Chuka University
info@chuka.ac.ke | 020 231 0512 / 020 231 0518

MANAGEMENT OF PARASITIC ROOTKNOT NEMATODES IN SWEETPOTATO: REVIEW

Onchari, N. M[1],Githae.E.W[1],Franklin.N[2].Muraya.M.M[3]
[1]DepartmentofBiologicalSciences,ChukaUniversity,P.O. Box109-60400,ChukaTel:+254728666948,Email: oncharin5@gmail.com,egithae@chuka.ac.ke,nyabuga.franklin@embuni.ac.ke , moses.muraya@gmail.com or mmuraya@chuka.ac.ke

How to cite:
Onchari, N. M., Githae, E. W., Franklin, N. and Muraya, M. M. (2021). Management of parasitic root knot nematodes in sweet potato: Review. *In: Isutsa, D. K. (Ed.). Proceedings of the 7th International Research Conference held in Chuka University from 3rd to 4th December 2020, Chuka, Kenya, p.34-40*

ABSTRACT
Agriculture is the mainstay in Kenyan economy, it currently contributes to 29% in gross domestic product (GDP) and creates employment of over 80% in the rural population. There are four major sub sectors in the agricultural sector which are food crops, industrial crops, livestock, fisheries and horticulture. Sweet potatoes are based under horticultural crops production which are now constrained by many biotic factors including root knot nematodes (RKN).Root knot nematodes pose a significant threat to a wide range of agricultural crops. The effect of RKNs in sweet potatoes are seen through the formation of galls, which reduce water and nutrient uptake, stunted vines and discoloured cracks in root tubers. These effects cause poor quality of tubers hence yield loss and high costs of production leading to poor income. Root knot nematodes diversity depends on ecological conditions and change of environmental conditions with time. Management strategies to control RKN have been practiced over time; cultural methods including fallowing of fields, intercropping and crop rotation have been used however root knot nematodes have ability to infect a wide host range; use of resistant varieties against RKN were adopted however some resistant genes tend to be silent in soil temperatures above 30°C rendering the crop susceptible; use of synthetic nematocides were then found effective against RKN species however they leave residues on plants which are harmful to human consumption and are environmentally unfriendly hence they were banned. With these challenges scientists are focusing on discovery of nematocides from medicinal plants. The use of medicinal plants especially *Canavalia ensiformis* has shown 87% mortality rate on juveniles at stage two. Due to limited exploration of medicinal plants, more studies are encouraged on the same for RKN management and increase food security.
Keywords: Root knot nematodes(RKN), sweet potatoes, medicinal plants, food security, agriculture

INTRODUCTION
Sweet potato (Ipomoea batatas) is traditionally viewed as a “poor person’s crop” and has attracted limited attention to other staple crops (Mwanga *et al*., 2017). Studies have investigated its importance and more attention has been directed to its production in developing countries (Drapal *et al*., 2019). Sweet potatoes have shown to play a critical role in food security and alleviating poverty (Wadl*et al.,* 2018). It is ranked the sixth important food cropworldwide after wheat, maize, potatoes and cassava (International Potato Centre, 2018). Sweet potatoes have high nutritional value of vitamin C, minerals, β carotenoids, carotene and phenolic compounds (Lee and Lee, 2017). Sweet potatoes are valued as a functional staple food for human consumption due to its phytochemicals, antioxidants, immunomodulatory, antimicrobial and anticancer properties (Ayeleso *et al*., 2017). They provide source of income however its production has faced a crisis due to presence of abiotic, social and biotic stress. Biotic stress affecting production of sweet potatoes is the presence of parasitic root knot nematodes (Wabere *et al*., 2016). *Meloidogyne* species are ranked the most common damaging harmful species (Karuri *et al*., 2017). These root knot nematodes(RKNs)causecrackingofrootsandnecrosis whichinturnreduces marketquality(Laurence *etal*.,1986; Karuri *et al*., 2017). Moisture and temperature elevation leads to an increased rate of RKNs reproduction, development and infection (****). Common genera of infectious RKNs are *Trichodorous, Tylenchus, Pratylenchus, Hoplolaimus* and *Aphelenchus* (*****). This review shades light on parasitic root knot nematodes in sweet potato farms focusing on the most common and damaging nematodes. Due to their abundance and diversity, problems tend to aggravate and farmers experience losses and economic crisis is faces bythe nation. Thisreview also shows a way forward on how to control and manage parasitic RKN in more effective criteria.

