KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

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SCREENING TOMATO (*Solanum lycopersicum* L.) GENOTYPES FOR RESISTANCE TO ROOT-KNOT NEMATODES (*Meloidogyne* species)

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BY

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DECLARATION

I hereby declare that this thesis has not been submitted for a degree to any other university. It is entirely the student's own account of his research, except that for references to other people's work which have been duly cited.

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DEDICATION

To my parents, Habbie and Nfansu Jaiteh, my sisters, Hawa, Mariam, Fatou, Zainab and Amie Jaiteh. You all love me unconditionally, I couldn't ask for more. God bless you mightily.

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ABSTRACT

The use of root-knot nematode resistant tomato cultivars is an attractive alternative for nematode management as their use does not require major adaptations in farming practices. These experiments were conducted to determine the effect of inoculum density of *Meloidogyne* spp. on the severity of root-knot disease on tomato and to evaluate different tomato genotypes for resistance against root-knot nematodes. Two pot experiments were separately conducted to determine the influence of five inoculum levels (100, 500, 1000, 1500 and 2000 nematode eggs/ 1.6liters soil/pot) of root knot nematodes on tomato and host evaluation for resistance to root- knot nematodes. The pot experiments were laid out in a completely randomised design with four replications. Root-knot nematode reproduction and host damage were both affected by the initial inoculum levels and the results revealed an increase in mean number of juveniles, galls and eggs/root system. Plant height, stem diameter, fresh root weight, fresh shoot weight and number of eggs, juveniles and root galling were measured. The field experiment was laid out in a randomised complete block design with three replications. Pot and field experiments revealed a considerable variation in response against *Meloidogyne* spp among the genotypes evaluated. Out of the 33 tomato genotypes, Tomato Mongal T-11 and Tomato Beef master were found to be highly resistant. They recorded the lowest number of eggs in both the planthouse and under field conditions. They also scored the least number of galls. Burpee Roma was found to be moderately resistant and Tomato F1 2026 was the most susceptible genotype to attack by root-knot nematodes.

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CHAPTER ONE

1.0 INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most popular and widely consumed vegetables in the world (Norman,1992).The crop has developed into a great number of cultivated types suitable to different environments, method of production, and food uses. Its versatility in fresh or processed form has played a major role in its rapid and widespread adoption as an important food commodity (Kasem and Siemonsma, 1999). According to Di Mascio *et al*. (1998), tomatoes are major sources of lycopene, a dietary carotenoid found in high concentrations in processed tomato products. This compound is an antioxidant known to combat cancer, heart diseases and premature aging (Wener, 2000).

Tomatoes are high in vitamins A, B and C and also contain good amounts of potassium, iron, and phosphorus (Wener, 2000). Fresh tomatoes and canned tomato products such as concentrates, puree and paste, are increasingly in demand in West Africa where they form an essential part of the diet of the inhabitants (FIAN, 2007).

In Ghana, tomato is probably the most important vegetable grown, and a wide range of areas are suitable for its production (FAO, 1995). It is grown in the forest, transitional and savannah zones (Norman, 1992). Total land area for its production increased from 28,400ha in 1996 to 37,000ha in 2000 (GIPC, 2001). According to Wolff (1999), vegetables account for 9.6% of total food expenditure and 4.9% of total expenditure in Ghana, and tomato alone makes up to 38% of the vegetable expenditure. Tomato production is an important source of income for smallholder

farmers. In recent years, domestic tomato production has intensified across Ghana but local production is not able to meet the domestic high demand and therefore tomatoes are often imported, mainly from Burkina Faso (Horna *et al.*, 2006).This situation is as a result of a number of constraints in tomato production, among them are root-knot nematodes which play prominent role.

Root-knot nematodes *(Meloidogyne* spp.) are economically important pests of a wide range of vegetables throughout the world (Castagnone-sereno, 2006)). In order to reduce these losses, an estimated amount of US$500 million was spent on nematode control globally (Keren-Zur *et al*., 2000).They are considered to be the most destructive and difficult pest to control in tropical and subtropical countries (Simpson and Starr, 2001). The short life cycle of six to eight weeks enables root knot nematode populations to survive well in the presence of a suitable host and their populations build up to a maximum usually as crops reach maturity (Shurtleff and Averre, 2000).

The potential host range of *Meloidogyne* species encompasses more than 3000 plant species (Abad *et al*., 2003).The most economically important species are *M. arenaria, M. incognita, M. javanica* and *M. hapla*. They are one of the group of root parasitic nematodes that establish specialised feeding cells in roots, redirecting photosynthate produced in the leaves to supply the energy demands of the nematode in the roots (Hunt *et al*., 2005). Heavily infested plants according to Eisenback *et al.* (1991), have a very shallow and knotted root system. Normal development of plants, is impaired and distribution of hormones and minerals is altered. Root weight, as a result of nematode parasitism, increases whereas shoot weight declines, shifting the root-shoot balance (Roberts, 1995). Heavily-diseased plants do not respond to water or fertilisers.

This is because the nematodes have severely damaged the conducting tissues of the plant at the roots. As a consequence, top growth is reduced, yields are low and plants wilt during the hot periods of the day even through soil water is plentiful. Symptoms of mineral deficiency are common and often additional fertilizer is applied, increasing further the costs of producing a poor crop (Eisenback *et al.*, 1991).

According to Singh and Sitaramaiah (1969), the initial inoculum levels of root knot nematodes had a significant effect on the growth and yield of tomato. This shows that when the inoculum levels are high, greater number of juveniles are able to infect the plant roots which results in reduced nutrient and water uptake by the roots and consequently, poor growth (Karssen and Moens, 2006).The growth of plant is also inversely proportional to the population density of root knot nematode (Kinloch, 1982), hence as nematodes population rises above the economic threshold, control becomes difficult.

Riaz *et al.* (2000) also reported significant increase in the decrease of plant height over the non-inoculated plants with increase in the inoculum density of root-knot nematodes in tomato. In addition to the losses caused by the direct effect of nematode infestation, predisposition or even breakdown of resistance to other root or soil-borne diseases is common. For example, nematode-susceptible lines resistant to bacterial wilt did not survive well if in addition to nematodes, conditions for the bacterial disease were present (Gilbert, 1974).

In Ghana, Root-knot nematode infestations are the major nematode problems in tomato production (De Lannoy, 2001). They cause serious damage to tomatoes, impacting both the quantity and quality of marketable yields. Addoh (1970) reported that *Meloidogyne* species caused about 33% loss in vegetable crops such as tomatoes, okra, and cucurbits in a single season. Farmers often use pesticides to control the nematodes, but they may be ineffective if the plant is already infested.

Chemical soil treatment is recognized as an essential means of controlling nematodes on a number of crops in the tropics. In Ghana, Hemeng (1981) reported that phenamiphos, 1,3-D and carbofuran each at 5kg ai/ha were recommended for the control of root-knot nematodes in the northern savanna zones whilst the rates of application changed from 47 ai/ha to 10 ai/ha for remarkable results in the transitional zone. In many instances, many crops cannot be grown economically without the use of nematicides (Sikora and Fernandez, 2005). However, their use is becoming limited or no important in developing countries on most field crops, especially at the subsistence level (Luc *et al*., 2005). Nematicides usage in many countries and by smallscale growers has been strongly limited by their high prices (Freckman *and* Sasser, 1987). Availability of many is also limited due to the banning from most of the world markets of the fumigants D-D, ethylene dibromide and dibromochloropropene (Luc *et al*., 2005). More importantly, the recent global movement to ban the highly effective and broad spectrum fumigant methyl bromide, because of its side effect on atmospheric ozone, has had a major impact on how many horticultural crops especially (Starr *et al*., 2001). Some of the more easily applied granular, non-volatile nematicides are effective and are used extensively on a number

of crops. They have disadvantages in being expensive and extremely toxic to man and animals when used improperly. Their use is often curtailed because of their solubility and threat to groundwater as well as long waiting periods between use and marketing of crops, resulting in increased restrictions on the use of these toxic materials such that no effective nematicides are legally available for many nematode-crop combinations (Luc *et al.*, 2005).

The modification of existing agricultural practices in order to manage nematode populations is one of the most acceptable alternatives to chemical control for both the small and large scale farmers in the tropics (Starr *et al*., 2001). Crop rotation decreases the potential for substantial yield losses due to nematode (Luc *et al*., 1990; Whitehead and Hemming, 1965) and provides at least short-term suppression of nematode population densities. The magnitude of these benefits is generally positively correlated with the number of cropping seasons between the planting of susceptible crops. However, most of the rotation schemes in operation have been designed to prevent disease outbreaks or increase available nutrients, and are not always compatible with nematode control (Luc *et al.*, 2005).

Biological control holds some promise for the future, but with current knowledge it is difficult to promote or establish a microflora or fauna in soils that effectively suppresses nematode population densities, especially in the relative short period of time of a single growing season (Evans *et al.*, 1993). Reliable and effective biological control systems are likely to be limited to specialised situations (e.g. intensely managed crop systems where the environment can be manipulated to promote

biological activity) for the near future (Starr *et al*., 2001). It is, therefore, necessary for an alternative solution to keep damage below economic threshold level.

Exploitation of resistance in crops is one of the most effective and ecofriendly components of integrated pest management and inclusion of this property ensures increased crop yield in the presence of nematode (Khan and Mukhopadhyay, 2004). Screening for resistance remains a major goal as new diseases achieve significance or new races of existing pathogens become established. Nematode resistance in host plant is manifested by reduced rates of nematode reproduction and, consequently, lower nematode population densities in the crop rhizosphere than that of a susceptible one (Medina-Filho and Tanksley, 1983). According to Khan (1994), genetic resistance in tomato against root knot nematodes is efficient in reducing their population densities and, thereby, reducing the need for pesticide application. Crop cultivars showing high degree of resistance with acceptable agronomic characteristics are commonly recommended for nematode- infested fields either as a routine crop or in a rotational sequence of the crops.

