Chapter 17
Nematode Pests of Minor Tropical and Subtropical Crops

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17.1 Introduction

Besides banana (see Chap. 16), various subtropical and tropical crops are grown in South Africa (SA). These include avocado (*Persea americanum*), which is the biggest crop in terms of production, followed by mango (*Mangifera indica*), macadamia (*Macadamia integrifolia*), guava (*Psidium guajava*), pecan (*Carya illinoinensis*), papaya (*Carica papaya*), litchi (*Litchi chinensis*), ginger (*Zingiber officinale*), granadilla (*Passiflora edulis* and *P. edulis* f. *flavicarpa*), coffee (*Coffea arabica*), tea (*Camellia sinensis*) and black pepper (*Piper nigrum*).

Although a wide range of plant-parasitic nematodes is associated with the different subtropical and tropical crops, only those that are economically important are presented in this chapter.

17.2 Avocado

Avocado originates from Central America and is consumed primarily as fresh fruit. The local avocado industry consists of 18,000 hectares (ha) of commercial orchards. The majority of these orchards are situated in the north-eastern part of the country in the Limpopo and Mpumalanga provinces. Avocado is also grown commercially in certain areas of the KwaZulu-Natal Province. Annual production is in the region of 100,000 metric tons (MT), of which approximately 46,000 MT is exported to Europe and the United Kingdom (UK) (SAAGA 2014).

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H. Fourie et al. (eds.), *Nematology in South Africa: A View from the 21st Century*, DOI 10.1007/978-3-319-44210-5_17

17.2.1 Plant-Parasitic Nematodes Associated with Avocado

Thirty-seven plant-parasitic nematode species have been recorded on avocado in SA (Kleynhans et al. 1996, SAPPNS[1]) of which only *Meloidogyne javanica* (Treub, 1885) Chitwood, 1949, *Criconemoides xenoplax* (Raski, 1952) de Grisse and Loof, 1989, *Helicotylenchus dihystera* (Cobb, 1893) Sher, 1961 and *Xiphinema elongatum* Schuurmans Stekhoven and Teunissen, 1938 are potential pests.

17.2.2 Damage, Symptoms, Interactions with Other Pathogens and Management Strategies

Although large populations of plant-parasitic nematodes can occur, there are no reports of nematode damage to avocado in SA (Willers 2001). It is, therefore, difficult to determine the economic importance of nematode pests on avocado production, as also noted by El-Borai and Duncan (2005). However, the root rot pathogen *Phytophthora cinnamomi* is responsible for severe decline on avocado orchards in SA and it might be possible that the nematode pest effect is overshadowed by this fungus, as suggested by Milne (1982a).

Willers (1999, 2001) reported that a large avocado producer in the Nelspruit (now known as Mbombela) area of Mpumalanga reversed decline in tree performance in orchards by using cadusaphos (10 % granules). Before this intervention, the application of potassium phosphate for *Phytophthora* root rot control was not successful. Ultimately, soil and root samples taken from the orchards revealed the presence of *C. xenoplax* and *H. dihystera* in high and *X. elongatum* in moderate numbers.

In Israel, *Xiphinema diffusum* Lamberti and Bleve-Zacheo, 1979 is often recovered from avocado orchards in high numbers. Cohn (1968) reported reduced seedling growth in pot trials, but post-plant treatment with 1,2-Dibromo-3-chloropropane (DBCP) treatments in orchards did not consistently improve tree performance. Sher (1955) attributed reduced tree growth in California (USA) to the presence of *Pratylenchus vulnus* Allen and Jensen, 1951. This was confirmed in glasshouse inoculation experiments and pre-plant fumigation trials with 1,2-Dichoropropane; 1,3-Dichloropropene (DD) (Sher et al. 1959). Locally the coffee lesion nematode, *Pratylenchus coffeae* (Zimmerman, 1898) Filipjev and Schuurmans Stekhoven, 1941, was often found in high numbers in avocado root and soil samples from the Levubu area (Limpopo Province) (Willers 2001).

No nematicides are registered for use on avocado in SA. Orchards with declined tree performance often react negatively to *Phytophthora* root rot treatments in the presence of high plant-parasitic nematode numbers. For such situations, Willers

[1] Dr Mariette Marais of the Nematology Unit, Biosystematics Division, Agricultural Research Council–Plant Protection Research Institute is thanked for the use of data from the South African Plant-Parasitic Nematode Survey (SAPPNS) database; E-mail: maraism@arc.agric.za.

(2001) recommended the use of organic amendments, including kraal manure, to supplement the fertilizer program. The possible interaction between nematode pests and *Phytophthora* root rot on avocado still has to be investigated locally.

17.3 Mango

In SA, the mango industry expanded rapidly in the 1980s and 1990s but subsequently declined. Currently the commercial production area is about 7,500 ha and is situated mainly in the Limpopo Province, followed by Mpumalanga Province and a small area in the KwaZulu-Natal Province.

