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INTEGRATED CONTROL OF NEMATODES OF COOL SEASON FOOD LEGUMES

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Abstract.

Production of cool season food legumes can be severely limited by nematode attack. Symptoms are yellowing, wilting, stunting, decreased biomass and seed yield. The most damaging nematodes are root-knot (*Meloidogyne* spp.), cyst (*Heterodera* spp.), root-lesion (*Pratylenchus* spp.) and stem (*Ditylenchus dipsaci*). Integrated control is required where profit margins and environmental considerations preclude the use of nematicides. The main factors for effective integrated control are: correct diagnosis of the nematode problems, use of tolerant and resistant cultivars of the main crops, rotation with resistant cultivars of other crops, fallowing, control of weed hosts, choice of sowing time, soil amendment, and sanitation. Present knowledge and future requirements for effective integrated control of the main nematode diseases of each of the cool season food legume crops are discussed.

INTRODUCTION

Nematodes are severe constraints of many crops all over the world. Attacked plants have inefficient root systems and are much more sensitive to biotic and abiotic stresses, such as drought and infertile soil. They may show symptoms of yellowing, wilting, stunting, decreased biomass and poor seed yield. Nematodes may also interact with other soil-borne pathogens increasing disease severity. They may inhibit root nodulation of legumes by rhizobia, thereby limiting nitrogen fixation in cropping systems, and they may reduce the nutritional quality of grain.

The cool-season food legumes, chickpea (*Cicer arietinum* L), pea (*Pisum sativum* L.), faba bean (*Vicia faba* L.), and lentil (*Lens culinaris* Medik.) are parasitised by many species of nematodes. The most damaging genera are the root-knot (*Meloidogyne* spp.), cyst (*Heterodera* spp.), root-lesion (*Pratylenchus* spp.) and stem nematodes (*Ditylenchus dipsaci*). On the basis of responses by 371 nematologists to a worldwide survey, Sasser and Freckman (1987) reported an average yield loss from nematodes of 12.3% for all crops and 13.7% for chickpea, valued at US $328 million (Sharma et al., 1992). Because control with nematicides is largely uneconomic for field crops, other methods must be sought and applied. Often each method is only partially effective and a combination of methods is required in various farming systems to achieve integrated control. These methods principally involve crop rotation with resistant (non-host) or partially resistant and tolerant crop species or cultivars of the same species. Strategies are adopted so that an intolerant crop cultivar is not grown more frequently than about once every 3 years. Rotations should involve economically viable or otherwise useful crops and this becomes more difficult with polyphagous nematode species with wide

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host ranges. Other strategies may be invoked, such as altering the sowing date to when the soil is at a less favourable temperature for reproduction of the particular species or supplying supplementary fertiliser or irrigation to offset effects of root damage. Sanitation to exclude nematode introduction into clean fields via infested soil, seed or runoff water should be practised.

During the last two decades, awareness of the impact of nematodes on cool season food legumes has increased, and a number of investigations have been undertaken at national and international research centres. This has resulted in more insights on nematode problems of food legumes and their management, which have been partly discussed in previous conferences (Greco and Di Vito, 1993; Sharma et al., 1994), book chapters (Sikora and Greco, 1990; Riggs and Niblack, 1993) and a monograph (Ali, 1995). The present knowledge of nematode problems of cool season food legumes and integrated control strategies will be discussed here.

CHICKPEA

Reports on numbers of pathogens, particularly the plant parasitic nematodes, associated with chickpea have markedly increased over the past 17 years (Nene et al., 1996). Sharma (1985) reported 46 nematode species or genera found associated with chickpea all over the world and Ali (1995) listed 97 species mainly from the Indian sub-continent and Mediterranean basin. However, several of the reported nematode species were found in the chickpea rhizosphere and there is no certainty that they feed on chickpea. Therefore, emphasis will be placed only on species with confirmed pathogenicity to chickpea.

Root-knot nematodes (*Meloidogyne* spp.)

These sedentary endoparasitic nematodes are distributed worldwide and are considered the major nematode group economically, because of the magnitude of damage caused to different crops and their wide host ranges. Roots of severely infested plants show large galls, poor nodulation and rotting. Interaction of these nematodes with soil-borne fungi has been demonstrated. Three species of root-knot nematodes are important pathogens of chickpea, *Meloidogyne artiellia* Franklin, *M. incognita* (Kofoid et White) Chitwood and *M. javanica* (Treub) Chitwood.

Meloidogyne artiellia occurs in the Mediterranean region and causes severe damage to chickpea in Italy, Spain and particularly Syria. The nematode develops well in the temperature range 15-25 °C and only one generation per growing season occurs. The female stage is attained after an accumulation of about 240 degree-days above 10 °C. It survives in soil during hot, dry summer months as eggs or anhydrobiotic second-stage juveniles (Di Vito and Greco, 1988b), with an average population decline of only 13% by the next autumn. Galls caused by this species are rather small or absent but egg masses (about 500 eggs in a large gelatinous matrix) are easily visible on the roots.

M. artiellia reproduces very well on cereals, cruciferous and leguminous plants. However, maize and the legumes, cowpea, lupin and sainfoin are non-hosts, while oats, french bean, lentil and soybean are poor hosts. The typical rotation of the Mediterranean area, which alternates cool season food legumes with winter cereals, is inappropriate in fields infested with this nematode.