Host plant resistance has been prioritized over chemical, biological, cultural, and regulatory control components as a major goal for pest management because it provides an effective, sustainable and economical method for managing nematodes in both high and low value cropping systems. Resistant crops in annual cropping systems can also reduce or suppress nematode population densities in soils to levels that are non-damaging to subsequent crops (Starr *et al*., 2001).

According to Starr *et al*. (2001), additional important benefits of resistant crops are their environmental compatibility that do not require specialised applications, and apart from preference based on agronomic or horticulture desirability, they usually do not require an additional cost input or deficit. Because resistance to nematodes is usually developed by selection of plants with reduced rates of nematode reproduction, nematode population densities are typically lower following a resistant cultivar than a susceptible cultivar. The susceptibility of tomato varieties has important implications on the yield and economic returns. Thus, information on susceptibility to root knot nematode can be useful to farmers (Khan, 1994).

Host plant resistance remains a very important potential component of a solution to many nematode problems of tropical agriculture especially, for the low input, smallscale farmers when used in combination with cultural techniques and traditionally grown crops (Luc *et al*., 2005). There is therefore, the need to identify sources of resistance in tomato cultivars for seed multiplication or breeding against root-knot nematode disease.

This study was to identify resistance in some exotic and local tomato genotypes against root-knot nematodes.

The objectives of this study were to;

(i) determine the best egg inoculum level for screening tomatoes for resistance to root-knot nematodes to avoid misclassification,

(ii) evaluate tomato genotypes for their reaction to root-knot nematodes in pots,

(iii) screen the tomato genotypes for their reaction to root-knot nematodes in the field, and

(iv) to select the appropriate tomato genotypes for cultivation by farmers.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1.0 Cultivation of tomato in Ghana

Tomato cultivation has been a significant economic activity in Ghana, especially in the Northern, Upper East and around southern Volta regions of Ghana (Third world network (TWN), 2007). It has long been the most lucrative crop in the Upper East region and it is more profitable than rice, maize, groundnuts, yam, pepper and dairy.

Close to 90% of the two million people living in these areas cultivate tomato. Tomato production is also vibrant at Akumadan, and Wenchi Districts. Cooperative farming, according to Norman, (1992), is concentrated around Mankessim, Swedru, Agogo. Nsawam, Amasaman, Sege and Dodowa. The common tomato varieties grown in Ghana include Roma, Pectomech, Royal, Burkina and Power (Khor, 2006).

In Ghana, tomato production per hectare is very low, compared to the developed countries, and this can be attributed to several reasons. The most important among these is the vulnerability of tomato crop to various diseases including fungal, viral, bacterial and nematode diseases (Horna *et al.*, 2006). Unlike the other pathogens, nematodes give more problems because nematodes live in the soil and cannot be easily seen by farmers. They are only noticed when the population is widespread and yield reduction is high (Mai, 1977).

2.2.0 **Root-knot nematodes (*Meloidogyne* spp.)**

According to Belinger (1986), over 60 different species representing 19 genera of plant parasitic nematodes attack tomato, but the most destructive nematode is the root-knot nematode (Norman, 1992). Root-knot nematodes are obligate parasites capable of feeding inside the roots of over 2000 plant species, causing extensive crop losses worldwide (Sasser and Freckman, 1987; Roberts, 1995).

A yield loss of between 73 and 100% caused by root-knot nematodes has been reported in the Guinea Savannah zone of Northern Ghana (Hemeng, 1981). These sedentary

endoparasitic *Meloidogyne* spp. are among nature's most successful parasites and are known to occur across a broad range of climatic conditions. Their worldwide distribution, extensive host ranges, and interaction with other plant pathogens in disease complexes rank them among the major plant pathogens affecting world food production (Sasser, 1980).

While *Meloidogyne* contains more than 70 described species, four species, namely, *M. incognita*, *M. arenaria*, *M. javanica* and *M. hapla* are responsible for 95% of infestations (Sasser *et al.*, 1983).The former three species are widespread between 35°S and 35°N latitudes whereas *M. hapla* is a more temperate region species (Sasser and Taylor, 1978). According to Sasser *et al.* (1983), root knot nematode got its common name from the classic symptom of heavy root galling in the areas of infection. These external symptoms are pronounced and diagnostic.

2.2.1 **Biology and life cycle of root-knot nematodes**

Most species of plant parasitic nematodes have a relatively simple life cycle consisting of the egg, four juvenile stages and the adult male and female. The rootknot nematodes complete most of their life cycle within their host roots (Mai and Abawi, 1987).

A first-stage juvenile develops and molts while still in the egg to become a secondstage juvenile which hatches from the egg. After hatching, root-knot nematodes move through the soil to find areas on plant roots to feed.

The nematodes survive in soil as eggs and also second stage juveniles. Mature females of root knot nematodes deposit eggs up to 1000 or more in a gelatinous matrix (egg sac or egg mass) which can be observed attached to the protruding posterior end of the females on the root surface (Mai and Abawi, 1987). This sac protects the eggs from dehydration (Pattison, 2007). The infective second-stage juveniles hatch from the eggs and move through the soil in search of roots of suitable host plants (Davis *et al.*, 2004). The juveniles usually penetrate host roots just behind the root tip region and establish their special permanent feeding sites (giant cells) in the vascular tissues of the root (Mai and Abawi, 1987). The giant cells provide nutrients for the sedentary nematodes which continue to feed, enlarge, and molt three times. Root cells around the feeding sites are also induced to enlarge and form galls (knots) and often extensive secondary root formation and branching of the main root. Depending upon the host and soil temperature, the entire life cycle may be completed in 17 to 57 days (Hussey, 1989).

2.2.2 Symptoms of root-knot nematode damage on tomato

Typical symptoms of nematode injury can involve both above-ground and below-ground plant parts. According to Nicol and van Heeswicjk (1997), above-ground symptoms may be variable and confused with nutritional deficiency or water stress. The above-ground symptoms are stunting, wilting and general off-coloured appearance of the affected plants. The undersides of the leaves develop a purple discoloration which resemble symptoms caused by phosphorus deficiency. These symptoms include poor shoot growth and necrosis. Heavily infected tomato plants appear as moderate to severe leaf chlorosis and dwarfing (Nicol and van Heeswicjk, 1997). In some plants wilting may occur during periods of peak transpirational stress on the plant. Damage to a susceptible tomato occurs through loss of roots and impaired

root function, which in turn limits the plants capability to manage water and nutrient uptake, restricting growth and increasing the opportunity for other infections (Nicol and van Heeswicjk, 1997).

Tomato roots attacked by root-knot nematodes also show varying degrees of galling, depending on the number of the nematode in the soil or the subsequent hatching of eggs, migration of the juveniles and reinfection of surrounding tissue. Intensive galling seriously reduces root efficiency and often results in permanent wilting, premature defoliation, and eventually plant death (Mai and Abawi, 1987).

The female root-knot nematode and most of her egg masses are usually completely embedded in the root tissue. Root systems may be somewhat reduced because terminal infections of roots cause swelling and cessation of further elongation (Mai and Abawi, 1987). According to Sasser and Carter (1985), severe galling of roots and stunting of tomato due to root knot nematodes have been observed primarily in sandy soils. Galling may be so extensive on seedlings that they may be killed as a result. In some loam or clay soils, galling is light to moderate without noticeable above-ground symptoms (Sasser and Carter, 1985).

2.3.0 General management considerations of root-knot nematodes

In most crops, root-knot nematode damage is related to the initial numbers of the nematode in soil. Management strategies are, therefore, aimed at reducing these initial numbers (McSorley and Gallaher, 1991). These management strategies can be divided into non chemical treatments and chemical treatments. The non-chemical treatments

include Soil solarisation and hot water treatment of planting materials, crop rotation and cover crops, rogueing and burning diseased plants, land fallowing, flooding, organic amendments, nematode-suppressive plants, ploughing, biological control, and hostplant resistance while the chemical treatment include the use of synthetic nematicides.

2.3.1 Soil solarisation and hot water treatment of planting materials

High temperatures will kill nematodes. Steam sterilization or other forms of heat treatment are, therefore, often used for sterilising soil used in greenhouses or nurseries. Soil solarisation is receiving increased attention for the management of nematodes and other soilborne pests. It involves covering raised and moist beds with clear plastics for two-to-four months during the hottest part of the year, allowing the sun to heat the uppermost layers of soil (Elmore *et al.,* 1997).

Performance has been variable, depending on application technique and season (Gallaher and McSorley, 1991).This increased soil temperature helps to kill many soil borne pests and pathogens including root-knot nematodes. According to Elmore *et al.* (1997), plant material infected with nematodes can be treated in hot water, provided that a suitable temperature range can be found which is high enough to kill nematodes but not lethal to the plant. The main drawback of this strategy is that temperature must be controlled critically and is usually just below that which injures plant tissues. The only problem is that most small-scale farmers in developing countries do not have enough knowledge and equipment to detect the precise temperature necessary for killing nematodes and at the same time not fatal to the plants.

2.3.2 **Crop rotation and cover crops**

In general, crop rotation is a very effective means of managing plant-parasitic nematodes. Crop rotation with a non-host crop is often adequate by itself to prevent nematode populations from reaching economically damaging levels. Asparagus, corn, onions, garlic, small grains, Cahaba white vetch, and Nova vetch are good rotation crops for reducing root knot nematode populations. *Crotalaria*, velvet bean, and grasses such as rye are usually resistant to root-knot nematodes. However, it is necessary to positively identify the species of nematode in order to know what plants are its host(s) and non-hosts (Wang *et al.,* 2004; Peet and Mary, 1996: Yepsen, 1984). Rotation crops and cover crops can be helpful in manipulating nematode populations during those times of the year when most susceptible crops cannot be successfully grown (Elmore *et al.*, 1997). Diversified crop interplantings and crop rotations can interrupt the spread, reproduction, and survival of nematodes.

According to Sherf and MacNab (1986), crop rotation will not eliminate infestations because root knot nematodes can remain in the soil as eggs for at least a year between host crops, and most species can feed on a wide range of weeds. Due to the wide host range of root knot nematodes, care must be taken in selecting alternative crops for rotation.

