KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

SCHOOL OF RESEARCH AND GRADUATE STUDIES

DEPARTMENT OF CROP AND SOIL SCIENCES

EVALUATION OF THE EFFECTIVENESS OF ROOT-KNOT NEMATODE RESISTANT TOMATO (*SOLANUM LYCOPERSICUM* L.) AND PEPPER (*CAPSICUM ANNUUM* L.) IN GHANA

BY

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AUGUST, 2011

EVALUATION OF THE EFFECTIVENESS OF ROOT-KNOT NEMATODE RESISTANT TOMATO (*SOLANUM LYCOPERSICUM* L.) AND PEPPER (*CAPSICUM ANNUUM* L.) IN GHANA

THESIS SUBMITTED TO THE SCHOOL OF RESEARCH AND GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, GHANA, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE, MASTER OF SCIENCE IN CROP PROTECTION (NEMATOLOGY)

BY

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AUGUST, 2011

DECLARATION

I declare that, except for references to other people's work which have been duly cited, this work is the result of my own original research and that this work has neither in whole nor in any part been presented for a degree elsewhere.

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DEDICATION

To my parents, Mr Issah Kwara and Mrs Zaratu Issah, and my siblings, Ayishietu, Zenabu, Kubra, Humaimatu, Foziatu and Abdul Wahab. I thank you all for your love and support. I could not have done this without you. God richly bless you.

ACKNOWLEDGEMENTS

My sincerest gratitude goes to the Almighty God for his constant love, support and strength He gave to me throughout this programme.

I want to express my warm and sincere gratitude to my supervisor, Dr. Charles Kwoseh of the Department of Crop and Soil Sciences of KNUST, for his constructive criticisms and advice in putting this thesis together. God richly bless you. I equally thank Mr Opoku Asiamah of the School of Agriculture, University of Cape Coast (UCC) for his pieces of advice, encouragement and prayer support throughout the programme.

I am also indebted to Prof. James L. Starr of the Department of Plant Pathology and Microbiology, Texas A&M University, College Station, USA, for providing the tomato and pepper seeds and assisting in the Molecular identification of the root-knot nematodes for this project.

My appreciation goes to Dr B.K. Maalekuu, Head of Department of Horticulture, KNUST, and Edmund for assisting me in determining the total soluble solids and firmness of the tomato fruits. I acknowledge Alhaji Issah, the MD and Hans of the Tono Irrigation Project Site, for assisting me in the collection of the soil samples for the tomato and pepper bioassays.

To my colleagues and friends at the Department of Crop and Soil Sciences, Mr Osei Akoto, Mr Boniface Milana, Mr Joe Acquah, Aziz, Henry, Asieku, Inusah and all those I have not been able to mention here, I want to say I really appreciate all that you have done for me.

Lastly, my sincere gratitude and thanks go to my family for their emotional and financial support.

ABSTRACT

Nematode-resistant cultivars are the most useful, economical and effective means of managing nematodes. Three root-knot resistant tomato cultivars; Small Fry, Jetsetter and Celebrity and three root-knot resistant pepper cultivars Carolina Cayenne, Carolina Wonder and Charleston Belle obtained from College Station, Texas, USA, were used for the study. Power and Ohene Sateaa, tomato and pepper cultivars, respectively, were used as checks. Three experiments, pot and field experiments and soil bioassays, were conducted to determine the reactions of the tomato and pepper cultivars to root-knot nematodes. The bioassay was carried out on soils collected from tomato growing areas in Navrongo, Vea and Pwalugu in Ghana. The experimental design for the pot and bioassays was completely randomized design with three replications each and the field experiment was randomized complete block design with three replications. The tomato and pepper seeds were nursed separately in steam-sterilized black soil in plastic pots and transplanted after two weeks. *Meloidogyne* eggs were extracted from root-knot nematode-infested tomato roots. Each of the potted seedlings was inoculated with 2000 *Meloidogyne* eggs. The tomato and pepper bioassays were not inoculated because the soils were already infested with root-knot nematodes. After harvesting all the tomato and pepper plants, the infected plants were scored for galling on a 0-5 rating scale. The *Meloidogyne* eggs were extracted and counted. The reproduction factors of the treatments were determined. With the pot experiment, the tomato and pepper cultivars were variously galled, recording high *Meloidogyne* egg count and with reproduction factors greater than one. The root-knot resistant tomato and pepper cultivars recorded low numbers of *Meloidogyne* eggs and low gall scores for both the field and bioassays. However, Ohene Sateaa and Power recorded the highest gall scores of three and five, respectively, as well as high nematode egg counts. All the resistant tomato and pepper cultivars recorded higher yields than the local checks. The resistant tomato Jetsetter,

Celebrity and Small Fry fruits stored better than Power tomato and were also firmer than Power. The soil temperature range during the study period in the field was 24-32°C. The soil temperature seems to have no effect on the resistant tomato and pepper cultivars. All the resistant tomato and pepper cultivars could manage the *Meloidogyne* species.

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CHAPTER ONE

1.0 INTRODUCTION

Tomato (*Solanum lycopersicum* L.) originated from the area lying between Mexico and the West Coast of South America (Obeng-Ofori *et al*., 2007). Bosland *et al*. (1996) reported that pepper (*Capsicum* species) probably originated from Bolivia and Peru.

Vegetable production, especially that of tomato and pepper has become a key component in the economic stability of most farmers in Ghana. This is because they are well adapted to all the ecological zones of the country, namely; the forest-savannah transition, the savannah and forest zones. In Ghana, tomato is the most important vegetable crop in the Northern, Upper East and Volta Regions. It is also a fairly important cash crop in the outskirts of urban areas in the forest zone, in the greater Accra area, Akumadan, Wenchi, and Mankesim (Obeng-Ofori *et al*., 2007).

Tomato and peppers have many uses and are a key component in the diet of the resident population. Obeng-Ofori *et al*. (2007) reported that tomato fruits contain a lot of water with calcium, carbohydrate, carotene, iron, niacin, riboflavin, thiamine, protein and some other vitamins. Peppers, especially red chilli, contain high amounts of vitamin C and carotene. In addition, peppers are a good source of most of the vitamin B-complex, vitamin B6 in particular. They are also very high in potassium, magnesium, and iron (Andrews, 2000).

The sale of these vegetables is a vital source of income for many producers. A survey report by Trade Aid Integrated (an NGO) pointed out that tomato production in the Upper East Region gave employment to about 11,728 farm families and it is estimated that 58,640 persons benefit from its production (Clottey *et al*., 2009).

The total land area utilized for tomato production in Ghana grew from 28,400 ha in 1996 to 37,000 ha in 2000, an increase of 30 percent as reported by the Ghana Investment Promotion Council (GIPC), 2001).The average yield is 7.5 MT/ha and producers hope to double this figure to 15 MT/ ha in the near future in order to increase both local and export market share (GIPC, 2001).

The production volume of chilli peppers remained relatively constant during the last 10 years. It increased slightly from 270,000 MT in 2000 to 277,000 in 2006 and 279,000MT in 2008 due to increased availability of the Legon 18 seed variety and the Millennium Development Authority (MIDA's) chilli pepper production training programmes. According to the Millenium Challenge Account (MCA, 2006), Ghana is producing about 279,000 MT. Ghana is the fifth largest exporter of chilli peppers to the European Union with top export destinations to Germany, the United Kingdom and Switzerland. Ghanaian chilli farmers are only producing at 50 percent of attainable yields because of the lack of irrigation systems, improved inputs and the incidence of diseases including root-knot nematodes (MCA, 2006). MIDA has supported farmers in Akwasiho in the Kwahu East District of the Eastern Region to produce green pepper for export to the United Kingdom. According to MCA (2006), 47 out of the 50 members of Blessing Farmers Association in the district that received technical and financial support from the Authority sold 5.6 MT of the produce to the United Kingdom.

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. In recent years, domestic tomato production has intensified across Ghana but local production is not able to meet the high domestic demand. Consequently, there has been increased importation of tomato paste from the United States of America and Italy, and fresh tomato from neighbouring Burkina Faso to supplement the local production (Horna *et al.*,

2006). In addition, Unilever Ghana imported bulk-pressurized tomato from Europe for local repackaging and distribution (GIPC, 2001). This situation is as a result of a number of constraints, including root-knot nematodes infestation in tomato production. According to Sorribas *et al.* (2005), tomato is highly susceptible to the root-knot disease caused by *Meloidogyne* spp.

Root-knot nematodes (*Meloidogyne* spp.) are obligate endoparasites that infect a large number of crop plants including tomato and pepper, and cause severe losses in yield (Williamson and Hussey, 1996). Root-knot nematode attack is one of the factors responsible for the frequent crop failure in tomato and pepper. Hemeng (1981) reported yield loss of 73-100% in tomato in Northern Ghana. The rapid rate of reproduction of root-knot nematodes in good hosts, several generations during one cropping season leads to severe crop damage. Damage may consist of various degrees of stunting, lack of vigour, and wilting under moisture stress (Moens *et al.*, 2009).

Root-knot nematodes predispose plants to other pathogenic infections (Starr *et al.*, 2009). Attack by nematodes may greatly increase the severity of bacterial, *Fusarium* and *Verticillium* wilt diseases. Root-knot diseases caused by fungi, plant viruses and plant parasitic nematodes are especially important in tomato and pepper production due to limited options for their control.

Chemical soil treatment is an essential means of controlling nematodes on a number of crops in the tropics. In Ghana, Hemeng (1981) recommended Phenamiphos, 1,3-D and Carbofuran each at 5 kg ai/ha for the control of root-knot nematodes in the northern savanna zones whilst the rates of application ranged from 47 kg ai/ha to 10 kg ai/ha for remarkable results in the transitional zone. Many crops cannot be grown economically without the use of nematicides (Sikora and Fernandez, 2005). However, their use, especially in subsistence agriculture in

developing countries, is becoming limited because nematicides are expensive, and their use poses environmental and human health concerns (Starr *et al*., 2002).

Biological control also holds some promise for the future, but it is difficult to establish microflora or fauna in soils that effectively suppress nematode population densities in a short period of time under a single growing season (Evans *et al*., 1993). Also, effective biological control systems are limited to specialized situations such as intensely managed crop systems where the environment can be manipulated to promote biological activity.

Crop rotation decreases the potential for substantial yield losses due to nematodes (Luc *et al*., 1990) and provides short-term suppression of nematode population densities. 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 tactics (Luc *et al*., 2005). Also, nematode species have a wide host range which poses a challenge in selecting suitable crops for rotation.

Host plant resistance is an effective management tool that improves crop yield in the presence of nematode population densities that exceed the damage threshold (Starr *et al*., 2002). With the several management techniques, host plant resistance has been prioritized over chemical, biological, cultural and regulatory components (Barker, 1994). Host resistance, when available, is the preferred tactic because; resistant crops can reduce or suppress nematode population densities to levels non-damaging to crops. The use of genetic resistance, unlike pesticides, presents no potential hazard to human or environmental health. Additionally, they do not require specialized applications and usually do not require additional costs (Roberts, 2002).

According to Starr and Mercer (2009), the major limitations of resistance are that, resistance is race specific, and increased used of a particular species can lead to the development of

virulent nematode species to that particular resistance gene. Fortunately, a case of specific virulence within *Meloidogyne* species is rare.

Starr *et al.* (2002) reported that resistant tomato and pepper cultivars are under-utilized by resource-limited farmers in tropical and sub-tropical Africa inspite of the many benefits of using resistant cultivars.

1.1 OBJECTIVES

The objectives of the study were to:

- determine the reaction of the resistant tomato and pepper cultivars against root-knot nematodes.
- determine the quality of the tomato fruits after harvest.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1.0 Botany of Tomato

Tomato belongs to the family *Solanaceae*. The wild tomato cultivars are either biennials or perennials while those under cultivation are normally grown as annuals. Tomato has hairy stems, soft when young but become woody as they age. According to Tony (2002), there are basically two growth habit types of tomato. Determinate types that produce flowers at almost every internode until terminal flowers are formed and the plant growth stops at this point. Determinate tomato usually has a bushy appearance hence, often referred to as bush tomato. Indeterminate types continue growing almost indefinitely and need staking and pruning .They produce flowers at every third internode.

Tomato roots can grow to a depth of 40 cm to 60 cm and its adventitious roots readily grow from the stem (Obeng-Ofori *et al.*, 2007). The structure of the flowers helps in self pollination since the style rarely extends beyond the stamina cone. About 2-5% of natural cross pollination is reported in the tropics where temperatures are high (Obeng-Ofori *et al.*, 2007).

The fruits come in different shapes such as round and smooth, elongated and pear-shaped. The first fruits of each truss are usually larger than the subsequent fruits. The fruit size is directly linked to the number of loculi. Tomato seeds are small, round, flat and greyish- white in colour, and hairy. According to Obeng-Ofori *et al.* (2007), tomato seeds can retain their viability for about four years under favourable conditions (4 to 10°C) with a relative humidity of below 50%.

2.2.0 Botany of Pepper

The domesticated *Capsicum* species are *C. annuum* L., *C. frutescens* L., *C. chinense* Jacq., *C. baccatum var. pendulum* L. *and C. pubescens* Ruiz and Pav. (Pickersgill, 1997). *C. annuum* is the most widely cultivated of these species throughout the world and includes the mild sweet bell peppers as well as many varieties of hot peppers. Sweet pepper and hot pepper belong to the family *Solanaceae*. Dykes (2010) reported that hot pepper have broader or slender foliage. The fruit varies in shape from elongated, flexuous or conical. It is usually yellow, green or red in colour at maturity. The leaf shapes vary according to cultivar from broadly rounded to elongated with a tapering tip. The colour ranges from dark to light green and occasionally purple.

According to Obeng-Ofori *et al*. (2007), sweet peppers are herbaceous annuals with erect branching stems measuring 50-80 cm high. Some cultivars are bushy, with woody stems. The height of a full grown plant ranges between 0.5 and 1.5 m. The stems are sturdy so pepper plants do not have to be tied up. The leaves are glabrous and sometimes lanceolate. The fruit is a berry, very pungent and aromatic. Blossoms are white to greenish and appear in the leaf axil. They appear singly, not in clusters as in the tomato plant.

2.3.0 Description of tomato and pepper cultivars used for the study

Tomato cultivar Small Fry

Small Fry tomatoes are red, cherry-sized tomato around 2.5 cm in diameter, perfect for salads. The small fry tomato plants are determinate, grow to a height of 1.2 m and mature within 65 days. The tomato plants bear tiny fruits in stem clusters, with seven to eight tomatoes per bunch (www.grow.cook.eat.com, 16 July, 2011). Small Fry tomato varieties produce tomato over a long period and are more suitable for growing in warmer climates. The

Small Fry tomato cultivar is unique because it produces continuously during the growing season on a determinate or bush plant. Small Fry tomato is resistant to *Verticillium* Wilt, *Fusarium* Wilt, and root-knot nematodes (www.tomatodirt.com, 16 July, 2011). The average yield with good management practices should be 45-50 t/ha.

Tomato cultivar Jetsetter

Jetsetter plants grow to a height of 1-1.2 m. The plants do not set seed, flowers are sterile, or plants will not come true from seed. They are determinate plants with red colour, smooth, soft and medium sized juicy fruits. Jetsetter matures within 69-80 days after planting. They are used fresh, and in salad. Jetsetter is resistant to root-knot nematodes (N), *Verticillium* wilt (V), *Fusarium* wilt (F), and Tobacco mosaic virus (T) (www.Early-tomato.com, 16 July, 2011). The tomato yield for the average grower is 45-50 t/ha.

Tomato cultivar Celebrity

They are determinate plants with red colour smooth, soft and large sized juicy fruits. Celebrity tomato grows to a height of 90-120 cm and matures within 70 days after planting. Celebrity tomato cultivars are highly productive and resistant to *Verticillium* wilt (V), *Fusarium* wilt (F), root-knot nematodes (N) and Tobacco mosaic virus (T). The plants do not set seed, flowers are sterile, or plants will not come true from seed (www. Dave's Garden.com, 18 July, 2011). The tomato yield for the average grower is 45-50 t/ha.

Tomato cultivar Power

Power tomato are indeterminate plants and bear medium sized fruits. They grow to a height of 1.2-1.4 m. Power tomato plants are late maturing and, thus, take more than 80 days to mature. They produce tomato fruits over a long period of time and are suitable for growing in warmer climates. Power tomato fruits are used in salads, fresh and canning. They are susceptible to root-knot nematodes (www. Dave's Garden.com, 18 July, 2011). The tomato yield for the average grower is 45-50 t/ha.

Chilli pepper cultivar Carolina cayenne

A mature Carolina Cayenne (*Capsicum annuum* L.) will be over 12 cm in height and about 2.3 cm in width. This pepper appears green and at maturity it turns to blood red colour. It matures within 90 days after planting. They have very wrinkled and thin skin with the shape of an elongated teardrop. Carolina Cayenne is nearly two times as hot as the typical cayenne pepper (www.scovillescaleforpeppers.com, 12 June, 2011). Chilli pepper fruits are irregular in shape, highly pungent, often used as dried, ground powder. They are used fresh in salads, sauces and dishes. Carolina Cayenne is a well-adapted cultivar that is highly resistant to *M. incognita*. The pepper yield for the average grower is 10 t/ha.

Pepper cultivar Carolina wonder

Carolina Wonder (*Capsicum annuum* L.) plants have compact growth habits, and the period from transplanting to first harvest ranges from 63 to 70 days. The plants grow to a height of 43 cm. Harvest-stage, mature-green fruits are dark green; the fruits mature to become bright

red. The pepper fruits are large, smooth, are of good quality and have three or four locules. Carolina Wonder is a nematode-resistant pepper cultivar, which has a single dominant gene N and is resistant to root-knot nematodes, *M. incognita*, *M. javanica*, and *M. arenaria* (www.real food, real farmers, real community.com, 18 July, 2011). The pepper yield for the average grower is 10 t/ha.

