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FARMER KNOWLEDGE, MANAGEMENT PRACTICES AND OCCURRENCE OF TOMATO ROOT KNOT NEMATODES IN KENYA

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ABSTRACT

Root-knot nematodes (RKNs) (*Meloidogyne* spp.) is a major constraint to tomato (*Solanum lycopersicum* L.) production in sub-Saharan Africa; yet there is low adoption of recommended nematode control measures in regions like east Africa due to inadequate farmer knowledge about the pest and associated diseases. The objective of this study was to assess farmers' knowledge status, and intensity of damage of root-knot nematodes and their management practices in Kenya. A survey was conducted in Kenya, during February to August 2021; using a semi-structured questionnaire administered to 282 randomly selected household heads of actively growing tomato farmers, at two elevations in three counties. Most farmers (98.9%) could not identify the disease precisely. They mostly attributed its symptoms to moisture stress and nutrient deûciencies. Most farmers (63%) practiced mono-cropping; while only 4.3% of farmers amended soils with manure. Respondents preferred growing RKN susceptible tomato varieties, mainly Rio-Grande, Cal J, Onyx and Kilele FI. A total of 92% expressed willingness to shift to RKNs resistant varieties, if recommended varieties match their desirable characteristics. Majority of the respondents lacked knowledge on nematode characteristics and its associated disease control. A total of 37.9% of the respondents did not use control measures against the RKNs. There was high disease incidence, severity and galling index in the surveyed areas.

Key Words: *Meloidogyne*, nematode resistant, *Solanum lycopersicum*

RÉSUMÉ

Les nématodes à galles (RKN) (*Meloidogyne* spp.) constituent une contrainte majeure à la production de tomates (*Solanum lycopersicum* L.) en Afrique subsaharienne ; pourtant, les mesures de lutte contre les nématodes recommandées sont peu adoptées dans des régions comme l'Afrique de l'Est en raison d'une connaissance insuffisante des agriculteurs sur le ravageur et les maladies associées. L'objectif de cette étude était d'évaluer l'état des connaissances des agriculteurs et l'intensité des dommages causés par les nématodes à galles et leurs pratiques de gestion au Kenya. Une enquête a été menée au Kenya, de Février à Août 2021 ; à l'aide d'un questionnaire semi-structuré administré à 282 chefs de ménage sélectionnés au hasard parmi les producteurs de tomates en pleine croissance, à deux altitudes dans trois comtés. La plupart des agriculteurs (98,9 %) ne pouvaient pas identifier précisément la maladie. Ils ont principalement attribué ses symptômes au stress hydrique et aux carences en nutriments. La plupart des agriculteurs (63 %) pratiquaient la monoculture ; tandis que seulement 4,3 % des agriculteurs ont amendé les sols avec du fumier. Les répondants ont préféré cultiver des variétés de tomates sensibles au RKN, principalement Rio-Grande, Cal J, Onyx et Kilele FI. Au total, 92 % ont exprimé leur volonté de passer à des variétés résistantes aux RKN, si les variétés recommandées correspondent à leurs caractéristiques souhaitables. La majorité des répondants manquaient de connaissances sur les caractéristiques des nématodes et le contrôle des maladies associées. Au total, 37,9 % des répondants n'ont pas utilisé de mesures de contrôle contre les RKN. L'incidence, la gravité et l'indice de galle de la maladie étaient élevés dans les zones étudiées.

Mots Clés : *Meloidogyne*, résistant aux nématodes, *Solanum lycopersicum*

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) plays a key role in sub-Sahara Africa countries as a source of food nutrition and income sourcing for small-holder farmers (Ochilo *et al.,* 2019). Although there has been increase in production land area in some countries like Kenya in the last decade, the country continues to record low fruit productivity statistics (Najjuma *et al.,* 2016; Ochilo *et al.,* 2019). This is attributed mainly to insect pests and plant parasitic nematodes (Varela *et al.,* 2003; Anonymous, 2005).