2.3.3 **Rogueing and burning diseased plants**

Rogueing is best for new farms or when disease is detected early. Rogueing and burning or discarding diseased plants in areas or farms where new outbreaks of rootknot disease are discovered have been found to be effective. According to Yepsen

(1984), rogueing will prevent or minimize the spread of nematodes from diseased plants to healthy plants along rows or between farms and nurseries. This strategy has disadvantages of being time-consuming and when disease eruption occurs the method is practically impossible.

2.3.4 Land fallowing

A fallow period of two years with no susceptible plants in the field decreases nematode populations. Fallowing, in which all vegetation is kept off the infested area, is a cheap and effective way to reduce nematodes numbers (Flint, 1999).This will not stop nematode eggs from hatching but, without food plant, the young nematode will die. Land scarcity in most countries has caused this control strategy to be unfeasible.

2.3.5 Flooding

Flooding is sometimes used as a management tool to control nematodes. Nematode densities can drop significantly when soils are flooded for prolonged periods of time (Bridge 1996.). Flooding the soil for seven to nine months kills nematodes by reducing the amount of oxygen available for respiration and increasing concentrations of naturally occurring substances such as organic acids, methane, and hydrogen sulphide which are toxic to nematodes (MacGuidwin, 1993). However, it may take two years to kill all the nematode egg masses (Yepsen, 1984). The duration of flooding for effective nematode control needs to be determined for each nematode species and it is a costly and uneconomic means of controlling nematodes. This method is practiced where water is very cheap and easily available.

2.3.6 **Organic amendments**

High soil organic matter content protects plants against nematodes by increasing soil water-holding capacity and enhancing the activity of naturally-occurring biological organisms that compete with nematodes in the soil (Akhtar and Malik, 2000). Beneficial fungi and bacteria are in high numbers in soil amended with different organic matter. Some fungi and bacteria are parasites of nematode eggs and also prey on nematodes. The parasitic nematodes do not hatch and thus population is reduced (Perry, 2008). The organic matter commonly used to control nematodes include poultry manure, saw dust and various crop residues.

2.3.7 **Nematode-suppressive plants**

Allelochemicals are plant-produced compounds (other than food compounds) that affect the behavior of other organisms in the plant's environment. For example, sudan grass and sorghum contain a chemical, dhurrin, that degrades into hydrogen cyanide, which is a powerful nematicide (Luna, 1993; Forge, *et al.*, 1995). Some cover crops have exhibited nematode-suppressive characteristics equivalent to aldicarb, a synthetic chemical pesticide.

Research has shown that incorporating sesame into rotation with cotton, peanuts, and soybeans reduced nematode population levels and yields significantly increased among those crops in fields (Anon, 1996).

According to Widmer and Abawi (2000), certain plants are able to kill or repel pests including nematodes, disrupt their lifecycle, or discourage them from feeding. Some of these plants are marigolds, castorbean, and various brassicas (powerful

nematodesuppressive cover crops). Plant extracts, such as those from marigold (*Tagetes* spp), *Ricinus communis* (L.), *Eucalyptus teretcormis* Sm. , *Tridax procumbens, Ruta, Cineraria or Pelargonium* have also been effective in killing plant-parasitic nematodes, but results refer mainly to *in vitro* or pot experiments and practical application of these extracts is yet to be profitable (Dover *et al.*, 2003).

2.3.8 **Ploughing**

Peacook (1957) adopted ploughing to control *Meloidogyne* species successfully at Achimota in Ghana. Also, Prasad and Chawla (1991) reported that summer ploughing in parts of India allowed land temperature to reached 40-42^{o}C thereby reduced populations of *Heterodera avenea*, *Meloidogyne* species and *Rotylenchus reniformis* by 40%. However, the labour needed, the difficulties of cultivating soil in the dry season, and lack of immediate and tangible benefits to the farmers normally rule out this practice for nematode control.

2.3.9 **Biological control**

According to Stirling (1991), biological control is an effective alternative that can be combined with other strategies within an integrated management system. In some soils, nematophagous fungi and bacteria have been reported to control the multiplication of nematode on susceptible crops but despite the commercialisation of a few organisms, none is in widespread use (Stirling, 1991).

At present there are no effective, commercially available, biological control agents which can be successfully used to control nematodes. It has proved difficult to develop a biological control agent that is effective worldwide for any soil-borne disease. Biological control is more inconsistent, less effective and slower acting than control normally achieved with other methods (Kratochvil *et al.,* 2004). It seems likely that these limitations are inherent in most biological control agents and that their successful application will depend on integration with other control measures.

2.3.10 **Chemical control**

Synthetic chemicals are one of the most effective means of controlling nematodes in infected fields. Maqbool *et al*. (1985) reported that two systemic chemicals, aldicarb and carbofuran, were effective in the control of root-knot nematodes.

According to Jagdale *et al*.(1985), phorate, a systemic chemical, was effective in reducing root knot nematode population and number of galls. Stephen *et al.* (1989) observed that phenamiphos 40% EC, miral 10%G and carbofuran 3%G, applied at recommended rates were effective in controlling the root knot nematode, *M. javanica* in egg plant and yield increased by 59% and 55%, respectively, compared with the untreated control.

According to McAvoy (2000), application of nematicides can be toxic to human and animals and they also kill the pest's natural predators, causing serious resurgence of some pests when not applied at the right time, in the right way and in the right dosage rate per hectare. Due to the side effects of the highly effective and broad spectrum

fumigant, methyl bromide, on atmospheric ozone, there is a global movement to ban its use (Luc *et al.,* 1990). It seems that the age of the traditional fumigants and nematicides has passed, and the opportunity for managing nematodes with synthetic chemicals with broad biocidal activity is declining.

2.3.11 **Host plant resistance**

Resistant cultivars can produce the most dramatic increase in yields of many crops and appear to hold the solution to most nematode problems (Luc *et al*., 2005). It is the most cost-effective and sustainable management tactic for preventing root knot nematode damage and reducing growers' losses (Khan, 1994). Resistance is crucial to the reliable production of food, and it provides significant reductions in agricultural use of synthetic chemicals and other inputs. Resistant crop cultivars have comparatively better crop yield than susceptible crop cultivars (Luc *et al*., 2005).

Plant disease resistance derives both from pre-formed defenses and from infectioninduced responses. In plant nematology, relative to a disease-susceptible plant, plant disease resistance is often defined as the ability of a plant to inhibit the reproduction of a nematode species relative to reproduction on a plant lacking such resistant (Friedman and Baker 2007). Although obvious qualitative differences in disease resistance can be observed when some plants are compared after infection by the same nematode strain at similar inoculum levels, a gradation of quantitative differences in disease resistance is observed between plant lines or genotypes (Lucas,

1998). A major limiting factor affecting the effectiveness of newly introduced resistance cultivars is the selection of pathotypes or races that are able to break down the resistance (Luc *et al*., 2005). However, strategies for utilizing resistance will be deployed to curtail breakdown of resistance.

2.4.0 **Screening genotypes for root-knot nematode resistance**

According to Khan *et al.* (1994), genotypes can be evaluated for root knot resistance based on the degree of galling, egg mass number, or total number of eggs collected from the root system. However, for some crops, root galling is not a completely satisfactory indicator of root knot nematode resistance and usually a preliminary test should be conducted to determine if a strong correlation exists between galling and nematode reproduction (Hussey and Boema, 1981).

According to Cook and Evans (1987), a relative simple screening technique is required to allow assessment of large numbers of test plants for nematode resistance. In addition, it should be sensitive to distinguish resistant plants from non-resistant ones. Screening of plant populations may be done in field plots, glasshouse, or screenhouse, or in the laboratory. Reproduction of species which have close relationship with their hosts can often be assessed by severity of plant symptoms, such as galling caused by root-knot nematodes (Cook and Evans,1987). However, tissue swelling does not always indicate that nematodes can reproduce, but may be the resistant plant's reaction to invasion. Conversely, reproduction may occur in the absence of swelling (Cook and Evans, 1987).

Amosu (1976) screened 35 cultivars of tomato for resistance to root knot nematodes and found cultivars, Atkinson, Nematex, Rossol, Ven 8 and Ife 1 to be resistant. Screening of crop cultivars is time-consuming, but if a stable cultivar is discovered, it covers many years' expenses (McDonald and Linde, 2002). The main targets in most screening work are resistance to pests and diseases, immunity to wart disease, good farming and marketing characteristics of the new hybrid clones. To incorporate resistance into commercially acceptable cultivars requires reliable, efficient screening techniques for identifying resistant progeny within segregating breeding populations (McDonald and Linde, 2002).

2.5.0 **Benefits of resistance**

Resistant cultivars have several advantages over other methods of reducing nematode population and their use requires little or no technology, and is cost effective. According to Roberts (1993), resistant crops provide an effective and economical method for managing nematodes in both high and low-value cropping systems. They allow rotations to be shortened and make best use of the land. They also do not leave toxic residues (Tindall, 1988). In contrast, nematicides are uneconomic on many low-value crops and when used on high-value crops, they are applied at relatively high rates with the risk of toxic residues.

If resistance is coupled with tolerance to nematode infection, the resistant crop is 'self-protected' and will yield well on infested land. Furthermore, resistant crops in annual cropping systems can reduce or suppress nematode population densities in soils

to levels that are non-damaging to subsequent crops, thereby enabling shorter and more manageable rotations (Roberts, 1993). Additional important benefits of resistance cultivars are their environmental compatibility that they do not require specialised applications, and apart from preference based on agronomic or horticultural desirability, usually they do not require an additional cost input (Roberts, 1993). In developing countries and in low cash crop systems, plant resistance is probably the only viable long-term solution to nematode problems. Resistance and tolerance are also amenable to integration with other management tactics, an important consideration for promoting resistance durability (Roberts,
1993).