Tolerance limits to the nematode of 0.1 and 0.01 eggs/cm^3 soil have been reported for winter and spring chickpea, respectively, with no yield in fields infested with 8 or 1 eggs/cm^3 soil respectively. The reproduction factor (ratio of the final to the initial population of the nematode) after growth of wheat, winter chickpea and spring chickpea, was 189, 55 and 3 respectively (Di Vito and Greco, 1988a).

Control

Although no chemical control has been attempted against this nematode, the use of nematicides should be effective. However, their use is not recommended as chemicals are expensive and are environmental hazards. Soil solarization also would be very effective in most of the Mediterranean countries but also too expensive for chickpea. Therefore, the management of the nematode should be based on proper crop rotations. In warm and irrigated areas, rotation of chickpea with summer crops is a useful option. Winter chickpea should be preferred over spring chickpea, which suffers more damage. Fallow can be effective but not economic in many situations.

Cultivars of chickpea, resistant to *M. artiellia,* are not available. However, resistance to the nematode has recently been found in the accessions ILWC 64 of *Cicer bijugum* Rech. and ILWC 92 of *C. pinnatifidum* Jaub et Sp., in ICARDA's collection (Di Vito et al., 1996b), but unfortunately these *Cicer* species cannot be crossed with *C. arietinum.* Therefore, it is necessary to search further for resistance in wild germplasm, compatible with *C. arietinum,* or find ways to transfer resistance from incompatible species.

Meloidogyne javanica and *M. incognita*

These two species are serious pests of chickpea (Sharma and McDonald, 1990). They are widespread in the chickpea growing regions of Asia, Africa and South America (Nene et al., 1996). However, most farmers in these countries are unaware of these insidious pests in their soils and damage to chickpea crops is often confused with declining soil fertility or micronutrient deficiencies. Stunting of plants, uneven crop growth, yellowing and bronzing of leaves, delayed flowering and podding, and reduction in number of pods per plant are the above-ground symptoms associated with nematode infection. Symptom expression varies with nematode population densities and chickpea genotypes. Patches of stunted plants in a nematode-infested soil appear earlier in infertile, moisture deficient sandy soils with low pH (Sharma et al, 1992). The characteristic root-swellings (galls) produced from attack by root-knot nematodes are often mistaken for rhizobia nodules. Galls produced at 25-30°C are 30-35% larger than those produced at 15-20°C. Many developing countries have inadequate human resources, trained in nematology, to help farmers identify and manage the damage caused by these nematodes.

The damage threshold levels of *M. incognita* and *M. javanica* range between 0.2 and 2.0 juveniles per cm^3 soil at the time of sowing. Trials conducted in India between 1989 and 1994 revealed that *Meloidogyne* spp may cause loss in yield from 17% to 60% depending on the nematode population levels at planting time (Ali, 1995).

These species complete their life cycle in about 4 weeks at 25-30°C producing several generations in a crop season. Association of these nematodes with *Fusarium oxysporum f. sp. ciceri* advances the onset of wilt and increases wilt incidence. Co-infection of *F. oxysporum* with *M. javanica* moderates the wilt resistance in chickpea cultivars (Maheswari et al, 1995). These nematode species interact with other species of *Fusarium, Rhizoctonia and Sclerotium.* Formation of rhizobia nodules on chickpea roots is also suppressed by these root-knot nematode species.

Control

Summer fallow, solarisation with transparent polyethylene sheets during hot summer months, and seed treatment with biocides such as aldicarb, carbofuran and phorate reduces the population densities of these nematode species (Sharma et al., 1992). The traditional agronomic practices in some parts of India of keeping the land fallow during summer months, deep ploughing, and addition of organic manure to the soil have suppressive effects on the nematodes.

At the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Asia Center, all of the 5,000 accessions of chickpea and 40 accessions of wild species were susceptible to *M. javanica* (Sharma et al, 1993). However, some chickpea accessions (N 31, N 59, ICCC 42 and ICCV 90043) have been identified with tolerance to the nematode (Sharma et al, 1995). Sesame, mustard and winter cereals are poor hosts and a 2-3 year rotation of chickpea with these crops may be useful management of these root-knot nematodes for chickpea production.

Cyst forming nematodes.

The most important cyst nematode attacking chickpea is *Heterodera ciceri* Vovlas, Greco et Di Vito. This species is present in Syria, Turkey and recently has been found in Jordan and Lebanon. *H. ciceri* develops better when soil temperature is in the range 15-25°C and usually completes only one generation per growing season of chickpea after an accumulation of 370 degree days (Kaloshian et al., 1986). A reproduction factor of about 250 on chickpea and a population decline of 35% in the absence of a host for seven months were determined in microplots (Greco et al., 1988). Other good hosts of this nematode besides chickpea, are lentil, pea and grass pea (*Lathyrus sativus*). Reproduction on other leguminous species is poor or nil. The tolerance limit of chickpea to the nematode is about 1 egg/cm^3 soil and complete crop failure must be expected in soil infested with 32 or more eggs/cm^3. Moreover, a 20% reduction of seed protein content occurs at high population densities (Greco et al., 1988).

Control

Split application of 10 kg aldicarb/ha and 6-8 weeks of soil solarization significantly reduced root infestation by *H. ciceri* and increased yield of spring chickpea (Di Vito et al., 1991). Other nematicides are also expected to be effective against *H. ciceri*, but they too are expensive and are pollutants. Because of its narrow host range, the control of this cyst nematode should be based primarily on crop rotations. In Syria, chickpea yields increased by 2.1, 4.5 and 7.9 times in fields where cultivation of host crops was suspended for one, two or three years, respectively, in comparison with continuous chickpea cropping (Saxena et al., 1992). Fallowing is rather common in Turkey and Syria and would reduce the soil population density of the nematode by 35-50% per year.