ParasiticRootKnotNematodes

ParasiticRKNsareobligate nonsegmentedroundworms withawidehostrange;allcultivatedplants(Seesayo *etal*., 2017). They are ranked the most economically damaging species that reduce sweet potato yield and production (Jones *et al.*, 2013). Parasitic RKNs have the ability to rapidly spread and colonize new localities hence their management is tedious (Bebber *et al.,* 2014). Parasitic root knot nematodes release a certain protein (m protein) which mimics the plant proteins, this protein modifies the plant host cell wall and causes disruption, it further localizes in host plant cell nucleus resulting in suppression of host defense (Khalil *et al.,* 2017). Parasitic RKNs further feeds on plant parts causing discolored cracks in the root tubers which results to stunted vines whereby the plant doesn't fully develop (Hunja *et al*., 2017). *Meloidogyne* genera is the common worldwide threat with five majorspecies*M.fallax*,*M.javanica,M.incognita,M.hapla*and*M.arenaria*knowntobeextremelypathogenic (Moens *et al*., 2009; Abd-Elgawad, 2019). Severely infected plants by parasitic RKN have altered normal root system with a completely disorganized vascular system. Infected roots are ultimately hindered from their main functionofuptakeand transportationof water and nutrients.Consequently,theplantsexperience stunted growthand are easily affected by drought. This may render plants death (Danish *et al*. 2018). In addition, infected plants by parasitic root knot nematodes have wounds which makes the plant vulnerable to other pathogens such as fungi and bacteria that are present in the soil.

ParasiticRootKnotNematodesinsoil

Constituents of parasitic root knot nematodes among free living microorganisms in soil do act as bio indicators of a healthy soil because their amount correlates with decomposition and nitrogen cycling activities (Neher *et al*, 2001). Some are bacteria feeding root knot nematodes which eliminate bacteria that affect plants (Ntalli *et al*., 2019).

PrevalenceofParasiticRootKnotNematodes

Prevalence can be characterised by gall index (GI), disease index (DI) and egg mass index (EI). Information of prevalence is helpful to develop control strategies of soil-borne disease complex based on their pathological characteristics (Seo *et al*., 2018). Parasitic root knot nematode species have shown high prevalence in the roots ofthe plant where they reproduce successfully and in high amounts causing galls and this leads to death of the plant (Danish *et al*. 2018). Composition and abundance of root knot nematodes are significantly influenced bytemperature and rainfall (Hoang *et al.*, 2014). When scaled globally, the abundance of root knot nematodes (RKN) increases with rise in mean annual temperatures (Nielsen *et al*., 2014). Data analysis of long term temperature in Kakamega, Makueni and Kisii, the sweet potato growing areas show that minimum and maximum temperatures increaseannuallyand thatKenyahasexperienced anincreaseintemperatureby1°Cinthelasttwo decades(Omoyo *et al*., 2015). This shows that abundance of RKN is bound to increase with increase in temperatures.

DistributionofParasiticRootKnotNematodes

Parasitic root knot nematodes (RKN) are aerobic and require moisture content in their immediate surrounding (Kim *et al*., 2017). Parasitic RKNs among other soil microbes are unevenly distributed across dry landscapes and cold areas where there is lack of vascular plants (Shaw and Wall, 2019). Parasitic root knot nematodes can be describedas root feeding larvae and their prevalence is affected by soil types. Most parasitic RKNs show high mortality, persistence and virulence in marlsoil(richincalciumcarbonate) whencompared to sandysoil(Shapiro *etal*,2000). Parasitic RKNs abundance increases during the super bloom in soils of annual plants. Soil organic matter content showsignificantand positivecorrelationto parasiticRKNs abundance.Overall,nematodesinextremeenvironments are adapted to drought conditions, but are highly dependent on the growth and distribution of both annual and perennial plants for their supply of soil organic matter that they rely upon (Treonis *et al.*, 2019). Parasitic root knot nematodes are rich and abundant in moist soils when associated with cryptogamic vegetation and are poor in dry fields and in ornithogenic soils. Species distributions are highly variable within particular environments and are related primarily to organic matter, nutrient and moisture but availability and quality of food resources is the major underlying driver (Smykla *et al.,* 2018).