2.6.0 **Sources of resistance**

According to Hussey and Janssen (2001), even though resistance to root knot nematodes is available in several crop species, new sources of resistance are needed for some of these species to improve the level of root knot resistance. Genetic material has still not been identified for resistance in many other crop species. The transfer of resistance into an acceptable commercial cultivar is greatly simplified if resistant germplasm can be found in adapted cultivars or in advanced breeding lines or populations (Hussey and Janssen, 2001).

Nematode resistance traits in plants have come from wild plant species or their derived breeding lines. This important source of resistance genes continues to hold considerable potential for identification of additional genes. For example, focused

efforts to identify additional root-knot resistance genes in tomato beyong the original *Mi* gene have revealed the presence of at least eight additional genes in the tomato relative to *lycopersicon peruvianum*, and more are likely to be discovered (Robert *et al*., 1998). Most programmes for breeding cultivars and rootstocks resistant to nematodes have utilised simply inherited major gene resistance.

Fassuliotis (1979) also recommended searching for resistance for a crop species among germplasm in the following order: (1) commercial cultivars of self pollinators, inbred parents of hybrid cultivars, or parents of synthetic cultivars; (2) elite breeding lines that may soon become cultivars; (3) acceptable breeding lines with superiority for one or a few characters (i.e germplasm lines or absolete cultivars); and (4) plant introductions of the cultivated species. According to Barker and Hussey (1973), if a systematic search within the crop species is unsuccessful or levels of root knot resistance identified are inadequate, germplasm accessions of wild relatives of the crop species should be screened.

Plant resistance has also been found and developed mainly to the highly specialised parasitic nematodes such as *Globodera, Heterodera, Meloidogyne, Rotylenchulus, Tylenchulus and Ditylenchus.*These nematodes, except *Ditylenchus*, have a sedentary endoparasitic relationship with their host. According to Roberts (1982), resistance may be effective against nematode species of different genera, against more than one species from the same genus, against a single species, or against certain species within variants.

Resistance to less specialised parasitic groups such as the migratory endoparasitic genera *Aphelenchoides* and *Pratylenchus* has been developed in only a few cases, and also few ectoparasitic nematodes (Meredith *et al*., 1982; Harris, 1983).

2.7.0 **Resistance and nematode population**

The effect of resistance on nematode population is determined by the extent to which the resistance trait restricts the ability of the nematode to reproduce on the plant. Some reproduction occurs on the resistant genotype and at very low initial nematode population densities, a multiplication rate (or reproductive factor, defined as final density (Pf), over initial density (Pi), or Pf/Pi ratio) (Roberts, 2001).

Host plants have varying degrees of susceptibility with some plants being highly susceptible while others are less susceptible or resistant to root knot nematodes. The highly susceptible host plants allow the juveniles to enter the roots, reach maturity and produce many eggs while the resistant plants suppress their development and thus, do not allow reproduction (Sasser and Taylor, 1978; Karssen and Moens, 2006).

Koshy *et al*. (1979) reported severe damage at the lowest inoculum levels when semi wood cuttings of *Piper nigrum* L. were inoculated with *M.incognita* at 10, 100, 1000, 10000, or 100000 juveniles per pot in a glasshouse experiment. Percentage infestation by *M. naasi* Franklin of barley plants decreased with increasing inoculum level; 500 and 1000 juveniles/plants gave 10% infestation whilst inoculation with 8000 resulted in 5% (Ogunfowora, 1977). Several factors can influence seasonal nematode

population dynamics on resistant plants. The level of resistance gene expression may be modified in the plant according to genetic constitution, environmental effects and virulence status of the nematode population.

According to Jones (1985), in quantitative polygenic resistance, the number of genes and their additive effects will determine the level of resistance expression. Some major resistance genes have been shown to be incompletely dominant under certain conditions. For example, the resistance in common bean to root knot nematode conferred by gene *Me*2 (Roberts and Omwega, 1992) was found to be completely dominant at 26^{o} C but showed an allelic dosage response of incomplete dominance at 28^{o} C. The resistance to root knot nematodes identified recently in carrot also has a tendency toward incomplete dominance in the heterozygous condition (Simon *et al.*, 2000), although heterozygous resistance is still quite effective in preventing significant galling and forking of carrot tap root.

2.8.0 **Tomato genotypes resistant to root-knot nematode**

Root-knot nematodes are one of the major pathogens of tomatoes worldwide and limit fruit production (Sikora and Fernandez, 2005). Plant resistance is one of the most environmentally safe and economically viable means of controlling the pathogen, yet few resistance genes have been identified and their effectiveness can vary, depending on the environment (Roberts 1995).

Several cultivars of tomatoes such as Montelle, Sun6082, Pik Red, Celebrity, Baja, Roma VFN, Lemon Boy, enchantmen, Betterboy and Beefmaster have been

developed in an attempt to produce root-knot nematodes resistant cultivars (Milligan *et al.* 1998). Tomato cultivars have varying degrees of resistance to root-knot nematodes and difference in quality and quantity of fruit production. The *Mi* gene originally found in wild tomato species, *Lycopersicon peruvianum* (Mill). is one of the best characterized nematode resistance genes and has been genetically engineered into many commercial tomato varieties (Nono-womdim *et al*., 2002;
Abad *et al*., 2003).

2.9.0 **Tomato *Mi* gene**

Resistance to root knot nematode was observed originally in some accessions of the wild tomato species *Lycopersicon peruvianum* (Bailey, 1941), and subsequently shown to be due to a single dominant gene named *Mi* (Gilbert & McGuire, 1956). Further studies demonstrated that this gene controls the three major species *Meloidogyne arenaria*, *M. incognita* and *M. javanica* (Barham & Winstead, 1957).

Milligan *et al*. (1998), reported that the *Mi* gene was discovered 50 years ago in an accession of *L. peruvianum*, a wild relative of the edible tomato that was grown in the western coastal region of South America. This resistance was transferred and expressed in F1 plants derived from a cross between L. *peruvianum* P.I. 128657 and *L. esculentum* made by Smith (1944). Williamson and Hussey (1996) had shown that the *Mi* gene is located on the short arm of chromosome six. This chromosome has been mapped in considerable detail, and multiple markers for other traits linked to *Mi* have been identified. The *Mi* locus is located at least 40 Mbp from the linked *Aps-1* gene

(Zhong *et al.*, 1999), which codes for the enzyme acid phosphatase and has been used as a marker for root-knot nematode in the past (Rick and Fobes, 1974).

According to Sasser (1980), the most important source of resistance is conferred by the *Mi* family of genes from the wild tomato *Lycopersicon peruvianum,* providing effective resistance to *M. incognita, M. javanica* and *M. arenaria* and secondary opportunistic organisms such as the soil-borne bacterial pathogen, *Ralstonia solanacearum* (Deberdt *et al.*, 2003). *Mi* also provides resistance to the aphid *Macrosiphum euphorbiae* (Rossi *et al.*,1998) and biotypes Q and B (Jiang *et al.*, 2001) of *Bemisia tabaci.*

The resistance mechanism of *Mi* gene in response to invasion by root knot nematodes involves the formation of necrotic cells at the infection site to prevent the juveniles from developing any further. However, a high level of genetic variability of root knot nematodes has led to the existence of races and virulent populations which can reproduce even on plants carrying the resistance genes (Castagnone-Sereno, 2006).

According to Roberts *et al.* (1998) most sources of heightened resistance in tomato are not available in the tropics and sub tropical countries because of temperature and are poorly adapted to commercial production. Having low yields, non-marketable seed types, and other undesirable traits which means that a substantial breeding effort will be required to utilize their resistances. This single gene (*Mi*) helps broaden the genetic

base of resistance to root-knot, but additional non-allelic resistance would be desirable to enhance the durability and perhaps the level of nematode resistance in tomato. Recent identification of several isolates of *M. incognita* which overcome the resistance conferred by *Mi* (Roberts, 1995) indicated that *Mi* may become less effective for managing *M. incognita* in the future. Also, resistance conferred by *Mi* is only partially effective at high temperatures (Roberts, 1995). These facts support the need to identify additional sources of resistance to root knot nematodes in tomato.

CHAPTER THREE

3.0 MATERIALS AND METHODS

Two main experiments were conducted, pot and field trials. The pot trial was conducted in the plant house and the field experiment at the Plantation Crops Section, all of the Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology (KNUST).

3.1.0 Sources of tomato genotypes and root-knot nematodes inoculum

A total of 33 genotypes of tomato were evaluated for resistance to *Meloidogyne* species. Nine of the genotypes were collected from Burkina Faso, three from South Africa, seven were from the United States of America, eight from Vietnam, and six collected from agrodealers and farmers in Ghana.

Table 3.0: The list of tomato genotypes evaluated and their country of origins

Tomato genotype	Origin
Popvriend Seed T-311	Burkina Faso
Ventura F	Burkina Faso
Tomato Tima	Burkina Faso
Tomato Petomech 94971	Burkina Faso
Tomato Petomech EEC	Burkina Faso
Tomato Petomech CEE	Burkina Faso
Burpee Roma	Burkina Faso

Popvriend T-315	Burkina Faso
Tomato unknown	Burkina Faso
Tomato Roma VF	South Africa
Starke money maker	South Africa
Starke Heinz 1370	South Africa
Royal sluis	United States of America
Tomato jam Roma	United States of America
Tomato Floradade	United States of America
Tomato Cherry	United States of America
Big boy hybrid	United States of America
Tomato Beef master	United States of America
Tomato Red Cherry	United States of America
Tomato F1 Tropic	Vietnam
Tomato F1 Terminator	Vietnam
Tomato Mongal T-11	Vietnam
Tomato F1 NO. 7	Vietnam
Tomato F1 2026	Vietnam
Tomato F1 Mongal No. 5	Vietnam
Tomato F1 AN-67	Vietnam
Tomato F1 Tyking 5	Vietnam
Burkina	Local Farmers and Agrodealers (Ghana)
Ashanti	Local Farmers and Agrodealers (Ghana)
Caterpillar	Local Farmers and Agrodealers (Ghana)
Power	Local Farmers and Agrodealer (Ghana)
Cocoaba	Local Farmers and Agrodealers (Ghana)
Rando	Local Farmers and Agrodealers (Ghana)

The nematode inoculum used was obtained from heavily root-knot nematode infested tomato root collected from vegetable farms around KNUST, Kumasi.