Soil borne RKNs (*Meloidogyne* spp.) are among the most damaging tomato parasites due to their wide host range (Saxena, 2004). Typical symptoms of RKNs infection are underground associated with root-knot (swellings or galls), sometimes not easily recognised (Karssen *et al.,* 2013). Root galls hinder nutrient and water uptake by host plants. Above ground symptoms associated with RKNs infection include stunted growth, leaf chlorosis, incipient wilting, low and poor quality crop yields that are similar to those of nutrient and water deficiency (Anwar and McKenry, 2010). Additionally, damage by RKNs increases severity of opportunistic pathogens (Suleman *et al.,* 1997).

Commonly recommended control measures for RKNs include crop rotation, land fallowing, use of resistant varieties, proper disposal of crop residues, use of nematopathogenic microorganisms and application of synthetic nematicides (Luc *et al.,* 2005). Though synthetic nematicides are the most promising control measures against nematodes, they have been widely abandoned due to their associated ozone depleting properties and hazardous effects to man and biodiversity (Radwan *et al.,* 2012).

The knowledge, attitude and practices model is a good tool for assessing what farmers know about the subject being evaluated, and how they perceive their present control measures (Schreinemachers *et al.,* 2017). The model assumes that a change in practice is a result of collective effects of changes in awareness and perceptions. In spite of its power when used in related studies, this model has not been adequately tested on tomato RKNs control shortfalls in Kenya.

Tomato farmers in Kenya are invariably advised to plant root-knot nematode resistant varieties. However, there is low adoption of this intervention due to limited awareness about the pest, and/or the recommended varieties to match their desirable traits. The objective of this study was to assess farmers' knowledge status and management practices of tomato RKNs disease; and determine root-knot nematodes induced disease damage in Kenya.

MATERIALS AND METHODS

This study was conducted in high altitude agro-ecological zones (1890.7 to 1934.0 meters above sea level) in Nakuru County, and mid-altitude agro-ecological zones (1334.3 to 1434.7 m.a.s.l.) in Kirinyaga and Kajiado Counties, regions where tomatoes are mostly grown in Kenya (Ministry of Agriculture, 2018). The rural communities of Bahati and Subukia in Nakuru County, Mwea East and Mwea West in Kirinyaga County, Kimana and Rombo in Kajiado County were selected based on having some differences in the relevant environment (Table 1).

The selected areas received bimodal rainfall, with long rains occurring between March to June and short rains occurring in October to December; with rainfall amounts varying between 600 and 1400 mm (Anonymous, 2012). Temperatures in the region range from 20 to 27 °C, with well drained volcanic loamy soils.

A multi-stage sampling technique (Mugenda and Mugenda, 2003) was adopted for selecting respondents. Farmer characteristics considered in the survey were gender, education level, age and experience in tomato production. Thirty one to 68 farm households per community were randomly selected based on the formula of Hamed (2017):

$$n = \frac{P\ (100\text{-}P)\ Z^2}{E^2}$$

Where:

n is the required sample size, P is the proportion of interviewed farmers who recognised RKNs symptoms in their farm; E is the percentage maximum error; and Z is the value corresponding to level of confidence required set at 5%. Application of this formula gave N = 282 respondents, of which 88 were sampled in high altitude zones, 184 were in mid altitude zones (Table 1).

Data on farmers' level of awareness, perceptions and management practices of RKNs were collected through a survey using a pretested semi-structured questionnaire. Interviews were conducted in Kiswahili and/ or local dialects, common among communities in Kenya. To determine the status of farmers' knowledge of RKNs, respondents were shown a diseased plant and asked whether they were aware of its existence in their tomato farm. The respondents were further probed on the causative agent and means spread.

To evaluate farmers' perception of the disease, questions on cropping systems adopted, land fallowing time period, type of fertiliser used; and perceived yield losses were queried. Additionally, respondents were interrogated on their preferred tomato varieties and the criteria they used in selecting these varieties. To determine farmers' actions against RKNs disease, the respondents were asked for the immediate and long term control measures used against the disease. They were furthermore asked to rate effectiveness of the measures they used on a three-point scale; i.e. 1= not effective (do not control the disease), 2 = moderately effective (control up to 50% of the disease) and 3 = very effective (controls 75-100% of the disease).