Meloidogyne hapla was first recorded in Kenya in sweet potato large farm areas of Teso South, Nzaui, Matayos, Manyatta and Mosocho. Their assessment was done by number of eggs present and the level of galling on a scan scale of 0-5 whereby 0= no galls and 5≥100galls (Karuri *et al*., 2017). For common physical characteristics of *Meloidogyne* species especially for the *M. fallax* are the female stylet length of 14.6 µm having an oval rounded basal knob, an oval perineal pattern with a moderately high dorsal arch (Topalovic *et al*., 2017). As in the males, there is presence of a slender stylet of 18.5 µm with a set off and rounded basal knob, a slightly set off male head with one post-labial annule and an incomplete transverse incisures. In second-stage juveniles (J_2) they have a large and rounded stylet basal knobs with a gradually tapering tail of 46.9µm long with a broadly rounded tip and aclearlydelimitatedsmoothhyalinepartsometimes marked byconstrictionsof12.9µmlong(Topalovic *etal*.,2017). Root knot nematodes mobility leads to rapid spread and colonize new localities in the farms (Bebber *et al.* 2014).

DamageduetoParasiticRootKnotNematodes

Meloidogyne species are soil-borne pathogens that cause a negative effect on plants like wilt which may result to death if plant has no resistant mechanisms (Danish *et al*. 2018). The infected potato tubers have small, rough swellings on the surface area called galls. Cells where nematodes feed are stimulated to multiply and swell forming galls within a dayafter infection. Parasitic root knot galls varyin shape and size on highly infected plants, galls fuse together so that large mass areas or the entire root, may be swollen. Presence of lateral roots appears on root crops resulting in a condition known as hairy root and stunted growth.Plants' ability to take up water and nutrients is affected by the changes and wilted plants exhibit nutrient-type deficiencies.The more frequent the infection, the more severetheaboveground effects(Seebold,2014).Pathogenicityonsweetpotato showsthat *M.incognita* causes quality reduction, reduced growth and poor yield in sweet potato farming (Osunlola and Fawole, 2015).

MANAGEMENTSTRATEGIESANDCONTROLMEASURES

Parasitic nematodes have become difficult to manage over time due to their hidden nature hence generally overlooked and this makes them rapidly spread through the farm and colonize new localities. Type of farming system also plays a role in parasitic root knot nematodes infestation of sweet potatoes (Waiganjo et al., 2006). In effective management strategies like frequent reusing of land byfarmers leads to aggravated soil diseases (Barker et al., 1994; Karuri et al., 2017). There are strategies adopted in the management of parasitic root knot nematodes to increase yield and production of sweet potatoes and they are use of plant resistant varieties, synthetic nematicides, cultural control methods as well as biological controls of parasitic RKNs.

PlantResistance

Plants have the ability of self-defence against parasitic RKN in post infection by release of chemicals present in the host tissues after penetration of parasitic root knot nematodes (Mashela *et al.,* 2016). Ordinarily, plants carrying major resistance genes for root knot nematode are invaded in similar manner as would occur in susceptible plants. Nutritional inadequacies, chemical or physical barriers can be the cause of pre-infectional resistance. Fullyexpressed pre-formed chemicals are mainly the cause of pre infectional resistance in root tissues before infectionand do not rise to high levels in response to attacks by parasitic root knot nematodes (Ferraz and Brown, 2002).