3.1.1 Extraction and counting of root-knot nematode eggs

Extraction of nematode eggs was done by using modified method of Hussey and Barker, (1973). Root-knot nematodes–infested tomato roots were washed, dabbed dry and then cut into pieces with a pair of scissors. A reasonable quantity of the chopped roots were placed in a big jam bottle and 0.5% sodium hypochlorite (NaOCl) solution was added to cover the roots and then covered. The content of the bottle was agitated vigorously for four minutes.

The chopped root and NaoCl mixture was collected and rinsed with tap water on 200 µm-pore mesh sieve over 500 µm-pore mesh sieve and rinsed with tap water. Water was added to obtain the actual egg-water suspension. Root-knot nematode eggs were counted using a counting tray with the aid of a stereo microscope. Counting was done three times per entry.

3.1.2 Extraction and counting of root-knot nematode Juveniles

Juveniles were extracted from infested tomato roots, using modified Baermann tray method (Whitehead and Hemming, 1965). The roots were chopped with a pair of scissors and 5g weight of each entry was placed in a plastic sieve lined with a twoply

tissue paper placed in a plastic plate. Tap water was poured gently into the plastic plate in which the sieve was placed until the tissue became moist.

The set-up was left for 48h and the plates were then poured separately into beakers and left overnight for the juveniles to settle. Each nematode water suspension was separately topped with tap water to 30ml for standardisation. Each suspension was homogenised by blowing air through with a pipette. Counting was done three times to obtain the mean number of juveniles.

3.1.3 Soil preparation and Sterilisation

Soil for pot experiments was sterilised using the steam sterilisation method. Black soil was mixed with river sand at 3:1 ratio (v/v) and sterilised for 3h at 100^{o} C, left for 24hrs, with fire wood as the source of heat. The barrel steam sterilizer has two compartments, the minor compartment (upper) containing water and the major compartment (lower) containing the sand-black soil mixture. The sterilised soil was left in the barrel for 24 h to cool.

3.1.4 Nursing of tomato seeds

The 33 different tomato seeds collected were nursed separately in plastic bowls filled with sterilised black soil. Three weeks after germination, the most uniform and apparently healthy-looking seedlings were transplanted into plastic pots. For the seedlings for field tests, each bowl was inoculated with 2000 *Meloidogyne* eggs.

3.1.5 **Filling and transplanting of plants in pot**

Two-litre pots were filled with 1.6L of the sterilised soil. The provision for proper drainage in each of the pot was essential to prevent water logging or stagnation of water. Three-week old tomato seedlings were transplanted into the pots to observe their reactions to root knot nematodes.

3.1.6 **Experimental designs**

The plant house studies were set up in completely randomised design (CRD) with four replicates. However, randomised complete block design (RCBD) with three replicates was used for the field experiment.

3.1.7 **Statistical Analysis**

Data collected were analysed, using the Genstat statistical package (Discovery edition 3). Least significant difference (Lsd) at 5% was used for comparing mean differences. All counting data were transformed using square root transformation of

$\sqrt{(x+0.5)}$, where x is the mean count.

3.2.0 **Experiment 1: Determination of the best inoculum density for screening tomato plants for root-knot nematode resistance.**

This experiment was conducted at the Plant house and the Plant Pathology laboratory of the Department of Crop and Soil Sciences, Faculty of Agriculture,

KNUST.

3.2.1 **Source of the tomato genotypes**

Two local tomato genotypes, namely, Power and Rando, were used for the experiments. The genotypes were purchased from a local Agrodealer in Kumasi, Ghana. These genotypes are known to be susceptible to *Meloidogyne* species. The tomato seeds were nursed separately in pots and seedlings were transplanted as in sections 3.1.4 and 3.1.5.

3.2.2 **Application of different inoculum levels**

The seedlings were inoculated with 100, 500, 1000, 1500 and 2000 eggs per pot two weeks after inoculation. Three holes were made in a triangular form near the plant roots and the egg suspension was poured into them using 10 ml micropipette. Four replicates were kept for each of the inoculum levels, including a control without any inoculation (0 eggs). The pots were arranged in a complete randomised design and kept in the plant house and watered once every second day.

3.2.3 **Harvesting of tomato plants**

The test plants were harvested eight weeks after inoculation. To ensure easy removal of the plants from the soil, the sides of the plastic pots were pressed to loosen the soil. The soil was then removed from the roots by gently shaking the plants.

3.2.4 **Assessment of root knot nematode galls**

The roots of the harvested tomato genotypes were each washed separately and dabbed dry with tissue paper. Galling was scored using the rating chart by Bridge and Page (1980). Fresh weight of each treatment was recorded.

3.2.5 **Data collected**

- Fresh root weight (g)
- Root gall score (Bridge and Page, 1980)-Appendix 7
- Number of root-knot nematode juveniles /5g chopped tomato roots and,
- Number of root-knot nematode eggs/5g chopped tomato roots.

3.3.0 **Experiment 2: Reaction of 33 tomato genotypes to root-knot nematodes in pots**

This trial was conducted in the Plant house at the Department of Crop and Soil Sciences, KNUST, Kumasi.

The same 33 tomato genotypes, method of soil preparation and sterilisation and raising of tomato seedlings as described in sections 3.1.0, 3.1.3, 3.1.4 were used.

3.3.1 **Inoculation of tomato seedlings**

The potted tomato seedlings of all genotypes were inoculated with root-knot nematode eggs two weeks after transplanting. A total of 1500 *Meloidogyne* eggs were used to inoculate per pot. Three holes were made in a triangular form 2cm from the stem. The egg-water suspension was then dispensed into the holes and covered with soil. The pots were arranged in a completely randomised design with four replicates and left in the plant house and watered, as and when necessary. The test plants were harvested eight weeks after inoculation.

3.3.2 **Assessment of root-knot nematode galls**

The roots of the harvested tomato plants were each washed separately and dabbed dry with tissue paper. Galling was scored on the scale of 0-10 rating chart by Bridge and

Page (1980). Fresh weight of roots of each entry in the screen was measured, using an electronic balance.

3.3.3 Data collected

The same data were collected as described in section 3.2.5.

3.4.0 Experiment 3: Assessment of 33 tomato genotypes to root-knot nematodes in the field

This experiment was conducted at Kwame Nkrumah University of Science Technology, Plantation Crops Section, Kumasi, Ghana.

3.4.1 Source of tomato genotypes

The same genotypes used for the plant house evaluation were used for the field experiment.

3.4.2 Raising and inoculation of tomato seedlings for the field test

The genotypes were nursed separately in plastic trays containing sterilised top soil and river sand mix in a 3:1 ratio (v/v). Seedlings were inoculated with 2000 meloidogyne eggs/tray in the plant house two weeks after sowing. All the 33 genotype seedlings were planted on ridges for their reaction to *Meloidogyne* species.

3.4.3 **Field land preparation**

The land was slashed, ploughed, hallowed and ridges made at 1m between rows and 20cm within rows. The experimental design was a randomised completely block design with 3 replication.

3.4.4 **Harvesting of the tomato genotypes**

The test plants were harvested three months after transplanting. To ensure easy removal of the plants from the soil, the sides of the ridges were dug and the plants were carefully lifted from the ground. The soil was then removed from the roots by gently shaking the plants.

3.4.5 **Data collected**

The following data were collected at harvest:

- Plant height (cm),
- Stem diameter (cm),
- Fresh shoot weight (g) ,
- Fresh root weight (g),
- Root gall score (Bridge and Page, 1980)-Appendix 7
- Number of root-knot nematodes juveniles /5g chopped tomato roots and,
- Number of root-knot nematodes Eggs/5g chopped tomato roots.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1.0 **Experiment 1:** Determination of the best inoculum level for screening tomato for root-knot nematodes resistance

Table 4.1**:** Effect of Inoculum density of *Meloidogyne* species on root galling and number of juveniles in tomato genotype (power) eight weeks after inoculation

Meloidogyne inoculum level(eggs)	Mean gall score (0-10)#	Mean no. of juvenile (Transformed)*
100.00	3.67	6.47
500.00	6.23	10.83
1000.00	6.33	9.90
1500.00	8.00	11.90
2000.00	9.67	8.57
Lsd(5%)	2.49	1.49
CV (%)	20.10	4.20

# 0=No knots on roots
10=All roots severely knotted, Plant usually dead
*√x+0.5 transformed, where x is the mean number of juveniles

Generally, when inoculum level increased, mean gall score also increased (Table 4.1). The roots of tomato plants inoculated with 2000 eggs/plant had the largest gall infestation of 9.67 as compared with all inoculum levels. The 100 eggs inoculum density/ per tomato plant scored the least gall index of 3.67 (Table 4.1). There was no difference (P=0.05) between the 2000 eggs/plant and 1500eggs/plant but the former was significantly different (P=0.05) from all other treatments. It can be observed that 1500 eggs/plant had the largest mean of *Meloidogyne* juveniles of

11.90 as compared with the other inoculum levels (Table 4.1).
The least number of juveniles of 6.47 was recorded by the 100 eggs/ tomato plant. This followed the same trend as the gall scores. There was no difference (P=0.05) between the 500 eggs/plant and1000 eggs/ tomato plant and also between 1000 eggs/tomato plant and 2000eggs/tomato plant. However, there was significant difference (P=0.05) between the 1500 eggs/ tomato plant and all the treatments

(Table 4.1).