TABLE 1. Areas involved in RKNs study selected across two agro-ecological zones

Agro-ecological zones	County	Sampling site	Sample size
High	Nakuru	Bahati	40
		Subukia	48
Mid -altitude	Kirinyaga	Mwea East	65
		Mwea West	68
	Kajiado	Kimana	30
		Rombo	31

Estimation of RKNs disease incidence, galling index and severity were done by destructive sampling, in a zig-zag pattern in the fields of 10 tomato plants at different times in three farms per county. RKN disease incidence was estimated based on method outlined by Nchore (2012). For disease incidence, tomato roots from different varieties grown by farmers at two-three months after transplanting were collected, washed separately and dried with paper towels. Galling index was scored using the rating scale outlined by Bridge and Page (1980); where: 0 = no knots on roots; 5 = 50% of roots knotted with knotting on parts of main root system and 10 = all roots severely knotted.

Root-knot nematodes disease severity was rated using the scale developed by Taylor and Sasser (1978); where 0 = disease free plant (no knots on roots); 1-2 = very mild (1-25 knots on root); 3 = mild severity (26-30 knots on roots); 4 - 5= moderate (31-50 knots on roots); 6 - 8 = severe (51-75 knots on roots); 9 - 10 = very severe (all roots knotted)

Data collected were analysed using the Statistical Package for Social Sciences (SPSS) Version 25, IBM SPSS®, Chicago, IL. Chi-square test was used to determine relationships between farmers' knowledge of RKNs and socio-demographic factors. Fisher's exact test was used to establish the relationship between zones and farmer practices. Data on RKNs disease incidence, galling index and severity were subjected to ANOVA and significant means separated using the Least Significant Difference. Pearson correlation was used to establish the relationship between disease incidence, severity and galling index, using R package (ver. 2.10, CRAN®, Vienna, Austria).

RESULTS

Farmers' awareness of the RKN disease. Majority of the tomato farmers (98.9%) were not aware of the existence of RKNs disease in their farms. Only 3.2% of the respondents attributed the diseased plant to nematode infection. Most of the tomato farmers (62.8%) misdiagnosed the disease for nutrient deficiency; while 27.0% believed the disease was result of moisture stress (Table 2). Most interviewees (48.6 %) perceived the disease to be soil borne, with 22.0% believing that the disease was spread through infected seeds; while 16.7% perceived the disease to be spread by rain water. A Chi-square test showed that recognition of RKNs disease did not depend on a farmer's gender (χ^2=1.34, *ddl*=1, P= 0.28), age (χ^2=0.78, *ddl*=2, P= 0.35), education (χ^2=2.58, *ddl*=3, P= 0.51) or years of experience in tomato growing (χ^2=0.2, *ddl*=2, P= 0.67).

Majority of the tomato farmers (77.0%) depended on their own experience to identify the tomato diseases on their farms. Other sources of relevant information included mass media such as local FM radios and televisions (44.7%), fellow tomato farmers (38.3%), agricultural extension (30.9%) and research institutions (15.2%).

Farmers perception of the RKN disease and criteria of selecting tomato varieties. Poor farming practices were prevalent among tomato farmers in Kenya; for instance all the farmers (100%) piled up tomato plants residues in their farms after harvest. Majority of the tomato farmers (96.1%) practiced mono-cropping; while only 1.1% practiced crop rotation. Intercropping tomatoes with either spinach, cabbage or beans was mainly for crop diversity purposes and to cater for the production risks. Although land fallowing for two years was recommended as a control strategy against the RKNs, majority of the farmers (96.5%) did not (Table 3). Most of the respondents' (85.3%) relied on inorganic fertilisers for nutrient supply to their tomatoes (Table 3). Also, majority of the tomato farmers (69.9%) perceived losses attributed to RKNs disease to be less than 25% of the total yield (Table 3).