Presence of galls on roots gives an assessment of sweet potato cultivars for resistance to *M. incognita* populations indicating them as host confirming that the nematode was able to reproduce within the cultivars (Olabiyi, 2007). Performed resistant studies suggest that post infectional nematode resistance is in place and confirmed that the identified nematode resistance in *C. africanus* and *C. myriocarpus* to *Meloidogyne species* is post infectional (Ramatsitsi, 2017). Screened sweet potato cultivars against *Meloidogyne* species demonstrated that most cultivars were hosts to *M. javanica* and *M. incognita* races 2 and 4, whereas ′Bophelo′, ′Bosbok′ and ′Mvuvhelo′ are non-hosts to all *Meloidogyne species* and races (Pofu *et al*., 2016). Parasitic root knot nematodes resistance in sweet potato varieties are observed and found highly resistant to *M. incognita* and few showed sensitivities. Same outcomes are observed on sweet potato resistant clones to *M. incognita* races (Karuri *et al*., 2017).

Nematocides

Non-fumigant nematocides are non-volatile toxic chemicals that are applied prior to planting, at planting, or after planting by drip irrigation, soil drenching or spraying on the crop foliage to reduce population densities ofnematodes and their damages (Ohri and Pannu, 2010). These products are dispersed by water movement in soilwhen applied in the soil. There are two categories of these products: systemic nematocides which are taken up bythe roots and kill nematodes while they feed from plant roots and contact nematocides which kill nematodes in soil by direct exposure to the compounds. Contrary to fumigant nematocides, the efficiency of non-fumigants does not depend on soil temperature (Hajihassani, 2018).

A major drawback of Non-fumigant nematocides is that their efficiency is lower than that of fumigants such as Telone II, and has a quick leaching effect of the active ingredients particularly in sand soil (Osunlola and Fawole, 2015). Nematocides; methyl bromide carbamate and organophosphate are found environmentally harmful and to non-targeted soil biota (Jones *et al.,* 2016). Concerns about a negative impact of improvised synthetic nematocides on general public health and the environment has led to a limited use of such products. An example is the high useof soil fumigant, methyl bromide which was found to result in contamination of the ground, drinking water and the surface in Netherlands. This led to a ban on its use in the 1980's (Mus & Huygen, 1992). Later on, methyl bromide was then listed as ozone-depleting compound in the 4th meeting of Montreal Protocol in Copenhagen, 1992, and in their accordance with the US Clean Air Act its use as a fumigant was banned in several nations (Ploeg, 2008).

CulturalControl

In chitinous wastes there are crushed shells of crustaceans of crab and shrimp also, cover crops suppress nematodes through chemical residues, especially when grown and tilled into the soil (Khalil, 2013). Cultural control methods involvepracticesliketimeofplantingandcroprotation(Sorensen*etal.*,2016).Useofcompostasatraditional cultural method showed decrease in damage caused by root knot nematodes (RKN) which related to a direct dosage ofappliedcompost (Coelho *et al.*, 2018).Cropscanberotated,intercroppedortherecanbesolecroppingperformed (Atandi *et al.*, 2017).According to Dayan *(*2010), *Sorghum bicolour* manufactures a chemical compound, sorgoleone, which has nematocidal activities that result in inhibition of mobility in nematode (Aydinli and Mennan, 2012). Cruciferous vegetables from Brassicaceae family have been identified to contain glucosinolate chemical compounds which release toxic products against parasitic RKNs such as thiocyanate and isothiocyanate when they decompose (Caboni, 2012), these products are toxic to parasitic RKNs (Larkin, 2013). Control of RKN cannot be limited by fallowing or crop rotation due to a wide host range and survival rate of RKN in soil(Jones *et al*., 2016).

BiologicalControlofParasiticRootKnotNematodes

Studies have shown that biological control agents effectively control nematodes by acting in different waysincluding antibiosis, cell wall degradation, interfere with vital processes like enzymatic system, respiratory and nervous system (Abd-Elgawad, 2016; Rocha *et al*., 2017). Pre-treatment and combined tests decreases hatching. Growers do not generally use bio control products due to lack of rapid and adequate control (Felde *et al.*, 2006). Discordantperformanceofappliedbiocontrolagentsinfarms hasbeenreportedasaprimaryhindranceinexploring this mode of nematode management (Meyer and Roberts 2002).