Pepper cultivar Charleston belle

Charleston Belle (*Capsicum annuum* L.) is the first nematode-resistant bell pepper. The plants have compact growth habits, and the period from transplanting to first harvest ranges from 63 to 70 days. The plants grow to a height of 45 cm. Harvest-stage, mature-green fruits are dark green; the fruits mature to become bright red. Charleston Belle pepper are large, smooth, beautiful fruits and of good quality. Charleston Belle are open-pollinated bell pepper cultivars, are homozygous for the *N* gene, which confers resistance to *M. incognita* (www.real food, real farmers, real community.com, 18 July, 2011). The pepper yield for the average grower is 10 t/ha.

Pepper cultivar Ohene Sateaa (Local check)

Ohene Sateaa pepper is local pepper cultivar which is hardy and late maturing. The period from transplanting to first harvest ranges from 70 to 75 days. The plants grow to a height of about 50 cm. It produces thin leaves with finger-like fruits. It is susceptible to root-knot nematodes. The pepper yield for the average grower is 10 t/ha.

2.4.0 Constraints of Tomato and Pepper Production in Ghana

According to Clottey *et al.* (2009), several factors affect tomato production and ultimately the cost of tomato production. Farmers obtain seeds either from their own fields, from neighbours and friends, or from women's groups that maintain and distribute varieties that are in high demand. This reduces seed prices, but has a negative effect on the seed quality (Obeng-Ofori *et al.*, 2007). Also, most tomato and pepper cultivars used in commercial production are exotic, which are not well adapted to the local conditions in Ghana. Seasonality of tomato production creates periods of abundance and scarcity, which dramatically affect market prices. Averagely, labour represents more than 50 percent of total production costs (Clottey *et al.*, 2009). During the rainy season, fungal diseases and pests are common and synthetic pesticides including fungicides are generally too expensive for the average farmer to use (Clottey *et al.*, 2009).

Clottey *et al.* (2009) reported that unreliable and lack of ready market for tomato produced at dam sites in the Upper East and Northern Regions are major concern to most farmers who often run into debt. Market queens from southern Ghanaian markets sometimes prefer to buy from farmers in neighbouring Burkina Faso. Despite these constraints, farmers consider tomato and pepper production to be a profitable activity.

2.5.0 Root-knot nematodes (*Meloidogyne* species)

Root-knot nematodes belong to the genus *Meloidogyne* (Goldi, 1892). The genus *Meloidogyne* is comprised of more than 90 species (Karssen, 2002). Root-knot nematodes are distributed globally and parasitize on almost every higher plant (Moens *et al.*, 2009). *Meloidogyne* spp. have a wide host range, causing problems in more than 2000 species of annual and perennial crops (Bleve-Zacheo *et al.*, 2007). They feed and reproduce on living

plant cells in roots, causing galls (swellings or "knots") to form on the roots of infected plants (Fox, 2001).

There are many species and races of the root-knot nematode the world over, but the most widely distributed species are *M. arenaria* (Neal), *M. incognita* (Kofoid & White), *M. javanica* (Treub), and *M. hapla* (Chitwood), the latter being adapted to the temperate regions. The most economically important species are *Meloidogyne incognita, M. javanica,* and *M. arenaria. M. incognita* is found in temperate and tropical countries, and it is possibly the single most damaging crop pathogen in the world (Trudgill and Blok, 2001). Addo (1970) reported that *M. incognita* is the commonest root-knot nematode in Ghana.

Different *Meloidogyne* species often have different basal temperature or thermal requirements for physiological processes such as embryogenesis, host penetration, reproduction and generation time (Evans and Perry, 2009). *Meloidogyne incognita* dominates over *M. javanica* and *M. hapla* at high temperature (25-32°C). *M. javanica* matures at 30°C. Soil temperature of 20°C is suitable for invasion and development of *M. hapla* and *M. javanica* (Kinloch and Allen, 1992).

Meloidogyne enterolobii (Yang and Eisenback) was originally described in 1983 from a population isolated from pacara earpod tree (*Enterolobium consortisiliquum* Vell.) in China (Yang and Eisenback, 1983). The species being tropical and sub-tropical in nature was reportedly distributed in Africa (Burkina Faso, Côte d'Ivoire, Malawi, Senegal, and South Africa). Kiewnick *et al.* (2008) reported that *M. enterolobii* is considered as one of the most aggressive root-knot nematodes mainly for its high reproductive rate, induction of large galls and wide host range.

Symptoms of *M. enterolobii* infestation may range from chlorosis, defoliation, wilt, stunted growth and yield reduction. The presence of small to large fleshy galls on the root systems is

the primary symptom associated with the infection of this nematode. *M. enterolobii* is now considered to be one of the most pathogenic root-knot nematodes known (Anon., 2008).

Brito *et al*. (2007) demonstrated that the isolates of *M. enterolobii* were able to overcome the resistance of tomato and pepper genotypes carrying the Mi-1, N, and Tabasco genes. These are all genes in tomato and pepper that confer resistance against the three most economically important root-knot nematode species, namely; *M. incognita, M. javanica, and M. arenaria* (Thies *et al*., 2008). Furthermore, field and greenhouse studies revealed a wider host range, increased pathogenicity and higher reproductive potential of *M. enterolobii*, compared to other *Meloidogyne* spp. *M. enterolobii*, as root-knot nematode species, can easily be transmitted with soil and plant root material.

2.5.1 Biology and life history of root-knot nematodes

According to Noling (2009), most species of root-knot nematodes have a relatively simple life cycle consisting of the egg, four juvenile stages and the adult male and female. Second stage juveniles hatch from eggs to find and infect plant roots or in some cases foliar tissues. Many species can develop from egg to egg-laying adult in 21 to 28 days during warm months (Dreistadt *et al*., 2004).

Depending on the root-knot nematodes species, young juvenile stages will invade root tissues, establishing permanent feeding sites within the root. Immature stages and adult males are long, slender worms. Mature adult females of root-knot nematodes change to a swollen, pear-like shape (Moens *et al*., 2009).

For most root-knot nematode species, as many 2000 eggs may be produced (Noling, 2009). According to Noling (2009), under suitable environmental conditions, the eggs hatch and new juveniles emerge to complete the life cycle within 28 to 56 days, depending on temperature.

2.5.2 Disease symptoms and damage of root-knot nematodes on tomato and pepper

Root-knot nematode damage symptoms on plants depend on the genera of nematode involved, plant species and the part of the plant parasitized, nematode population density, crop susceptibility, and prevailing environmental conditions (Noling, 2009).

Dobson *et al.* (2002) reported that root-knot nematode-infested plants are stunted, have yellow leaves and have a tendency to wilt in hot weather. Very heavily root-knot nematode-infested plants die. If infested plants are pulled from the soil, the roots are severely distorted, swollen and have galls or root knots. The galls range in sizes from smaller than a pinhead to 25 mm or more in diameter (Dobson *et al.*, 2002). These galls damage the water and nutrient-conducting abilities of the roots. Galls can crack or split open, especially on the roots of vegetable plants, allowing the entry of other soil-borne, disease-causing microorganisms. Mostly galls on chilli and sweet pepper are usually small. The root system of severely infested roots is reduced to a limited number with a completely disorganised vascular system without rootlets.

According to Dreistadt *et al.* (2004), above-ground symptoms of a root-knot nematode infestation include wilting during the hottest part of the day even with adequate soil moisture, loss of vigour, yellowing leaves, and other symptoms similar to a lack of water or nutrients. Infested vegetable plants grow more slowly than neighbouring, healthy plants, consequently the plants produce fewer and smaller leaves and fruits, and once heavily infested early in the season, can die.

Root-knot nematodes cause yield reduction and at times total crop failure. According to Singh and Khera (1979), tomato yield was reduced following inoculation with 100 juveniles of root-knot nematodes/plant. They infest the roots of crop plants and inhibit water and

nutrient absorption, thus resulting in the reduction of crop yield and the quality of products. According to De Waele and Elsen (2007), damage and yield losses caused by plant pathogens, including plant-parasitic nematodes, are, on average, greater in tropical than temperate regions because of greater pathogen diversity, more favourable environmental conditions for pathogen colonization, development, reproduction and dispersal, and lack of human, technical and financial resources to combat infections.

2.5.3 Root-knot nematodes interaction with other pathogens

Meloidogyne species frequently play a role in disease interactions (Khan, 1993; Perry *et al.*, 2009) especially, with other soil-borne pathogens. In addition to the direct crop damage caused by nematodes, root-knot nematode species have also been shown to predispose plants to infection by fungal or bacterial pathogens or to transmit viral diseases, which contribute to additional yield reductions (Noling, 2009).

An interaction between the plant and the nematode may transform a genetically resistant host plant into one that is susceptible to the wilt-fungus and which subsequently develops wilt symptoms. Perry *et al.* (2009) reported that among the most common disease complexes in which the root-knot nematodes are key components are those involving the vascular wilt pathogen, *Fusarium oxysporium* (Wollenweber).

In most cases, the presence of both pathogens results in greater mortality than when only one is present. Plants affected by root-knot nematodes are more easily infected by soil-borne diseases caused by *Ralstonia solanacearum* (Smith), *Sclerotium rolfsii* (Saccardo), *Fusarium* species, *Pythium* species, or *Rhizoctonia* species (Manzanilla and Starr, 2009). This secondary infection may lead to extensive discoloration of internal stem and root tissue, and rapid plant death (Cerkauskas, 2004).

Agrios (2005) reported that wounding of plant roots during nematode parasitism is the major factor contributing to the plant's increased susceptibility to other pathogens. Studies by Fattah and Webster (1983) revealed that the giant cells appear to be highly susceptible to fungal infection, as they degenerate rapidly when infected by the fungus. Genotypes which are resistant to *Fusarium* wilt have their resistance breakdown in the presence of nematodes. Sidhu and Webster (1981) presented strong evidence that *M. incognita* increases wilt severity in tomato genotypes having a single gene for resistance to *Fusarium* wilt.

In complexes with fungal pathogens, the galls appear to be the initiation site of fungal penetration, because root necrosis is first observed associated with galls (Starr and Mai, 1976). This suggests that the galls are more susceptible than non-galled tissues and the root rot fungi are specifically attracted to the galls, where it forms *sclerotia* on the gall surface but actual penetration of the host tissues is delayed until the galls are four-five weeks old (Perry *et al.*, 2009). This delayed penetration corresponded in time to when there was an increase in nitrogenous compounds in root leachates, which favoured pathogenic activity of *Rhizoctonia solani* (Kuhn), (Van Gundy *et al.*, 1977). It has been demonstrated that *Meloidogyne* induce profound changes in plant gene expression, both in the giant cells specifically (Wang *et al.*, 2003), and globally in the roots (Schaff *et al.*, 2007). Expression of some genes is increased, in some cases, by more than 50 fold (Wang *et al.*, 2003), while expression in response to infection by *M. incognita* were reduced rather than increased (Schaff *et al.*, 2007). Many of the host genes with altered patterns of expression due to infection by root-knot nematodes are genes related to plant defence pathogens (Bird and Wilson, 1994).

Verticillium wilt is a fungal disease that attacks more than 200 species of plants, including most vegetables, flowers, fruit trees and in some hosts, *Verticillium* wilt develops primarily in

seedlings, which usually die shortly after infection. *Verticillium* penetrates young roots of host plants directly or through wounds (Agrios, 2005).

In a field infested with both *M. incognita* and *Verticillium dahlia* (Kleb), reduction of the nematode population density with soil fumigation did not reduce the incidence of wilt disease relative to plots not fumigated (McClellan *et al*., 1955). The lack of interaction may be due in part to the fact that *Verticillium* wilts are favoured by fine-textured soils. According to Manzanilla-Lopez and Starr (2009), in the field, wilt symptoms are more severe, develop more rapidly and are at greater frequency when the plants are also infected by root-knot nematodes than in the absence of nematode infestation. In many cases, the presence of both pathogens results in much greater plant mortality than when only one is present (Manzanilla-Lopez and Starr, 2009).

2.5.4 Nematode population and damage levels

Nematodes live, feed and reproduce in the soil. They cause damage to crops under low, medium and extreme conditions for nematodes and plants. However, nematode damage is high when conditions are better suited for the nematodes than the plant (Di Vito and Greco, 2009).

With increasing initial nematode population density, food and space availability to each individual nematode of the population is reduced. Also, with increasing initial population, the root system becomes increasingly damaged, and this results in further reduction of food supply and, therefore, of the nematode reproduction rate (Di Vito and Greco, 2009). At very high initial population densities, the roots of the host crop can be severely damaged and there is substantial competition among individuals for limited resources. When the plant root rots or dies or in the absence of a suitable host, the nematode population decreases.

Di Vito and Greco (2009) reported that for a given nematode species/host combination, the nematode population will not increase indefinitely with increasing initial population densities, but will reach a maximum and cannot be surpassed. This maximum value of the final nematode population is called the ceiling level of the nematode population and it will depend upon the intrinsic reproduction ability of the nematode species, the suitability and size of the root system of the host crop, the ability of the host crop to tolerate nematode parasitism, and the environmental conditions (Di Vito and Greco, 1988).

Nematode population densities depend on several factors such as the type of nematodes, the crop and cropping system, the season, and the soil. Nematodes depend on crops for their food, so plants with deep roots and those with adventitious roots support high final nematodes population (Di Vito and Greco, 2009). In pots, transplanted tomato more than doubled reproduction rates and population densities of *M. incognita* compared with sown tomatoes of the same cultivar and length of growing cycle (Ekanayake and Di Vito, 1984).

2.6.0 Methods of root-knot nematodes control

2.6.1 Steam sterilization and hot water treatment of soil and planting materials

Soils and planting mixes for use in pots and nurseries can be steam-treated in enclosed containers. Mckenry and Roberts (1985) reported that negative effects have been observed in some soil treatments. Coyne *et al*. (2009) indicated that hot water treatment can be used effectively to decontaminate potentially infected material and ensure nematode-free seed stocks. High temperatures can cause changes to soil, resulting in the release of excessive amounts of manganese, nitrite and ammonium nitrogen, resulting in phytotoxicity (Mckenry and Roberts, 1985). The problem with stem sterilization is that, other organisms, besides nematodes, are likely to be killed.

2.6.2. Solarization

Soil solarization is a nonchemical technique of exposure of the soil to solar radiation lethal to nematodes and other soil-borne pathogens. According to Noling (2009), for soil solarization to be effective, soils must be wetted and maintained at high soil moisture content to increase the susceptibility (thermal sensitivity) of soil-borne pests and thermal conductivity of soil. Though there has been success with nematodes, it has been proven to be more effective for the control of weeds and fungal pathogens because of the depth of effectiveness of treatment. Nematodes are found typically as deep as crop roots penetrate; effectiveness is likely to be greater for shallow than for deep rooted cropping systems (Mckenry and Roberts, 1985).

2.6.3. Crop rotation

Crop rotation is one of the most effective ways of managing nematodes. The principle of crop rotation is to distance the susceptible crop from the target nematode (Coyne *et al.*, 2009). This will cause the nematodes to starve to death, thereby resulting in the maintenance of nematodes levels below damage threshold. Sikora (1992) reported that in addition to the immediate effect of crop diversity in nematode multiplication, multi-cropping cycles may also facilitate the increase of microbial antagonists of nematodes.

To be most effective, non-host crops, poor hosts or those with resistance or tolerance to root-knot nematodes should alternate with a susceptible crop. One rotation that appears quite common involves solanaceous crops with cereals, while rotation with groundnut is generally accepted for *M.incognita* management (Dickson and De Waele, 2005). Although several cultivars of a crop may provide useful resistance against root-knot nematodes, the level of control may differ by geographical site and variation in pathotypes and *Meloidogyne* species (Hussey and Jansen, 2002).

It is, therefore, important not to cultivate the same crop on the same land for too long, and also good agricultural practices should be taken into consideration when using different crop types in the rotation (Coyne *et al*., 2009). Unfortunately, very few of these non-susceptible vegetable crops are of high value to be attractive to small-scale farmers.

2.6.4. Land fallow

According to Coyne *et al*. (2009), clean fallow during the off-season is probably the most important and effective cultural control measure available for nematodes. When food sources are no longer readily available, soil population densities of nematodes gradually decline with death occurring as a result of starvation.

During fallow periods, there is reduced soil erosion, reduced weed problems, restoration of soil fertility and natural balance of beneficial soil micro-organisms which are additional benefits of fallowing. However, during fallow periods, there is no crop production and that leads to a loss to the farmer which may even be greater to the farmer than the loss due to nematode parasitism (Perry *et al*., 2009).

2:6:5: Trap cropping

According to Dobson *et al*. (2002), a trap crop is a crop planted to attract a pest and is then destroyed together with the pest. A number of trap crops have been identified for use in controlling root-knot nematodes. Cerkauskas (2004) indicated that in small vegetable plantings, interplanting with French marigold (*Tagetes patula* L.) or African marigold (*T. erecta* L.) is very effective in lowering the nematode density in soil. Marigold produces a substance called alpha-terthienyl, which can aid in the reduction of root-knot nematodes and other disease-promoting organisms, such as fungi, bacteria, insects, and some viruses (Soule, 1993).

However, many good trap crops are plant species with potentially undesirable characteristics, such as toxicity to domestic animals or weedy traits (Mcsorley, 1998), and therefore limiting grower acceptance.

2.6.6 Soil amendments

The effect of soil amendments is generally accepted as an indirect mechanism for promoting nematode suppression through enhanced activity of naturally occurring nematode antagonists such as fungi, bacteria and carnivorous nematodes (Ferraz and de Freitas, 2004). The application of soil amendments such as fertilizers and organic amendments is practiced for the improvement of soil fertility and structure, which often contribute to a healthier and more robust crop, which is better able to withstand nematode invasion and subsequent damage (Coyne *et al*. 2009).