The use of resistant cultivars would be the easiest, simplest and most cost effective way to control *H. ciceri*. Unfortunately, no resistant chickpea cultivar is available. Screening of about 10,000 lines of *C. arietinum* of the ICARDA's germplasm showed no resistance, but among the annual wild chickpeas most lines of *C. bijugum*, six of *C. pinnatifidum* and one of *C. reticulatum* were highly resistant to the nematode (Singh et al., 1989; Di Vito et al., 1996a). Although lines of the first two *Cicer* spp are incompatible with *C. arietinum*, *C. reticulatum* can be crossed and a resistant line of this species has been registered as ILWC 292 in the ICARDA germplasm collection (Singh et al., 1996). It is being used in a breeding programme at ICARDA to transfer resistance to kabuli cultivars with promising results.

Root lesion nematodes

The most important root-lesion nematodes that attack chickpea are species of *Pratylenchus*. All are migratory endoparasites of the root cortical parenchyma in which they cause large necrotic areas that may coalesce and affect most of the root. These symptoms can be confused with blackening caused by other stresses and, therefore, extraction of the nematodes from the roots is necessary for proper diagnosis.

Above-ground symptoms are similar to those described above for attack by other nematodes. Usually, these symptoms are not as severe as those caused by root-knot or cyst nematodes, but they were so in North Africa, Lebanon and Turkey (N Greco unpublished data). However, *Pratylenchus* spp. are more widespread than the previous nematodes. In many Mediterranean countries all chickpea crops are infested with one or more species of *Pratylenchus*. This indicates that the economic damage to chickpea caused by root-lesion nematode, on a country or regional basis, would be larger than that caused by the other nematodes. Among root-lesion nematodes, *P. thornei* Sher et Allen appears to be cosmopolitan, while *P. mediterraneus* Corbett, *P. penetrans* (Cobb) Filipjev et Schuurmans Stekhoven and *P. neglectus* (Rensch) Filipjev et Schuurmans Stekhoven are common on chickpea crops in the Mediterranean basin (Greco et al., 1992; Di Vito et al., 1994a; Di Vito et al. 1994b). A few other species of *Pratylenchus* and *Pratylenchoides*, and *Zygotylenchus guevarai* (Tobar Jiménez) Braun et Loof have also been reported from the Mediterranean basin, but their impact on chickpea has not been investigated.

Root-lesion nematodes pass through several generations per growing season and large numbers can be extracted from infested roots at the early flowering stage. In the absence of a host crop, soil populations can be low especially making prediction of yield loss difficult from pre-sowing populations. However, when rains occur early in autumn the nematode may complete one or more generations on volunteer plants and the following winter crop can suffer severe damage. These nematodes have rather wide host ranges, which include winter cereals. However, Mediterranean populations appear to be much more adapted to cool season than to summer crops. Field observations in Syria revealed that the tolerance limit of chickpea to *P. thornei* is 0.03 nematodes/cm^3 soil and that yield can drop to about 40% when the nematode population at planting is 2 nematodes /cm^3 soil (Di Vito et al., 1992). Unfortunately, similar information for the other root-lesion nematodes is lacking.

In Australia, chickpea is grown as an alternative crop to wheat and many older wheat fields contain the root-lesion nematodes *P. thornei* and *P. neglectus* which both attack chickpea. *P. thornei* prefers clay soils and is predominant in the northern grain region whereas *P. neglectus* prefers lighter-textured soils and is predominant in the southern grain region. Both species have a similar optimum temperature for reproduction of 22 to 25 C (O'Reilly and Thompson, 1993; Thompson, unpublished data; Vanstone and Nicol, 1993). *P. thornei* is the more damaging to wheat causing losses in grain yield of up to 75% in the most intolerant wheat cultivars. Field experiments with nematicides on chickpea have sometimes shown substantial increases (25-60%) in plant biomass or grain yield on sites heavily infested with *P. thornei* in northern New South Wales (T.R. Klein, pers. comm., 1988; M. Schwinghammer, pers comm., 1989), Queensland (Thompson, 1989) and Victoria (Eastwood and Smith, 1995). Similar responses to nematicide have been obtained with chickpea on land infested with *P. neglectus* in South Australia (Taylor, *et al.,* 1997). Many current cultivars of both wheat and chickpea are susceptible to both species of root-lesion nematodes (Table 1) and wheat-chickpea rotations maintain high nematode populations (20 nematodes/g soil) which can cause loss in both crops. This is a potential problem as chickpea is advocated as a break crop for wheat to improve available soil nitrogen and to reduce cereal cyst nematode (*Heterodera avenae* Woll) and fungal diseases caused by *Fusarium graminearum* Schwabe, take-all caused by *Gaeumannomyces graminis* Sacc., and rhizoctonia root rot caused by *Rhizoctonia solani* Kuhn. Root-lesion nematodes are widespread being present in virtually all grain fields in South Australia (V.A. Vanstone and S.P. Taylor, pers comm., 1995). In Victoria almost all grain fields are infested, of which 20% have populations above the damage threshold level of 2 nematodes/ g soil(Eastwood and Smith, 1995). In northern NSW and Southern Queensland, 50% of fields with putative in-crop symptoms of nematode damage are infested with root-lesion nematodes (JP Thompson unpublished data). Annual loss to grain crops from root-lesion nematodes in the eastern Australian grain belt is estimated to be AUD.$ 50-100 million

Table 1. Resistance and tolerance of crop and pasture species to *Pratylenchus thornei* and *P. neglectus*. (Combined information of R. Eastwood, V.A. Vanstone, S.P. Taylor and J.P. Thompson).

