation (Fig. 2). They rotated tomato with beans, cowpeas, watermelon, paddy, onions, pumpkins, maize, okra, sweet pepper, amaranth, Chinese cabbage, and hot pepper.

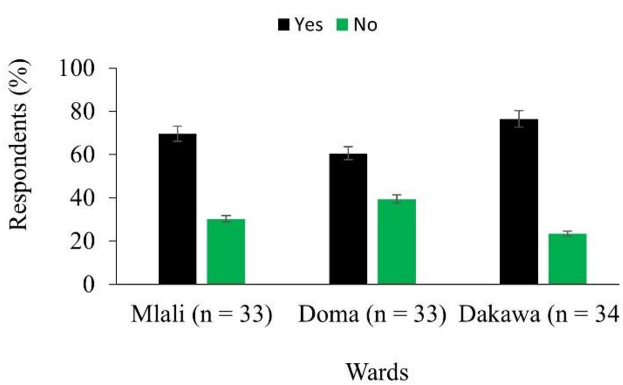

Figure 2. Crop rotation across the surveyed wards

Management measures for RKN in tomato fields

There was significant difference (χ^2 = 17.006; p = 0.03) on RKN control measures used by growers. Control measures adopted to mitigate RKN were applying chemicals (3%), adding manure (4%), crop rotation (20%), and uprooting (8%). The survey however, revealed that 59% of respondents did not know any method that could be used to manage root-knot nematodes (Table 3).

Pests and diseases challenges facing tomato growers

The distribution of ranking of the most important pest of tomato was similar (χ^2 = 7.119; p = 0.524) across categories of respondents (Table 3). According to the growers interviewed, the most important challenge was Tuta absoluta (72%) followed by bacterial wilt (16%), fungus (8%), RKN (1%) and virus (1%) (Table 3). Yield of tomato did not differ significantly (χ2 = 3.867; p = 0.424) across categories of respondents. Majority of respondents (52%) were obtaining a yield of 10 – 19 t/ha while a yield of 1- 9 t/ha and >19 t/ha were attained by 24% and 24% of tomato growers, respectively (Table 4).

Table 3. The awareness of tomato growers on RKN (n = 100)

RKN awareness	Wards						
	Mlali (n = 33)	Doma (n =33)	Dakawa (n = 34)	Mean (%)	df	χ2	p-value
Yes	21.2	57.6	44.1	41.0	2	9.226	0.01
No	78.8	42.4	55.9	59.0			
Symptoms							
Root galling	30.3	15.2	32.4	26.0			

Stunting	3.0	0.0	0.0	1.0	6	14.770	0.022
Wilting	27.3	6.1	5.9	13.0			
Don't know	39.4	75.8	61.8	59.0			
Control							
Adding manure	6.1	0.0	5.9	4.0			
Chemical	3.0	6.1	0.0	3.0			
Uprooting	27.3	3.0	11.8	14.0	8	17.006	0.03
Rotation	24.2	12.1	23.5	20.0			
Don't know	39.4	78.8	58.8	59.0			
Pest problems							
Tuta absoluta	69.7	75.8	70.6	72.0			
Bacteria	18.2	12.1	23.5	18.0	8	7.119	0.524
Fungi	9.1	12.1	2.9	8.0			
RKN	3.0	0.0	0.0	1.0			
Viruses	0	0	2.9	1.0			

*df = degree of freedom, χ2 = Chi-Square test, p ≤ 0.05 shows significant difference

Table 4. Tomato yield across categories of surveyed wards (n = 100)

Yield	Wards						
	Mlali (n =33)	Doma (n =33)	Dakawa (n =34)	Mean (%)	df	χ2	p-value
1-9 (t/ha)	21.20	27.30	23.50	24.0			
10-19 (t/ha)	48.50	60.60	47.10	52.0	4	3.867	0.424
>19 (t/ha)	30.30	12.10	29.40	24.0			

*df = degree of freedom, χ2 = Chi-Square test, p > 0.05 shows non-significant difference

Correlation between variables

The results presented in Table 5 indicate that farming experience was positively correlated with awareness on RKN and yield of tomato r (98) = 0.38, p < 0.001. Likewise, the awareness of RKN was positively correlated with the yield of tomato r (98) = 0.21, p = 0.04.