17.3.1 Plant-Parasitic Nematodes Associated with Mango

Although 40 plant-parasitic nematode species have been associated with mango in SA (Kleynhans et al. 1996, SAPPNS), none seems to be damaging. Milne (1982a) observed the ring nematode *Hemicriconemoides strictathecatus* Esser, 1960, feeding on mango roots together with *X. diffusum*. Later surveys, however, indicated that when litchi and mango orchards were adjacent to one another, *H. strictathecatus* was more prevalent in litchi than mango roots (Willers 1998). According to McSorley (1981), *H. strictathecatus* is the most widely distributed nematode species associated with mango. No endoparasitic nematode species have been recorded on mango in SA and according to McSorley and Parrado (1983), *Rotylenchulus reniformis* Linford and Oliveira, 1940, is the only sedentary nematode affecting mango. In the Onderberg region (Mpumalanga Province), this nematode occurs on papaya and banana but no records of infections of mango exist.

17.3.2 Damage Potential and Management Strategies

In inoculation trials, mango seedlings were damaged at a population level of 6 *H. strictathecatus* individuals cm^{-3} soil (Saeed 1974). However, in trials with fenamiphos in a 5-year-old orchard (cv. Sensation) Willers (1998) found no response to treatment, indicating that plant-parasitic nematodes had no significant effect on yield. He suggested that the local populations of *H. strictathecatus* might belong to a different biotype with a different host range than the potentially damaging species reported by Saeed (1974). Badra and Khattab (1982) found that the growth regulator, ethephon, reduced *R. reniformis* population levels in soil and roots of mango. This response should be evaluated on other subtropical crops where nematode problems occur and where ethephon is used.

17.4 Macadamia

Macadamia belongs to the Proteaceae family and originates from Queensland, Australia, from where it has been introduced to SA. About 21,500 ha are planted in the Mpumalanga, Limpopo, KwaZulu-Natal and the Eastern Cape provinces.

17.4.1 Plant-Parasitic Nematodes Associated with Macadamia

Twenty-eight plant-parasitic nematode species have been associated with macadamia in SA (Kleynhans et al. 1996; SAPPNS). These include potential pests such as *Meloidogyne ethiopica* Whitehead, 1968, *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949, *Criconema mutabile* (Taylor, 1936) Raski and Luc, 1985 and *H. dihystera*. In the Lowveld of Mpumalanga, very high numbers of *H. dihystera* have been associated with trees in macadamia orchards. However, no negative effects on crop production or growth of the infected trees were observed. Willers (2001) suggests that Proteaceae might have an intrinsic tolerance to plant-parasitic nematodes since no damage has been reported from the cut flower industry in the Cape where many *Protea* spp. are cultivated intensively for export.

17.5 Guava

Guava is indigenous to tropical America and is consumed as fresh fruit and in processed forms as juice, canned fruit and jelly. There are about 1,200 ha of commercial plantings in the Western Cape, Limpopo and Mpumalanga provinces.

17.5.1 Plant-Parasitic Nematodes Associated with Guava

Thirty-nine plant parasitic nematode species have been associated with guava in local orchards (Kleynhans et al. 1996, SAPPNS). Nonetheless, economic damage is limited to trees infected with *Meloidogyne* and *H. dihystera* (Willers 1997a). According to Willers (2001), economic nematode damage was limited to two species, namely, *Meloidogyne enterolobii* Yang and Eisenback, 1983 (previously known as *Meloidogyne mayaguensis* Rammah and Hirschmann, 1988), which is regarded as an emerging threat to crop production worldwide (Jones et al. 2013) (Box 17.1) and *H. dihystera*. Severe root-knot nematode damage on commercial guava plantings was observed for the first time in 1991 and the species initially identified was *M. mayaguensis* (Willers 1997b). More recently *M. incognita* and *M. javanica* have been recorded on guava trees in the Limpopo and Mpumalanga provinces in combination with *M. enterolobii*. In more than 50% of the orchards sampled, a combination of at least two *Meloidogyne* spp. was found (Agenbag 2016). More studies are underway to better understand the *Meloidogyne* spp. complex on guava and to determine the life cycle of *M. enterolobii* under local conditions.

Box. 17.1 *Meloidogyne enterolobii*
Meloidogyne enterolobii is a very aggressive root-knot nematode that is able to overcome the root-knot resistance genes in a number of crops, including tomato, bell pepper, cotton, cowpea, potato, sweet pepper, sweet potato and soybean (Fargette et al. 1996; Brito et al. 2004; Anonymous 2011; EPPO 2011; Castagnone-Sereno 2012; Jones et al. 2013).