Tomato varieties commonly grown in the study areas were classified into susceptible and

TABLE 2. Farmer knowledge of root-knot nematodes disease

Variable	Frequency (*n*)	Proportion (%)	P value
Knowledge on existence of the disease			
Not aware of the disease	279	**98.9**[a]	<0.001
Aware of disease existence	3	1.1[b]	
Causative agents of the disease			
Nutrient deficiency	177	62.8[a]	<0.001
Moisture stress	76	27.0[b]	
Unknown	20	7.1[c]	
Root knot nematode	9	**3.2**[c]	
Means of spread the disease			
Rain water	47	16.7[c]	<0.0011
Infected seeds	62	22.0[b]	
Soil	137	48.6[a]	
No idea	36	12.8[c]	

Means in the same column followed by the same letter (a, b) are not significantly different using Least significance difference (LSD) test, $\alpha = 0.05$

TABLE 3. Farmers cropping systems and perceived yield loss in surveyed areas

Variable	Frequency (*n*)	Proportion (%)	P value
Type of cropping system			
Monocrop	271	96.1[a]	<0.0001
Intercropping	8	2.8[b]	
Crop rotation	3	1.1[b]	
After how long do you undertake fallowing			
Never	272	96.5[a]	<0.0001
1-3 years	9	3.2[b]	
4-6 years	1	0.4[b]	
Type of fertiliser used			
Inorganic	214	75.9[a]	0.007
organic	12	4.3c	
organic +inorganic	56	19.9[b]	
Perceived % yield loss caused root-knot disease			
<25% of the total yield	197	69.9[a]	0.0012
26- 50% of the total yield	64	22.7[b]	
51-75% of the total yield	13	4.6[c]	
76-100%	8	2.8[c]	

Means in the same column followed by the same letter (a, b) are not significantly different using Least significance difference (LSD) test, $\alpha = 0.05$

moderately resistant. A total of 78.4% of the respondents from mid-altitude zones cultivated RKNs susceptible tomato varieties (Rio-grande, Cal J and Onyx and Kilele F1), compared with 72.1% in the high altitude zones. Moderately resistant varieties (Anna F1 and Assila FI) were grown by 10.9 and 18.1% of the farmers in the mid- and high altitude zones, respectively. Majority (87.2%) of the respondents were unaware of existence of nematode resistant varieties.

Table 4 presents the most farmer preferred tomato varieties identified in the study areas. The farmers' top five desired traits as varieties of choice included high yielding, early maturity, long shelf life, pest/disease resistance and tolerance to harsh weather conditions. All the tomato farmers (100%) indicated willingness to shift to cultivatation of RKNs resistant varieties, so long as the varieties had farmer and consumer desirable characteristics.

TABLE 4. Most preferred tomato varieties by at least 50% of the farmers in rural communities

Sampling site	Preferred tomato varieties
Bahati	Assila FI, Cal J, Rio Grande
Subukia	Anna FI, Cal J, Rio Grande,
Mwea East	Kilele FI, Rio Grande, Onyx
Mwea West	Cal J, Kilele FI, Rio Grande, Onyx
Kimana	Cal J, Rio Grande, Onyx
Rombo	Cal J, Kilele FI, Onyx

It was evident that farmer preferred characteristics for tomatoes were significantly related to the agro-ecological zones in which they lived (χ^2 =13.26, *ddl* = 1, P = 0.01%).

Farmers' management practices against RKNs. Tomato farmers controlled RKNs using four different options (Table 5). There was similarity in both farmers' immediate and long-term RKNs disease control measures. Upon disease detection, only 4.3% of the respondents' contacted an agricultural extension officers for advice; 6.5% implemented field sanitation; while only 8.8% practices the cultural options. The associated control practices included rouging infected plants, burying/burning infected plants and application of wood ash. As long term control measures, 39.7% took no further action, 27.3% applied inorganic fertilisers, 19.5% flooded/ furrow irrigated their farms, 12.1% observed cultural practices; while only 1.4% sought advice from agricultural extension officers (Table 5).