Table 5. Pearson's correlation coefficients used to assess correlation among farming experience, tomato yield, awareness on RKN and their related p-values (n = 100)

	Farming experience	Awareness on RKN	Yield
Farming experience	1		
Awareness on RKN	0.258** 0.001	1	
Yield	0.381** 0.001	0.205* 0.04	1

*Correlation coefficient values are significant at p ≤ 0.05 level

Popular tomato cultivars grown in Mvomero District

Popular tomato varieties grown by farmers included open pollinated varieties (OPV) and hybrids. Open pollinated varieties were Cal J (18%), Tanya (16%), Rio Grande (14%), and Roma (10%) while hybrids were Imara F1 (19%), Assila F1 (15%), Jarrah F1 (2%), Zara F1 (3%), Anna F1 (2%) and Kipato F1 (2%) (Figure. 3).

Incidence, prevalence, severity and population densities of RKNs

The mean RKN incidence varied significantly (p = 0.002) among the study areas (Table 6). There was also a significant difference (p < 0.001) in RKN prevalence along the studied locations. Doma had the highest RKN incidence and prevalence. The lowest RKN incidence and prevalence were observed in Dakawa. Root Galling scores for RKN on tomato roots did not vary significantly (p = 0.06) between the studied areas.

Moreover, RKN populations per 100 cm^3 of soil did not differ significantly (p = 0.074) between studied locations. There was no significant difference (p = 0.809) in RKN population per 5 g of roots.

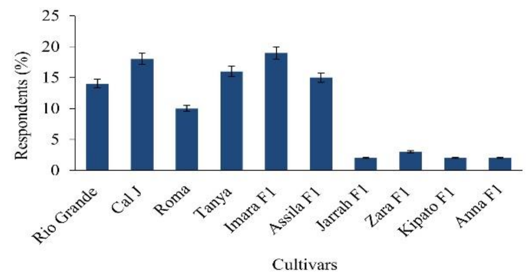

Figure 3. Popular tomato cultivars grown in Mvomero District

Table 6. The mean incidence, prevalence, and gall scores (GS) of *Meloidogyne* spp. in the study area

Location	Incidence	Prevalence	(GS)	RKN/100 cm^3 soil (transformed)	RKN/5g (root transformed)
Dakawa	16.00a	36.00a	2.30	0.524	0.49
Doma	32.00b	80.00c	2.30	0.631	0.36
Mlali	20.00a	64.00b	1.80	0.220	0.44
LSD (5%)	9.15	13.32	ns	ns	ns
p-value	0.002	< 0.001	0.06	0.074	0.809

*Means within a column followed by the same letter are not significantly different (p ≤ 0.05); LSD = Least significant difference; GS = gall score; ns = non-significant

DISCUSSION

Tomato production in the study area was dominated by males, denoting that they were the majority of tomato growers. The finding is in line with that of Mwatawala et al. (2019) who reported 86.4% and 13.6% of male and female tomato farmers, respectively in Mvomero District. This could be linked to fact that men are the principal landowners in the farming community. Furthermore, Masunga (2015) reported the dominance of men (66.7 %) over women (33.7 %) engaged in tomato production in Musoma Municipality, Tanzania. Other reason could be deduced from the fact that tomato production is a capital and labour intensive activity and men have greater access to capital than women as reported by Anang et al. (2013).