NematodeTrappingFungi

Use of bio control organisms like endophytes is important because nematocides are prohibited; example is inorganic farming and in areas where low nematode densities were recorded over time (Felde *et al.*, 2006). These Nematode-trapping fungi are classified under endoparasitic fungi as well as parasite of nematode eggs and theircysts which produce metabolites known to be toxic to parasitic root knot nematodes. The predacious fungi growand reproduce saprophytically until they are in contact with the parasitic RKNs. Study on predacious fungi, have shown possible in vitro bio control activity (Mankau, 1980; Gray, 2018). Nematode Trapping Fungi inhibit parasitic RKNs throughdevicessuchasadhesiveknobs,adhesivebranchesorhyphae,adhesivenetworks orconstrictingrings,orby means of enzymes as well as metabolic products. These fungi are capable of regulating nematode behaviour by interfering with nematode-host plant recognition giving opportunity for plant growth (Devi, 2018).

MedicinalPlantsasBio controls

Phytochemical plant extracts including terpenoids, saponins, alkaloids and flavonoids of Tithonia, Neem and Tephrosia are found to be effective against parasitic root knot nematodes (Njenga *et al.*, 2019). Botanical pesticides such as neem oil pressed from fruits and seeds of the neem tree *Azadirachta indica* are also used as nematocides. Neem oil contains triterpenoid compounds and the main component is Azadirachtin. On the other hand, there are essential oils extracted from aromatic and culinary herbs which have shown promising potential sources for new nematocides; thymol and carvacrol (Osunlola and Fawole, 2015).

Tagetes minuta has essential oils that can be used as nematocidal agent (Gakuumbi *et al.*, 2016). *Plectranthus barbatus*was found to bearichsource ofactive metaboliteswhich willbeused for nematocidalactivity.(Ibrahim*et al*., 2018). *Hyptis suaveolens* (L.) plant has a wide variety of secondary metabolites (Mozhiyarasi and Anuradha, 2016). *Senna occidentalis* has the most important active metabolites extracts which need further investigation forother uses like nematocidal effect (Olantuji *et al.*, 2019).

Phytochemical analysis of *Tephrosa vogelii* was conducted to find the bioactive components that were present and abundance of the principles in this plant species across three countries in East Africa: Malawi, Kenya and Tanzania. Analysis with use of methanol extract of *T. vogelii* parts revealed the occurrence of two distinct chemo types that wereseparated bythepresenceofrotenoidsinone, flavones and flavanonesthatarenotbioactiveagainstinsectsbut could be active against parasitic root knot nematodes (Mkindi *et al.*, 2019).

CONCLUSION

There can be no doubt that sweet potato production has faced a crisis due to the presence of root knot nematodes which caused reduced quality of tubers leading to reduced food security and alleviation of poverty. Presence of root knot nematodes especially *Meloidogyne* genera, are known to be economically damaging pests with a wide host range to nearly all cultivated crops. Different management strategies have been practiced over the years to reduce theirpresence.Culturalmethodswhichinvolvefieldfallowing,intercropping,croprotation,timeofplantinganduse ofcompostshowedreducespresenceofrootknotnematodes withinashortperiodoftime howeverduetotheirwide hostrangetheytendtobepersistentandmultiply.Useofresistantvarietiesshowedapromisingfuturehowever some host plant resistant genes tend to be silenced in soil temperatures of above 30C rendering them susceptible to rootknotnematodeinfections. Synthetic nematocideshavebeenused to latehowever in greatlimitations,theyshow great response in reducing root knot nematode density but they are expensive thus not overall affordable, they leave residues on plants which are harmful for human consumption and were found to be ecologically unfriendly. With these challenges faced by farmers as well as counties that rely on production of sweet potato as their source of income, thereisneed for developmentoflowcostand ecologicallyfriendlymodeof managingrootknotnematodes. Biological control methods are being explored and so far they are showing great nematocidal effects whereby their mechanism of action is based on nematode's respiratory system, enzymatic and nervous system. With this strategy, more affordable means will be developed biologically from medicinal plants. This will lead to increased sweetpotato production which will alleviate source of income to small scale farmers, counties as well as the nation and maintain food security.