Majority of the respondents (87.9%) perceived the disease control measures (Table 5) as ineffective, 7.8% indicated the practices were moderately effective; and only 4.6% concurred that actions taken were effective. With an average score of 1.1 and standard

TABLE 5. Immediate practices and long term measures taken by farmers in RKN disease management

Variable	Immediate practice Proportion (%)	Long term action Proportion (%)
Reported to agricultural officer/	4.3c	1.4e
Field sanitation	14.5b	12.1d
No action taken/control	34.4a	39.7a
Fertiliser application	31.9a	27.3b
Flooding/watering the farms	14.9b	19.5c
P-value	0.001	<0.0001

Means in the same column followed by the same letter (a, b) are not significantly different using Least significance difference (LSD) test, $\alpha = 0.05$

TABLE 6. Disease incidence, galling index and severity in the surveyed areas

Sampling site	Disease incidence	Galling Index	Disease severity
Mwea West	94.1±5.1a	7.2±1.7a	7.6±1.6a
Mwea East	93.4±4.8a	6.5±1.5a	7.1±1.5a
Kimana	91.4±3.5a	5.9±2.1a	6.4±1.7a
Rombo	90.8±4.1a	5.7±1.1a	6.3±2.3b
Kabazi	84.1±3.2b	2.8±0.9b	3.5±0.8b
Subukia	79.7±3.9b	3.7± 1.5b	3.1±1.8b
P value	0.0001	0.001	0.0001

Root knot nematode disease incidence estimated based on method proposed by Nchore (2012)
Galling index scored based on rating scale proposed by Bridge and Page (1980)
Disease severity rated using the scale developed by Taylor and Sasser (1978)
Means in the same column followed by the same letter (a, b) are not significantly different using Least significance difference (LSD) test, $\alpha = 0.05$

deviation of 0.82, the overall level of effectiveness of the RKNs disease control measures taken by the farmers could be categorised as ineffective.

Fisher's exact test showed that agro-ecological zones and farmers' practices were not related (P = 0.467). Thus, agro-ecological zones are not factors to consider when choosing RKNs management practices to be taken by the farmers.

Incidence and severity of RKNs. All the farms surveyed (100%) were infested with RKNs (Table 6); disease incidence differed significantly across AEZ (P< 0.001). The highest disease incidence was recorded in Mwea West (94.1%); and the lowest incidence in Subukia (78.7%). Tomato root systems showed damage due to RKNs as was inferred from the development of root galls.

Galling index. The galling index (GI) varied significantly (P < 0.05) across the AEZs (Table 6). The highest GI was recorded in Mwea West (7.2); while the lowest GI was recorded in Kabazi (2.8). Additionally, RKNs disease severity differed significantly (P<0.05) between the AEZs (Table 6).

Severe disease intensities were recorded in Mwea West (7.6), Mwea East (7.1), Kimana (6.4) and Rombo (6.3); while mild disease severity was recorded in Subukia (3.5) and Kabazi (3.1) (Table 6). There was a significant positive relationship between disease incidence and severity (r = 0.78, P > 0.05); and galling index and disease severity (r = 0.521, P > 0.05).

DISCUSSION

Farmers' knowledge of RKNs disease. Farmers' knowledge on RKNs disease was limited as only 3.2% associated the diseased plants shown to them with nematodes infection (Table 2). Previous reports also showed that most farmers in Africa lack precise knowledge of pests and diseases affecting vegetable crops in their fields (Abang *et al.,* 2014; Auwal *et al.,* 2015). Lutuf *et al.* (2018) reported low farmers' awareness of plant parasitic nematodes associated with tomatoes in Ghana. Farmers attributed disease symptoms RKNs infected plants to nutrient deficiency and/or moisture stress (Table 2) perhaps because it is the root apparatus that facilitates nutrients and soil water uptake. This further emphasises the need for wide knowledge on disease diagnosis.