According to Noling (2009), many different types of amendments and composted materials have been applied to soil to suppress populations of plant parasitic nematodes and improve crop yield and plant health. Animal manures, poultry litter, and disc-incorporated cover crop residues are typical examples of soil amendments used in agriculture to improve soil quality and as a means for enhancing biocontrol potential of soil. Some amendments which contain chitin and inorganic fertilizers that release ammoniacal nitrogen into soil suppress nematode populations directly and enhance the selective growth of microbial antagonists of nematodes (Noling, 2009). The amount of ammonia produced varies with the level of nitrogen in the type of organic amendment. Oil-cakes and animal manures have high nitrogen contents of 2–7% and are the most useful nematicidal amendments, but they must be applied at 4–10 t/ha to be effective (Noling, 2009).

Application of composted horticultural by-products or fresh poultry waste increased vegetable yields and decreased soil populations of *Meloidogyne incognita* (Riegel and Noe, 2000).

Waste products for use as amendments are usually inexpensive, but may become unattractive or expensive through costs of transport to the field, especially if high rates of application are recommended.

2:6:7 Chemical control

Chemical management involves the identification and application of nematicides to control nematodes. These chemicals are both soil fumigants and non-fumigants (Gowen *et al.*, 2005). Dazomet (Basamid) is a granular formulation that can be used for seedbed treatment and in moist soil, it releases methyl isocyanate gas, which kills nematodes. Fenamiphos (Nemacur) is another granular formulation that can be used before or at planting or in established crops. Oxamyl (Vydate) is a liquid formulation which is supplied with an application gun (Gowen *et al.*, 2005). Information regarding the use of nematicides in resource-limited agricultural systems remains limited. Although their use offers one of the most reliable control strategies against a wide range of plant parasitic nematodes, use of these products in subsistence agriculture on low value crops is more often not recommended (Bridge, 1996) and limited or non- existent (Sikora and Fernandez, 2005). The use of nematicides by resource-poor farmers is low because of the high cost (Coyne *et al.*, 2009). Vegetable farmers, also tend to have limited knowledge of nematicides and their potential impact.

The loss of effective nematicides has given rise to virulent nematodes to previously uninfected areas, and, therefore, more complex management programmes are sought ((Sikora and Fernandez, 2005). Good yields often follow nematicides applications, but nematode numbers at harvest can return to higher levels so additional control measures are needed when planting again on previously treated land. Nematicides are amongst the most contaminating and highly toxic agrochemicals that are used world-wide and, if adequate precautions are not taken, people can be easily poisoned directly or by the pollution of water courses (Gowen *et al*., 2005).

2.6.8 Biological control

According to Williamson and Roberts (2009), biological control of *Meloidogyne* species occurs when the action of antagonists maintains the nematode population at a density below the level that would occur in their absence.

Hallman *et al*. (2009) reported that microbial pathogens such as fungi, bacteria and other antagonists are most effective for the control of nematodes. A naturally occurring saprophytic fungus of nematode eggs, *Verticillium chlamydosporium* (Goddard), has been shown to effectively reduce the number of healthy nematode eggs being produced in soils by 85% (Agrios, 2005). Nematophagous fungi and bacteria have also been reported to control the multiplication of nematode on susceptible tomato and pepper crops (Stirling, 1991). There has not been any record of the use of biological agents for the control of nematodes in the field in Ghana. Hallman *et al*. (2009) concluded that biological control faces the obstacle for its practical use in the field.

2.6.9 Host plant resistance

Although root-knot nematodes have very broad host range, resistance has been described in many plant species. According to Roberts (2002), resistance is used to describe the ability of a plant to suppress the development and reproduction of nematodes. Resistance may be controlled by one gene (monogenic), a few genes (oligogenic) or many genes (polygenic) (Roberts, 2002). Many modern tomato varieties carry a single, dominant gene, *Mi*, which confers effective resistance against three major *Meloidogyne* species, including *M. incognita*, from which the gene derives its name (Roberts and May, 1986). This gene has been an excellent example of the use of host resistance to effectively reduce the need for pesticide application. The *Mi* gene of tomato is one of the best characterized nematode resistance genes in plants (Williamson, 1998).

Roberts (2002) reported that resistance can range from low to moderate (partial or intermediate), to high resistance. A completely or highly resistant plant allows no nematode reproduction, or only trace amounts. A susceptible plant allows normal development of nematodes and associated diseases. A tolerant plant is one which can withstand nematode infection.

In a resistant variety, nematodes fail to develop and reproduce normally within root tissues, allowing plants to grow and produce fruit even though nematode infection of roots occurs. Some crop yield loss can still occur, however, even though the plants are damaged less and are significantly more tolerant to root-knot infection than that of a susceptible variety (Noling, 2009).

Host plant resistance is used to protect plant yield potential and reduce pathogen infection. Resistance can be dominant, recessive or additive in expression and can be conferred by single major genes or by combination of two or more genes or quantitative trait loci. The

resistance phenotype can be characterized as strong or partial, depending on the extent to which nematode reproduction and root galling are suppressed (Roberts *et al*., 2008).

However, there are limitations to the efficacy of the Mi gene. The Mi gene is not effective against *M. hapla or M. enterolobii* (Liu and Williamson, 2006). Due to the presence of virulent nematode species which can compromise the resistant cultivars, there is the need to manage these resistant varieties. For annual crops, alternating resistant and susceptible cultivars, and using resistant crops in rotation with other host crops, including those with resistance, are approaches to managing virulence selection (Petrillo *et al*., 2006). According to Sasser and Carter (1982), a crop having resistance to *M. incognita* and *M. javanica* would be resistant to 82% of the major *Meloidogyne* populations around the world. Tomato carrying resistance to *M. incognita, M. javanica* and *M. arenaria* would be resistant to 90% of the root-knot populations (Sasser and Carter, 1982).

2.6.9.1 Benefits of host plant resistance

Starr *et al*. (2002) reported that if resistance was more readily available, crop productivity could be improved with little effort or cost to the producer. The use of resistant crop cultivars fits all cropping systems and is ecologically friendly as compared with the use of nematicides. Additionally, resistant crops are environmentally compatible, they do not require specialized applications, and apart from preference based on agronomic or horticultural desirability, they do not usually require an additional cost input.

In developing countries such as Ghana and in low-cash crop systems, plant resistance is probably the only viable long-term solution to nematode problems (Roberts, 1993). Areas which are heavily infested with nematodes can be cultivated with highly resistant cultivars

and then susceptible crops can be grown afterwards without measureable yield loss. The reduction of nematode population will, thus, avoid the need for nematicides protection. A highly resistant cultivar can provide at least two years of nematode control benefit (Ogallo *et al.*, 1999).

In Ghana, there is a complex cropping system and a greater diversity of nematode genera and species and hence, the need for nematode management and introduction of resistant cultivars. Nematodes also generally have shorter life cycle and generations per crop season at higher temperatures, putting the crops under much greater pest pressure (Di Vito and Greco, 2009). Another important feature in tropical agriculture is that often, a number of concomitant species of the same or several different genera occur together and they may all be major pests of the crop grown, which is obviously very relevant to the introduction of resistant cultivars (Starr *et al.*, 2002).

Cook and Evans (1987) reported that nematode-resistant crop cultivars can be one of the most useful, economical and effective means of managing nematodes for both large commercial and small-scale farmers in the tropics and developing countries. Their use can be the ideal solution to managing nematode pests, particularly, in farming systems with low inputs. Tomato has the most cultivars with resistance to *Meloidogyne* and it is these cultivars that are, or can be, mostly used by farmers in the tropics (Starr *et al.*, 2002).

2.6.9.2 Host plant resistance and nematode populations

The effect of resistance on nematode multiplication is determined by the extent to which the resistance trait restricts the ability of the nematode to reproduce on the plant (Ferris, 1985). Susceptible crops allow large increase in nematode populations from even low initial inoculum densities, although the rate of population increase declines at higher inoculum densities. This relationship reflects the density dependent effect of increased competition for

feeding sites and food reserves at high inoculum densities, and is compounded on intolerant plants by the presence of smaller root systems due to nematode injury (Mcsorley, 1998). Because of these interacting factors, different initial nematode population can produce the same final population.

The *Mi* gene in tomato is another factor that highly expresses resistance that prevents all, but trace amounts of root-knot nematode reproduction, resulting in final population densities consistently much lower than the initial densities (Roberts and May, 1986).

Several factors can influence seasonal population dynamics of nematodes on resistant plants. The level of resistance gene expression may be modified according to the genetic constitution, environmental effects and virulence status of the nematode species.

The *Mi* gene in tomato, long recognised as a completely dominant resistance gene able to suppress root–knot nematode reproduction, has been shown to have some gene dosage response in the presence of nematode isolates that express moderate levels of virulence to *Mi* (Tzortzakakis *et al.,* 1998).

2.6.9.3 Host plant resistance and crop yield

According to Starr *et al.* (2002), resistance is an effective management tool that improves crop yield in the presence of nematode population densities that exceed the damage threshold. Because the plants are resistant, they tend to produce healthy roots and there is also less damage per nematode, thus resulting in better yields than when exposed to high population densities. Nyczepir and Becker (1998) reported that there is successful development of cultivars and rootstocks with resistance to several nematode groups. Yield and longevity are the main objectives of incorporating nematode resistant and tolerant cultivars. Fery and Dukes (1984) reported that marketable yields from resistant cultivars are significantly greater than those from susceptible cultivars grown in nematode-infested soils.

2.6.9.4 Factors influencing host plant resistance to nematodes

Temperature effects on resistance gene expression may not only influence expression of incomplete dominance, but at high soil temperatures, several nematode resistance genes show a loss of expression, rendering plants susceptible and allowing high nematode multiplication rates (Roberts *et al.*,1998). A further complication is the greater number of nematode generations that are completed under warm growing conditions. The *Mi* gene in tomato is a classic example of resistance gene sensitivity to temperature, with almost complete loss of expression at or above 28-30°C (Roberts, 2002).

The resistance to root-knot nematodes conditioned by some unidentified genes in pepper was stable at 28°C soil temperature (Djian-Coporalina *et al.*, 2001). The resistance conferred by the *N* gene in bell pepper 'Charleston Belle' was partially lost at soil temperatures of 28 to 32°C under controlled conditions (Thies and Fery, 2001).

Dropkin *et al.* (1969) found that application of exogenous kinetin to tomato seedlings altered their expression for resistance. There is indication that tissue culture techniques which use phytohormones in the media for plant regeneration from various tissues may reverse the resistance of the plants to root-knot nematodes.

Thies and Fery (2001) reported that nematode effect on the plant growth of susceptible plants is influenced by plant age at inoculation. Older plants have more tissue already differentiated which the nematode usually does not penetrate. Plant age also influences host efficiency for *M. incognita* and the resulting nematode damage in resistant plants of several crops. According to Thies and Fery (2001), high nematode final population in older plants is a function of greater availability of roots and less individual competition. The less root system in younger plants at transplanting time cause a concentration of juveniles around the root tips.

This situation can lead to the stoppage of root tip growth, resulting in a dramatic reduction in size of root system.

Nematode reproduction in some susceptible plants is also affected by the mode of propagation of the plant. The nematode final population is higher in plants originating from cuttings and tubers, while number of eggs/g of root is higher in seedlings (Thies and Fery, 2001).

2.6.9.5 Constraints of using resistant crop cultivars

The instability of the root-knot nematode resistance genes in both tomato and pepper at high soil temperature limits their usefulness to manage *Meloidogyne* spp. in vegetable production in warm climates (Haroon *et al.*, 1993). The *Mi* gene in tomato is sensitive to temperature, therefore loses expression at or above 28-30°C (Omwega and Roberts, 1992).

Noling (2009) reported that in addition to problems of heat instability, the continuous or repeated planting of resistant plant varieties will select for virulent races of *Meloidogyne* capable of overcoming the resistance. Therefore, the duration and/or utility of the resistance may be time-limited. Coyne *et al.* (2009) indicated that with resistant tomato, resistance breaking nematode races have been shown to develop within one to three years.

Populations of *M. enterolobii* from Africa have the capability to overcome root-knot nematode resistant genes in some important crops such as soybean, sweet potato, and tomato with the *Mi*-1 gene (Fargette, 1987).

Even though resistance is a novelty in the management of root-knot nematodes, most resource-limited farmers in the country are not making use of root-knot resistant crop varieties. This is because the nematode-resistant cultivars are not readily available for many crop-nematode combinations. According to Starr *et al.* (2002), farmers have misconceptions

about using them because they are mostly bred in the temperate regions and brought to the tropical countries. The farmers, therefore, think the nematode-resistant cultivars may be susceptible to local endemic pests and diseases, or they may require high input or their quality may be poor in relation to local cultivars or their growing period and harvesting time or their appearance and marketability may not be acceptable relative to locally grown cultivars (Starr *et al.*, 2002).

2.7.0 Firmness of tomato fruits

Firmness is a critical aspect of tomato quality (Wu and Abbott, 2002). The degree of fruit firmness has been used as an indication of fruit quality, and it is also closely associated with the acceptability levels of the fruits (Batu, 1998). Fruit firmness is an effective way for evaluating fruit maturity as the fruit ripens (Olmo *et al.*, 2000). The most commonly used methods for the assessment of textural properties are those which apply large deforming forces (for example, via puncture or compression), and are therefore destructive (Abbott, 2004). Flat plate compression is a technique very similar to that of puncture, except that the perimeter effect is eliminated through the use of flat plates with an area exceeding that of the sample (Jackman *et al.*, 1990). The firmness of fresh fruits and vegetables typically exhibit a large variation between individual fruits, and even within the different tissues in the same individual fruits (Lesage and Destain, 1996).

2.8.0 Sugar content of tomato fruits

Total soluble solids content is a key determinant of tomato fruit quality for processing. There are two main markets for tomato; as a fresh fruit product and as a processed foodstuff primarily tomato paste and sauces (Gould, 1992). Economic success in the latter market is dictated, in part, by a combination of total fruit yield and fruit soluble solids content (Baxter

et al., 2003). In addition, since sugar is a major constituent of total soluble solids, such tomato fruits are also likely to be sweeter and, therefore, require the addition of less sugar during processing. According to Baxter *et al.* (2003), these processing savings can have a significant bearing on the profitability of processed tomato products and, thus, from a commercial standpoint, there is considerable interest in manipulating the soluble solids content of tomato varieties.

Increased soluble solids content in ripe fruit was shown to be the result of increased sucrose and glucose, with minor contribution from aspartate and alanine (Roessner-Tunali *et al.*, 2003). Fruits with high soluble solids contain less water and, therefore, require less processing to generate pastes of the appropriate consistency for consumer tastes.

2.9.0 Shelf life of ripe tomato fruits

Shelf life of tomato fruits is a period of time which starts from harvesting and extends to the start of rotting of the fruits (Mondal, 2000). Tomato fruits are highly perishable and, thus, have an inherently short shelf life. High quality fruit have a firm, turgid appearance, uniform and shiny colour, without signs of mechanical injuries, shrivelling or decay (Steven and Celso, 2005).

Post-harvest losses of tomato are decay, external damage incurred during harvest and handling and harvest at an improper maturity stage (Steven and Celso, 2005). Bachmann and Earles (2000) reported that tomato fruits that have been stressed by too much or too little water, high rate of nitrogen or mechanical injury (scrapes, bruises, abrasion) are particularly susceptible to post harvest diseases. The rapid quality loss at relatively short period of four to seven days calls for an efficient means of storing the fruits to reduce wastage (Thompson *et al.*, 1998) and improve intake and acceptability. Commercially, preservation of tomato is difficult in the tropics because of poor transportation and high environmental temperatures

that favour decay rather than storage. Proper harvesting determines the nutrient contents as well as storage durability of any fruit. Tomato is normally harvested at different maturity stages, such as green mature stage, half ripen stage and red ripen stage. Anju-Kumari *et al.* (1993) reported that the shelf life of all tomato cultivars were longest when harvested at green mature stage. The fruit acid content is lower in immature fruit and highest when the colour starts to appear, with a rapid decrease when the fruit ripens. Apart from physical quality, serious losses also occur in the essential nutrients, vitamins and minerals. Improper harvesting time (maturity), ripening conditions and lack of suitable storage facilities cause a glut during the peak harvesting period and a large portion of yield is sold very cheap.

According to Cerkauskas (2004), long-life varieties that remain firm up to 10-15 days, with some lasting as long as a month, have already been developed. This long storability characteristic, combined with resistance to a variety of major diseases and pests, such as root-knot nematode and *Fusarium* wilt, give these high yielding tomato lines a major advantage over local varieties.

CHAPTER THREE

3.0 MATERIALS AND METHODS

Three experiments were conducted in this study at the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi.

3.1.0 GENERAL METHODOLOGY

The general methodologies were basic activities carried out in all the three experiments.

3.1.1 Source of soil for nursing seedlings and for the pot experiment

The black soil was collected from an old refuse dump site and the river sand was collected from the KNUST campus. The black soil was sieved to remove stones, broken glasses and other debris.

3.1.2 Sterilization of soil

The black soil-river sand mixture in 3:1 proportions was sterilized by steam, using a modified barrel-sterilizer. The steam sterilizer has two compartments; the lower chamber which contained water and the upper chamber, were filled with the soil-mix spread on moist jute sack, and also covered with a moist jute bag. Heat energy was then supplied from firewood set under the steam sterilizer supported on three metal stands. When a temperature of 103°C was obtained at the top layer of the soil for two hours, the soil was considered well sterilized and allowed to remain on the fire for 24 hours, and then left overnight to cool.