ACKNOWLEDGEMENT

I wish to thank Chuka University Institution for providing me the platform to further my studies and increase my knowledge which willbehelpfulto thesociety.I sincerelythank mysupervisorsDr.Eunice W.Githae,Dr.Franklin Nyabuga and Dr. Moses M. Muraya for the support and great input in this work.

REFERENCES

Abd-Elgawad, M. M. (2019). Plant-parasitic nematodes of strawberry in Egypt: a review. *Bulletin of the National*

Research Centre, *43*(1), 7.

Atandi,J.G.,Haukeland,S., Kariuki,G.M.,Coyne, D. L.,Karanja,E.N.,Musyoka,M. W.,&Adamtey,N.(2017). Organic farming provides improved management of plant parasitic nematodes in maize and bean cropping systems. *Agriculture, Ecosystems & Environment*, *247*, 265-272.

Ayeleso, T. B., Ramachela, K., &Mukwevho, E. (2017).A review of therapeutic potentials of sweet potato: Pharmacologicalactivitiesandinfluenceofthecultivar.*TropicalJournalofPharmaceutical Research*, **15**(12), 2751– 2761

Barker KR, Hussey RS, Krusberg LR, Bird GW, Dunn RA, Ferris H, Ferris V, Freckman DW, Gabriel CJ, Grewal PS,MacguidwinAE,RiddleDL,RobertsPA,SchmittDP(1994)Plantandsoilnematodes:Societalimpact and focus for the future. *Journal of Nematology* 26:127– 137

Bebber DP, Holmes T, Gurr SJ (2014) The global spread of crop pests and pathogens.*Global Ecology Biogeography* 23:1398–1407

Coelho, L., Reis, M., Bueno-Pallero, F., Guerrero, C., & Gonçalves, M. A. (2018). Influence of organic compost application on soil characteristics and biological control of nematodes in carrots. (pp. 326-333).

Danish, M., Seikh, H., & Robab, M. I. (2018). Study on Morphological and Biochemical Characteristics of Babchi (*Psoralea corylifolia*) Infected with the Root-Knot Nematode, *Meloidogyne incognita*. *Journal of Agricultural Science and Technology*, *20*(3), 633-645.

Devi, G. (2018). Utilization of Nematode Destroying Fungi for Management of Plant-Parasitic Nematodes-A Review.*Biosciences Biotechnology Research Asia*, *15*(2), 377.

Drapal, M., Rossel, G., Heider, B., & Fraser, P. D. (2019). Metabolic diversity in sweet potato (Ipomoea batatas, Lam.) leaves and storage roots. *Horticulture Research*, *6*(1), 1-9.

Ferraz, L.C.C.B. and D.J.F. Brown. 2002. An Introduction to Nematodes: *Plant Nematology*. *Pensoft:* Sofia, Bulgaria.

Gakuubi, M. M., Wanzala, W., Wagacha, J. M., & Dossaji, S. F. (2016). Bioactive properties of Tagetes minuta L.(Asteraceae) essential oils: a review. *American Journal of Essential Oils and Natural Products*, *4*(2), 27-36.

Gray,N.F.(2018).Fungiattackingvermiformnematodes.*InDiseasesofnematodes*(pp.13-48).CRCPress.

Hoang MHH, Namirembe S, van Noordwijk M, Catacutan D, Öborn I, Perez-Teran ASS, Nguyen HQQ, Dumas-Johansen MKK (2014) Farmer portfolios, strategic diversity management and climate-change adaptation– implications for policy in Vietnam and Kenya. *Clim Dev* 6: 216–225

Hunja, W. E., & Ogechi, B. A. (2017). land use land cover changes and implications for food production: a case study of keumbu region kisii county, Kenya.

Ibrahim, M. M., Arafa, N. M., & Aly, U. I. (2018). Antioxidant activity, phenol and flavonoid contents of plant and callus cultures of *Plectranthus barbatus* andrews. *Egyptian Pharmaceutical Journal*, *17*(1), 32.

International Potato Center (2018). *Sweetpotato Facts and Figures.*Available at: https://cipotato.org/crops/sweetpotato/sweetpotato-facts-and-figures/ [accessed March 27, 2018].