Farmers' reliance on their own and other farmers' experiences for RKNs disease identification, could be a major hindrance to RKNs diagnosis and management. This calls for farmers' training on simple techniques that can be used to distinguish RKNs infected plants from other abiotic factors. Training in areas using such as field disease diagnosis *via* visual examination of the affected tomato root systems will be critical in control of nematodes in Kenya.

Farmers' perception of RKNs control in Kenya. Intercropping with tomatoes was only practiced by 2.8% of the surveyed households (Table 3), and mainly as diversification strategy to reduce production risks. Only a few farmers were aware of its disease management attribute. Additionally, tomato farmers (2.8%) also cultivated nematode alternative hosts such as spinach, cabbage and beans as intercrops for the tomatoes. This and the under-exploitation of intercropping in diseased control, underscores the importance of farmer training to build farmer diseased management capacity, as well as bolster environmental safety on tomato farms.

Other cultural practices such as crop rotation and land fallowing have been advocated for a long time, as eco-friendly management strategies for RKNs; though their adoption in the surveyed areas in Kenya is still insignificant (Table 3). All (100%) the respondents reported pilling tomato plant residues on their farms after fruit harvesting. These residues acted as reservoirs for this parasitic nematodes during off-season periods (Bayuh *et al.,* 2013). Intervention in this practice is necessary through customised farmer training programmes, which emphasize chemical free and inexpensive disease management measures.

The significant reliance on use inorganic fertilisers (61.7%) to supply tomato crops with required nutrients in Kenya is quite worrying (Table 3) with respect to environmental quality and public health. This is in spite of the fact that previous studies have shown that use of manures on farms results in increase of population of predatory nematodes populations, release of toxic phenolic compounds by the plant and reduce RKNs in the soil (Oka *et al.,* 2007; Wachira *et al.,* 2009).

The overwhelming preference of respondents for nematode susceptible tomato varieties is surprising but could be attributed to farmers' inherent consumption and market preferences, as well as the associated yield levels and varietal adaptation to various environmental stresses (Ochillo *et al.,* 2019). In fact pest and disease resistance were ranked fourth on farmers' preferred characteristics for new variety to be adopted in the area; signifying RKNs as a major constraint to tomato production in Kenya, . Incidentally, farmers rarely consider RKN resistant varieties as part of the prerequisites for selecting varieties to grow. Nevertheless, 92% of the respondents were willing to accept RKN resistant tomato varieties, so long as they are endowed with their desirable characteristics.

Farmers' management practices against RKNs. Although integrated RKNs management practices have been developed by various research institutions, their adoption by the farmers has been low (Bayuh *et al.,* 2013). A significant number of farmers (39.7%) did not control measure against the RKNs in the study area (Table 5). This could be due to farmer's inadequate knowledge of the pest or lack of information of these practices and relevant training on how to implement them. Our findings concur with earlier studies by Torkpo *et al.* (2017) in Ghana, who reported that farmers hardly adopted the management strategies aimed at preventing the spread of cassava mosaic disease on their farms.

Farmers opined that they lacked effective control options, while others reported that inspire of the available agricultural extension advice was ineffective on the subject. Thus, we can conclude that extension services and training support for RKNs diagnosis and management are essential for stakeholders in the study areas.

Incidence and severity of RKNs. Root-knot nematodes (RKNs) were detected in all tomato plants across the two agro-ecological zones. High RKNs disease incidence (94.1%), galling index (7.2), and disease severity (7.6) on tomatoes in the study areas were recorded (Table 6). This could be due to poor cropping practices reported by the farmers, including furrow irrigation, sole-cropping, absence of land fallowing and cultivation of nematodes susceptible varieties that allows reproduction and spread of nematodes (Tables 3 and 4). This concurs with earlier studies by Mbogoh *et al.* (2013), who reported that poor farming practices favoured root-knot nematodes inoculum build up in indigenous leafy vegetables in Western Kenya. Surveyed farmers reported that intercropping tomatoes with nematodes susceptible crops such as beans, cabbage and spinach that acted as alternative hosts for the nematodes during off season; and hence increased disease incidence and severity in most farms.