Table 4.2**:** Confirmation test to establish the best inoculum level for screening tomato for resistance to *Meloidogyne* species using tomato var rando eight weeks after inoculation

Meloidogyne levels (eggs)	Mean gall score (0-10)#	Mean no. of juvenile (Transformed)*	inoculum
100	4.00	24.10	

500	6.00	33.00
1000	6.67	34.53
1500	7.00	47.13
2000	8.67	36.77
Lsd(5%)	1.88	2.17
CV (%)	15.80	16.41

#0=No knots on roots
10=All roots severely knotted, Plant usually dead (see Appendix 7)
*√x+0.5 transformed, where x= mean number of juveniles

There was significant increase in mean gall score with increase in the inoculum density. The mean gall score ranged from 4.00 to 8.67 for 100 eggs/ tomato plant and 2000eggs/tomato plant, respectively (Table 4.2). There was no significant difference (P=0.05) between the 500eggs/tomato plant and 1000eggs/tomato plant and also between 1500eggs/plant as well as 2000eggs/tomato plant. However, there was significant difference (P=0.05) between the100eggs/tomato plant and all the treatments (Table 4.2 : Plate 1&2).

Plate 1: A susceptible tomato genotype, infested with galls

Plate 2: A resistant tomato genotype, without galls

These obsevations are in accordance with reports by Nadary *et al.* (2006) and Chindo *et al*. (2006) that as initial inoculum level of *M. incognita* populations increased, populations that had high infection incidence and reproduction rates induced greater root galling than did other populations.

According to Khan (2000), the influence of nematode inoculum density on number of galls developed on tomato seedlings revealed significant increase in the number of galls with increase in the inoculum density.

Dickson *et al*. (1983) also reported that as the initial inoculum concentration increased, more *M.incognita* and *M.javanica* egg masses were produced on plant roots, thereby increasing root galling on susceptible cultivars.

Mean number of *Meloidogyne* juveniles ranged from 24 to 47 for 100 eggs/ tomato plant and 1500 eggs/tomato plant, respectively (Table 4.2). There was significant difference (P=0.05) between the treatments except between the 500 eggs/tomato plant and1000 eggs/tomato plant and 1000eggs/tomato plant and 2000eggs/tomato plants (Table 4.2).

This study showed that increasing initial population of *Meloidogyne* spp. in the soil had a direct effect in increasing juvenile population in the tomato root. 2000 eggs/tomato plant root system could not support increased juvenile population and probable because of limited living tissue led to declined population. This relationship

reflects the density dependent effect of increased competition for feeding sites and food reserves at high initial densities of nematodes.

This observation is in agreement with the report by El-Sheriff *et al.* (2007) who studied the effect of fifteen population densities of *M. incognita* race 1 ranging from zero to 5000 eggs on yield of tomato, and found that maximum number of nematode juveniles were recorded at moderate population density (1000 to1500 eggs), and at very high population densities the reproduction potentials of root-knot on the plant declined because the population in the root system reached its peak and could not support further reproduction.

Niblack *et al.* (1986) demonstrated that at moderate to high initial population densities, root-knot nematodes reached their maximum level on a susceptible cultivar. Whereas on partially resistant cultivars that were less damaged by the nematodes, the population densities were still increasing.

Table 4.3**:** Effect of different inoculum densities of *Meloidogyne* species on number of root-knot nematodes eggs in tomatoes eight weeks after inoculation

Meloidogyne inoculum levels (eggs)	Mean number of eggs /5g chopped tomato roots*	
	POWER	RANDO
100	15.57	35.83
500	25.97	44.20
1000	24.50	47.40
1500	28.43	64.77
2000	25.23	50.43

Lsd (5%)	0.75	1.35
CV (%)	13.60	12.50

*√x+0.5 transformed where x = mean number of eggs

Mean number of root-knot nematode eggs recovered from roots of Power tomato ranged from 15.57 to 28.43 for the 100 eggs/ tomato plant and 1500 eggs/tomato plant, respectively. There was significant difference (P=0.05) between the treatments (Table 4.3).It can be observed for Rando that 1500 eggs/tomato plant had the largest number of *Meloidogyne* eggs of 64.77, as compared with the lowest inoculum level (100 eggs/tomato plant) recovering only 35.83. All the treatments were significantly different (P=0.05) (Table 4.3). It is evident that when the inoculum level increased, the number of eggs recovered from roots also increased up to 1500 eggs/plant and at 2000 eggs/plant the root system could not support further population increase leading to decline in their population.

The results of influence of inoculum density on root-knot eggs of tomato are also in conformity with those reported by El-Sheriff *et al.* (2007) in respect to *Meloidogyne* spp. reproduction and host damage that were both affected as the initial inoculum levels increased from 250 to 2000 eggs/tomato plant. They reported that the final population density of root knot on tomato cultivars increased proportionally with the increase of initial inoculation levels and all inoculum levels suppressed the plant growth regardless of the cultivar.

According to Dickson *et al*. (1983), the degree of resistance or susceptibility of a host can be assessed by establishing the relationship between the initial density and the final number of eggs produced after one life cycle has occurred under control conditions. Nematode reproduction and host damage are both affected by the initial inoculum levels and revealed an increase in number of juveniles and egg masses of the plant as the inoculum level increased from 250 to 1000 eggs/ tomato plant (Salem *et al*., 2007).

According to Ahmad *et al*. (1994), a step-wise increase in the initial population level of *M. javanica* induced a progressive increase in the number of egg mass and galls on the roots of root knot affected plants compared to the untreated control. Increased initial penetration of *Meloidogyne* in the roots had a direct effect in decreasing tomato plant growth. Regarding the egg mass population in the root, a significant reduction was recorded as the inoculum levels increased.

Table 4.4**:** Effect of different inoculum density of *Meloidogyne* species on fresh root weights of two tomato genotypes (power and rando) eight weeks after inoculation

Meloidogyne inoculum levels (eggs)	Mean fresh root weight (g)	
	POWER	RANDO
100	2.87	2.92
500	3.59	3.92
1000	3.45	4.39
1500	4.54	4.71
2000	2.20	4.91
Lsd (5%)	0.75	1.06
CV (%)	24.80	15.60

The 1500 eggs/tomato plant recorded the largest fresh root weight of 4.54g whilst 100 eggs/tomato plant had the least fresh weight of 2.87g for the tomato Power. The fresh root weight of the 1500 eggs/tomato plant was significantly different (P=0.05) from all the other treatments (Table 4.4).

It can be observed that there was a trend of increase in the fresh root weight with the increase in inoculum levels. The 2000 eggs/plant recorded the largest fresh root weight of 4.91 whilst 100 eggs/ plant had the least fresh root weight of 2.92g for tomato Rando. Although, the 2000 eggs/plant recorded the highest root weight, there was no difference (P=0.05) between the 2000 egg/plant and the other treatments, except the 100 eggs/plant.

Wonang and Akueshi (1990) studied the relationship between population densities of *M. incognita* and crop yield in tomato and found that there was greater increase in the fresh weight of tomato roots with increase in the inoculum density. This is in line with the observation aboe.

Ahmad *et al.* (1998) also studied the effect of *M. javanica* at 0, 1000, 2000 and 3000 juveniles inoculum levels on 6 chilli (*Capsicum annuum* L.) varieties grown in pots under controlled conditions and found that there was a general trend of decrease in

shoot parameters (plant height, number of leaves, fresh and dry weight) and an increase in root parameters (fresh and dry weight) with increase in inoculum levels.

4.2.0 **Experiment 2:** Reaction of tomato genotypes to root-knot nematodes (*Meloidogyne species*) in pots.

Table 4.5: Effect of root-knot nematodes on number of eggs, root galling and *Meloidogyne* reproduction on 33 tomato genotypes in pots eight weeks after inoculation

Genotypes	Mean number of eggs (transformed)*	Mean gall score (Scale 0-10)#	Reproductive factor (Rf)®	Reactions
Royal sluis	30.75	3.75	2.19	S
Popvriend T-315	44.50	8.00	2.26	S
Popvriend Seed T-311	49.00	6.50	2.31	S
Tomato Roma VF	41.25	7.50	2.24	S
Ventura F	37.75	7.00	2.21	S
Tomato Tima	51.50	6.75	2.48	S
Petomech 94971	51.50	7.75	2.48	S
Petomech EEC	37.00	6.00	2.22	S
Petomech CEE	45.50	8.00	2.29	S
Tomato jam Roma	34.50	5.50	2.23	S
Tomato Floradade	38.00	7.50	2.25	S
Starke money maker	43.50	6.75	2.26	S
Tomato Cherry	36.25	8.00	2.21	S
Starke Heinz 1370	46.00	6.25	2.30	S
Tomato F1 Tropic	43.75	7.25	2.27	S
Tomato F1 Terminator	50.00	7.25	2.33	S
Tomato Mongal T-11	21.50	3.25	0.71	R

Tomato F1 NO. 7	41.74	6.25	2.24	S
Tomato F1 2026	63.25	8.75	2.56	S
Tomato F1 Mongal No. 5	57.00	7.25	2.47	S
Tomato F1 AN-67	57.50	7.50	2.48	S
Tomato F1 Tyking 5	59.50	7.25	2.53	S
Burkina	41.50	6.25	2.24	S
Ashanti	56.75	7.75	2.51	S
Caterpillar	26.00	7.00	2.14	S
Big boy hybrid	41.25	7.25	2.23	S
Power	50.25	7.00	2.32	S
Cocoaba	54.25	6.00	2.51	S
Rando	54.00	7.00	2.66	S
Beef master	18.00	3.75	0.53	R
Burpee Roma	28.75	4.00	1.38	MR
Red Cherry	53.00	7.00	2.55	S
Tomato unknown	51.25	6.25	2.48	S
Lsd(5%)	10.97	1.62	2.99	
CV (%)	17.47	17.22	28.58	

0=No knots on roots, 10=All roots severely knotted

*√x+0.5transformed x= mean egg number

® Rf=final egg number/Initial egg number Rf<1=No reproduction, Rf>1=Reproduction

R=Resistant, MS=Moderately resistant and S=Susceptible

The mean number of root-knot nematodes eggs recovered from the roots of the 33 tomato genotypes ranged from 18.00 to 63.25 for Beef master and Tomato F1 2026, respectively. There was no significant difference (P=0.05) between Beef master, tomato mongal T-11 and Burpee Roma (Table 4.5).