3.1.3 Sources and characteristics of the planting materials for the experiments

Three exotic each of root-knot resistant tomato and pepper cultivars and a local tomato and pepper cultivars were used. All the exotic vegetables were obtained from Texas A & M University, College Station, Texas, USA, and the local cultivars from Bentronic, a licensed Agrochemical shop at Kejetia, Kumasi.

The three exotic root-knot nematode resistant tomato cultivars and the local check in the study were:

- Small Fry
- Jetsetter
- Celebrity
- Power (Local tomato check)

The three exotic root-knot nematode resistant pepper cultivars and the local check were:

- Carolina Cayenne
- Carolina Wonder
- Charleston Belle
- Ohene Sateaa (Local pepper check)

3.1.4 Nursing of seedlings

The tomato and pepper cultivars were nursed separately in steam-sterilised soil in plastic pots. The plastic pots had holes under them to drain excess water. The seeds were evenly spread on the soil surface and then covered with soil. The nursed seeds and seedlings were watered adequately as and when necessary.

3.1.5 Source and extraction of *Meloidogyne* inoculum

The inoculum was obtained from root-knot nematode-infested tomato roots collected from a vegetable farm near the Plantations Section of the Department of Crop and Soil Sciences, KNUST. The harvested galled roots were washed under running tap water to remove soil and plant debris and then dabbed dry with tissue paper. The roots were then chopped with a pair of scissors. *Meloidogyne* species eggs were extracted, using Hussey and Baker (1973) method. Enough chopped roots were placed in a jam bottle and 0.5% sodium hypochloride (NaOCl) solution was added to just cover the roots and the jam bottle was tightly covered. The jam bottle and its content were then shaken vigorously by hand for three and a half minutes. Over exposure of *Meloidogyne* eggs to NaOCl will reduce egg viability (Hussey and Janssen 2002). After shaking, the content of the bottle was then quickly strained through a 200 µm pore mesh sieve nested over a 500 µm pore mesh sieve. The 500 µm mesh sieve was removed and the eggs on the 200 µm mesh sieve were thoroughly rinsed with a stream of tap water to remove residual NaOCl in a beaker. Finally, some eggs on the 500 µm-mesh sieve were also rinsed into the beaker.

The number of *Meloidogyne* eggs in the suspension was determined by taking one ml aliquot of the suspension with a pipette after blowing air through it to homogenise. The one ml nematode-water suspension was then uniformly pippetted onto a counting tray and the number of nematodes counted under a stereomicroscope. Three separate countings were done and the mean calculated. The number of eggs per millilitre was then multiplied by the total volume of water-eggs suspension to obtain the total number of eggs.

DATA COLLECTED

3.1.6 Measurement of Plant height and number of leaves

Plant height in cm was measured two weeks after transplanting for both the field and pot experiments. Plant height was measured with a metric rule. The height measurements were continued every week until the plants started flowering for the field trial, and till the potted plants in the plant house were harvested at eight weeks after inoculation. The numbers of leaves were counted every week, just as in the plant height. The mean was calculated separately per week for the plant height and the number of leaves.

3.1.7 Harvesting and evaluation of the tomato and pepper cultivars

The field tomato and pepper cultivars were harvested four months after planting and the potted tomato and pepper plants at eight weeks after inoculation. Before harvesting the tomato and pepper cultivars, the soil around the plants were loosened to prevent damaging the roots. After uprooting the plants, the roots were washed under a running tap water to remove all adhering soil particles and debris. The vegetative parts were cut off, and the fresh roots dabbed dry with tissue paper and then weighed (g) with an electronic weighing scale. Thereafter, the roots of each treatment were immersed in a glass beaker of water and root-knot nematode damage scored using the scale of 0-5 by Hussey and Boerma (1981) (Appendix 1). *Meloidogyne* eggs ~~were then~~ extracted from the roots and counted as described in section 3.1.5.

Below is the galling index rating used (Appendix 1), where;

0 = complete and healthy root system, no galling

1 = trace infection with a very few small galls

2 = less than 25% roots galled

3 = 25-50% roots galled

4 = 51-75% roots galled

5 = greater than 75% roots galled

Plant reactions falling into categories 0, 1 and 2, are considered immune, very resistant and moderately resistant, respectively (Hussey and Boerma, 1981). Plants falling in categories 3 are slightly resistant, 4 are susceptible and those in 5 are considered highly susceptible.

3.1.8 Reproduction factor (Rf)

The main criterion for determining resistance or susceptibility of a host is the reproduction factor. According to Taylor and Sasser (1978), nematode reproduction can be used to measure root-knot nematode resistance, since reproductive ability on a given host is directly related to resistance. Reproduction factor (Rf = final nematode population (Pf) /initial nematode population Pi) is used to measure the reproductive capacity of nematodes. Where the final population density was lower than the initial population density Pf/Pi <1, meant there was no reproduction. Also, where the final population density was higher than the initial density Pf/Pi > 1, there is reproduction (Roberts *et al.*, 1986).

3.1.9 Identification of *Meloidogyne* species of inoculated and bioassay tomato and pepper cultivars

Equal volume of the *Meloidogyne* juvenile-water suspension from each tomato and pepper cultivar and 98% ethanol were separately put in Eppendorf tubes and tightly covered to preserve the *Meloidogyne* species. The samples of the nematode extracts were sent to the Department of Plant Pathology and Microbiology, Texas A&M University, USA for *Meloidogyne* species identification and confirmation based on esterase and MDH isozyme phenotypes and by species specific PCR tests.

Deoxyribonucleic Acid (DNA) was extracted from individual juveniles by cutting in worm lysis buffer [WLB; 50 mm KCl, 10 mm Tris pH 8.2, 2.5 mm $MgCl_2$ 60 µg Ml^{-1} proteinase K (Roche), 0.45% gelatine] (Castagnone-Sereno *et al.*, 1995). The Juveniles were picked with the tip of a needle and placed in 15 µg of WLB on a glass microscope slide and cut into two pieces with a needle under a stereomicroscope. The cut nematode, in 10 µL WLB, was then transferred by a pipette into a 0.5 ml centrifuge tube containing another 10 µL of WLB. The tubes were centrifuged at 13500 revolutions per minute for two minutes, and then placed at -80°C for 15 minutes. Mineral oil (7 µL) was added to each tube and incubated at 60°C for one hour, followed by 90°C for 10 minutes. The mineral oil was removed by pipette after the aqueous sample was frozen at -20°C. PCR amplification using rDNA primers were carried out in 25 µl of DNA extract, or Taq polymerase (Promega). The reactions using Taq polymerase also included 2.5 µL 10X buffer, 1.5 µL of 50mm $MgCl_2$ and 2.5 µL 200 mm of each dNTP and two units of enzyme.

3.2.0 EXPERIMENT 1: Evaluation of root-knot nematode resistant tomato and pepper cultivars in pots in the plant house

This experiment was carried out in the plant house of the Department of Crop and Soil Sciences, KNUST, Kumasi. Two-week old seedlings of the tomato and pepper cultivars were transplanted into 2 L plastic pot sizes containing 1.8 L of the sterilized 1:3 river sand-black soil. One seedling was transplanted per pot for each cultivar. The seedlings were each watered copiously after transplanting. The seedlings were then inoculated a week after transplanting. Before inoculating the seedlings, several holes were made with the index finger 2 cm from the stem of each tomato and pepper seedling and the egg-water suspension was dispensed into the holes and then covered with soil. While pipetting the suspension, it was

vigorously stirred to homogenize the suspension. The potted seedlings were inoculated with 2000 *Meloidogyne* eggs.

Eight weeks after inoculation, the plant house tomato and pepper plants were harvested. Before harvesting the plants, the side of each container was gently pressed to loosen the soil to prevent damaging the roots. The plants were then evaluated for *Meloidogyne* egg count and root-knot gall score as described in 3.1.7.

3.2.2 Data collected

- Gall index (scale 0-5) by Hussey and Boerma (1981)
- Number of *Meloidogyne* eggs

3.3.0 EXPERIMENT 2: Reaction of root-knot resistant tomato and pepper cultivars in the field

3.3.1 Site characteristics

The field experiment was carried out on the field behind the insect laboratory of the Department of Crop and Soil Sciences, KNUST. The area is within the semi-deciduous forest zone, and it has both wet and dry seasons with a bimodal rainfall pattern. There is heavy rainfall from May to July, which is interrupted by a dry period of about four weeks in August; this is followed by another period of heavy rainfall from September to October. The dry season lasts between 120 -130 days. Annual rainfall is about 1375 mm. Annual temperature range is between 25°C to 35°C. The soil at the site is sandy loam.

3.3.2 Extraction and counting of *Meloidogyne* juveniles

Root-knot juveniles were extracted from soil using modified Baermann tray method (Whitehead and Hemming, 1965). The soil was collected from the field behind the insect

laboratory of the Department of Crop and Soil Sciences, KNUST. The soil was thoroughly mixed by hand and 100 cm^3 of it was weighed with a beaker and placed in a plastic plate lined with 2-ply tissue. Tap water was carefully and slowly poured by the side into the plastic plate in which the sieve was placed until the tissue became moist. The edges of the tissue paper were then folded over to prevent the soil from drying. The set-up was left undisturbed on the laboratory table for 48 h and the content of each plastic tray was then poured separately into beakers and left overnight for the juveniles to settle. The supernatant was poured off and each nematode water suspension was separately topped with tap water to 50 ml for standardisation. Each suspension was homogenised by blowing air through with a pipette. Counting was done twice per tomato and pepper cultivar under a microscope and the mean number of juveniles was calculated.

3.3.3 Land preparation

The field was slashed with a cutlass and burnt. The field was then lined and pegged with the use of wooden pegs and a tape measure. Ridges were then constructed. Thirty ridges were raised with each measuring 3 m long and 50 cm wide and 1 m between ridges. The plants were spaced 1 m between rows and 20 cm between plants.

3.3.4 Transplanting of tomato and pepper seedlings to the field and cultural practices

The tomato and pepper seedlings in plastic pots in the plant house, were inoculated with 5000 *Meloidogyne* eggs at three weeks old. At inoculation, several holes were made with the index finger 2 cm from the stem of the tomato and pepper seedlings and a quantity of the

Meloidogyne egg-water extract with 5000 eggs then released into the holes and subsequently covered with surrounding soil.

The inoculated tomato and pepper seedlings were transplanted to the field two weeks after inoculation. The seedlings in the pots were watered before transplanting to soften the soil for easy uprooting. The seedlings were transplanted onto ridges 1 m between rows and 20 cm within rows. A seedling was planted per hill and there were five plants each of tomato and pepper cultivars per ridge serving as a replicate. There were three replications per cultivar. They were watered copiously after transplanting.

The plot was cleared of weeds three times by using a hoe to prevent weeds from competing with the crops for nutrients, sunlight and water and to prevent the weeds from harbouring some nematodes. The plants were watered as and when necessary. The plants were also sprayed with 10 ml Cypedem (insecticide) and Kocide (fungicide) to prevent insect attack and fungal infection. The plants were also mulched with grass a week after transplanting to conserve water and control weeds and 15:15:15 NPK fertilizer was applied at the recommended rate two weeks after transplanting.

3.3.5 Determination of the soil temperature for the field experiment

Expression of resistance to root-knot nematodes is heat sensitive in tomato and pepper. A large portion of tomato and pepper production occurs in hot climates where root-knot nematodes are a severe pest (Thies and Fery, 2001). Therefore, knowledge about the expression of resistance under high temperatures is essential for tomato and pepper resistance breeding programmes and for recommending cultivars for high temperature production regimes. An EL-WIN-USB (Lascar Electronics Limited) was used to determine the soil temperature. Before the drive was used, the EL-WIN-USB configuration software CD was

inserted into a computer and installed and then configured to take daily recordings of the soil temperature. After transplanting the seedlings, the EL-WIN-USB was taken to the field and inserted into the soil of the ridges. At the end of the experiment, the USB was removed from the soil and inserted into the computer again and the data collected from the soil was transferred unto the computer.

3.3.6 Tomato and pepper crop yield

The matured tomato fruits were harvested every four days while the pepper fruits were harvested weekly. The number of ripe fruits and the weight of the fruits harvested were recorded. The fruits were harvested over eight weeks' period. The fruits were weighed, using an electronic scale and the yield was recorded in t/ha.

3.3.7 Data collected

- Plant height (cm)
- Number of leaves
- Crop yield (t/ha)
- Shelf life of ripe tomato fruits
- Sugar content of tomato fruits (°B)
- Firmness of tomato fruits (N)

In addition, root gall index was also scored as described in section 3.1.7 on Page 35.

3.3.8 Determination of firmness of the tomato fruits

A random sample of 20 tomato fruits of similar colour at maturity and size from Small Fry, Jetsetter, Celebrity and Power tomato cultivars were used for the firmness test. A digital penetrometer was used to test for firmness. Two puncture tests were made per fruit, one on each opposite cheek except for the small Fry which had very small fruits. Each fruit was held against a stationary table on the ground and the tip of the digital penetrometer forced into the fruit by hand. The reading from the penetrometer was then recorded. Two readings were taken per fruit and a mean calculated. Firmness was expressed in Newton (N).

3.3.9 Determination of sugar content of tomato fruits

A random sample of 20 red ripe tomato fruits selected randomly from Small Fry, Jetsetter, Celebrity and Power were used for the test. The fruits were sliced with a scarpel and the soluble solids (Brix) content of the resulting juice squeezed onto a portable digital refractometer, and the reading was recorded. Two readings were taken per fruit and the mean calculated. The results were expressed in °B.

3.3.10 Assessment of shelf life of riped tomato fruits

A random sample of 20 tomato fruits of similar colour at maturity were placed in plastic plates and left uncovered in a well ventilated room at a temperature of 26°C and 36% relative humidity. The number of days the fruits stored before rot was recorded. The symptoms of the rotten fruits such as mould were also recorded.

3.3.11 Experimental Design and Data analysis

Randomized Complete Block Design with three replications was used for the field experiment. The data collected was subjected to analysis of variance (ANOVA). All count data were square- root transformed ($\sqrt{x+0.5}$), where x is the mean count. Least Significant Difference (LSD) at 5% was used to compare mean differences. All statistics were performed using Genstat statistical package (Discovery edition 3).

3.4.0 EXPERIMENT 3: Tomato and pepper bioassays for assessing root-knot nematodes population in soils

Soil samples were collected from tomato and pepper growing areas from the northern parts of Ghana, namely; Tono in Navrongo, vea in the Bolgatanga Municipality, and Pwalugu. From each area, soils were collected randomly from 40 different spots at depth of 0-15cm from farmers' fields with an auger. These subsamples were then bulked to constitute the composite soil. The soils were then put in polythene bags, labelled and transported to KNUST for the bioassays. Before the bioassay was carried out, samples of the soils from each of the three areas were taken and the root-knot nematodes extracted and counted as described in section 3.3.2.

The bioassay was carried out in the plant house of the Department of Crop and Soil Sciences, KNUST, Kumasi. Three seeds each of the tomato cultivars Small Fry, Jetsetter, Celebrity, Power, and the pepper cultivars Carolina Cayenne, Carolina Wonder, Charleston Belle, and Ohene Sateaa sown in each plastic pot. The pots were arranged on wooden benches in a completely randomized design with three replications. Each of the tomato and pepper cultivars were separately nursed in 2 L Plastic pots were filled with 1.8 L soil from Tono, Vea and Pwalugu. A week after germination, the seedlings were thinned to a plant per pot. The plants were watered as and when necessary. The tomato and pepper seedlings were not

inoculated because preliminary root-knot nematode assessment indicated that the soil was already infested. The plants were harvested eight weeks after planting, and the roots were washed carefully with running tap water. Nematode damage was rated using the root galling index by Hussey and Boerma (1981). The number of root-knot nematode eggs was also determined as described in section 3.3.2. The nematodes were identified by molecular tests done at Texas A&M University, U.S.A.

3.5.0 STATISTICAL ANALYSIS

Data collected were subjected to analysis of variance (ANOVA). All count data were square-root transformed ($\sqrt{x+0.5}$), where x is the mean count. Least significant difference (LSD) at 5% was used to compare mean differences. All statistics were performed using Genstat statistical package (Discovery edition 3, 2010).

CHAPTER FOUR

4.0 RESULTS

4.1.0 EXPERIMENT 1: Evaluation of root-knot nematode resistance in tomato and pepper cultivars in pots in the plant house

4.1.1 Number of leaves of the potted-tomato cultivars over a six-week-period after *Meloidogyne* eggs inoculation

At second week after inoculation, the mean number of leaves of the tomato cultivars was 3.0 (Table 1). The number of leaves increased as the number of weeks increased. From the second to the fourth week, there were no significant differences (P = 0.05) between the tomato cultivars after inoculation. There was no significant difference (P = 0.05) between Jetsetter and Celebrity from the second to the sixth week. However, there was significant difference (P = 0.05) between the resistant cultivars and Power (control) from the fifth to the sixth weeks (Table 1).

Table 1: Mean number of leaves of the potted-tomato cultivars over a six-week-period after *Meloidogyne* eggs inoculation in the plant house

Tomato cultivars	*Mean number of leaves/weeks				
	2	3	4	5	6
Small Fry	3.0	3.0	4.0	5.0	5.0
Jetsetter	3.0	3.0	4.0	5.0	5.0
Celebrity	3.0	3.0	4.0	5.0	5.0
Power (Control)	3.0	3.0	4.0	4.0	3.0
Lsd (P=0.05)	0.5	0.6	0.3	0.4	0.4
CV(%)	10.2	9.5	4.7	5.7	5.4

*$\sqrt{(x+0.5)}$ transformed, where x is the mean number of leaves

4.1.2: Plant height of the potted-tomato over a six-week-period after *Meloidogyne* eggs inoculation in the plant house

The mean height at the second week after inoculation of the tomato cultivars ranged from 30.7 to 36.2 cm. Jetsetter recorded the highest height and the least by Power tomato cultivar (Table 2). Generally, the height of the tomato cultivars increased as the number of weeks increased. There were no significant differences (P = 0.05) between cultivar means from the second to the fifth week. Small Fry tomato cultivar recorded the highest height of 88.5 at the sixth week (Table 2). All the resistant tomato cultivars differed significantly (P = 0.05) from Power (control) in the sixth week (Table 2).