Inadequate use of soil amendments in the form of manure could also have played a role in the prevalence of high disease incidence and severity recorded in the two AEZs (Table 6). Manure enhances release of toxic phenolic compounds by the plants, increase the presence of nematopathogenic microorganisms that reduces nematodes incidence and severity (McSorley, 2011). These findings agree with the report by Naz *et al.* (2012), who reported increase in nematodes severity on tomatoes in non-amended soils in Pakistan.

The high use of inorganic fertilisers also increases potassium and phosphorus in the soil that favours nematodes inoculum reproduction (Giné *et al*., 2016). High disease incidence and severity concur with earlier studies by Shahid *et al.* (2007) and Ravindra *et al.* (2014), who reported 75-100% RKNs disease incidence in tomato.

CONCLUSION

This study has revealed that RKNs and their associated disease are prevalent and ill managed in the tomato producing subsector in Kenya. Unfortunately, tomato farmers lacked the requisite management of both the pest and disease. There is promotion of use of synthetic fertilisers against manures, the latter of which are superior in terms of preventing reproduction, spread and activity of associated nematodes. There is urgent need to train farmers on simple techniques to detect and identify the disease so as to implement appropriate integrated control measures and reduce the rising tomato yield losses in Kenya. Farmers' willingness to accept resistant varieties provides for a viable entry point for research, development and further collaboration to promote integrated pest management.

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REFERENCES

Abang, A.F., Kouame, C.M., Abang, M., Hanna, R. and. A.K. 2014. Assessing vegetable farmer knowledge of diseases and insect pests of vegetable and management practices under tropical conditions. *International Journal of Vegetable Science* 20:240-253.

Anonymous. 2005. Research priorities at KARI-Thika. Report of the prioritization workshop held at Kenya Agricultural Research Institute (KARI), Thika, Kenya. pp.17-23

Anonymous. 2012. National horticulture policy. Ministry of Agriculture, Government of Kenya, Kilimo House, Nairobi, Kenya. pp. 10-15.

Anwar, S.A. and MKenry, M.V. 2010. Incidence and reproduction of *Meloidogyne incognita* on vegetable crop genotypes. *Pakistan Journal of Zoology* 42(2):135-141.

Auwal, H.M., Galadima, I.B., Madu, J. and Joseph, P. 2015. Evaluation of synergistic effect of neem and poultry manure on root knot nematode (*Meloidogyne* spp.) infecting rice. *Open Agriculture Library Journal* 2:1-4.

Bayuh, B., Sakhuja, P.K. and Tadele, T. 2013. Integrated management of root-knot nematode (*Meloidogyne incognita*) for tomato production and productivity. *Ethiopia Journal Science & Technology* 6(2):79-91.

Bridge, J. and Page, S.L.J. 1980. Estimation of root knot nematode infestation levels on roots using a rating chart. *Tropical Pest Management* 26(3):296-298.

Giné, A., Carrasquilla, M., Martínez-Alonso, M., Gaju, N. and Sorribas, F.J. 2016. Characterization of soil suppressiveness to root-knot nematodes in organic horticulture in plastic greenhouse. *Frontier in Plant Science* 7(174).

Hamed, T. 2017. Determining sample size; How to calculate survey sample size. *International Journal of Economic Management* 2:237-339.

Karssen, G., Wesemael, W. and Moens, M. 2013. Root-knot nematodes, pp. 73-108. In: Perry, R.N. and M. Moens. (Eds.). Plant Nematology, 2nd ed., CAB International, Wallingford, UK.

Lopez-Gomez, M., Flor-Peregrin, E., Talavera, M. and Verdejo-Lucas. S. 2015. Suitability of Zucchini and cucumber genotypes to populations of *Meloidogyne arenaria*, *M. incognita* and *M. javanica*. *Journal of Nematology* 47(1):79-85.

Luc, M., Sikora, R.A. and Bridge. J. 2005. Plant parasitic nematodes in sub-tropical and tropical agriculture. Centre for Agriculture and Bioscience International (CABI), Wallingford, UK. 871pp.