Since its discovery in roots of the Pacara Earpod tree (*Enterolobium contortisiliquum*) in China in 1983, this thermophilic root-knot nematode species has also been reported from various tropical and subtropical countries in Asia, Africa, Central America and the Caribbean, North and South America as well as Europe (Blok et al. 2002; Brito et al. 2004; Kiewnick et al. 2009; Tigano et al. 2010; Anonymous 2011; Ramirez-Suáres et al. 2014). *Meloidogyne enterolobii* was first recorded from SA, from roots of guava (*Psidium guajava*) and black-jack (*Bidens pilosa*), just prior to 1997 in the Mbombela area (Mpumalanga Province) (M. Marais, unpublished data; Onkendi and Moleleki 2013a). In 2011 and 2013, individuals of *M. enterolobii* were recorded from glasshouses near Barberton (Mpumalanga Province) in roots of green pepper (Marais 2014) and in Letsitele (Limpopo Province) in guava roots (Marais 2014). Moreover, after 2012 *M. enterolobii* was identified from potato tubers in the KwaZulu-Natal Province (Onkendi and Moleleki 2013b) and the Mpumalanga Province (Agenbag 2016). It appears that this species is more widespread in South Africa than previously anticipated.

It is important to note that the identity of *M. enterolobii* is often confused with that of *M. incognita*, which is widely distributed and a serious pest of numerous crops in SA. The reason for this is that to distinguish these two species from one another, using only morphological/morphometrical characters, identification is challenging. Rather, molecular techniques should be used in combination with the standard measurements to ensure accurate identification of these two cryptic species.

17.5.2 Symptoms, Interactions with Other Pathogens and Management Strategies

Root-knot nematodes can have a devastating effect on the more recently available guava cvs. Root systems of guava vines are severely galled (Fig. 17.1a) and rotting takes place due to infection by other soil pathogens. Above-ground symptoms are

Fig. 17.1 (**a**, **b**) Galled roots of a guava tree infected with *Meloidogyne enterolobii* (**a**), resulting in a poorly growing and dying tree on the left (**b**) in the Mbombela area (Mpumalanga Province) (Kirk West, Port Elizabeth, South Africa)

reduced growth and vigor, leaf yellowing, smaller leaves, reduced fruit set, smaller fruit and, in severe cases, trees die (Fig. 17.1b).

Fan Retief, a highly resistant cv. to root-knot nematodes, was used historically as the only germplasm source for production and is still widely grown in the Western Cape Province. Root stock TSG2, resistant to the crippling guava wilt disease caused by *Nalanthamala psidii*, was reported as highly susceptible to plant-parasitic nematodes in the late 1970s (Willers 1997a) (Box 17.2).

Box. 17.2 Breeding for Resistance Against Pests and Diseases. An Example from the Guava Industry

During the early 1990s, a new disease, guava wilt disease (GWD) caused by *Nalanthamala psidii*, broke out in SA and almost crippled the guava industry in the Limpopo and Mpumalanga provinces. At that time one cultivar (cv.), Fan Retief, was used in practically all the guava orchards. Plant material from local and international seed was screened for resistance to this disease and eventually, during the late 1990s, a cv., TSG2, was developed that was highly resistant to GWD. However, it soon became obvious that this cv. was much more susceptible to plant-parasitic nematodes than Fan Retief. Before the advent of TSG2, plant-parasitic nematodes were not perceived to be a real problem on guava. However, this scenario changed and nematode pests proved to be a major problem with damage so severe that adult trees were dying.

It is important, when evaluating plant material, to include the major pests and diseases in the screening programs. As part of the guava breeding program at the Agricultural Research Council–Institute for Tropical and Subtropical Crops (ARC–ITSC), plant material is now routinely tested for resistance against GWD and the more damaging nematode pest species, to identify resistance or tolerance before the plant material is released.

When planting a new orchard, it is very important to establish the presence or absence of root-knot nematodes in the field. When root-knot nematodes are present, nematode control is compulsory prior to planting or at planting with one of the below-mentioned products.

Screening for resistance or tolerance of guava cvs to *M. incognita*, *M. javanica* and *M. enterolobii* (Willemse et al. 2014) and guava wilt disease is conducted on an ongoing basis.

Nematicides that contain the active substances (a.s.) fenamiphos and cadusaphos are registered on guava in SA. Application should be done at the correct time to ensure that no residues are found in the fruit at harvesting. The pre-harvesting interval (PHI) for fenamiphos is 120 days. Nematodes should be monitored annually to prevent the build-up of high nematode population densities. Application of organic material (e.g., cattle or chicken manure) at 40 MT ha^{-1} can help to suppress nematode pest densities (Willers 2001). Any organic amendments (mulches, compost, manure) and root growth stimulants (e.g., *Trichoderma*) can be used to improve root growth, especially in the initial 6 months after planting.

17.6 Pecan

Pecan is indigenous to the central southern states of the USA. It is well adapted to large areas of SA where short, cold winters and long, very hot summers occur. Trees have been successfully established in valleys and along rivers where the winter temperatures are low and frost occurs. The main production area is in the Northern Cape Province, with small plantings in other provinces.