Table 2: Mean height of the potted tomato over a six-week-period after *Meloidogyne* eggs inoculation in the plant house

Tomato cultivars	Mean plant height (cm) /week after inoculation				
	2	3	4	5	6
Small Fry	31.1	40.1	52.3	59.6	88.5
Jetsetter	36.2	43.5	47.7	58.4	73.4
Celebrity	33.9	45.6	53.7	60.9	84.5
Power (Control)	30.7	36.6	45.1	52.8	52.3
Lsd (P=0.05)	15.1	12.0	11.2	8.3	10.3
CV(%)	24.3	15.4	12.0	7.6	7.3

4.1.3 Number of leaves of the potted-pepper cultivars over a six-week-period after *Meloidogyne* eggs inoculation in the plant house

At the second week after inoculation, the mean number of leaves of the pepper cultivars ranged from 2.0 to 3.0 (Table 1). Carolina Cayenne recorded the highest number of leaves and the least by Carolina Wonder and Ohene Sateaa pepper cultivar (control) (Table 3). The number of leaves increased as the number of weeks also increased. There was significant difference (P = 0.05) between Carolina Cayenne and Ohene Sateaa (control) pepper cultivar in the second, fifth and sixth week (Table 3). There was no significant difference (P = 0.05) between the pepper cultivars in the fourth week. There were also, no significant difference (P = 0.05) between Carolina Wonder and Charleston Belle from the second to the sixth week (Table 3).

Table 3: Mean number of leaves of the potted-pepper cultivars over a six-week-period after *Meloidogyne* eggs inoculation in the plant house

Pepper cultivars	* Mean number of leaves/weeks after inoculation				
	2	3	4	5	6
Carolina Cayenne	3.0	4.0	4.0	5.0	5.0
Carolina Wonder	2.0	3.0	4.0	4.0	5.0
Charleston Belle	3.0	3.0	4.0	4.0	5.0
Ohene Sateaa (control)	2.0	4.0	4.0	4.0	4.0
Lsd (P=0.05)	0.5	0.3	0.3	0.3	0.3
CV(%)	8.4	5.4	3.7	4.4	4.1

*$\sqrt{(x+0.5)}$ transformed, where x is the mean number of leaves

4.1.4 Plant height of potted-pepper over a six-week-period after *Meloidogyne* egg inoculation in the plant house

At the second week after inoculation, the mean height of the pepper cultivars ranged from 18.9 to 25.6 cm (Table 4). Ohene Sateaa (control) recorded the highest height and the least by Carolina Wonder pepper cultivar (Table 4). The height increased as the number of weeks increased. There were no significant differences (P = 0.05) between the resistant pepper cultivars and the control in the second week after inoculation (Table 4). There were no significant differences (P=0.05) between Carolina Wonder and Charleston Belle from the second to the fifth week after inoculation. However, there was significant difference (P = 0.05) between Carolina Cayenne and Ohene Sateaa in the fifth and sixth week (Table 4).

Table 4: Mean Plant height of the potted-pepper over a six-week-period after *Meloidogyne* egg inoculation in the plant house

Pepper cultivars	Mean height (cm)/week after inoculation				
	2	3	4	5	6
Carolina Cayenne	20.3	25.0	38.2	51.0	60.2
Carolina Wonder	18.9	19.8	29.8	42.8	58.4
Charleston Belle	23.4	27.7	26.2	37.7	44.7
Ohene Sateaa (control)	25.6	31.6	31.6	33.7	38.2
Lsd (P=0.05)	7.4	7.3	6.9	10.0	11.0
CV(%)	17.9	14.8	11.6	12.5	11.8

4.1.5 Root gall score, *Meloidogyne* egg count and reproduction factor of potted-tomato cultivars after eight weeks of *Meloidogyne* egg inoculation in the plant house

All the *Meloidogyne* egg-inoculated plants were galled. The mean gall score ranged from 3 to 5 (Table 5). Power (control) was heavily galled (Plate 1). Root-knot egg count was highest in the Power and the least in Small Fry. There were variations of susceptibility of the tomato cultivars to the root-knot nematodes (Table 5). The reproduction factor of all the tomato cultivars was greater than one. However, susceptibility varied among the tomato cultivars.

Table 5: Root gall score, mean *Meloidogyne* egg count and reproduction factor of potted-tomato cultivars after eight weeks of *Meloidogyne* egg inoculation in the plant house

Tomato cultivars	Root gall score (0-5)#	Mean nematode egg count/5 g root	Rf
Small Fry	3	4333	2
Jetsetter	5	6805	3
Celebrity	4	5460	3
Power (Control)	5	9680	5

#0= No galls on root and 5= greater than 75% roots galled (Appendix 1)

Reproduction factor (Rf) = Final population (Pf) / Initial population (Pi), where Pi = 2000; If Rf < 1, no reproduction and Rf >1 means there is reproduction

4.1.6 Root gall score, *Meloidogyne* egg count and reproduction factor of potted-pepper cultivars after eight weeks of inoculation in the plant house

The gall score carried out indicated that Ohene Sateaa recorded the highest number of galls and the least by Carolina Cayenne, Carolina Wonder and Charleston belle (Table 6). The mean number of *Meloidogyne* egg count also followed the same trend with Carolina Cayenne recording *Meloidogyne* egg count of 2120 and Ohene Sateaa, 5700. Carolina Wonder and Charleston Belle recorded 3096 and 3767, respectively. The reproduction factor was greater than 1 for all the pepper cultivars (Table 6). They were also susceptible to the root-knot nematodes.

Table 6: Root gall score, mean *Meloidogyne* egg count and reproduction factor of potted-pepper cultivars after eight weeks of *Meloidogyne* egg inoculation in the plant house

Pepper cultivars	Root gall score (0-5)#	Mean egg count/5 g root	Rf
Carolina Cayenne	2	2120	1.1
Carolina Wonder	2	3096	1.6
Charleston Belle	2	3767	1.9
Ohene Sateaa(Control)	3	5700	2.9

#0= No galls on root and 5= greater than 75% roots galled (Appendix 1)

Reproduction factor (Rf) = Final population (Pf) / Initial population (Pi), where Pi = 2000; If Rf < 1, no reproduction and Rf >1 means there is reproduction

Plate 1: A susceptible tomato genotype (Power tomato cultivar)

Plate 2: A resistant cultivar without galls (Small Fry tomato cultivar)

4.2.0 EXPERIMENT 2: Reaction of root-knot resistant tomato and pepper cultivars in the field

4.2.1 Root gall score, *Meloidogyne* egg count and reaction of field pepper cultivars in the field after harvest

Gall score of the pepper cultivars ranged from 0 to 2 with Ohene Sateaa recording the highest and the least by Carolina Cayenne, Carolina Wonder and Charleston Belle (Table 7). Ohene Sateaa also recorded the highest number of nematode egg count of 2700 and the rest recorded 25, 35, and 50, respectively. All the exotic pepper cultivars were resistant to the root-knot nematodes. However, Ohene Sateaa (control) was susceptible to the root-knot nematodes (Table 7).

Table 7: Root gall score, *Meloidogyne* egg count and reaction of pepper cultivars in the field after harvest

Pepper cultivars	Root gall score(0-5)#	Mean egg count/5 g root	*Reaction
Carolina Cayenne	0	25	R
Carolina Wonder	0	35	R
Charleston Belle	0	50	R
Ohene Sateaa (Control)	2	2700	S

#0= No galls on root and 5= greater than 75% roots galled (Appendix 1)

*R = Resistant and S = Susceptible

4.2.2 Root gall score, *Meloidogyne* egg count, and reaction of field tomato cultivars four months after planting in the field

Gall score of 0 (no galls, Plate 2) was recorded for the resistant tomato cultivars and the control cultivar had the highest gall score of 4 (Table 8). The root-knot egg count ranged from 20 to 2975/5 g root with Power (control) recording the highest and the least by Celebrity (Plate 3). Small Fry, Jetsetter and Celebrity were resistant to the root-knot nematodes while Power (Plate 6) was susceptible to the root-knot nematodes (Table 8).

Table 8: Root gall score, *Meloidogyne* egg count and reaction of field tomato cultivars four months after planting in the field

Tomato cultivars	Root gall score(0-5)#	Mean egg count/5 g root	*Reaction
Small Fry	0	150	R
Jetsetter	0	175	R
Celebrity	0	20	R
Power (Control)	4	2975	S

#0= No galls on root and 5= greater than 75% roots galled (Appendix 1)

*R = Resistant and S = Susceptible

4.2.1 Tomato yield obtained from the field experiment at harvest

The highest number of fruits harvested was recorded in Small Fry (Plate 4) and the least by Celebrity (Table 9, Plate 3). There were significant differences (P = 0.05) between resistant cultivars and control cultivars. There was no significant difference (P = 0.05) between Jetsetter and Celebrity cultivars (Table 9).

The yield of tomato ranged from 3.2 to 3.5 t/ha with Celebrity recording the highest and the least by Power (Table 9). There were significant differences (P = 0.05) between the tomato cultivars (Table 9).

Table 9: Mean number of tomato fruits and yield four months after planting

Tomato cultivars	* Mean no. of tomato fruits	Yield of tomato (t/ha)
Small Fry	200.0	3.3
Jetsetter	59.0	3.4
Celebrity	56.0	3.5
Power (Control)	86.0	3.2
Lsd (P=0.05)	26.6	0.1
CV(%)	14.1	2.2

*$\sqrt{(x+0.5)}$ transformed, where x is the mean number of tomato fruits

Plate 3: Celebrity tomato fruits

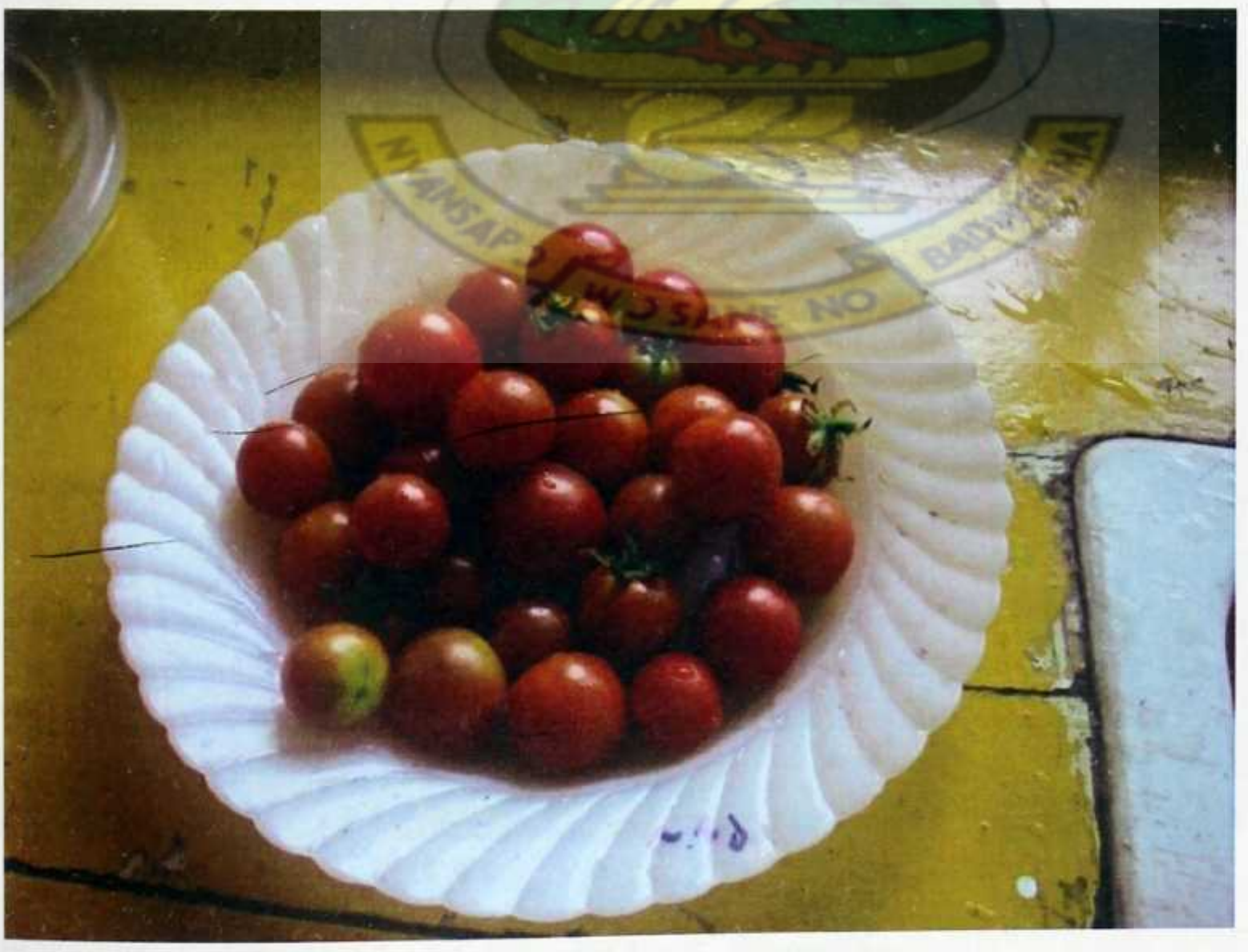

Plate 4: Small Fry tomato fruits

Plate 5: Jetsetter tomato fruits

Plate 6: Power plants infested with root-knot nematodes

4.2.2 Pepper yield obtained from the field experiment at harvest

The number of pepper fruits ranged from 42 to 222 with Ohene Sateaa (Plate 8) recording the highest and the least by Carolina Wonder (Table 10, Plate 5). There was significant difference (P = 0.05) between the resistant cultivars and control. There was no significant difference (P = 0.05) between Carolina Wonder and Charleston Belle (Table 14, Plate 6). The yield of pepper ranged from 1.9 to 2.5 t/ha with Carolina Cayenne cultivar recording the highest (Table 10). There was no significant difference (P = 0.05) between Carolina Wonder and Charleston Belle pepper cultivars. However, there were significant differences (P = 0.05) between the resistant and control pepper cultivars (Table 10).

Table 10: Mean number of pepper fruits and yield four months after planting under the field condition

Pepper cultivars	*Mean no. of fruits	Yield of pepper (t/ha)
Carolina Cayenne	204.0	2.5
Carolina Wonder	42.0	2.2
Charleston Belle	48.0	2.1
Ohene Sateaa (control)	222.0	1.9
Lsd (P=0.05)	13.1	0.2
CV(%)	5.4	4.9

*$\sqrt{(x+0.5)}$ transformed, where x is the mean number of pepper fruits

Plate 7: Carolina Wonder pepper fruits

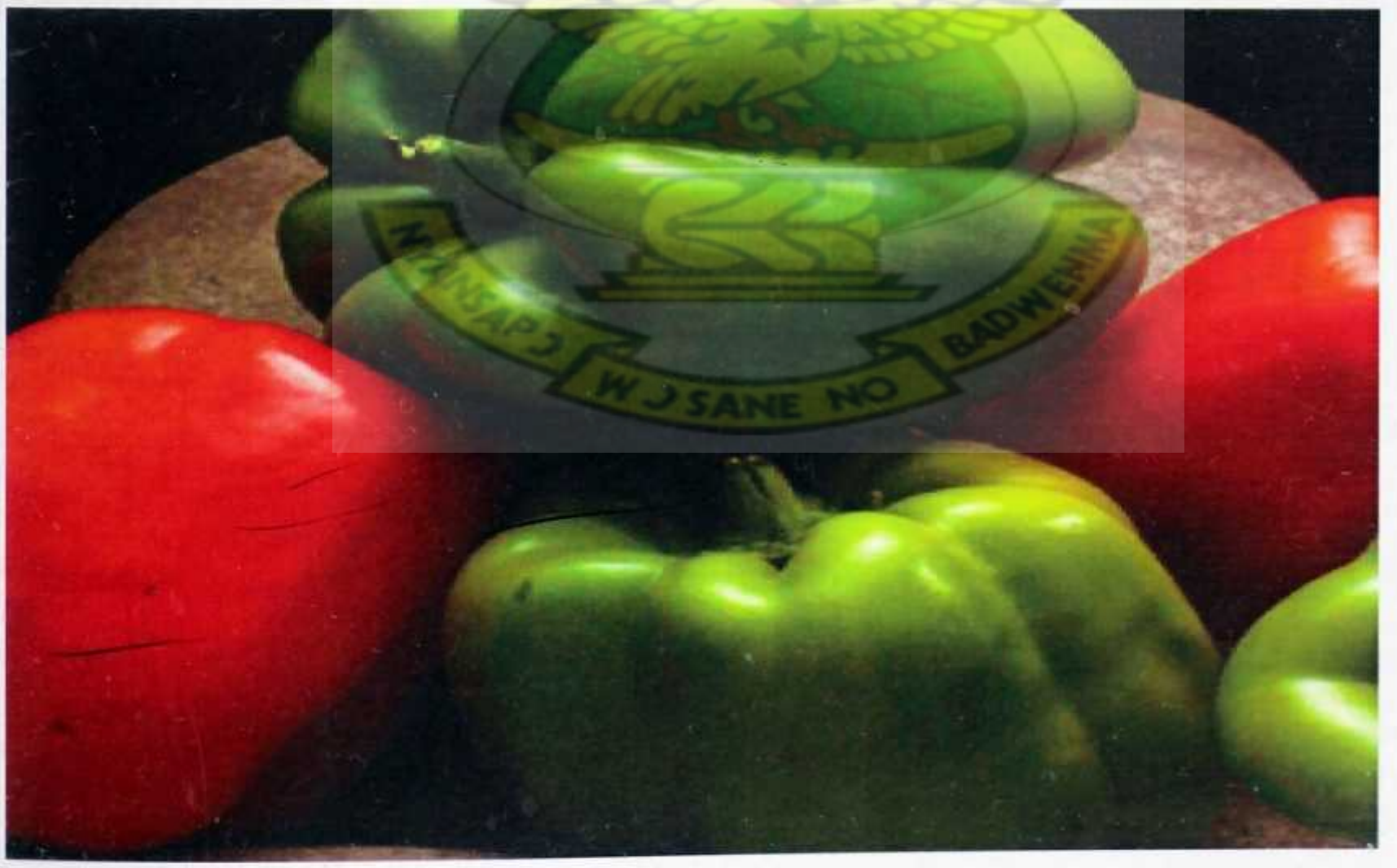

Plate 8: Charleston Belle pepper fruits

Plate 9: Carolina Cayenne pepper fruits

Plate 10: Ohene Sateaa pepper fruits

4.2.3 Shelf life of ripe tomato fruits stored under ambient conditions

The mean shelf life of the ripe tomato fruits ranged from 5.0 to 11.0 with Small Fry fruits (Plate 4) recording the longest shelf life in storage before rot set in and Power recording the least storage time (Table 11). There were significant differences (P = 0.05) between the root-knot resistant cultivars and control cultivar. Celebrity and Jetsetter cultivars did not differ significantly (P = 0.05) from each other (Table 11).