Lutuf, H., Nyaku, S.T., Cornelius, E.W., Yahaya, S.A.J. and Acheampong, M.A. 2018. Prevalence of plant-parasitic nematodes associated with tomatoes in three agro-ecological zones of Ghana. *Ghana Journal of Agricultural Sciences* 52:83-94.

Mbogoh, J.M., Omami, E., Ngode, L., Ochuodho, J., Njira, P. and Sunda, W. 2013. Occurrence of root-knot nematodes in African leafy vegetables production systems of Western Kenya. *African Crop Science Conference Proceedings* 11:215-220.

McSorley, R. 2011. Overview of organic amendments for management of plant parasitic nematodes, with case studies from Florida. *Journal of Nematology* 43(2):69-81.

Ministry of Agriculture (MOA). 2018. Provincial horticultural production statistics 2017-2018, Ministry of Agriculture, Nairobi, Kenya.

Mugenda, O.M. and A.G. Mugenda. 2003. Research methods: Quantities and qualitative aapproaches. ACTS Press, Nairobi, Kenya. pp. 61-69.

Najjuma, E., Mbeche, R., and Kavoi, M.M. 2016. Assessment of technical efficiency of open field tomato production in Kiambu County, Kenya (stochastic frontier approach). *Journal Agricultural Science Technology* 17(2):21-39.

Naz, I., Palomares-Rius, J.E., Blok, V., Saifullah, Ali, S. and Ahmed, M. 2012. Prevalence, incidence and molecular identification of root-knot nematodes of tomato in Pakistan. *African Journal of Biotechnology* 11(100):16546-16556.

Nchore, S.B., Waceke, J.W. and Kariuki, G.M. 2012. Incidence, prevalence and management of root-knot nematodes (*Meloidogyne* spp.) in selected indigenous leafy vegetables in Kisii and Trans-Mara Counties, Kenya. Kenyatta University, Nairobi, Kenya, MSc Thesis. pp. 47-49.

Ochilo, W.N., Nyamasyo, G.N., Kilalo, D. Otieno, W. Otipa, M. Chege, F. Teresia, K. and Lingeera, E.K. 2019. Characteristics and production constraints of smallholder tomato production in Kenya. *Science African* 2: e00014.

Oka, Y., Shapira, N. and Fine, P. 2007. Control of root-knot nematodes in organic farming systems by organic amendments and soil solarization. *Crop Protection* 26:1556-1565.

Radwan, M.A., Farrag, S.A.A., Abu-Elamayem, M.M. and Ahmed. N.S. 2012. Efficacy of some granular nematicides against root-knot nematode, *Meloidogyne incognita* associated with tomato. *Pakistan Journal of Nematology* 30(1):41-47.

Ravindra, H., Sehgal, M. Manu, T.G. Murali, R., Latha, M. and Narasimhamurthy, H.B. 2014. Incidence of root-knot nematode (*Meloidogyne incognita*) in black pepper in Karnataka**.** *Journal of Entomology and Nematology* 6(4):51-55.

Rivera, L. and Aballay, E. 2008. Nematicide effect of various organic soil amendments on *Meloidogyne ethiopica* Whitehead on potted vine plants. *Chile Journal of Agricultural Research* 68:290-296.

Saxena, G. 2004. Biocontrol of nematode-borne diseases in vegetable crops. *Fruits Vegetable diseases* 1:397-450.

Schreinemachers, P., Chen, H., Nguyen, T.T.L., Buntong, B., Bouapao, L., Gautam, S., Le, N.T., Pinn, T., Vilaysone, P. and Srinivasan, R. 2017. Too much to handle? Pesticide dependence of smallholder vegetable farmers in Southeast Asia. *Science Total Environment* 594: 470-477.

Suleman, P., Sardanelli, S., Krusberg, L.R. and Straney, D.C. 1997. Variability among *Fusarium. oxysporum.* f. sp. *lycopersici* isolates in their ability to interact with *Meloidogyne incognita* race 1. *Kuwait Journal Science and Engineering* 24:299-307.