17.6.1 Plant-Parasitic Nematodes Associated with Pecan

In SA, 28 plant-parasitic nematode species have been associated with the roots of pecan trees (Kleynhans et al. 1996, SAPPNS). Of these, the pecan root-knot nematode *Meloidogyne partityla* Kleynhans, 1986, as well as *Xiphinema vitis* Heyns, 1974, and *C. xenoplax* are considered the major pests. *Meloidogyne partityla* only parasitises pecan trees and was probably imported with plant material from the USA (Kleynhans et al. 1996).

17.6.2 Symptoms and Management Strategies

The root symptoms caused by *M. partityla* are not the typical galling as presented on other crops by *Meloidogyne* spp., but rather a general absence of feeder roots in the top soil. When high numbers of *M. partityla* eggs and second-stage juveniles (J2) are present, newly formed roots are often swollen at the tip and club-shaped. Damage by the plant-parasitic nematode complex associated with pecan is of a subtle nature and symptoms manifest as a general decline in the overall growth of infected trees over a prolonged period. This may become serious if left untreated as both pecan kernel size and yield are influenced adversely (Willers 2001).

Products containing the a.s. fenamiphos (GR) are the only nematicides registered on pecan. It is applied in the irrigation zone underneath the tree canopy during spring each year with a 120 day PHI.

To prevent the spreading of *M. partityla* to other possible pecan-cultivating areas in SA, control measures were enforced on nurseries in Mpumalanga to ensure that they provide producers with trees that are free of nematode pests (Willers and Daneel 1993).

Recommendations to achieve this included:

(i) Soil fumigation with methyl bromide (hot-gas method) at 175 g m^{-3} for 48 h under gastight tarpaulins
(ii) Use of a primary water source for irrigation
(iii) Location of nurseries in areas where re-infestation by run-off water from infested orchards can be prevented

17.7 Papaya

Papaya originates from tropical America but is widely distributed today. Commercial production of the crop locally is limited to about 800 ha in the Limpopo and Mpumalanga provinces.

17.7.1 Plant-Parasitic Nematodes Associated with Papaya

In SA, 25 plant-parasitic nematode species have been associated with papaya (Kleynhans et al. 1996, SAPPNS), but only two genera (*Meloidogyne* and *Rotylenchulus*) seem to be linked with economic damage (Milne 1982a; Willers and Neethling 1997; El-Borai and Duncan 2005). *Rotylenchulus reniformis* Linford and Oliveira, 1940, has been reported on papaya from around the world (El-Borai and Duncan 2005). Locally it has been recorded from the Onderberg region in the Mpumalanga Province by Willers and Neethling (1994). Mean population levels were 4,100 second-stage juveniles (J2) 250 ml $soil^{-1}$, with numbers reaching 12,900 J2 250 ml $soil^{-1}$.

17.7.2 Symptoms, Interaction with Other Soil-borne Pathogens and Management Strategies

Root damage caused by root-knot nematode parasitism is often severe and galls can reach the size of golf balls (Milne 1982a). Additionally root infections enhance the chances of root rot, which reduces yield and life expectancy (Milne 1982a). Seedling growth in pot trials was greatly retarded as a result of root-knot nematode parasitism (Lamberti et al. 1980), with symptoms including severely chlorotic leaves, damage to the tap root and proliferation of lateral roots (Lamberti et al. 1980; Darekar and Mhase 1986).

Severe yield losses, toppling and plant death have been attributed to the *R. reniformis* infection of papaya trees (Ayala et al. 1971; Singh and Farrell 1972). The combined occurrence *of R. reniformis* and *Phytophthora nicotianae* var. *parasitica* killed papaya trees in Brunei in Asia (El-Borai and Duncan 2005). Damage by *R. reniformis* has not been determined in SA, but it is believed that this nematode pest might be of economic importance in papaya orchards in the Onderberg region (Mpumalanga Province) where it occurs in combination with *Meloidogyne* spp. (Willers and Neethling 1997). Root rot caused by *Phytophthora* might be enhanced by the presence of these nematode pests.

Fenamiphos is registered for control of plant-parasitic nematodes on papaya and producers have reported considerable yield and growth improvements using the product (Willers 2001).

17.8 Litchi

Litchi is endemic to southern China and is marketed as fresh, canned and dried fruit. Local production of litchi covers about 1,800 ha and is situated in the Limpopo, Mpumalanga and KwaZulu-Natal provinces.

17.8.1 Plant-Parasitic Nematodes Associated with Litchi

Nine plant-parasitic nematodes have been associated with litchi in SA (Kleynhans et al. 1996, SAPPNS). During a nematode survey from three provinces, Daneel et al. (2010) recorded that many plant-parasitic nematode species were limited to one area only (Table 17.1). For example, *Pratylenchus* and *Xiphinema* spp. were recorded only in the Tzaneen area (Limpopo Province),

Table 17.1 Plant-parasitic nematodes recorded from soil samples (250 g) obtained during a survey of litchi trees with the minimum and maximum numbers of nematodes, their frequency of occurrence (%) in the samples and the areas where the species occurred (Daneel et al. 2010)