Table 11: Mean shelf life of ripe tomato fruits stored under ambient temperature

Tomato cultivars	Mean number of days in storage before rot (shelf life)
Small Fry	11.0
Jetsetter	8.0
Celebrity	8.0
Power (Control)	5.0
Lsd(P = 0.05)	1.8
CV(%)	11.7

4.2.4: Soluble solids and firmness of ripe tomato fruits

The mean soluble solids of the tomato cultivars ranged from 4.3 to 3.2°B and Small Fry recorded the highest soluble solids content and the least by Power (Table 12). There were no significant differences (P = 0.05) between the resistant cultivars but there was significant difference (P = 0.05) between Small Fry and Power. Jetsetter fruits (Plate 5) were firmest and Small Fry fruits (Plate 4) the least firm. Small Fry was significantly different (P = 0.05) from Power cultivar in firmness (Table 12).

Table 12: Mean soluble solids and firmness of ripe tomato fruits

Tomato cultivars	Mean tomato Sugar content (°B)	Mean firmness of tomato fruits (N)
Small Fry	4.3	3.5
Jetsetter	3.8	7.1
Celebrity	3.8	6.4
Power (Control)	3.2	6.3
Lsd (P=0.05)	1.1	1.7
CV(%)	28.7	29.4

4.2:5 Determination of field soil temperature during tomato and pepper growth in the field

Field daily temperature recordings of soil where tomato and pepper cultivars were cultivated were taken within a four month period, from August to November, 2010. The highest temperature reading was 32°C and the lowest recorded was 24°C (Figure 1).

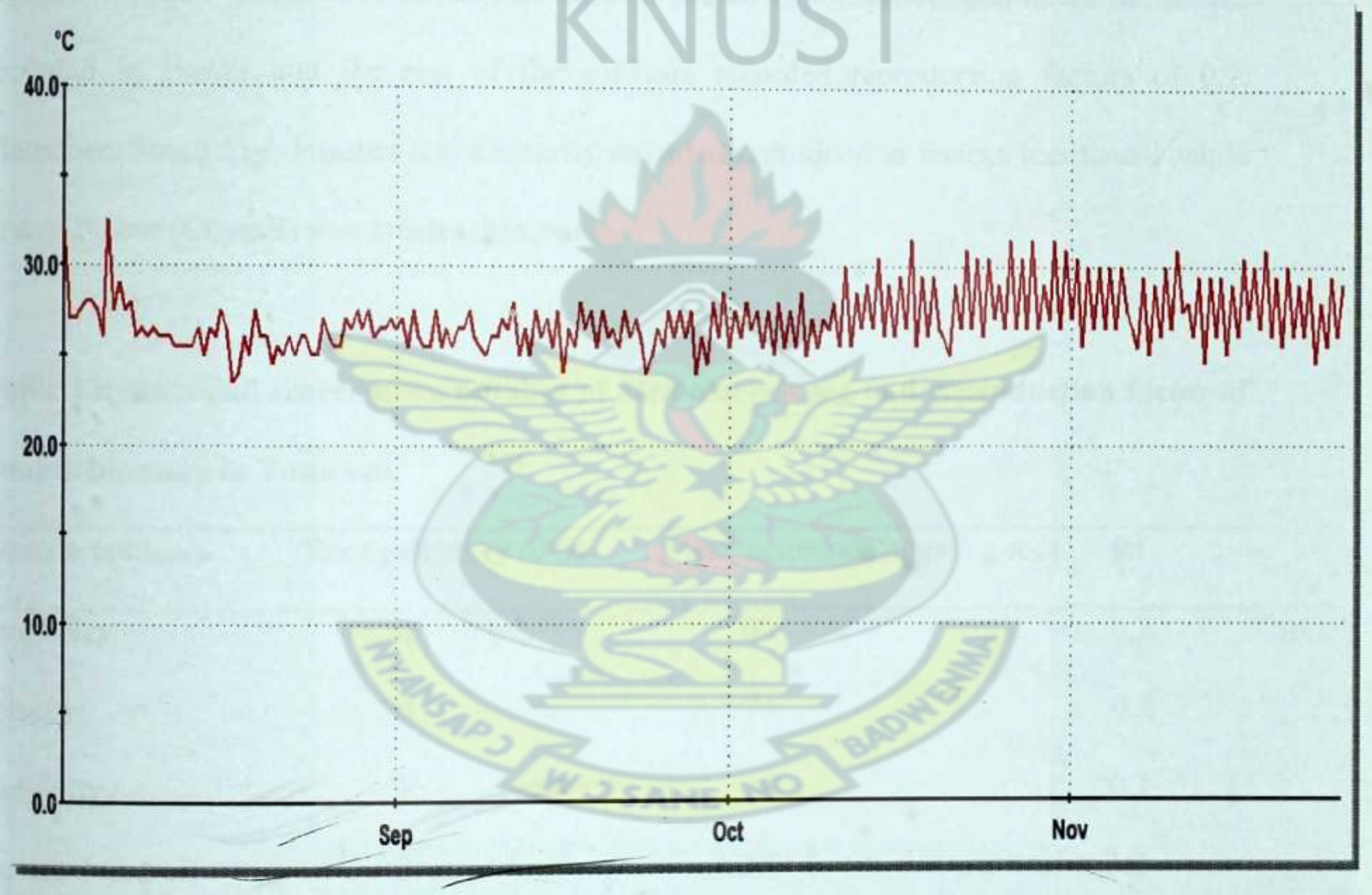

Figure 1: Daily field soil temperature reading over a four month period in the tomato and pepper.

4.3.0 EXPERIMENT 3: Tomato and pepper bioassays for assessing root-knot nematode population in different soils

4.3.1 Root gall score, *Meloidogyne* egg count, and reproduction factor of tomato grown on soils collected from Tono for the bioassay

The gall score of the tomato cultivars Small Fry, Jetsetter and Celebrity (root-knot resistant cultivars) ranged from 0 to 1 and Power (control) recorded the highest gall score of 3 (Table 13). The least number of nematode eggs of 60/5 g root was recorded in Small Fry and the highest of 1200/5 g root in Power tomato cultivar (Table 13). Reproduction factor of 3.2 was recorded in Power and the rest of the cultivars recorded reproduction factors of 0.2. Therefore, Small Fry, Jetsetter and Celebrity recorded reproduction factors less than 1 while that of Power (Control) was greater than one.

Table 13: Root gall score, mean number of *Meloidogyne* egg and reproduction factor of tomato bioassay in Tono soil

Tomato cultivars	Root gall score (0-5)#	Mean nematode eggs/5 g root	Rf
Small Fry	0	60	0.2
Jetsetter	0	74	0.2
Celebrity	1	90	0.2
Power (control)	3	1200	3.2

#0= No galls on root and 5= greater than 75% roots galled (Appendix 1)

Reproduction factor (Rf) = Final population (Pf) / Initial population (Pi), where Pi = 375; If Rf < 1, no reproduction and Rf >1 means there is reproduction

4.3.2 Root gall score, *Meloidogyne* egg count and reproduction factor of the Pepper cultivars grown on soils collected from Tono for the bioassay

All the exotic pepper cultivars, recorded gall score of 0 (no galls) while Ohene Sateaa, the local check recorded a gall score of 2 (Table 14). The mean number of nematode eggs of the pepper cultivars ranged from 108 to 1100/5 g root with the control cultivar recording the highest and the least by Charleston Belle (Table 14). There was reproduction in only Ohene Sateaa for it recorded a reproduction factor greater than one and it is thus said to be susceptible to the root-knot nematodes.

Table 14: Root gall score, mean number of *Meloidogyne* eggs and reproduction factor of pepper bioassay in Tono soil

Pepper cultivars	Root gall score (0-5)#	Mean nematode count/5 g root	Rf
Carolina Cayenne	0	120	0.3
Carolina Wonder	0	140	0.4
Charleston Belle	0	108	0.3
Ohene Sateaa (Control)	2	1100	2.9

#0= No galls on root and 5= greater than 75% roots galled (Appendix 1)

Reproduction factor (Rf) = Final population (Pf) / Initial population (Pi), where Pi = 375; If Rf < 1, no reproduction and Rf >1 means there is reproduction

4.3.3 Root gall score, *Meloidogyne* egg count and reproduction factor of Tomato cultivars grown on soils collected from Pwalugu for the bioassay

All the exotic tomato cultivars recorded gall score of 0 (no galls, Plate 2) while Power (control) recorded gall score of 2 (Table 15). The mean number of *Meloidogyne* eggs of the tomato cultivars ranged from 25 to 680/5 g root. The highest number of nematode egg count was recorded by Power and the least in Small Fry (Table 15). However, the reproduction factor of the cultivars indicated that Small Fry, Jetsetter and Celebrity recorded reproduction factor of 0.1, indicating that they were resistant to the root-knot nematode species while Power cultivar was susceptible to the root-knot nematodes because the reproduction factor was 1.2 (Table 15).

Table 15: Root gall score, mean *Meloidogyne* egg count and reproduction factor of tomato bioassay in Pwalugu soil

Tomato cultivars	Root gall score (0-5)#	Mean egg count/5 g root	Rf
Small Fry	0	25	0.1
Jetsetter	0	40	0.1
Celebrity	0	45	0.1
Power (Control)	2	680	1.2

#0= No galls on root and 5= greater than 75% roots galled (Appendix 1)

Reproduction factor (Rf) = Final population (Pf) / Initial population (Pi), where Pi = 550; If Rf < 1, no reproduction and Rf >1 means there is reproduction

4.3.5 Root gall score, *Meloidogyne* egg count and reproduction factor of pepper cultivars grown in soils collected from Pwalugu for the bioassay

Carolina Cayenne, Carolina Wonder and Charleston Belle pepper cultivars recorded 0 root gall score (no galls) while Ohene Sateaa (control) recorded the highest gall score of 3 (Table 16). The mean number of *Meloidogyne* eggs ranged from 25 to 840 with Ohene Sateaa pepper cultivar recording the highest and the least by Charleston Belle (Table 16). The reproduction factor of 1.5 was recorded in Ohene Sateaa and the other pepper cultivars recorded 0.1 and 0.2, respectively (Table 16).

Table 16: Root gall score, mean number of *Meloidogyne* egg and reproduction factor of Pepper bioassay in Pwalugu soil

Pepper cultivars	Root gall score (0-5)#	Mean eggs count /5 g root	Rf
Carolina Cayenne	0	85	0.2
Carolina Wonder	0	55	0.1
Charleston Belle	0	25	0.1
Ohene Sateaa (Control)	3	840	1.5

#0= No galls on root and 5= greater than 75% roots galled (Appendix 1)

Reproduction factor (Rf) = Final population (Pf) / Initial population (Pi), where Pi = 550; If Rf < 1, no reproduction and Rf > 1 means there is reproduction

4.3.5 Root gall score, *Meloidogyne* egg count and reproduction factor of tomato cultivars grown on soils collected from Vea for the bioassay

All the exotic tomato cultivars recorded gall score of 0, while Power, the local check, recorded a gall score of 4 (Table 17). The mean nematode egg count of the tomato cultivars ranged from 10 to 4251 with Power recording the highest and Small Fry the lowest (Table 17). There was reproduction only in Power (control) because it recorded a reproduction factor of greater than 1 and is thus said to be susceptible to the root-knot nematodes.

Table 17: Root gall score, Mean number of *Meloidogyne* egg and reproduction factor of tomato bioassay in Vea soil

Tomato cultivars	Root gall score (0-5)#	Mean egg count /5 g root	Rf
Small Fry	0	10	0.0
Jetsetter	0	15	0.0
Celebrity	0	85	0.3
Power (Control)	4	4251	14.2

#0= No galls on root and 5= greater than 75% roots galled (Appendix 1)

Reproduction factor (Rf) = Final population (Pf) / Initial population (Pi), where Pi = 300; If Rf < 1, no reproduction and Rf >1 means there is reproduction

4.3.6 Root gall score, *Meloidogyne* egg count and reproduction factor of pepper grown on soils collected from Vea for the bioassay

The gall score of the pepper cultivars ranged from 0 to 1 and Ohene Sateaa recorded the highest gall score of 1 and the other cultivars recorded gall score of 0 (no galls) (Table 18). The nematode egg count ranged from 70 to 750/5 g root with Ohene Sateaa (control) recording the highest root-knot egg count and the lowest by Carolina Wonder. A reproduction factor of 2.5 was recorded in Ohene Sateaa while the rest of the cultivars recorded reproduction factors of 0.2 and 0.3 (Table 18). Therefore, Carolina Cayenne, Carolina Wonder and Charleston Belle recorded reproduction factors less than 1 while that of Ohene Sateaa (control) was greater than 1.

Table 18: Root gall score, mean number of *Meloidogyne* egg and reproduction factor of pepper bioassay in Vea soil

Pepper cultivars	Mean gall score (0-5)#	Mean nematode eggs /5 g root	Rf
Carolina Cayenne	0	85	0.3
Carolina Wonder	0	70	0.2
Charleston Belle	0	90	0.3
Ohene Sateaa (Control)	1	750	2.5

#0= No galls on root and 5= greater than 75% roots galled (Appendix 1)

Reproduction factor (Rf) = Final population (Pf) / Initial population (Pi), where Pi = 300; If Rf < 1, no reproduction and Rf >1 means there is reproduction

4.1.7 Molecular identification of *Meloidogyne* juveniles extracted from potted tomato and pepper cultivars and soil bioassays

The molecular identification of the juveniles extracted from the tomato and pepper cultivars indicated only tropical *Meloidogyne* species. A few of the *Meloidogyne* populations were *M. incognita* and most were *M. javanica* with some *M. arenaria*.

Tomato and pepper cultivars	Root-knot nematodes identified
Small Fry	*M. javanica* and *M. arenaria*
Jetsetter	*M. javanica* and *M. arenaria*
Celebrity	*M .javanica* and *M. arenaria*
Power (Local check)	*M. incognita, M.javanica* and *M. arenaria*
Carolina Cayenne	*M. javanica* and *M. arenaria*
Carolina Wonder	*M. javanica* and *M. arenaria*
Charleston Belle	*M. javanica* and *M. arenaria*
Ohene Sateaa	*M. incognita, M.javanica, M. arenaria*
Tono	*M. incognita, M.javanica, M. arenaria*
Vea	*M. incognita, M.javanica, M. arenaria*
Pwalugu	*M. incognita, M.javanica, M. arenaria*

CHAPTER FIVE

5.0 DISCUSSION

5.1 Assessment of height and number of leaves of potted-tomato and pepper cultivars over a six-week-period after inoculation with *Meloidogyne* species.

There was gradual increase in the height and number of leaves of the root-knot resistant tomato and pepper cultivars than Power and Ohene Sateaa, the tomato and pepper local checks. Khan (2000) reported that there is a general trend of increase in shoot parameters (plant height, number of leaves) in root-knot resistant cultivars. Power and Ohene Sateaa (the local checks) recorded lower plant height and number of leaves than the root-knot resistant cultivars. This observation was similar to the findings of Sidiqqui and Alam (1987) who observed that heavily root-knot nematode-infested tomato and pepper exhibit stunted growth and declined shoot growth. 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 growth.

5.2 Evaluation of galling score and *Meloidogyne* egg count of potted tomato and pepper cultivars in the plant house.

The gall scores and number of *Meloidogyne* egg counted per 5g fresh root weight of the potted tomato and pepper were variable. This could be due to the fact that, in the pots, the roots of the tomato and pepper cultivars are confined thereby, exposing them more to the root-knot nematodes. This is in accordance with the findings of Ekanayake and Di Vito (1984), who reported that in pots, transplanted tomato and pepper more than doubled reproduction rates of *M. incognita*, compared with field tomato of the same cultivar and length of growing cycle.