According to Cousins and Walker (1998) root-knot nematode eggs developed poorly on resistant accession compared to susceptible accession. Also, the authors reported that quantity of eggs reflects the number of nematodes that reached reproductive maturity, and therefore provide one measure of resistance. Screening of individual seedlings for nematode resistance allows elimination of susceptible plants prior to field planting, conserving breeders' nursery resources.

Karssen and Moens (2006) reported that highly susceptible host plants allowed juveniles to enter the roots, reached maturity and produced many eggs while the resistant plants suppressed their development and thus, did not allow reproduction.

Tomato F1 2026 had the largest gall infestation compared with the other genotypes. According to the gall score rating used for host response, nematode mean gall score was lowest (3.25) in Tomato Mongal T-11, followed by Beef master (3.75) and Burpee roma (4.00), as compared to rest of the genotypes (Table 4.5).

All genotypes showed great variations in their responses or reaction to root-knot nematodes from resistant to susceptible (Table 4.5).Out of the 33 tomato genotypes screened, two (Tomato Mongal T-11) (Beef Master) were found to be resistant®, and only one (Burpee roma) was moderately resistant(MS), and the rest susceptible (S) (Table 4.5).

Resistance to plant parasitic nematodes is commonly defined as a reduction or inhibition of nematode reproduction. Fassuliotis (1979) reported that because galling occurs in most susceptible plants infected with root-knot nematodes, this can often be the sole measurement of resistance during screening experiments.

Hirunsalee *et al*. (1995) observed that reproduction and galling of nematodes on plant root were favoured on tolerant and susceptible cultivars but inhibited on resistant ones. Because resistance to nematodes is usually developed by selection of plants with

reduced rates of nematode reproduction and galling, nematode population densities are typically lower following a resistant cultivar than a susceptible cultivar (Starr *et al*., 2001).

Table 4.6: Effect of root-knot nematodes on fresh root weight of thirty three tomato genotypes in pots eight weeks after inoculation

Tomato Genotypes	Mean root weight (g)

Royal sluis	5.08
Popvriend T-315	4.88
Popvriend Seed T-311	3.84
Tomato Roma VF	5.08
Ventura F	4.52
Tomato Tima	6.92
Petomech 94971	6.64
Petomech EEC	3.81
Petomech CEE	4.72
Tomato jam Roma	6.88
Tomato Floradade	8.25
Starke money maker	7.05
Tomato Cherry	6.95
Starke Heinz 1370	4.24
Tomato F1 Tropic	9.71
Tomato F1 Terminator	4.75
Tomato Mongal T-11	6.07
Tomato F1 NO. 7	6.33
Tomato F1 2026	6.49
Tomato F1 Mongal No. 5	2.01
Tomato F1 AN-67	3.97
Tomato F1 Tyking 5	4.29
Burkina	5.74
Ashanti	6.96
Caterpillar	5.31
Big boy hybrid	3.91
Power	6.99
Cocoaba	9.27
Rando	6.64
Beef master	2.12
Burpee Roma	5.40
Red Cherry	4.85
Tomato unknown	3.79
Lsd (5%)	2.99
CV (%)	28.40

Beef master recorded the least root weight of 2.21g whilst Tomato F1 Tropic had the heaviest root weight of 9.71g.

According to el-Sherif *et al.* (2007), root-knot nematode increases root weight for the most susceptible cultivar compared to resistant cultivar. This is because root-knot functions as metabolic sinks similar to a developing fruit as nutrients produced in the leaves are re-distributed rapidly to the roots and into the bodies of the nematodes.

According to Hunt *et al*. (2005), root-knot nematodes establish specialised feeding cells in roots, redirecting photosynthate produced in the leaves to supply the energy demands of the nematode in the roots. Root weight of susceptible cultivar as a result of nematode parasitism increases whereas shoot weight declines, shifting the rootshoot balance (Roberts, 1995).

4.3.0 Experiment 3: Field assessment of 33 tomato genotypes for their reactions to root-knot nematodes

Table 4.7: Effect of root-knot nematodes on gall score and number of eggs of 33 tomato genotypes in the field ten weeks after inoculation

Tomato genotype	Mean gall score (0-10)#	Mean number of eggs/5g chopped roots (Transformed) *
Royal sluis	5.00	45.34
Popvriend T-315	4.33	43.31
Popvriend Seed T-311	4.34	32.30
Tomato Roma VF	4.67	40.31
Ventura F	4.67	51.00
Tomato Tima	6.00	51.07
Petomech 94971	5.67	57.03
Petomech EEC	4.00	37.30
Petomech CEE	3.67	31.11
Tomato jam Roma	4.67	28.34
Tomato Floradade	4.67	35.05
Starke money maker	5.33	38.50
Tomato Cherry	5.33	63.00
Starke Heinz 1370	5.33	23.00
Tomato F1 Tropic	4.00	63.32
Tomato F1 Terminator	6.33	48.00
Tomato Mongal T-11	5.33	3.03
Tomato F1 NO. 7	1.00	33.70
Tomato F1 2026	7.33	67.39
Tomato F1 Mongal No. 5	5.33	53.71
Tomato F1 AN-67	4.67	41.37
Tomato F1 Tyking 5	2.67	20.76
Burkina	4.33	42.77
Ashanti	3.67	30.71
Caterpillar	2.67	39.00
Big boy hybrid	4.00	49.32
Power	5.33	56.33
Cocoaba	5.33	55.05
Rando	4.67	39.00
Beef master	0.67	2.72
Burpee Roma	2.00	4.06
Red Cherry	5.57	57.33
Tomato unknown	6.00	44.72
Lsd(5%)	2.54	30.73
CV (%)	35.30	46.77

#0=No knots on roots, 10=All roots severely knotted (see Appendix 7)
*$\sqrt{x+0.5}$ transformed, where x = mean number of eggs

More eggs were recovered from the roots of Tomato F1 2026,Tomato Cherry and Red Cherry compared with Tomato Mongal T-11, Tomato Beef master and Burpee Roma (Table 4.7) . Roots of susceptible genotypes were found to be more favourable to root knot nematode galling (Table 4.7). Therefore, more eggs were identified on susceptible genotypes roots compared with the less susceptible and/or resistant genotypes. Root galling on tomato varied with different genotypes. Lower gall score was recorded on the roots of Tomato Mongal T-11 as compared to Tomato F1 2026. The primary symptom of root-knot nematode infection is the formation of typical root galls on the roots of susceptible genotypes.

The presence or absence of root galls tomato plants indicates whether a variety is resistant or susceptible to root-knot nematodes. However, significant differences in the number of galls present on roots indicate different levels of susceptibility. The level of susceptibility is controlled by the presence of resistance genes such as *Mi* gene and genetic background of the tomato cultivar (Castagnone-Sereno, 2006).

Khan (1994) reported that the nematode resistance in host plant was manifested by reduced rates of nematode reproduction, egg masses and consequently, low nematode population densities than that of a susceptible one. This observation is in accordance with the report by Khan (1994) that the development of galls on plant roots increased significantly on the susceptible genotypes compared with resistant genotypes.Mai and Abawi (1987) also reported that intensive galling seriously reduced root efficiency.

Table 4.8: Effect of root-knot nematodes on number of juveniles, stem girth and shoot weights of 33 tomato genotypes in the field ten weeks after inoculation

Tomato Genotypes	Mean number of juveniles /5g chopped tomato roots (Transformed)*	Stem girth (cm)
Royal sluis	12.00	1.90
Popvriend T-315	21.33	1.57
Popvriend Seed T-311	15.67	2.20
Tomato Roma VF	22.67	2.53
Ventura F	20.67	2.33
Tomato Tima	13.67	2.57
Petomech 94971	15.67	2.17
Petomech EEC	14.67	1.90
Petomech CEE	16.33	2.27
Tomato jam Roma	16.67	2.83
Tomato Floradade	12.67	2.47
Starke money maker	10.67	2.33
Tomato Cherry	19.00	2.27
Starke Heinz 1370	11.00	2.50
Tomato F1 Tropic	13.67	2.97
Tomato F1 Terminator	9.33	2.4
Tomato Mongal T-11	1.67	3.53
Tomato F1 NO. 7	14.33	2.63
Tomato F1 2026	23.33	1.43
Tomato F1 Mongal No. 5	18.00	2.70
Tomato F1 AN-67	17.33	2.20
Tomato F1 Tyking 5	8.67	1.90
Burkina	20.67	2.00
Ashanti	5.33	1.67
Caterpillar	12.00	2.30
Big boy hybrid	12.33	2.87
Power	23.00	2.33
Cocoaba	11.67	2.17
Rando	17.00	2.40
Beef master	4.00	3.93
Burpee Roma	2.33	3.90
Red Cherry	17.00	2.53
Tomato unknown	12.33	2.23
Lsd(5%)	9.32	0.92
CV (%)	39.03	23.38

*√x+0.5 transformed, where x = mean number of juveniles

Nematode juvenile reproduction on tomato varied with the different tomato genotypes. Least numbers of juveniles were recovered from the roots of Tomato Mongal T-11, Tomato Beef master and Burpee Roma (Table 4.8), as compared with Tomato Roma VF, Tomato F1 2026 and Power. The Tomato Mongal T-11 had the lowest number of juveniles of 1.67 whilst Tomato F1 2026 recorded the highest number of juveniles of 23.33 (Table 4.8).

According to El-Sherif (2007), roots of susceptible genotypes are found to be more favourable to root-knot nematode activities and promote reproduction and survival of juveniles. Therefore, more juveniles were identified on susceptible genotypes compared to the resistant genotypes (Table 4.8).

According to Chen and Dickson (2004), the susceptibility of a plant to root-knot nematodes depends on the ability of nematode juveniles to penetrate the roots of the plant and cause the formation of giant cells which appear as galls on the roots.