Plant-parasitic nematode species	Minimum and maximum population levels	Percentage occurrence in samples[a]	Presence of nematode species listed province		
			Limpopo	Mpumalanga	KwaZulu-Natal
Hemicriconemoides strictathecatus	0–4,950	100	+[b]	+	+
Meloidogyne sp.	0–900	43	–[c]	–	+
Helicotylenchus sp.	0–2,050	88	–	+	–
Pratylenchus sp.	0–50	7	+	–	–
Xiphinema spp.	0–900	100	+	–	–
Hemicycliophora sp.	0–8,350	17	–	–	+

[a]Percentages are valid for the provinces in which the nematode species were found. Except for ring nematodes all species were limited to one area only
[b]Presence of nematode species
[c]Absence of nematode species

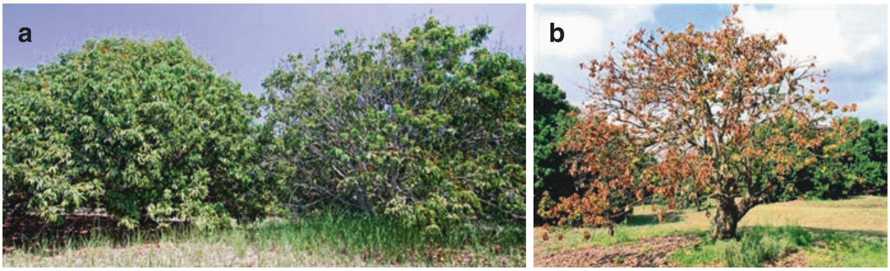

Fig. 17.2 (**a**, **b**) Typical symptoms of nematode damage in a litchi tree (**a**: *tree on right side*) with bare twigs and branches visible. This contrasts with symptoms of litchi dieback (**b**), which results in branches or the whole tree dying off and which is caused by a fungal complex (**a** Kirk West, Port Elizabeth, South Africa; **b** Mieke Daneel, Agricultural Research Council – Institute for Tropical and Subtropical Crops, Mbombela, South Africa)

whereas *Hemicycliophora* spp. (sheath nematode) was only observed in KwaZulu-Natal Province (Table 17.1). *Criconema* sp. (ring nematodes), *H. strictathecatus* and *Hemicycliophora* sp. are responsible for most of the damage associated with litchi-tree decline (Daneel et al. 2010). Milne (1982b) recorded *X. diffusum* also as a major pathogen, but from the survey by Daneel et al. (2010), *Xiphinema* spp. were only found in one production area and did not seem to be linked with severe damage to litchi trees.

17.8.2 Symptoms, Interaction with Other Pathogens and Management Strategies

Symptoms associated with nematode damage include the occurrence of stubby, darkened roots, with limited development of feeder roots resulting in low root mass. The loss of feeder roots culminates in poor uptake of nutrients and water (Daneel 2010).

Typical above-ground symptoms are the presence of bare twigs and branches, leaf chlorosis, leaf tip burn, poor flowering and excessive fruit drop (Fig. 17.2a). However, litchi dieback (when branches or the whole tree dies back: Fig. 17.2b) is caused by a series of fungal pathogens initiated by environmental stress, including soil compaction and water stress. In such situations, nematode control will not have a significant effect on tree vigor as the fungi need to be controlled (Daneel 2010; Steyn et al. 2013).

Recovery of trees can be facilitated by effective mulching, using any organic material such as manures throughout the year, while nematicide treatments should be done in spring or late summer after harvest. In poor performing orchards, all other cultivation practices such as fertilization and irrigation should be optimal to limit nematode-induced root damage.

Fenamiphos (Nemacur® GR) and cadusaphos (Rugby® GR and ME) are registered in SA for nematode control on litchi. The products should be applied evenly under the canopy after the area has been cleared from leaves and other organic material. Fenamiphos can only be applied in early spring because of a 70-day PHI. Cadusaphos has a zero day PHI and can be used throughout the season, but should preferably be applied after the first good rains have fallen. To minimize the possibility of accelerated microbial degradation (AMD) (see Sect. 6.4, Chap. 6), repeated applications of the same product or group of compounds with the same active substance should be avoided.

17.9 Granadilla

Granadilla is a vine and is mostly found in the tropics and subtropics. It is believed to have originated in a region ranging from southern Brazil to northern Argentina. In SA, a yellow form, *P. edulis* f. *flavicarpa*, and a purple form, *P. edulis*, of granadilla are grown. The yellow form is more tolerant to nematode damage (Milne 1982a) and was therefore commonly used as a root stock for the purple form as the latter is preferred in taste and colour. Both are produced in SA. The granadilla is mainly planted for juice although some fruit is sold for the fresh market, both locally and internationally. Granadilla is grown in most provinces in SA but the total production area does not exceed 500 ha in total.

17.9.1 Plant-Parasitic Nematodes Associated with Granadilla

Thirty-eight plant parasitic nematode species have been associated with granadilla (Kleynhans et al. 1996, SAPPNS), but only *M. incognita* and *M. javanica* are of economic importance in SA. *Rotylenchulus reniformis* is also described as causing economic damage to granadilla (El-Borai and Duncan 2005), but this nematode has not been recorded infecting granadilla in SA.