Crop	*P. THORNEI*		*P. NEGLECTUS*	
	Resistance[1]	Tolerance[2]	Resistance[1]	Tolerance[2]
Winter				
Wheat	VS	I-VT	VS	I-T
Durum	MR-S	MT-T	MR-S	MI
Barley	MR-S	T-VT	MR	MT
Oat	S	-	S	I-T
Rye	R	-	R	-
Triticale	MR-S	MT	R	I-T
Canaryseed	R	T	-	-
Chickpea	VS	MI	VS	-
Pea	R	T	R	-
Faba bean	MR-S	T	R	-
Lentil	R	T	S	-
Lupin	R	-	MR	-
Vetch	S	I	VS	-
Medic	R	-	VS	I
Sub-clover	VS	-	R	-
Canola	MR-S	-	S	MI
Mustard	-	-	S	-
Safflower	R	-	R	-
Linseed	R	T	-	-
Summer				
Sorghum	R	VT	-	-
Maize	S	-	-	-
Millet	R	-	-	-
Mungbean	VS	-	-	-
Pigeonpea	R	-	-	-
Cowpea	VS	-	-	-
Sunflower	R	-	-	-

1 Resistance: R = resistant, MR = moderately resistant, S = susceptible, VS = very susceptible, MR-S = cultivars ranging from moderately resistant to susceptible, - = no information
2 Tolerance: T = tolerant, MT = moderately tolerant, MI = moderately intolerant, I = intolerant, I-T = cultivars ranging from intolerant to tolerant, - = no information.

Control

Although nematicides are not used to control these nematodes on chickpea, several trials in the Mediterranean region have demonstrated that soil treatments with different chemicals can increase yield. With non-fumigant nematicides, better control can be achieved with split applications of 10 kg a.i./ha. Seed coating with paste containing nematicides has resulted in contradictory results. Soil solarization would also be effective (Di Vito et al., 1991).

Crop rotations and fallow are the only measures adopted for the management of these nematodes. However, alternation of winter with summer crops, fallow and summer ploughing would result in satisfactory control. Moreover, populations of the same nematode species from different geographical areas may have different host ranges that should be ascertained.

No chickpea cultivar resistant to root lesion nematodes is available. Recently, Di Vito et al. (1996b) found resistance to *P. thornei* in accessions of *C. bijugum, C. cuneatum* Hochst., *C. judaicum* Bois and *C. yamashitae* Kitamura, but none of these species can be crossed with *C. arietinum.*

In the eastern Australian grain belt, there are diagnostic services available to farmers specifically for root-lesion nematodes. Fields can be diagnosed before sowing to ascertain the nematode threat by extracting and enumerating nematodes in soil samples. In the northern region and the Victorian Wimmera, *P. thornei* occurs as deep as 90 cm in the subsoil of Vertisols and samples for diagnosis are taken to 30 cm depth. Pre-sowing diagnosis is a very useful management tool in areas where the nematodes are well established. *P. thornei* appears to be spreading into newer cropping lands of the northern region in many cases in runoff and flood water. Diagnosis of new infestations is best based on extraction of in-crop soil and root samples using above-ground symptoms as a guide on where to sample a patchy distribution. Where nematodes are well established in a field, rotation to other crops with partial resistance or tolerance (Table 1) is necessary to avoid losses. The aim is not to grow a susceptible, intolerant crop more often than once every 3-4 years. This is achieved in the northern region by rotations of chickpea or wheat with sorghum and barley. Switching between summer and winter crops is often accomplished via a weed-free fallow period of 11-14 months during which nematode numbers decline somewhat. When rainfall permits, chickpea (winter crop) can also be grown directly after sorghum (summer crop) which is resistant to *P. thornei.* Cropping chickpea after wheat should be avoided in nematode-infested fields. In the Victorian Wimmera region, root-lesion nematodes can be effectively controlled with rotations of winter crops. Research (Eastwood and Smith, 1995) showed that a single cycle of good hosts like chickpea and wheat and of poor hosts like pea or barley resulted in a doubling or a halving respectively of the initial soil populations of *P. thornei.* Targeted breeding in the northern region has produced wheat cultivars (Pelsart and Sunvale) with superior tolerance to *P. thornei.* Similar work is underway to ascertain the current levels of tolerance in Australian chickpea cultivars and to improve them through breeding. Tolerant cultivars yield well when attacked by nematodes but still allow nematodes to multiply in their roots leaving a burden in a field to attack subsequent crops or to disseminate the problem. Programs are underway to breed true resistance into wheat cultivars and to search for sources of resistance in chickpea germplasm and related species.