Karssen and Moens (2006) reported that the highly susceptible host plants allow the juveniles to enter the roots, reach maturity and produce many eggs while the resistant plants suppress their development and thus, do not allow reproduction. Khan (1994) also reported that root knot nematode juveniles develop poorly on the resistant accession as compared to susceptible accession.

According to Roberts (2001), susceptible crops allow large increases in nematode populations from even low initial densities, although the rate of population increase declines at very high inoculum densities.

On the basis of average stem diameter, Tomato Beef master was the thickest genotype, recording 3.93cm whilst the lowest of 1.43cm was recorded for Tomato F1 2026 (Table 4.8).

According to Hussey (1989), an increase in stem diameter was due to the uptake and transportation of water and nutrients which are dependent on the health of the roots. Gommers *et al.* (1991) also reported that increase in stem diameter was due to the translocation of water and nutrients to the shoots.

According to Eisenback *et al.* (1991), heavily diseased plants do not respond to water, this is because the nematodes have severely damaged the conducting tissues of the plant at the roots. As a consequence, stem diameter and top growth is reduced.

Table 4.9: Effect of root-knot nematodes on plant heights, fresh root weights and fresh shoot weights of 33 tomato genotypes in the field ten weeks after inoculation

Tomato Genotypes	Plant height (cm)	Fresh root weight (g)	Fresh shoot weight (g)
Royal sluis	50.90	6.73	46.19
Popvriend T-315	58.40	4.75	29.01
Popvriend Seed T-311	36.30	4.06	31.43
Tomato Roma VF	35.10	4.62	42.22
Ventura F	33.30	6.52	33.14
Tomato Tima	43.80	7.04	38.10
Petomech 94971	53.30	11.47	36.20
Petomech EEC	43.50	5.93	37.74
Petomech CEE	40.70	4.99	19.82
Tomato jam Roma	56.20	5.14	35.77
Tomato Floradade	37.70	4.83	35.07
Starke money maker	41.70	4.87	38.60
Tomato Cherry	48.50	6.14	37.89
Starke Heinz 1370	39.70	4.45	33.32
Tomato F1 Tropic	39.50	10.34	56.25
Tomato F1 Terminator	32.30	8.70	37.05
Tomato Mongal T-11	40.50	2.63	87.61
Tomato F1 NO. 7	46.90	5.17	33.84
Tomato F1 2026	55.20	15.40	31.31
Tomato F1 Mongal No. 5	50.20	5.73	50.43
Tomato F1 AN-67	39.40	4.95	24.55
Tomato F1 Tyking 5	41.40	5.19	39.23
Burkina	44.00	4.27	39.91
Ashanti	42.00	7.36	40.64
Caterpillar	43.50	7.58	28.18
Big boy hybrid	46.30	5.72	40.35
Power	46.70	6.25	45.30
Cocoaba	36.70	4.87	36.58
Rando	52.70	6.15	32.15
Beef master	34.00	3.16	142.90

Burpee Roma	53.40	2.77	84.09
Red Cherry	46.20	7.97	67.20
Tomato unknown	40.80	10.72	39.08
Lsd(5%)	23.64	5.54	24.07
CV (%)	15.50	18.70	33.55

Plant height ranged from 32.3cm for Tomato F1 Terminator to 58.4cm for Popvriend T-315. Heavily root-knot nematodes-infested plants, according to Sidiqque and Alam (1985), exhibited stunted growth and poor yield. Resistant varieties gave maximum increase in plant height and minimum increase in fresh root weight due to the less root-knot formation (Table 4.7).

Khan (2000) also reported that there is a general trend of increase in shoot parameters (plant height, number of leaves, fresh shoot weight) and decrease in root parameters (fresh and dry weight) with the increase in resistant level of cultivars.

The least mean root weight of 2.63g was recorded for Tomato Mongal T-11whilst Tomato F1 2026 had the heaviest weight of 15.40g. It was also observed that the root weights of Tomato Petomech 94971, Tomato F1 Tropic and Tomato F1 2026 were heavier than those of Tomato Mongal T-11, Tomato Beef master and Burpee Roma. Tthis may be due to higher number of galls formed on their roots. Susceptible cultivars develop heavier root systems because of root galling, compared to resistant cultivars. According to Hussey and Boerma (1989), this in turn reduces the uptake and

transportation of nutrients (Plate 3&4; Pg 59). The mean shoot weight of the 33 tomato genotypes ranged from 19.8g to 142.9g for Tomato Petomech CEE and Tomato Beef master, respectively.

Plate 3: Tomato beef master (most resistant genotype to *Meloidogyne* spp. attack)

Plate 4: Tomato F1 2026 (most susceptible genotype to *Meloidogyne* spp. attack)

According to Caveness and Ogunforowa (1985), *Meloidogyne* spp infested-plants are seriously affected by their uptake and transportation of water and nutrients, which in turn affect their shoot weight. Similar observation was made with regard to fresh shoot weight in this study (Table 4.9).

There was a decrease in the shoot weight with an increase in susceptibility to nematodes (Table 4.9). Heavily root-knot nematode-infested plants, according to Sidiqque and Alam (1987), exhibit stunted growth and declined shoot growth.

The increased shoot weight in tomato Beef master may be due to the ability of the roots to absorb more nutrients as compared to tomato Petomech CEE whose roots were

highly infested or galled. Heavily infested roots, according to Hussey (1989), reduce the uptake and transportation of nutrients to the shoot.

CONCLUSION

Since root-knot nematodes are of great economic importance, so much attention has been paid to their control. There has been an increase in the intensity of search for efficient, ecologically sound and safe control methods. Among various control measures, identification, exploitation and utilization of host plant resistance is the most ecologically safe and economically viable strategies for management of the root-knot nematodes (*Meloidogyne species*) in tomato (*Lycopersicon esculentum* Mill.). In Ghana, identification and selection of more tomato cultivars resistant to root-knot nematodes (*Meloidogyne* spp.) would reduce losses and increase yield as well as fruit quality.

The studies have showed that increasing initial population of *Meloidogyne* spp. in the soil had a direct effect in increasing nematode population and damage of tomato roots. Regarding root galling and population of juveniles and eggs in the root, a significant increase was recorded as initial inoculum level increases to a point when the root system couldn't support further population increase. A total of 1500 eggs/tomato plant was found as the optimum initial inoculum level for screening for resistance in tomato to *Meloidogyne* spp. It gave maximum number of eggs, juveniles and fresh root weight as compared to 100, 500, 1000 and 2000 eggs/plant.

The planthouse and field experiments conducted on the 33 tomato genotypes revealed a considerable variation in response to *Meloidogyne* spp. Although the severities of root galling and recovery of eggs and juveniles were significantly low in the field trial as compared to the planthouse, the general trend of root infestation by root-knot nematodes was the same. Tomato Beef master and Tomato Mongal T11 recorded the lowest number of juveniles and also scored the minimum gall index (Bridge and Page ,1980; Appendix 7). Tomato F1 2026 recorded the highest number of eggs and also scored the highest gall index.

Therefore, tomato Beef master and Tomato Mongal T-11 were found to be highly resistant, Burpee roma was moderately resistant and Tomato F1 2026 was found to be the most susceptible cultivar to root knot nematodes damage. Of the 33 tomato genotypes screened, two were found to be resistant to *Meloidogyne* spp., one was moderately resistant and 30 were found to be susceptible.

RECOMMENDATIONS

Resistance to nematodes is usually developed by selection of plants which reduces reproduction. Tomato Beef master and Tomato Mongal T-11 was more resistant to root-knot nematodes. They therefore are recommended to farmers for cultivation. However, farmers should use deployment of resistance such as rotation with nonhost to avoid breakdown of resistance.

These selected genotypes can also be used by plant breeders for further hybridization with local varieties to improve their adaptability, quality and yield.

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APPENDICES

Appendix 1. Summary Anova for inoculum density of *Meloidogyne* species on mean gall score and in tomato var power

Source of variation	d. f.	Sum of squares	Mean squares	F-value	F-probability
Treatments	4	59.73	14.93	8.00	0.004
Error	10	18.67	1.87		
Total	14	78.40			
Lsd (5%)	2.49				

CV (%)	20.10

Appendix 2. Summary Anova for inoculum density of *Meloidogyne* species on mean number of eggs in tomato var power

Source of variation	d. f.	Sum of squares	Mean squares	F-value	F-probability
Treatments	4	303.43	75.86	4063.79	<.001
Error	10	0.19	0.02		
Total	14	303.62			
Lsd (5%)	0.75				
CV (%)	3.60				

Appendix 3. Summary Anova for inoculum density of *Meloidogyne* species on and mean number of juveniles in tomato var Rando

Source of variation	d. f.	Sum of squares	Mean squares	F-value	F-probability
Treatments	4	819.93	204.98	143.75	<.001
Error	10	14.26	1.43		

Total	14	834.19
Lsd (5%)	0.75	
CV (%)	3.60	

Appendix 4. Summary Anova for inoculum density of *Meloidogyne* species on fresh root weight in tomato var Rando

Source of variation	d. f.	Sum of squares	Mean squares	F-value	F-probability
Treatments	4	8.21	2.05	5.98	0.010
Error	10	3.43	0.34		
Total	14	11.63			
Lsd (5%)	1.06				
CV(%)	15.60				

Appendix 5. Summary Anova for reactions of 33 tomato genotypes for resistance to root-knot nematodes in pots.

Source of variation	d. f.	Sum of squares	Mean squares	F-value	F-probability

Treatments	32	14399.97	450.00	7.41	<.001
Error	99	6011.75	60.72		
Total	131	20411.72			
Lsd (5%)	10.97				
CV(%)	17.47				

Appendix 6. Summary Anova for reactions of 33 tomato genotypes for resistance to root-knot nematodes under field environment.

Source of variation	d. f.	Sum of Squares	Mean squares	F-Value	F-probability
Treatments	32	2823.58	88.24	2.70	<.001
Error	64	2088.18	32.63		
Total	98	5476.91			
Lsd (5%)	9.32				
CV(%)	39.03				