The high root gall score and root-knot nematode egg count of the root-knot resistant tomato and pepper could be due to virulent root-knot nematodes present in the inoculum used for the screening of the cultivars, although they have not been used in Ghana. Roberts and Thomason (1989) reported that naturally resistance-breaking root-knot nematode populations have been observed even when they were not previously exposed to resistant cultivars. The high root gall score and root-knot egg count could also be due to high inoculum level. According to Khan (2000), the influence of nematode inoculum density on galls developed on tomato and pepper seedlings revealed significant increase in the number of galls with high inoculum density. Dickson *et al*. (1983) also reported that at high inoculum concentration, more *M. incognita* and *M. javanica* egg masses were produced on plant roots, thereby increasing root galling on tomato and pepper cultivars.

5.3.0 Reaction of tomato and pepper cultivars to root-knot nematodes under field condition.

The nematode count for the root-knot resistant tomato and pepper was low in the field experiment. According to Evans and Perry (2009), nematodes become dormant under adverse climatic conditions. However, the nematode counts in Power and Ohene Sateaa (control) cultivars were higher than in the root-knot resistant tomato cultivars. 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.

The gall score of the root-knot resistant tomato cultivars was lower than that of Power (local check). However, the pepper cultivars recorded low gall scores. 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.

5.3.1 Tomato yield obtained from the field experiment at harvest.

The study revealed that yield of the resistant tomato cultivars was higher than the control cultivar. The resistant cultivars had healthy roots, so, they were able to absorb water and nutrients for better growth. Fery and Dukes (1984) reported that marketable yields from resistant cultivars are significantly higher than those from susceptible cultivars grown in nematode-infested soils. The yield of the resistant tomato cultivars were below average tomato yield in Ghana. This could be attributed to the fact that, the cultivars are exotic and might not have been acclimatized to the local climatic conditions. The low yields could also be due to viral infections on the cultivars during the growing season. Even though the yields were low, they can be appreciated because, in some areas, tomato record yield data as low as 2 t/ha. Power (local check) produced considerable yield which could be due to the fertilizer and mulch that were applied. Also, Power, the local check, is indeterminate while the resistant cultivars are determinate (Tony, 2002).

5.3.2 Determination of sugar content and firmness of riped tomato fruits.

Soluble solids are of major economic significance to the tomato processing industry. The sugar content was highest in the Small Fry, Celebrity and Jetsetter cultivars. According to Baxter *et al.* (2005), ripe tomato fruits with high soluble solids contain less water and, therefore, require less processing to generate pastes of the appropriate consistency for consumer tastes.

According to Batu (1998), if the firmness values of tomatoes evaluated are above 1.28 N, they are suitable for making salad and for marketing. On the other hand, if the firmness value

is above 1.46 N, that tomato is definitely very firm and easily marketable in the supermarket. The study revealed that the tomato cultivars Celebrity and Jetsetter are suitable for salads and food preparation. Small Fry cultivars have sweet and juicy flavours and are, therefore, ideal for salads. Power tomato cultivar is suitable for food preparation.

5.3.3 Pepper yield obtained from the field experiment after harvest.

The yield of the *Meloidogyne* resistant pepper cultivars Carolina Cayenne, Carolina Wonder and Charleston Belle was higher than the Ohene Sateaa (Control) pepper cultivars. This agrees with observations by Starr *et al.* (2002) who reported that resistance is an effective management tool that improves crop yield in the presence of nematode population densities that exceed the damage threshold. In addition, the root-knot nematode resistant peppers are improved cultivars whilst Ohene Sateaa is an indigenous pepper. The low yields of the pepper cultivars below national average could also due to viral infections on the cultivars during the growing season.

5.3.4 Shelf life of ripe tomato fruits under ambient conditions.

Tomato is so highly perishable that it encounters several problems during transportation, storage and marketing (Ben-Arie and Susan, 1986). The results of this study indicated that the mean shelf life of the root-knot nematode resistant tomato cultivars' fruits was longer than the susceptible cultivar. This could be due to the fact that, the resistant tomato cultivars were firmer than Power (local check). Softer tomato fruits limit shelf life. This is in accordance with the findings of Cerkauskas (2004) who reported that, there are long-life varieties that remain firm up to 10-15 days, with some lasting as long as a month.

The long shelf life of the resistant tomato cultivars could also be attributed to the high sugar content of the tomato fruits. This agrees with the findings of Roessner-Tunali (2003) who reported that tomato fruits with high sugar content have a much lower water-to-soluble-particles-ratio and thus have longer shelf life. This long storability characteristic combined with resistance to a variety of major diseases and pests, such as root-knot nematodes and *Fusarium* wilt, give these high yielding tomato lines a major advantage over local varieties. The long shelf life of the tomato cultivars will be an incentive to local farmers since tomato is perishable, and marketing is often problematic especially during peak harvest periods.

5.4 Effect of root-knot nematodes-resistant tomato and pepper cultivars under different soil temperature in the field

At high soil temperatures, several nematode resistance genes show a loss of expression, rendering plants susceptible and allowing high nematode multiplication rates (Roberts *et al.*, 1998). According to Roberts (2002), the *Mi* gene in tomato is sensitive to temperature, with almost total loss of expression at or above 28-30°C. The resistant tomato and pepper cultivars in this study seemed not to have been affected by the soil temperature during the study period with a range of 24-32°C.

The study also showed low gall score and root-knot nematode egg count in the resistant tomato and pepper cultivars, indicating that the cultivars are resistant to the root-knot nematode species. Roberts *et al.* (1998) reported that temperature effects on resistance gene expression may not only influence expression of incomplete dominance, but at high soil temperatures, several nematode resistance genes show a loss of expression, rendering plants susceptible and allowing high nematode multiplication rates.

However, the high soil temperature of 32°C was recorded after two and a half months after transplanting when the plants had started fruiting. So, the high temperature did not seem to

affect the resistance of the plants. This is in accordance with Thies and Fery (2001) who stated that older plants have more tissue already differentiated which the nematodes do not penetrate.

5.5 Tomato and pepper bioassays for assessing root-knot nematodes populations in different soils

The study revealed that the resistant tomato and pepper cultivars are effective against the *Meloidogyne* species in Tono, Pwalugu and Vea since the tomato and pepper cultivars did not gall and their *Meloidogyne* egg counts were very low. Hirunsalee *et al*. (1995) observed that reproduction and galling of nematodes on plant root were favoured on tolerant and susceptible cultivars but were inhibited on resistant ones.

However, Tono, Pwalugu and Vea have very high annual temperatures of 45°C (MOFA, 2008). Haroon *et al*. (1993) reported that the instability of the root-knot nematode resistance genes in both tomato and pepper at high soil temperature limits their usefulness to manage *Meloidogyne* spp. in vegetable-production in warm climates. Multilocational evaluation screening in these areas is, therefore, recommended for confirmation.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The root-knot-resistant tomato (Small Fry, Jetsetter and Celebrity) and pepper (Carolina Cayenne, Carolina Wonder and Charleston Belle) were resistant to the root-knot nematodes in the field.

The local checks, Power tomato and Ohene Sateaa Pepper cultivars, were susceptible to the *Meloidogyne* species because they recorded the highest root-knot eggs counts and gall scores.

The root-knot nematode species in soils collected from Tono, Pwalugu and Vea did not reproduce on the root-knot resistant tomato and pepper cultivars.

Small Fry, Jetsetter and Celebrity tomato cultivars had higher yield than Power (local check) tomato. Also, the root-knot resistant pepper cultivars Carolina Cayenne, Carolina Wonder and Charleston Belle produced higher yields than Ohene Sateaa (local check) pepper. Therefore, the resistant cultivars were able to manage the root-knot nematodes.

Jetsetter and Celebrity cultivars were firmer and had longer shelf life than Power (Local check) tomato cultivar. Following the soluble solids analysis, Small Fry, Celebrity and Jetsetter tomato fruits recorded the highest sugar content.

Temperature did not seem to have an effect on the resistant tomato and pepper cultivars screened.

6.2 RECOMMENDATIONS

The root-knot resistant tomato cultivars (Celebrity and Jetsetter) and the resistant pepper cultivars were able to manage the root-knot nematodes. Therefore, they are recommended for planting.

Tomato cultivar, Small Fry, has small fruits so it is recommended for the preparation of salads.

Further studies should be carried out in other major tomato and pepper growing areas in Ghana such as Agogo and Akumadan to ascertain environmental effects on their resistance.

REFERENCES

Abbott, J.A. (2004). Textural quality assessment for fresh fruits and vegetables. **In**: *Quality of Fresh and Processed Foods* 39:327–332.9–10.

Addo, P.G. (1970). The root-knot nematode problem in Ghana: Host and non-host plants of *Meloidogyne* spp. *Ghana Journal of Agricultural Science* 3: 3-12.

Agrios, G.N. (2005). Plant Pathology, 5th edition. Academic Press, New York. pp. 922.

Andrews, J. (2000). *The Pepper Trail: History and Recipes from Around the World*. Denton, Texas: University of North Texas Press, 2000.

Anju-kumari, Bhardwaj, M.L., Guleria, S.P.S. and Kumari, A. (1993). Influence of stage of harvest on shelf life and quality of tomato. *Horticulture Journal* 6 (2):89-92.

Anonymous (2008). An emerging root-knot nematode, *Meloidogyne enterolobii*: Addition to the EPPO Alert List. *EPPO Reporting Service* 5:9-10.

Bachmann, J. and Earles, R. (2000). Post harvest handling of fruits and vegetables. ATTRA Horticultural Technical Note pp: 19. http://attra.org/attra-pub/PDF/postharvest.pdf, 10/ 01/ 2011.

Barker, K.R. (1994). Resistance/tolerance and related concepts/technology in plant nematology. *Plant Disease* 77: 111-113.

Batu, A. (1998). Some factors affecting the determination and measurement of tomato firmness. *Turkish Journal of Agriculture and Forestry* 22: 411-418.

Baxter, C.B, Carrari, F., Bauke, A., Overy S., Hill, S.A, Quick, P., Fernie, A. and Sweetlove, L.J. (2005). Fruit carbohydrate metabolism in an introgression line of tomato with increased fruit soluble solids. *Plant Cell Physiology* 46(3):425-37.

Baxter, C.J., Foyer, C.H., Turner, J., Rolfe, S.A. and Quick, W.P. (2003). Elevated sucrose-phosphate synthase activity in transgenic tobacco sustains photosynthesis in older leaves and alters development. *Journal of Experimental Botany* 54: 1813-1820.

Ben-Arie R. and Susan L. (1986). Prolongation of fruit life after harvest. **In**: hand book of fruit set and development,P.M. Shaul (ed.), CRC Press. ISSN 0258-7122.

Bird, D.M., and Wilson, M.A. (1994). DNA sequence expression analysis of root-knot nematode–elicited giant cell transcripts. *Molecular Plant-Microbe Interactions* 7: 419-424.

Bleve-Zacheo,T., Melillo, M.T. and Castagnone-Sereno, P. (2007). The contribution of biotechnology to root-knot nematode control in tomato plants. *Plant Technology* 1: 1-16.

Bosland P.W., Bailey, A.L., and Iglesias-Olivas, J. (1996). *Capsicum* pepper varieties and classification. N.M Coop. Ext. Serv. Circ., Las Cruces, 530 pp.

Bridge, J. (1996). Nematode management in sustainable and subsistence agriculture. *Annual Review of Phytopathology* 34: 201-225.

Brito, J. A., Stanley, J. D., Kaur, R., Cetintas, R., Di Vito, M., Thies, J. A., and Dickson, D. W. (2007). Effects of the Mi-1, N and Tabasco genes on infection and reproduction of *Meloidogyne mayaguensis* on tomato and pepper genotypes. *Journal of Nematology* 39(4):327-332.

Castagnone-Serano, p., Esparrago, G., Abad, p., Leroy, F. and Bongiovanni, M. (1995). Satellite DNA as a target for PCR-specific detection of the plant-parasitic nematode *Meloidogyne hapla. Current Genetics* 28: 566-70.

Caveness, F. E. and Ogunforowa, A. O. (1985). Nematological Studies Worldwide. **In**: Cowpea Research Production and Utilization. S.R. Singh and K.O. Rachie, (eds.) Wiley and Sons. pp. 273-285.

Cerkauskas, R. (2004). Root-knot nematodes. Asian Vegetable Research Development Center Publication 04-603.

Clottey, V.A., Karbo, N., and Gyasi, K.O. (2009). The tomato industry in Northern Ghana: production constraints and strategies to improve competitiveness. *African Journal of Food, Agriculture, Nutrition and Development*, ISSN 1684-5374. pp. 1436-1451.

Cook, R. and Evans, K. (1987). Resistance and tolerance. **In**: R.H. Brown, and B.R. Kerry (eds.) *Principles and Practice of Nematode Control in Crops*. Academic Press, Sydney. pp. 179-231.

Coyne, D.L., Fourie, H. H., and Moens, M. (2009). Current and future management strategies in resource-poor farming. **In:** Root-knot Nematodes, R.N. Perry, M. Moens, and J.L. Starr (eds.). CAB International, Wallingford, UK, 2009. pp. 444-475.

DeWaele, D. And Elsen, A. (2007). Challenges in Tropical Plant Pathology. *Annual Review of Phytopathology* 45: 457-485.

Di Vito, M. and Greco, N. (1988). The relationship between initial population densities of *Meloidogyne artiellia* and yield of wheat. *Nematologia Mediterranea* 16: 167-169.

Di Vito, M. and Greco, N. (2009). Population Dynamics and Damage Levels. **In:** Root-knot nematodes, R.N. Perry, M. Moens, and J.L. Starr (eds.). CAB International, Wallingford, UK, 2009. pp. 246-274.

Dickson, D. and De Waele, D. (2005). Nematode parasites of groundnut. **In**: M. Luc, R.A. Sikora, and J. Bridge (eds.). Plant Parasitic Nematodes in Subtropical and Tropical Agriculture, 2nd edition. CAB International, Wallingford, UK. pp. 393-436.

Dickson, D. W., Holbrook, C. C., and Knauft, D. A. (1983). A technique for screening peanut for resistance to *Meloidogyne arenaria*. *Plant Disease* 67:957-958.

Djian-Caporalino, C., Pijarowski, L., Fazari, A., Samson, M., Gaveau, L., O'Byrne, C., Lefebvre, V., Caranta, C., Palloix, A. and Abad, P. (2001). High-resolution genetic mapping of pepper (*Capsicum annuum* L.) resistance loci Me-3 and Me-4 conferring heat-

stable resistance to root-knot nematodes (*Meloidogyne* spp.). *Theoretical and Applied Genetics* 103: 592-600.

Dobson, H., Cooper, J., Manyangarirwa, W., Karuma, J. and Chiimba, W. (2002). Integrated Vegetable Pest Management. Natural Resources Institute, University of Greenwich, UK. ISBN: 0-85954-536-9.

Dreistadt, S. H., Clark, J. K. and Flint, M. L. (2004). Pests of Landscape Trees and Shrubs: *An Integrated Pest Management Guide*. Oakland: University of California Agriculture. Natural Resources Publication 3359. *Journal Arboriculture* 19:181-186.

Dropkin, V.H., Helgeson, J.P. and Upper, C.D. (1969). Hypersensitivity reaction of tomatoes resistant to *Meloidogyne incognita*- reversal by cytokinins. *Journal of Nematology* 27: 498.

Dykes, B.M. (2010). World's hottest pepper is 'hot enough to strip'. *Yahoo News*, December 3, 2010.

Ekanayake, H.M.R.K. and Di Vito, M. (1984). Effect of population densities of *Meloidogyne incognita* on growth of susceptible and resistant tomato plants. *Nematologia Mediterranea* 12: 11-16.

Evans, A.A.F. and Perry, R.N. (2009). Survival mechanisms. **In**: Root-knot Nematodes, R.N. Perry, M. Moens, and J.L. Starr (eds.). CAB International, Wallingford, UK, pp. 201-221.

Evans, K., Trudgill, D. L. and Webster, J. M. (1993). Plant Parasitic Nematodes in Temperate Agriculture. CAB International, Wallingford, UK, pp 648.

Fargette, M. (1987). Use of esterase phenotype in the taxonomy of the genus *Meloidogyne*. 2. Esterase phenotypes observed in West African populations and their characterization. *Revue de Nematologie* 10: 45-56.

Fattah, F.A. and Webster, J.M. (1983). Ultrastructural changes caused by *Fusarium oxysporum f. sp. Lycopersici* in *Meloidogyne javanica* induced giant cells in Fusarium resistant and susceptible tomato cultivars. *Journal of Nematology* 15: 128-135.

Ferraz, S. and de Freitas, L.G. (2004). Use of antagonistic plants and natural products. **In**: Z.X. Chen, S.Y. Chen, and D.W. Dickson, (eds.). *Nematology- Advances and Perspectives*. Volume 2: Nematode Management and utilization. CAB International, Wallington, UK. pp. 931-977.

Ferris, H. (1985). Density-dependent nematode seasonal multiplication rates and overwinter survivorship: a critical point model. *Journal of Nematology* 1: 93-100.

Fery, R.L. and Dukes, P.D. (1980). Inheritance of root-knot nematode resistance in cowpea [*Vigna unguiculata* (L.) Walp]. *Journal for the American Society of Horticultural Science* 95: 640-645.

Fery, R.L. and Dukes, P.D. (1984). Feasibility of breeding bell peppers (Capsicum annum) for resistance to the southern root-knot nematode, *Meloidogyne incognita*. *Hortscience* 19:545 (Abstract).

Fox, J. A. (2001). *Nematode Control in the Home Garden*. Mississippi State University Extension Service Publication 483. http://msucares.com/ pubs/pub483.htm.

Ghana Investment Promotion Council (GIPC) (2001). www.gipc.org.gh 23/11/09.

Glover B. Lack of market worries Upper East tomato farmers. The Daily Graphic of 26 March, 2007; 150007: 28. IDA. International Development Agency, Ghana.