Reniform nematode

Although *Rotylenchulus reniformis* Linford et Oliveira occurs in the Mediterranean area, it has not been reported to damage chickpea. *R. macrosomus* Dasgupta, Raski et Sher also has often been found in the chickpea rhizosphere but never in chickpea roots. *Rotylenchulus reniformis* has been associated with chickpea decline mainly in irrigated areas in parts of northern India (Ali, 1995). However, pathogenic effects of *R. reniformis* populations on chickpea have not been observed in southern and western India. The nematode damage to chickpea is greatly influenced by the preceding crop; sorghum, pigeonpea, mungbean, and urdbean enhance population build up of the nematode. Options to manage the damage caused by *R. reniformis* on chickpea are similar to those for the tropical root-knot nematodes *M incognita* and *M javanica.*

Other nematodes

Other nematodes have been reported from the rhizosphere of chickpea (Sharma, 1985; Ali, 1995; Castillo et al. 1996) but pathogenicity to this crop has only been demonstrated for *Tylenchorhynchus vulgaris* Upadhyay, Swarup et Sethi. Stem nematode (*Ditylenchus dipsaci*) affects chickpea in South Australia in a similar manner to pea (see fuller coverage later). Chickpea seedlings are susceptible and intolerant to stem nematode but resistant as adult plants.

PEA

Several nematode species have been found in association with pea. The most important are cyst-forming, root-knot, root-lesion and stem nematode *Ditylenchus dipsaci* (Kuhn) Filipjev (Sikora and Greco, 1990; Riggs and Niblack, 1993).

Cyst nematodes

The most important and studied nematode of pea is *Heterodera goettingiana* Liebscher. This cyst nematode is distributed in Europe and in the Mediterranean basin (Di Vito and Greco, 1986). In 1992 *H. goettingiana* was also found in several fields in western Washington state (USA) where it was probably causing damage for several years (Handoo et al., 1994). The nematode may interact with soil borne fungi and greatly suppresses rhizobia nodulation. *H. goettingiana* develops during spring and summer in temperate climates and from autumn to mid spring in the coastal area of the Mediterranean basin. Only one generation per growing season of pea is completed if the nematode does not form egg masses and two to three generations if egg masses are produced, which occurs when rhizosphere temperature remains below 15 °C and soil moisture is optimal (Greco et al., 1986). Large numbers of nematode females can be observed on the roots at flowering, when plants show yellowing, patchy growth and few flowers. *H. goettingiana* also damages faba bean, grass pea and vetch.

In microplots the tolerance limit of pea to *H. goettingiana* was 0.5 egg/g soil. Yield losses of 20 and 50% would occur at 3 and 8 eggs/g soil and complete crop failure at 32 eggs/g soil (Greco et al., 1991). Maximum reproduction factors of the nematode have been recorded as high as 90 in microplots of pea, and an average annual decline of 50% in fallow fields (which may increase in warm and arid areas) was determined.

Pea is also a good host for *H. ciceri*, but no damage by this nematode has been reported in farmers' fields. *H. trifolii* Goffart also reproduces on pea but the nematode does not seem to be a problem for pea crops.

Control

The economics of pea crops vary according to whether they are cultivated for fresh or frozen green grains or for dried grains (pulse). In the first case the use of nematicides and other costly means of control could be economical. In Italy (Di Vito and Lamberti, 1976) and England (Whitehead et al., 1979) satisfactory control of *H. goettingiana* was achieved by incorporating fenamiphos (10 kg/ha) or aldicarb and oxamyl (2.8-11.2 kg/ha) in the top 15 cm of soil before sowing. However, oxamyl would rapidily degrade in soils with pH higher than 6. As observed with other cyst nematodes, fumigant nematicides, such as 1,3D and methyl-isothiocyanate, would also be effective. Soil solarization has not yet been assessed against *H. goettingiana*, but in the Mediterranean area it would be as effective as observed for *H. ciceri*.

Like other cyst nematodes, *H. goettingiana* can be controlled by crop rotations. Although proper crop rotation can be designed on the basis of the nematode population density, in general growing a host crop once in three years in heavily infested soil or twice in three years in lightly infested fields would be satisfactory (Ferris and Greco, 1992).

No cultivar of pea resistant to cyst nematodes is available. Moderate resistance, governed by recessive gene(s) (Di Vito and Greco, 1986), was found in accessions of *Pisum abyssinicum* Brown, *P. arvense* L. and *P. elatius* Ster (Di Vito and Perrino, 1978), but no work is in progress to transfer this resistance into cultivars.

Root-knot nematodes

The root-knot nematode species mentioned above may also damage pea. In a pot experiment (Siddiqui et al., 1995) growth reduction of pea was observed at 500 juveniles of *M. incognita*/kg soil. However, in the Mediterranean basin pea is cultivated from mid autumn through spring, when soil temperature is too low for all root-knot nematodes except *M. artiellia* to affect plants. Therefore, only when pea is sown in early autumn would damage ccur. Moreover, damage by *M. artiellia* to pea has never been reported.

Control

Avoidance of early sowing generally is effective for controlling these nematodes. If pea is to be sown earlier in infested areas, then any means of control known to be effective on other crops would also result in satisfactory and economic protection of pea for green pod production.

Stem and bulb Nematode

Stem and bulb nematode *Ditylenchus dipsaci* is among the most destructive nematode species. Its behaviour is that of an endoparasitic, migratory nematode, which mainly attacks above-ground plant parts. It is a complex species comprising 21 recorded host races, each having a different host range. Some races have a rather limited host range while others may reproduce on a large number of plants including weed species. Identification of the nematode race is a difficult task. However, rather than identifying the nematode race it is important to know the reproduction potential of local populations of the nematode on the annual crops cultivated in the same area. In general, depending on the nematode population, bulbous plants, alfalfa, clover, corn, sugarbeet, oats and strawberry are commonly attacked by *D. dipsaci*. Moreover some particular local populations have been found to damage rye, wheat, carrots and Italian ryegrass.