17.9.2 Symptoms, Interactions with Other Pathogens and Management Strategies

Root damage as a result of nematode infection manifests as typical galling with a reduced root system. Above-ground symptoms are leaf chlorosis, excessive leaf and fruit drop, reduced growth and faster (premature) wilting on hot days.

The life span of the vine is drastically reduced by either the nematode infection alone or by the concomitant occurrence of nematode pests and root and soil fungal pathogens, including *Phytophthora*, *Pythium* and *Fusarium* spp. Daneel and Garber (2009) reported the frequent concurrent occurrence of root rot pathogens with root-knot nematodes in granadilla, with devastating effect on the vines.

Management practices such as optimal irrigation schedule, good fertilization and proper soil preparation can reduce the effects of pests and pathogens and extend the life span of the crop. No post-plant nematicides are registered for use on granadilla in SA, but more environmentally-friendly products were tested locally. Results showed that CropGuard® (a.s. furfuraldehyde), Bioneem (a neem-based product) and cadusaphos provided excellent nematode control in all areas tested, while other products only gave good control in some of the areas (Daneel and Garber 2009). However, until now no nematicide, synthetically-derived or biological agent, is registered on granadilla in SA (Van Zyl 2013).

For new granadilla plantings, it is important to ensure that nematode-free nursery material is obtained. Field trials with fumigants showed yield increases of 40 % over a 3-year period (De Villiers and Milne 1973). This practice is, however, not used in the granadilla industry. New plantings can be started with the application of a nematicide prior to, or at, planting. Milne (1982a) suggested that crop rotation should be useful for nematode control as well as the use of rootstocks that are tolerant to root-knot nematodes, but limited research has been done on this aspect. Research conducted recently on resistance screening showed that cv. Edulis maintains the highest nematode numbers followed by cv. Ester. By contrast, *Passiflora alata x* (*P. alata x P. caerulea*) and *P. edulis* f. *flavicarpa* selections seemed to exhibit resistance (Husselman et al. 2014). However, much more research is needed before a resistant cv. will be available for release.

17.10 Ginger

Ginger is the rhizome of a herbaceous perennial belonging to the Zingiberaceae family. The country from where ginger originated is unknown but is believed to be China or India where more than 50 % of the world's dried ginger is produced. Ginger plantings are propagated by seed rhizomes or setts, which are cut into small pieces of 2.5–5 cm length with each having one or two good buds (Koshy et al. 2005). In SA, the main ginger-producing areas are Burgershall and Kiepersol in the Mpumalanga Province. Production is limited to areas with high temperatures and humidity in summer.

17.10.1 Plant-Parasitic Nematodes Associated with Ginger

A large number of plant-parasitic nematodes have been recorded from ginger worldwide, but the most important are *Meloidogyne* spp., *Radopholus similis* (Cobb, 1893) Thorne, 1949, and *P. coffeae* (Koshy et al. 2005). All these nematode pests occur in SA, but severe damage is only caused by *M. incognita* and *M. javanica*. Although *R. similis* is present in banana plantations in the main ginger-producing areas, no natural infection of ginger by this nematode pest has been recorded (Willers 2001) since old banana soils are seldom used for ginger cultivation. High numbers of *H. dihystera* have often been associated with ginger but the pathogenicity has not been evaluated. In the Levubu area of the Limpopo Province, isolated cases of severe *P. coffeae* infections have been recorded on ginger.

17.10.2 Symptoms, Damage Potential and Management Strategies

Root-knot nematodes cause galling and rotting of the roots and rhizomes. When ginger is exported as a fresh market commodity, nematode-infected rhizomes adversely affect the appearance and quality of the produce and limit its shelf life drastically by decay, rapid water loss and shrinkage of the rhizomes (Willers 2001). Second-stage juveniles of *Meloidogyne* spp. invade the rhizome through the axils of the leaf sheaths in the shoot apex during the early growth stages. In fleshy roots, the entire length is invaded while in fibrous roots, invasion takes place in the differentiation zone behind the root tip. In the roots, the life cycle takes about 21 days, whereas in the rhizome the life cycle is completed in 40 days at 30 °C (Cheng and Tu 1979). Galls are limited to the fibrous roots whereas internal necrosis is visible in fleshy roots and rhizomes. Infected rhizomes have brown, water soaked areas in the outer tissues, particularly in the angles between shoots. In these areas, root-knot females

Fig. 17.3 Stunted growth of root-knot nematode infected ginger plants (*front*) (Kirk West, Port Elizabeth, South Africa)

can be observed. Nematodes continue to develop in the rhizome even after harvest and induce seed breakdown. Infected rhizomes, used as seed pieces, serve as a source of infection and dissemination. Root-knot nematode infestations in the field are observed as patchy areas where plants are stunted and appear chlorotic, and premature wilting occurs even where soil moisture levels are adequate (Fig. 17.3). In addition, despite proper fertilization nematode-infected plants often show various degrees of macro- and micronutrient deficiencies. Potassium uptake, in particular, is reduced when plants are infected by root-knot nematodes (Willers 2001).