Goldi, E.A. (1892). Relatorio sobre a molestia do cafeeiro na provincial do Rio de Janeiro. Extrahido do VIII Vol. Dos Archivos do Museu Nacional, Rio de Janeiro, Imprensa National, pp. 1-121+4 plates and a map.

Gould, W.A. (1992). Tomato Production, Processing, and Technology. CTI Publishing, Baltimore, MD. pp. 550.

Gowen, S.R., Ruabete, T.K. and Wright, J.G. (2005). Pest Advisory Leaflet no. 9 3rd edition / Secretariat of the Pacific Community. ISSN 1017-6276.

Hallman, J., Keith, G., Davies and Sikora, R. (2009). Biological control using microbial pathogens, endophytes and antagonists. **In:** Root-knot Nematodes, R.N. Perry, M. Moens, and J.L. Starr (eds.). CAB International, Wallingford, UK, pp. 380-411.

Haroon, S.A, Baki, A.A. and Huettel, R.N. (1993). An *in vitro* test for temperature sensitivity and resistance to *Meloidogyne incognita* in tomato. *Journal of Nematology* 25:83–88.

Hemeng, O.B. (1981). Efficacy of selected nematicides for control of root-knot nematodes. Proc. Res. Planning conf. On *Meloidogyne* spp. Nov. 16-20, 1981. IITA, Ibadan, Nigeria, pp. 52-56.

Hirunsalee, A., Barker, K. R. and Beute, M. K. (1995). Infection, reproduction potential, and root galling by root-knot nematode species and concomitant populations on peanut and tobacco. *Journal of Nematology* 27(2):172-177.

Horna, D. P., Zabel, H. and Lindout, P. (2006). Assessing the potential economic impact of genetically modified crops in Ghana: Tomato, garden egg, cabbage and cassava. Program for Bio-safety Systems report, October.

Hussey, R.S. and Barker, K.R. (1973). A comparison of methods of collecting inocula of *Meloidogyne* spp., including a new technique. *Plant Disease Reporter* 57: 1025-1028.

Hussey, R.S. and Boerma, H.R. (1981). A greenhouse screening procedure for root-knot resistance in soybean. *Crop Science* 21: 794-796.

Hussey, R.S. and Jansen, G.J.W. (2002). Root-knot nematodes: *Meloidogyne* species. **In**: J.L. Starr, R. Cook, and J. Bridge, (eds.) Plant Resistance to Parasitic Nematodes. CAB International, Wallingford, UK, pp. 43-70.

Jackman, R.L., Marangoni, A.G. and Stanley, D.W. (1990). Measurement of tomato fruit firmness. *HortScience* 25: 781–783.

Karssen, G. (2002). The Plant-Parasitic Nematode Genus. *Meloidogyne* Goldi, 1892 (Tylenchida) in Europe. Leiden, Netherlands: Brill. pp. 224.

Karssen, G. and Moens, M. (2006). Root-knot nematodes. **In**: *Plant Nematology.* R.N. Perry, and M. Moens, (eds.). CAB Publishing, Wallingford. UK. pp. 59-90.

Khan, M. R. (2000). Screening of crop germplasms for resistance against root-knot nematode, *Meloidogyne incognita* race 2. *Environment & Ecology*, 22: 445-448.

Khan, M. W. (1993). Mechanisms of interactions between nematodes and other plant pathogens. **In**: Nematode interactions. Khan, M.W. (ed.). Chapman and Hall, pp. 55-78.

Kiewnick, S., Karssen, G., Brito, J. A., Oggenfuss, M., and Frey, J.E. (2008). First report of root-knot nematode *Meloidogyne enterolobii* on tomato and cucumber in Switzerland. *Plant Disease* 92:1370.

Kinloch, R.A. and Allen, M.W. (1992). Interaction of *Meloidogyne hapla* and *M. javanica* infecting tomato. *Journal of Nematology* 4: 7-16.

Lesage, P. and Destain, M.F. (1996). Measurement of tomato firmness by using a non-destructive mechanical sensory. *Postharvest Biology and Technology* 8: 45–55.

Liu, Q.L. and Williamson, V.M. (2006). Host–specific pathogenicity and genome differences between inbred strains of *Meloidogyne hapla. Journal of Nematology* 38: 158-164.

Luc, M., Sikora, R.A. and Bridge, J. (2005). Plant Parasitic Nematodes in Subtropical and Tropical Agriculture. 2nd edition, CABI publishing, Wallingford, UK, pp. 6-61.

Manzanilla-Lopez H. Rosa and Starr, J.L. (2009). Interactions with other pathogens. **In:** Root-knot nematodes. R.N. Perry, M. Moens, and J.L. Starr (eds.). CAB International, Wallingford, UK, pp. 223-245.

McClellan,W.D., Wilhelm, S. and Geroge, A. (1955). Incidence of *Verticillium* wilt in cotton not affected by root-knot nematodes. *Plant Disease Reporter* 39:226-227.

Mckenry, M.V. and Roberts, P.A. (1985). *Phytonematology Study Guide*. University of California Press, Oakland, CA: UC Publication 4045; p. 56.

Mcsorley, R. (1998). Alternative practices for managing plant-parasitic nematodes. *American Journal of Alternative Agriculture* 13: 98-104.

Millenium Challenge Account (MCA) (2006). Investment Opportunity in Ghana. Chilli peppers. Seventh edition. pp. 1-93.

Ministry of Food and Agriculture (MoFA) (2008).

Moens, M., Roland, N. Perry and Starr, J.L. (2009). *Meloidogyne* species - a Diverse Group of Novel and Important Plant Parasites. **In**: Root-knot Nematodes. R.N. Perry, M. Moens, and J.L. Starr (eds.). CAB International, Wallingford, UK. pp. 1-17.

Mondal, M. F. 2000. Production and storage of fruits (in Bangla). *BAU Campus, Mymensingh*-2202. pp-312.

Noling, J. W. (2009). Nematode Management in Tomatoes, Peppers and Eggplant ENY-032. 15 pp.

Nyczepir, A.P. and Becker, J.O. (1998). Fruit and citrus trees. **In**: Plant-Nematode Interactions. K.R. Barker, K.R. Peterson, G.A. and G.L Windham (eds.). American Society of Agronomy, Madison, Wisconsin, pp. 637-684.

Obeng-Ofori, D., Yirenkyi Danquah, E. and Ofosu Anim, J. (2007). Vegetable and spice production in West Africa. The City Publishers Limited. pp. 53-75.

Ogallo, J.L., Goodell, P.B., Eckert, J.W. and Roberts, P.A. (1999). Management of root-knot nematodes with resistant cotton *cv* Nemx. *Crop Science* 39: 418-421.

Olmo, M., Nadas, A., and Garcia, J.M. (2000). Nondestructive Methods to Evaluate Maturity Level of Oranges. *Journal of Food Science* 65: 365-369.

Omwega, C.O. and Roberts P.A. (1992). Inheritance of resistance to *Meloidogyne spp*. **In**: common bean and the genetic basis of its sensitivity to temperature. *Theoretical and Applied Genetics* 83: 720-7726.

Perry, R. N., Moens, M., Starr, J. L., (2009). Root-knot Nematodes. CAB International, Wallingford, UK. pp. 488.

Petrillo, M.D., Mathews, W.C. and Roberts, P.A. (2006). Dynamics of *Meloidogyne incognita* virulence to resistance genes RK and RK (2) in cowpea. *Journal of Nematology* 38: 90-96.

Pickersgill, B. (1997). Genetic resources and breeding of Capsicum spp. *Euphytica* 96:129-133.

Riegel, C. and Noe, J.P. (2000). Chicken litter soil amendment effects on soilborne microbes and *Meloidogyne incognita* on cotton. *Plant Disease* 84: 1275-1281.

Roberts, P.A. (1993). The future of nematology: integration of new and improved management strategies. *Journal of Nematology* 25: 383-394.

Roberts, P.A. (2002). Concepts and consequences of resistance. **In:** Plant Resistance to parasitic nematodes. J.L. Starr, R. Cook and J. Bridge, (eds.). CAB International, Wallingford, UK. pp. 23-41.

Roberts, P.A. and May, D.M. (1986). *Meloidogyne incognita* resistance characteristic in tomato genotypes developed for processing. *Journal of Nematology* 18: 353-359.

Roberts, P.A. and Thomason, I.J. (1989). A review of variability in four *Meloidogyne* spp. Measured by reproduction on several hosts including *Lycopersicon. Agricultural Zoology Reviews* 3: 225-252.

Roberts, P.A., Frate, C.A. and Mathews, W.C. (1985). Quantitative aspects of the interaction of *Meloidogyne incognita* with Fusarium wilt on Acala cotton in field plots. *Proceedings Beltwide Cotton Conference*, National Cotton Council of American. Memphis, Tennessee, p.21 (Abstr.).

Roberts, P.A., Mathews, W.C. and Veremis, J.C. (1998). Genetic and mechanisms of host plant resistance to nematodes. **In**: *Plant-nematode interactions*. K.R. Barker, G.A. Pederson, and G.L. Windham (eds.). American Society of Agronomy, Madison, Wisconsin, pp. 209-238.

Roberts, P.A., Mathews, W.C., Ehlers, J.D. and Helms, D. (2008). Genetic determinants of differential resistance to root-knot nematode reproduction and galling in lima bean. *Crop Science* 48: 553-561.

Roessner-Tunali, U., Hegemann, B., Lytovchenko, A., Carrari, F., Bruedigam, C., Granot, D. and Fernie, A. (2003). Metabolic profiling of transgenic tomato plants over expressing hexokinase reveals that the influence of hexose phosphorylation diminishes during fruit development. *Plant Physiology* 133: 84–99.

Sasser, J.N. and Carter, C. C. (1982). Root-knot nematodes (*Meloidogyne* spp): Identification, morphological and physiological variation, host range, ecology, and control, pp.21-32. **In:** Nematology in the southern region of the United States, R.D. Riggs (ed.). *Southern Cooperative Service Bulletin* 276. pp. 206.

Schaff, J.E., Neilsen, D.M., Smith, C.P., Scholl, E.H., and Bird, D. McK. (2007). Comprehensive transcription profiling in tomato reveals a role for glycosyltransferase in *Mi*-mediated nematode resistance. *Plant Physiology* 144: 1079-1092.

Siddiqui, M.A. and Alam, M.M. (1987). Efficacy of seed dressing with extracts of neem, persian lilac against *Meloidogyne incognita* and *Rotylenchus reniformis*. *Nematologia Mediterranea* 15(20):339-403.

Sidhu, G. and Webster, J.M. (1981). Influence of population levels of root-knot nematodes on Fusarium wilt severity of tomato. *Phytoprotection* 62: 61-66.

Sikora, R. A. and Fernandez, E. (2005). Nematode parasites of vegetables. **In**: Plant Parasitic Nematodes in Subtropical and Tropical Agriculture. M. Luc, R.A., Sikora, and J. Bridge, (eds.). 2nd edition, CABI publishing, pp. 319-392.

Sikora, R.A. (1992). Management of antagonistic potential in agriculture ecosystems for biocontrol of plant- parasitic nematodes. *Annual Review of Phytopathology* 30: 245-270.

Singh, R.V. and Khera, S. (1979). Pathogenicity of *Rotylenchulus reniformis* on brinjal (*Solanum melongena* L.). *Indian Journal of Nematology* 9: 117-124.

Sorribas, F.J., Ornat, C., Verdejo-Lucas, S., Galeano, M. and Valero, J. (2005). Effectiveness and profitability of the *Mi*-resistance gene in tomato over three consecutive growing seasons. *European Journal of Plant Pathology* 111: 29-38.

Soule, J. (1993). *Tagetes minuta:* A potential new herb from South America. **In**: New crops, Proceedings of the New Crops Conference. J. Janick and J. E. Simon (eds.), New Crops, Wiley, NY. pp. 649-654.

Starr, J. L., Bridge, J. and Cook, R. (2002). Resistance to Plant-parasitic Nematodes: *History, current use and future potential.* **In**: Plant Resistance to Parasitic Nematodes, J.L. Starr, R. Cook and J. Bridge (eds.), CAB International, Wallingford, UK. pp. 5-17.

Starr, J.L. and Mercer, C.F. (2009). Development of resistant varieties. **In**: Root-knot Nematodes, R.N. Perry, M. Moens, and J.L. Starr (eds.). CAB International, Wallingford, UK, pp. 326-337.

Starr, J.L., Cook, R. and Bridge, J. (2002). Plant Resistance to Parasitic Nematodes. CAB International, Wallingford, UK, pp. 1-70.

Steven, A.S. and Celso, L.M. (2005). Tomato. http://usna.usda.gov/h666/138tomato, 11/8/2010.

Stirling, G.R. (1991). Biological Control of Plant Parasitic Nematodes. CAB International, Wallingford, UK. pp. 275.

Taylor, A.L. and Sasser, J.N. (1978). Biology, Identification and Control of Root-Knot Nematodes (Meloidogyne spp.). North Carolina State University Department of Plant Pathology and USAID, Raleigh, North Carolina. pp 111.

Thies, J. A., Dickson, D. W., and Fery, R. L. (2008). Stability of resistance to root-knot nematodes in 'Charleston Belle' and 'Carolina Wonder' bell pepper in a sub-tropical environment. *Horticultural Science* 43:188–190.

Thies, J.A., and Fery, R.L. (2001). Characterization of *Capsicum chinensis cultigens* for resistance to *Meloidogyne arenaria, M. hapla, and M. javanica. Plant Disease* 85: 267-270.

Thompson, J.F., Mitchell F.G. and Kashmire, R.F. (1998). Room, Vacuum Transport and Ice Cooling. **In**: Commercial Cooling of Fruits, Vegetables and Flowers, J.F. Thompson, F.G. Mitchel, T.R. Rumsey, R.F. Kasmire and C.H. Crissesto (eds.). University of California, Division of Agriculture and Natural Resources, USA. pp. 28-32.

Tony, L. (2002). Sustainable tomato production. Pest management notes 13. A briefing for the IPM in developing countries, Pesticide Action Network, UK.

Trudgill, D.L. and Blok, V.C. (2001). Apomictic, polyphagous root-knot nematodes: exceptionally successful and damaging biotrophic root pathogens. *Annual Review of Phytopathology* 39: 53-77.

Tzortzakakis, E.A., Trudgill, D.L. and Philips, M. (1998). Evidence for a dosage effect of *Mi* gene on partially virulent isolates of *Meloidogyne javanica*. *Journal of Nematology* 30: 76-80.

Van Gundy, S.D., Kirkpatrick, J.D. and Golden, J. (1977). The nature and role of metabolic leakage from root-knot nematode galls and infection by *Rhizoctonia solani*. *Journal of Nematology* 9: 113-121.

Wang, Z., Potter, R.H. and Jones, M.G.K. (2003). Differential display analysis of gene expression in the cytoplasm of giant cells induced in tomato roots by *Meloidogyne javanica*. *Molecular Plant Pathology* 4: 361-371.

Whitehead, A.G. and Hemming, J.R. (1965). A comparison of some quantitative methods of extracting small vermiform nematodes from soil. *Annals of Applied Biology* 55: 25-38.

Williamson, V.M. (1998). Root-knot resistance genes in tomato and their potential for future use. *Annual Review of Phytopathology* 36: 277-293.

Williamson, V.A. and Roberts, P.A. (2009).). Mechanisms and Genetics of Resistance. **In**: Root-knot nematodes, R.N. Perry, M. Moens, and J.L. Starr (eds.). CAB International, Wallingford, UK. pp. 301-325.

Williamson, V.M. and Hussey, R.S. (1996). Nematode pathogenesis and resistance in plants. *Plant Cell* 8:1735–45.

Wolff, H. (1999). Economics of Tomato Production with special Reference to Aspects of Plant Protection: A case study of two tomato production systems in Brong-Ahafo Region, Ghana. Ghanaian-German Project for Integrated Crop Protection, GTZ Eschborn. pp. 131.

Wu, T. and Abbott, J.A. (2002). Firmness and force relaxation characteristics of tomato stored ~~intact~~ or as slices. *Postharvest Biological Technology* 24: 59–68.

Yang, B. and Eisenback, J. D. (1983). *Meloidogyne enterolobii* n.sp. (*Meloidogynidae*), a root-knot nematode parasitizing Pacara Earpod Tree in China. *Journal of Nematology* 15:381–391.

http://www. Dave's Garden.com, browsed, 18 July, 2011.

http://www.Early-tomato.com, browsed, 16 July, 2011.

http://www.grow.cook.eat.com, browsed, 16 July, 2011.

http://www.real food, real farmers, real community.com, browsed, 18 July, 2011.

http://www.scovillescaleforpeppers.com, browsed, 12 June, 2011.

http://www.tomatodirt.com, browsed, 16 July, 2011.

APPENDICES

Appendix 1. Root gall index rating system by Hussey and Boerma (1981)

Interpretation of the root-knot galling score:

0 = complete and healthy root system, no galling

1 = trace infection with a very few small galls

2 = less than 25% roots galled

3 = 25-50% roots galled

4 = 51-75% roots galled

5 = greater than 75% roots galled

Appendix 2. Summary ANOVA of the sugar content of riped tomato fruits

Source of variation	d.f.	Sum of squares	Mean squares.	F pr.
Treatment	7	12.074	1.725	0.83
Residual	24	25.825	1.176	
Total	31	37.899		
LSD (5%)	1.5			
CV (%)	27.6			

Appendix 3. Summary ANOVA of the firmness of riped tomato fruits

Source of variation	d.f.	Sum of squares	Mean squares.	F pr.
Treatment	7	11.090	1.584	0.951
Residual	24	131.090	5.462	
Total	31	142.180		
LSD (5%)	3.4			
CV (%)	40.3			