Its epidemiology is greatly influenced by environmental conditions. Air temperature in the range 15-20°C and wet conditions caused by sprinkler irrigations, rain, fog and dew, which usually occur from autumn to spring in the Mediterranean basin, favour nematode infection and reproduction. In central and northern Europe these conditions may also occur in the summer months. Little or no infection occurs during warm and dry periods. *D. dipsaci* attacks all aerial plant parts and is favored by the prostrate habit of pea. Infected stems show large brown to black necrotic areas that may encompass the entire diameter. Because of concomitant infection of other micro-organisms, the stems may rot, become weak and break during windy days. Leaves present black necrotic areas while flowers and pods may show distortion and irregular growth. A few nematodes can be found in the grains and survive as quiescent fourth stage juveniles. The yield can be negligible where nematode infection is heavy.

In South Australia, the oat race of stem nematode is one of the most destructive nematodes causing loss in oat, faba bean, pea and chickpea crops that varies from 10% to crop failure. This race was first recorded in South Australia in 1973 and has since spread to twenty-seven districts covering an area of 150,000 ha. In 1991, the estimated losses to these industries totalled AUD $6m/year. So far this nematode has not been reported in other states. Its weed hosts include wild oats (*Avena fatua* and *Avena sterilis)* and bedstraw (*Galium tricornutum*) which can carry high nematode populations in non-host crop rotation years. It can be spread in hay and in faba been seed and has the potential to spread further in SA. It can be spread within a farm or district, in machinery, water run-off and plant debris. Crop losses can be expected to increase as areas sown to oats, oaten hay and faba beans increase (Scurrah, 1997).

Peas are very intolerant to stem nematode. Crop damage during cold, wet weather is directly related to initial nematode numbers. Stem nematode reduced seedling emergence in trials by up to 30%, and plants that emerged were stunted and deformed. A further 10-30% died during winter but surviving plants produced new tillers and recovered in spring. Yield loss resulted from reduced plant density and delayed maturity. Pea seedlings in South Australia are susceptible and intolerant, but adult plants of all cultivars are resistant (Scurrah, 1997). Pea seed and straw pose a low risk for nematode spread. The current pea cultivars vary significantly in their ability to tolerate stem nematode: Alma and Glenroy are the most tolerant cultivars available; eight weeks after emergence they harbour 50% fewer nematodes than Dinkum, which is very intolerant. With tolerant cultivars, nematodes leave plants earlier and the plants recuperate faster (Scurrah and Szot, 1996).

Control

The European race seems to attack adult pea plants and infest seed while the South Australian race has not been found in pea so far, Therefore the control strategies for stem nematodes differ slightly. Although there is clear evidence that the nematode can survive in seeds and be transported over a long distance, this aspect has been neglected so far. Therefore, control measures must be adopted to produce seed-stock free of the nematode. This goal can be achieved by growing pea in areas where major host plants of the nematode are not cultivated and in fields free of the nematode. The choice of fields having good sunlight and air-flow, the use of pre- and post-planting nematicide treatments and proper weeding are suggested. Examination of the seed-stocks obtained will also be necessary to ensure freedom from nematodes. For this purpose, preplant soil fumigation with 1,3D (100-200 kg/ha) or dazomet (500 kg/ha), or the use of pre-sowing granular non-fumigant nematicides, such as aldicarb, fenamiphos, oxamyl or prophos, all at the rate of 10-12 kg a.i./ha, are suggested. Combination of soil fumigation with post-emergence split application of 5-10 kg/ha of one of the first three granular nematicides will certainly give better nematode control.

Control of stem nematode with nematicides in pea crops for human consumption would be profitable, but post-emergence applications of non-fumigant nematicides is not recommended to avoid residues in the grain. Usually, control of *D. dipsaci* in pea is overlooked and when rotations are adopted they are not designed just to control this nematode. However, proper rotations should consider the geographical origin of the nematode population (race) and the cropping history of the area. Usually, rotating pea with cereal or summer crops is effective in the Mediterranean basin.

No pea cultivar resistant to *D. dipsaci* is available. In South Australia, 800 pea lines have been screened for tolerance by comparing their yield with Alma and by response to nematicide. A number of lines with good tolerance have been selected. These yielded up to 70% more than Alma and gave small responses to nematicide compared with other cultivars (up to 140% increase)(M Scurrah unpublished data). Current advice to farmers in South Australia is to avoid growing susceptible oat cultivars in succession with pea or faba bean and to control the major weed hosts.

Other nematodes

Riggs and Niblak (1993) reported another 30 nematode species hosted by pea. Several of them interact with soil-borne fungi but their impact on pea growth has not been determined. In Brasil, *Helicotylenchus dihystera* (Cobb) Sher is a severe ectoparasite of wheat and pea and 41% yield loss of pea was observed in pots (Sharma et al., 1993).

LENTIL

Few nematode species have been reported in association with lentil and most of them are found in the rhizosphere. Generally, ectoparasitic nematodes found in the rhizosphere of other annual crops in a given area can also be found in lentil crops, but their pathogenicity to lentil is not known.