In SA, severe root-knot infections of ginger plants may result in complete crop failure. Infected ginger is downgraded and can only be dried and milled for the spice market, at great financial loss. Root-knot nematode damage is aggravated by various stress factors experienced during ginger cultivation. A fertilizer programme based on leaf analysis, sufficient water and cooling irrigation during hot days (>28 °C) are prerequisites to achieve quality ginger rhizomes for export purposes (Willers 2001). When harvesting ginger during autumn and early winter, lifting of the rhizomes should happen as quickly as possible to prevent root-knot nematode infections in the rhizomes, especially when soil temperatures have not dropped during that period.

Effective nematode control on ginger starts with producing nematode-free planting material by selecting nematode-free rhizomes. In Australia (Pegg et al. 1974) and Fiji (Anonymous 1971), hot water treatment for 10–20 min, dependent on temperatures, is recommended to kill nematodes inside rhizomes. The rhizomes should be planted within one week after treatment. When severe nematode problems have been experienced in a field, it might be necessary to select an area where no ginger was planted previously.

Willers (2001) recommended soil fumigation as a basic requirement for the production of ginger for the export markets. Post-plant applications of fenamiphos granules at 1 kg 100 m^{-1} row should only be used as a supplementary control measure. Residues of systemic post-plant nematicides tend to accumulate in ginger rhizomes at the end of the season when reserves from the foliage are stored in rhizomes. Thus on ginger, a PHI of 250 days following application of fenamiphos must be strictly applied. Composted cattle manure applied at 40 MT ha^{-1} is recommended as a cultural control measure to suppress nematode numbers in ginger plantings. In Australia, a high level of root-knot nematode control was obtained by sawdust mulching to a depth of 5.0–7.5 mm, combined with post-plant applications of fenamiphos (Koshy et al. 2005).

In Queensland, Australia, Pegg et al. (1974) were able to increase yields by 80 % after fumigation of soils with DD before planting nematode-free seed rhizomes. Significant weight loss was recorded by Sukumaran and Sundararaju (1986) 6 months after inoculation of 10,000 root-knot nematodes plant^{-1}. They also reported significant yield losses with a soil population of 1 J2 30 g soil^{-1}.

17.11 Coffee

After a growing interest in local production from the 1970s to the 1990s, coffee plantings are almost non-existent in SA. At present, only about 50 ha is under coffee production. However, local communities have recently revived the interest in coffee and some new commercial plantings are planned (Naudé 2016). Two species in the Erythrocoffea group, namely, *Coffea arabica* (Arabica coffee) and *Coffea canephora* (Robusta coffee) are grown locally.

17.11.1 Plant-Parasitic Nematodes Associated With Coffee

Twenty-four plant-parasitic nematode species from 13 genera have been associated with coffee in SA (Cohn 1976; Anonymous 1989; Kleynhans et al. 1996, SAPPNS) but *P. coffeae*, which is an economically important pest of coffee worldwide (Campos and Villain 2005), has not been recorded (M Marais, Agricultural Research Council–Plant Protection Research Institute, Pretoria, 2016, personal communication). In a survey in the Hazyview area, undisclosed species of the three important nematode genera associated with coffee, namely, *Meloidogyne*, *Rotylenchulus* and *Pratylenchus* were recorded (Anonymous 1989). In 1999, *M. incognita* was identified for the first time on coffee plantings in the Bush Buck Ridge area of the Limpopo Province (Willers 2001).

17.11.2 Symptoms and Management Strategies

Root symptoms of nematode-infected plants appear as typical galling, peeling and cracking of infected roots. Above-ground symptoms include a general decline in tree growth, chlorosis, leaf fall and eventually plant death. Willers (2001) stated that only 0.6 MT ha^{-1} of green coffee beans was harvested in nematode-infested plantings. Leaf analysis indicated deficiencies of nitrogen (N), magnesium (Mg), manganese (Mn) and zinc (Zn).

For the control of *M. incognita*, clean planting material should be used at all times and when replanting, the land should be treated with a registered fumigant. No post-plant nematicides are registered on coffee and the use of organic fertilizer or organic amendments, together with foliar applications of macro and micronutrients, to compensate for root damage, is recommended.

17.12 Tea

Tea is grown in various areas where a wide variety of climatic conditions prevail. It requires well drained acid soil with a pH range of 4.5–5.5 and well distributed rainfall, totaling not less than 1000 mm annum^{-1} (Campos and Villain 2005). Previously in SA, there were some 3,000 ha of tea plantations, mainly in the subtropical area of the Limpopo Province, with small areas established in the Mpumalanga, KwaZulu-Natal and the Eastern Cape provinces. Currently hardly any tea (less than 50 ha) is cultivated in SA, but projects are underway to establish plantations in the Limpopo Province.