Majority of tomato growers (41%) in the study area were aged between 18 - 35 years suggesting that a large segment of youths in the study area were actively participating in tomato production. It is also an indication that there may be a high potential for boosting tomato production in the area through educating youths on how to manage RKN in their farms. This could be due to the reason that tomato is a high value crop which attracts youths. A similar result on dominance of youths was reported by Mwatawala and Yeyeye (2016) who did a study concerning tomato production in Mvomero District. However, the results by Mwangi et al. (2015) indicated that 56% of tomato growers interviewed in Mwea sub-county in Kenya who aged between 20 - 40 years were actively participating in tomato production.

The highest percentage of respondents had primary school education, and a few had secondary education. The results imply that tomato growers in the study area could understand and implement basic management practices against RKN that affect tomatoes. The results are in line with that of Mwatawala et al. (2019) who reported most respondents (94%) were with primary education in Mvomero District.

The average farm size for tomato production was 0.4 to 0.6 ha. The finding suggests that the majority of farmers involved in tomato production are smallholder farmers with limited awareness on RKN (Janssen et al., 2017). Mwatawala et al. (2019) also reported an average farm size under tomato production of 0.56 ha in Mvomero District, Tanzania. The finding further concurs with that of Moranga (2016) who reported the average farm size of 0.4 ha under tomato in Kenya.

This study revealed that most farmers were not using hybrid seeds. Limited adoption of hybrid varieties could be the result of limited income/capital for smallholder farmers' which lead to preference for open pollinated varieties as an alternative to hybrid varieties which are relatively expensive. Majority of growers were sourcing seeds from agro dealers indicating that they had access to quality seeds, which in turn may increase their production levels. Other results (Hanani, 2016; Ochilo et al., 2019) have indicated that profitable farmers are capable of accessing quality inputs for crop production.

This study found that respondents with more than five years of farming experience in tomato production were aware of RKN. Benjamin et al. (2017) reported that knowledge of the prominently visible pests is normally known by the farmers given the extended period of cultivation. This is similar to the findings reported by Janati et al. (2018) indicating that RKN associated symptoms can easily be identified by farmers due to the presence of characteristic galls on the root systems. However, only one percent of respondents declared RKN as a serious problem. This could mean that the problem is overlooked, and respondents are ignorant of the damage caused by RKN in their fields. This finding is in line with the study by Ijani et al. (2000) who reported that 80% of respondents in Morogoro were ignorant of the damage caused by RKN.

Moreover, this study has revealed that RKN are prevalent in all of the tomato fields surveyed in Mvomero District. This finding is in line with previous reports (Nono -Womdim et al., 2002; Testen et al., 2018), which reported RKN damage in different tomato growing areas in Tanzania. The widespread distribution of RKN in the study areas could be due to the prevailing favourable weather conditions and the polyphagous nature of RKN. It could also be attributed to continuous growing of susceptible tomato varieties on the same site and/or rotation of tomatoes with RKN susceptible crops such as okra and eggplant by the growers as noted during the survey. Santos et al. (2019) reported the widespread of RKN associated with the cultivation of susceptible vegetable crops such as cabbage, pepper, carrot, eggplant, okra and tomato in Sub-Saharan Africa. Seid et al. (2015) pointed out that tomato is a universal host for *Meloidogyne* spp.

CONCLUSION

This study has demonstrated that root-knot nematodes infect most of the cultivated tomato varieties in growers' fields in Mvomero District. However, the problem is neglected and considered as a low priority factor for crop production and protection due to lack of awareness to small scale farmers. Majority of farmers are not aware that RKN is a serious tomato production constraint. Hence, there is a need for awareness campaign on how to diagnose and manage RKN in tomato growers' fields in Mvomero District.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by Authors.

AUTHORS CONTRIBUTIONS

SO performed the conception or design of the work, data collection, data analysis, interpretation and was a major contributor in writing the manuscript (drafting the article). HM, NL and BK performed a critical revision of the article, providing critical comments concerning the discussion of results, conclusions, and recommendations. All authors read and approved the final manuscript.

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