Heterodera ciceri is the only nematode for which the pathogenicity has been ascertained. This nematode causes yield losses of lentil in Syria and has been reported on the crop in Turkey (Di Vito et al., 1994b). The tolerance limit to the nematode is 2.5 eggs/cm^3 soil and yield losses of 20 and 50% should be expected in fields infested with 20 and 64 eggs/cm^3 soil (Greco et al., 1988). Reduced protein content has been observed in lentil heavily infested by nematode. The pathogenicity of other cyst nematodes reported associated with lentil has not been investigated.

Root-knot nematodes should not constitute a problem for lentil. In the Mediterranean basin lentil is a winter crop while the major root-knot nematodes develop during the warm season and *M. artiellia* reproduces poorly on this food legume.

Ditylenchus dipsaci has been found in stems of lentil in Syria and Turkey in crops with no obvious damage. However, the nematode could affect yield in rainy years.

Pratylenchus spp. have also been extracted from roots of lentil but never in as large numbers as from chickpea roots.

Control

Control measures suggested for the nematodes mentioned would be similar for lentil as for the other crops. In Europe no lentil cultivar resistant to any of the nematodes mentioned is available. In South Australia, the two lentil cultivars tested were resistant to the local race of stem nematode.

FABA BEAN

Faba bean is cultivated either for green pods or for its dried grain. In both cases cyst, root-knot and root-lesion nematodes and *D. dipsaci* are the major nematodes that can damage the crop.

Heterodera goettingiana is the only cyst nematode damaging faba bean. However, the tolerance limit of this food legume to the nematode is about 0.8 egg/g soil, a little less than that of pea, and yield losses of 20 and 50% are expected in soils infested with 5 and 15 eggs/g soil. Complete crop failure would occur when the nematode population at sowing is about 64 eggs/g soil (Greco et al., 1991). The biology and dynamics of the nematode population are similar to those reported for pea.

Control

Control measures are similar to those reported for pea. No source of resistance to the nematode has been found in faba bean.

Root-knot nematodes

Root-knot nematodes, *Meloidogyne* spp., are potentially capable of damaging faba bean. This food legume is cultivated as a winter crop and therefore the soil should be too cool for root-knot nematodes of warm seasons to cause damage. However, damage by these nematodes has been observed in Egypt and in Italy when faba bean is sown early in autumn after a susceptible summer crop. Faba bean is a good host for *M. artiellia*, but no crop damage by the nematode has been observed in the field.

Control

Sowing late in autumn would prevent infection by the warm season root-knot nematodes in infested fields.

Ditylenchus dipsaci

The stem and bulb nematode is considered a serious problem of faba bean because of its survival in seeds and therefore its implication in quarantine regulations. Extensive coverage of the problems caused by this nematode have been published recently (Greco, 1993; Sharma et al., 1994; Caubel and Esquibet, 1995). Most countries will only permit imports of seed stocks free of the nematodes. Two races of stem nematode attack faba bean. The biology of *D. dipsaci* on broad bean is similar to that on other host crops but some differences may occur according to the nematode race. In the Mediterranean basin and Europe the normal race with 2n = 24 chromosomes is common in broad bean crops. This race mostly infects the basal leaves and stems, while infection of the upper plant parts, including pods and seeds can be negligible. In South Australia heavy seed infestation occurs during wet springs. Symptoms are not specific and diagnosis depends on nematode extraction. In Europe and the Mediterranean basin, symptoms of the nematode attack are browning of stem bases and leaf necrosis. These symptoms can be confused with those of other diseases, such as chocolate spot caused by *Botrytis fabae*. The giant race of the nematode with 2n = 48 chromosomes is common in North Africa and much more pathogenic on broad bean. This race attacks the upper parts of the plant also, including pods and seeds in which it survives in large numbers as quiescent fourth stage specimens. In addition to the symptoms already described, this race causes distortion and deformation of stems and pods and swelling of the stems, which are characteristic of the nematode infection. Heavily infected grain shows necrotic areas on the cotyledons. Planting infested seeds in healthy soil could result in more damage than planting healthy seeds in infested soil. In the case of soil-borne infections, the crop presents a few areas showing symptoms of the nematode attack, whereas with seed-borne infection the symptoms appear in several small patches depending on per cent of infected seeds.

Control

Because of the seed borne nature of the nematode, strict quarantine regulations and guidelines must be followed to avoid exporting, importing and sowing of infested seed.. Treating infested seed stocks with methyl bromide in a closed container under partial vacuum conditions, at CTP of 1000 mg hr/l (Powel, 1974), 100 g/m^3 x 18h or 80 g/m^3 x 12h (Caubel and Esquibet., 1995) greatly reduced but did not eradicate the nematode without substantially affecting seed germination. Moreover, hot water treatment of the seeds could also be an effective and easy method at farm level. The nematode *Aphelenchoides besseyi* in rice seeds is controlled by hot water treatment of 15 min. at 52-54 °C (Hollis and Keoboonrueng, 1984), but investigations are necessary to ascertain the best combination of temperature and time to kill nematodes without affecting germination of faba bean seeds. Infested seed should be consigned to human or animal consumption, although there is evidence that some nematodes may survive in the animal intestinal tract. Burning of the plant residues is also recommended. High populations of the oat race of stem nematode develop on faba bean in South Australia and the pods and seed pose the danger of long distance dispersal to other areas.