Jones, J. G. (2016). Examination of chemical, biological, and cultural control measures of root-knot nematodes in lima beans (Doctoral dissertation, University of Delaware).

Karuri, H. W., Olago, D., Neilson, R., Mararo, E., & Villinger, J. (2017). A survey of root knot nematodes and resistance to Meloidogyneincognitain sweet potato varietiesfrom Kenyan fields. *Crop protection*,*92*, 114-121.

Khalil, M. S., Ebrahim, E., Mahmoud, A. E., & Ghorab, M. A. (2017). The Parasitism of Root Knot Nematodes: A Mini review. *International Journal of Environmental Sciences & Natural Resources*, *5*(3), 66-69.

Kim, E., Seo, Y., Kim, Y. S., Park, Y., & Kim, Y. H. (2017). Effects of soil textures on infectivity of root-knot nematodes on carrot. *The Plant Pathology Journal*, *33*(1), 66.

Larkin,R.P.2013.Greenmanuresandplantdiseasemanagement.*CABReview*8:1-10.

Lawrence,G.W.,Clark,C.A.,&Wright,V.L.(1986).InfluenceofMeloidogyneincognitaonresistantand susceptible sweet potato cultivars. *Journal of nematology*, *18*(1), 59.

Lee,B.H.,&Lee,Y.T. (2017).Physicochemicalandstructuralpropertiesofdifferentcoloredsweetpotato starches. *Starch/Staerke*, **69**(3–4), 1600001– 1600009

Mankau,R.(1980).Biocontrol:fungiasnematodecontrolagents.*Journalofnematology*,*12*(4),244.

Mkindi, A.G.,Tembo,Y.,Mbega,E.R.,Medvecky,B.,Kendal-Smith, A.,Farrell,I.W. &Stevenson,P.C.(2019). Phytochemical analysis of Tephrosia vogelii across East Africa reveals three chemotypes that influence its use as a pesticidal plant. *Plants*, *8*(12), 597.

Mozhiyarasi, P., & Anuradha, R. (2016). A study on phytochemical analysis and antimicrobial activity of Hyptis suaveolens (L.) Poit. *Journal of Chemical and Pharmaceutical Research*, *8*(6), 438-442.

Mus, A., & Huygen, C. (1992). Methyl Bromide. The Dutch Environmental Situation and Policy. TNO. *Institute of Environmental Sciences*. order No. 50554. 13pp.

Mwanga, R. O., Andrade, M. I., Carey, E. E., Low, J. W., Yencho, G. C., & Grüneberg, W. J. (2017). Sweetpotato (Ipomoea batatas L.). In *Genetic improvement of tropical crops* (pp. 181-218). Springer, Cham.

Neher, D. A. (2001). Role ofnematodesin soilhealthand their use asindicators. *Journalofnematology*,*33*(4),161.

NielsenUN,AyresE,WallDH,LiG,BardgettRD,WuT,GareyJR(2014)Global-scalepatternsofassemblage structure of soil nematodes in relation to climate and ecosystem properties.*Global Ecology Biogeography* 23: 968–978

Njenga, J. K., Gathungu, G. K., & Mbaka, J. N. (2019). Evaluation of Plant Extracts on egg hatching and juvenile mortality of french bean root-knot nematodes. *African Journal of Horticultural Science*, *15*, 23-30.

Ntalli, N., Tsiafouli, M. A., Tzani, K., Mavridi, O., Oplos, C., Menkissoglu-Spiroudi, U., & Monokrousos, N. (2019).Whey:TheSoilBio-CommunityEnhancerThatSelectivelyControlsRoot-Knot Nematodes. *Plants*, *8*(11), 445.

Olabiyi,T.I.2007.Susceptibilityofsweetpotatovarietiestoroot-knotnematodes*Meloidogyneincognita*. *American-EurasianJournalofAgricultureandEnvironmentalSciences*2:318-320.

Olatunji, K. T., Ya'aba, Y., Mohammed, S. B., Akah, I. J., Daniel, O. C., & Oladosu, P. O. (2019). In vitro Antibacterial and Antitubercular Activities of Leaf Extracts of *Senna occidentalis*. *Microbiology Research Journal International*, 1-8.