17.12.1 Plant-Parasitic Nematodes Associated with Tea

Twenty-three plant-parasitic nematode species have been associated with tea in SA (SAPPNS). However, records of nematode damage on tea in SA are absent (Willers 2001). According to Campos and Villain (2005), *Meloidogyne* is the most commonly encountered nematode pest in tea plantations in the different tea-growing areas of the world. *Meloidogyne brevicauda* Loos, 1953, was identified in a few limited areas in India and Sri Lanka. *Pratylenchus brachyurus* (Godfrey, 1929) Filipjev and Schuurmans Stekhoven, 1941, has also been recorded as a major pathogen of tea especially in young (1–3-year-old) plants (Campos and Villain 2005). In SA, this species has a wide distribution on a variety of crops but has not been recorded on tea, while *Pratylenchus zeae* Graham, 1951, has been recorded locally on tea.

17.12.2 Symptoms and Management Strategies

Meloidogyne spp. cause losses to mature tea with symptoms visible as stunting of bushes and yellow, small and dull colored leaves (Loos 1953). However, *Meloidogyne* spp. seem to mostly attack roots of young plants; mature plants seem to become less susceptible to this pest. Cohn (1976) recorded above-ground stunting and yellowing of tea seedlings in a nursery near Tzaneen (Limpopo Province) due to root-knot nematode parasitism. It is therefore important to ensure that potting soil and water that are free of nematode pests are used in tea nurseries. No chemicals have been registered for nematode control on tea.

17.13 Black Pepper

Black pepper is a perennial climber belonging to the Piperaceae family and is cultivated in the hot and humid parts of the world. It originated from the hills in the south-west of India where it is known as the 'king of spices' (Koshy et al. 2005). In SA, pepper production is restricted to the Levubu (Limpopo Province) and Hazyview (Mpumalanga Province) areas. Pepper can be propagated by cuttings or seed but the former is universally adopted.

17.13.1 Plant-Parasitic Nematodes Associated with Black Pepper

Meloidogyne incognita, *Meloidogyne hapla* Chitwood, 1949, *X. diffusum* and *Xiphinema mampara* f. *major* Hutsebaut, Heyns and Coomans, 1989, are associated with pepper locally (Kleynhans et al. 1996). Although *R. similis* is present in several banana-producing areas in SA, it has not been recorded from pepper roots, probably due to the small pepper production area and the use of virgin land to establish such crops.

17.13.2 Symptoms, Damage Potential and Management Strategies

Damage caused by *Meloidogyne* spp. is characterized by a gradual decline in the growth of black pepper vines and is visible as unthrifty growth and yellowing of leaves. The leaves exhibit a yellow discoloration of the interveinal areas, making the leaf veins quite prominent with a deep green color. On the other hand, leaves of vines attacked by *R. similis*, a major pathogen on pepper worldwide, have a uniform pale yellow or whitish discoloration and typical drooping (Koshy et al. 2005).

Root-knot nematode infected pepper roots can become heavily galled (Fig. 17.4). Although no damage studies have been done on pepper in SA, studies in India have shown that a 16 % growth reduction was observed over a period of 1 year in sterile soil in pots, with an initial *M. incognita* population of 10 J2 rooted cutting^{-1}.

Fig. 17.4 Root-knot nematode damage on pepper roots (Kirk West, Port Elizabeth, South Africa)

However, up to a 50 % growth reduction was recorded when 100,000 J2 were inoculated in the same experiment (Koshy et al. 1979). Freire and Bridge (1985) found *M. incognita* to be highly pathogenic when inoculated at 100–10,000 J2 seedling^{-1}.

No post-plant nematicides have been registered on pepper in SA, but the use of kraal manure at 5 kg vine^{-1} to replace standard fertilization programs would, in part, be useful to suppress nematode pest levels over the long term and provide sustainable production of the crop. Other amendments like sugarcane tops, grain straw and grass could also contribute toward higher carbon contents in soil in pepper production areas and contribute toward effective management of nematode pests. Effective irrigation scheduling and fertilization based on the exact requirements of plants, including micronutrients, would enhance pepper production and compensate for root damage caused by root-knot nematodes (Willers 2001). Additionally, nursery practices such as steam sterilization or fumigation should be such that potting soil and water are nematode free.

17.14 Conclusions

Plant-parasitic nematodes are not considered a serious problem of minor subtropical crops in many countries. However, nematode pests may adversely affect the production of coffee, ginger, granadilla, guava and litchi in certain countries, including SA. Furthermore, some plant-parasitic nematodes can cause severe damage when in combination with other soil-borne pathogens (e.g., bacteria and fungi). Due to the small size of the crops, in area planted and production quantities, limited funds are available for research. Also, chemical companies do not seem to be particularly interested in obtaining registrations for nematicides on these relatively minor crops. Therefore, it is important that alternative strategies are developed to control the nematode pests.

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