Resistance to *D. dipsaci* has been found in faba bean lines from Morocco, Syria, Tunisia and France (Sharma et al., 1994). Over 100 accessions of faba bean were tested in the UK but no resistance to the oat race of stem nematode was found (Hooer, 1976). Caubel (1989a, b) first reported resistance to the Giant race in INRA 29H. Resistance has also been found in accessions of *Vicia narbonensis* but no information is available on the genetics of these resistances. One hundred accessions tested in South Australia were highly susceptible to the oat race. To date no cultivar with resistance is available. Faba bean cultivars are considered relatively more tolerant to the oat race of stem nematode than pea cultivars in South Australia and do not show obvious symptoms unless heavily infested. Nevertheless, treatment with nematicide increased yield of faba bean cultivars-Fiord by 13%, Icarus by 18%, Ascot by 23% and Aqualdulce by 30%. Breeding for resistance to the oat strain is hampered by the lack of plant symptoms, but counts of nematodes on dried stems indicate that useful variation (800 to 32,000 nematodes/plant) exists in advanced material from the South Australian faba bean breeding program and that higher levels of resistance may be achieved by recurrent selection.

Other nematodes

Specimens of *Pratylenchus* spp. are often extracted from necrotic roots and many ectoparasitic nematode species have been found in the rhizosphere of faba bean, but information on their impact on the crop is lacking. Faba bean appears to be a poorer host than chickpea for *P. thornei* and *P. neglectus* (Table 1) and may prove a better rotational crop with wheat (K. Moore pers. comm., 1997; G. Holloway and R. Eastwood pers. comm., 1997).

GRASS PEA

Investigation on nematodes of grass pea has received little attention probably because of the limited importance of the crop for human consumption. However, grasspea is a good host for the cyst nematodes *Heterodera goettingiana* and *H. ciceri*. In a trial in Syria a cultivar for animal feed was severely damaged by *H. ciceri*. The root-knot nematode *Meloidogyne artiellia* has been shown to reproduce well on grass pea. Pot experiments showed growth reduction by *M. incognita* when soil population densities were at least 0.75 second stage juveniles/cm^3 soil (Thakar et al., 1986). In India severe damage by *Pratylenchus thornei* was observed on *Lathyrus odoratus* (Mishra and Gupta, 1988). This would indicate that this nematode and other species of *Pratylenchus* might also affect grass pea.

LUPINS

Lupins have been shown to have high levels of immunity to most common nematode species of temperate climates and are often recommended as a rotation crop. However information on nematodes affecting lupins is limited. Species of *Pratylenchus* and *M. hapla* have been found in the roots. *Xiphinema lupini*, several species of root-knot, root-lesion, cyst and ectoparasitic nematodes have been reported associated with different lupins (Riggs and Niblack, 1993), but the pathogenicity of most of them is doubtful and the impact of the others on lupins has not been ascertained. However, lupin is a winter crop and, therefore, the warm season root-knot nematodes and *M. artiellia* would not affect it.

GENERAL CONSIDERATIONS ON CONTROL

Control of plant parasitic nematodes must consider the economics of the control measures, which may vary from country to country according to the use of the legume. Usually when a legume is cultivated for the production of green pods or green grain to be consumed fresh or as canned or frozen food, more expensive means of control can be afforded. In this case nematicides or soil solarization would be very useful. This may not be so when cool season legumes are cultivated for dried grain (pulse) production. Moreover, these legumes are very often cultivated on rather marginal land returning net profits that do not allow the use of expensive control measures. In addition, awareness of nematode problems is very poor in many countries and no action is taken to limit yield loss caused by these hidden enemies. In such situations current crop sequences or fallow are not specifically designed to control nematodes or any other parasites, but just to reduce damage by "soil sickness". Instead, a sound approach to minimize yield losses requires precise information on the nematode species, its population density and the pathotype occurring in a given field. Although this may not be possible at farmer field level, surveys and investigations at regional level, would be useful. In general, if crop rotation can be of help in controlling nematodes, rather than suggesting a particular crop sequence, the goal could be the introduction to the area of other crops having different disease problems. This will automatically lead to the adoption of longer term rotations.

The best way to control nematodes of cool season food legumes and by-pass farmer unawareness is to release cultivars resistant to the nematode(s) pests occurring in the area. The second course of action is to educate farmers about nematodes and alternative strategies. Unfortunately, although resistance to nematodes has been reported in cultivated and wild legume species, not enough resources are being assigned to transferring these resistances into cultivars. A breeding program to transfer resistance to *Heterodera ciceri* from *Cicer reticulatum* to kabuli type cultivars of *C. arietinum* is in progress at ICARDA (Aleppo, Syria) (Di Vito et al., 1996). Similar breeding programs should be undertaken for all cool season legumes. However reported resistance should always be confirmed against local populations of a nematode. Moreover, we must be aware that although nematodes are often the major disease problem they usually occur with other pests and diseases. Therefore, breeding programs should aim to produce cultivars with multiple resistances.

In areas infested with nematodes that have wide host ranges, such as root-knot and root-lesion nematodes, the use of resistant cultivars of other crop plants must be considered. For instance, cultivars of tomato, cowpea and haricot bean resistant to root-knot nematodes are available and their inclusion in a rotation can be of help in reducing nematode populations before sowing a susceptible crop.

Until such cultivars are released, the integrated use of nematicides, soil solarization, crop rotation, soil amendments, choice of sowing time, ploughing the soil in summer, weed control, fallow and sowing nematode-free seed should provide satisfactory nematode control and crop benefit in farming systems.

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