Omoyo Popa, N. E. Băbeanu, I. Popa, S. Niţă, and C. E. Dinu-Pârvu, "Methods for obtaining and determination of squalene from natural sources," *BioMed Research International*, vol. 2015, Article ID 367202, 16 pages, 2015.

Ploeg A. (2008) Biofumigationto Manage Plant-Parasitic Nematodes. In: Ciancio A., Mukerji K.G. (eds)Integrated Management and Biocontrol of Vegetable and Grain Crops Nematodes. Integrated Management of Plant Pests and Diseases, vol 2.

Pofu,K.M.,Mashela,P.W.,Laurie,S.M.andD.Oelofse.2016.Host-statusofsweetpotatocultivarstoSouthAfrica root-knot nematodes. *Acta Agriculturae Scandanavica- Section B — Soil & Plant Science* 67:62-66.

Rocha, T. L., Soll, C. B., Boughton, B. A., Silva, T. S., Oldach, K., Firmino, A. A., ... & Silva, L. P. (2017). Prospection and identification of nematotoxic compounds from Canavalia ensiformis seeds effective in the control of the root knot nematode Meloidogyne incognita. *Biotechnology Research and Innovation*,*1*(1), 87-100.

Seesao, Y., Gay, M., Merlin, S., Viscogliosi, E., Aliouat-Denis, C. M., &Audebert, C. (2017).Areviewof methods for nematode identification. *Journal of Microbiological Methods*, *138*, 37-49.

Seo,Y.,Park,J.H.,&Kim,Y. H. (2018).Pathologicalcharacteristicsofsoil-bornediseasesincucurbitaceouscrops caused by *Fusarium* species and *Meloidogyne incognita*. *2018*, 106-106.

Shapiro, D. I., McCoy, C. W., Fares, A., Obreza, T., & Dou, H. (2000). Effects of soil type on virulence and persistence of entomopathogenic nematodes in relation to control of *Diaprepes abbreviatus* (Coleoptera: Curculionidae). *Environmental Entomology*, *29*(5), 1083-1087.

Shaw, E. A., & Wall, D. H. (2019). Biotic Interactions in Experimental Antarctic Soil Microcosms Vary with Abiotic Stress. *Soil Systems*, *3*(3), 57.

Smykla, J., Porazinska, D. L., Iakovenko, N. S., Devetter, M., Drewnik, M., Hii, Y. S., & Emslie, S. D. (2018). Geochemical and biotic factors influencing the diversityand distribution of soil micro fauna across ice-free coastal habitats in Victoria Land, Antarctica. *Soil Biology and Biochemistry*, *116*, 265-276.

Sorensen, K. A., Mohankumar, S., & T hangaraj, S. R. (2016). Physical, Mechanical and Cultural Control of Vegetable Insects. In *Integrated pest management of tropical vegetable crops* (pp. 131-148).

Topalović,O.,Moore,J.F.,Janssen,T.,Bert,W.,&Karssen,G.(2017).Anearlyrecordof*Meloidogynefallax* fromIreland.*ZooKeys*,(643),33.

Treonis, A. M., Sutton, K. A., Unangst, S. K., Wren, J. E., Dragan, E. S., & McQueen, J. P. (2019). Soil organic matterdeterminesthedistributionandabundanceofnematodesonalluvialfansinDeathValley,California. *Ecosphere*, *10*(4), e02659.

Wabere, G. N. (2016). Evaluation of root-knot nematode management strategies based on nematode distribution in tomato (*Solanum lycopersicum*) fields in Mwea, Kirinyaga County, Kenya (Doctoral dissertation, Thesis Master of Science, School of Pure and Applied Sciences, Kenyatta University. 113p).

Wadl, P. A., Olukolu, B. A., Branham, S. E., Jarret, R. L., Yencho, G. C., & Jackson, D. M. (2018). GeneticdiversityandpopulationstructureoftheUSDAsweetpotato(Ipomoeabatatas)germplasmcollectionsusing GBSpoly. *Frontiers in plant science*, *9*, 1166.

****