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Review Article

The damage potential of pin nematodes, *Paratylenchus* Micoletzky, 1922 *sensu lato* spp. (Nematoda: Tylenchulidae)

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Abstract: The genus *Paratylenchus sensu lato* includes members belonging to the genera *Paratylenchus sensustricto* (species with 10 to 40µm long stylet), *Gracilacus* (species with 40-120µm long stylet), *Gracilpaurus* (species having cuticular punctuations) and *Paratylenchoides* (species having sclerotized cephalic framework). Long stylet species become swollen and feed as sedentary parasites of roots, some feed from cortex of perennial host roots, but most species feed as sedentary ectoparasites on roots. In other words, species with stylet shorter than 40µm commonly feed on epidermal cells, whilst the species with longer stylet nourish primarily in cortical tissue, without penetration into the plant tissue. In general, pin nematodes, *Paratylenchus* spp. are parasites of higher plants with a higher abundance in the rhizosphere of trees and perennials. In present review, an attempt is made to document published information on the pathogenicity and damage potential of the pin nematodes to plants.

Keywords: *Gracilacus*, damage, pathogenicity, perennials, pin nematodes, population, trees

Introduction

The pin nematodes, *Paratylenchus* Micoletzky, 1922 *sensu lato*, firstly have long been considered as free-living nematodes, but further studies on their life cycle led researchers to find evidence on their damage to plants (Solov'eva, 1975). *Paratylenchus* species seem to be a common component of the fauna of cultivated crops, plantations and natural vegetation (Solov'eva, 1975), with a higher abundance in perennial plants, such as grass stands, hop gardens, orchards or forest trees and shelterbelts (Čermák and Renčo, 2010). Large number of these nematodes are common in the rhizosphere of fruit trees (Weischer, 1960; Nesterov and Lisetskaya, 1963; 1965; Braun *et al.*, 1966; Fisher, 1967; Ghaderi and Karegar, 2013), and in some nurseries of conifers, the density of population was increased to more than 1000 individuals per 100cm^3 of soil (Ruehle, 1967; Rossner, 1969). Distribution and host preference of *Paratylenchus* species has already been reviewed a few times (Loof, 1975; Brzeski, 1976; Bell and Watson, 2001; Eroshenko and Volkova, 2005; Čermák and Renčo, 2010; Ghaderi *et al.*, 2016).

These nematodes are described as a group responsive to environmental fluctuations and root development. Their shorter generation time and smaller body size compared to other nematode groups, allow faster buildup of their populations after environmental changes (Yeates and Lee, 1997). In addition, they are more resistant to dehydration and easily dispersed by wind (Gaur, 1988). Usually fourth-stage and sometimes third-stage

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juveniles serve as resistant (or resting) stage of *Paratylenchus* species which they may have a well-developed stylet, reduced stylet or no stylet (Brzeski and Háněl, 1999). Additional effects of different climatic factors on population of these nematodes have been discussed earlier (Reuver, 1959; Fisher, 1965; 1967; Wu and Hown, 1975; Brzeski, 1991; Bell and Watson, 2001).

Feeding behavior of pin nematodes

The feeding behavior somewhat differs among *Paratylenchus species*. It seems that long stylet bearing species become swollen as sedentary feeders, some of them feed from deeper layers in cortex of perennial host roots; most others are ectoparasites on roots (Ghaderi *et al.*, 2016). In other words, species with stylet shorter than 40µm commonly feed on epidermal cells and root hairs (Lindford *et al.*, 1949; Rhoades and Linford, 1961; Brzeski *et al.*, 1975; Wang *et al.*, 2016), but species with longer style tend to feed primarily on cortical tissue (Inserra and Vovlas, 1977; Cid del prado Vera and Maggenti, 1988; Troccoli *et al.*, 2002; Inserra *et al.*, 2003). The long and robust stylet enables these species to penetrate several cells deep and become permanently attached to the root surface in a sedentary manner without penetration of their body into the root tissues (Inserra and Vovlas, 1977).The long stylet also enable spin nematodes to parasitize deep root tissues of trees and shrubs, but they can change their host preference from woody species to several grasses and herbs with changes in the soil ecosystems and nutrient cycling (Čermák and Renčo, 2010). Feeding behavior of *Paratylenchus spp*. has been studied in more detail by some researchers (Linford, 1942; Linford *et al.*, 1949; Rhoades and Linford, 1961; Brzeski *et al.*, 1975; Inserra and Vovlas, 1977; cid del prado Vera and Maggenti, 1988; Troccoli *et al.*, 2002; Inserra *et al.*, 2003; Wang *et al.*, 2016).

Damage potential, host range and symptoms of pin nematodes infection

In the present paper, the damage potential and pathogenicity of pin nematodes to plants is reviewed. Associated plants and hosts are mentioned for each species, and symptoms of the nematode infection are discussed as described and reported in literature. However, it should be noted that information on pathogenicity is available only for few species, which are discussed in alphabetical order as follows.

***Paratylenchus bukowinensis* Micoletzky, 1922**

Brzeski (1971) observed *P. Bukowinensis* did not cause visible injuries to cabbage roots; however, the fresh weight of roots was reduced markedly, and that of aerial parts was decreased slightly. Although *P. bukowinensis* may cause yield decrease of cabbage, this species seems most injurious to root crops of Apiaceae. In pot experiments (Brzeski, 1976), hosts of *P. bukowinensis* were found in the families Brassicaceae and Apiaceae including carrot, celery, parsley, cabbage and rutabaga. No hosts were found among examined species of Solanaceae, Papillionaceae, Asteraceae, Chenopodiaceae or Poaceae.

Parsley and carrot roots were misshapen, shorter or forked (Weischer, 1961) and finally, the whole plant may be completely destroyed (Brzeski, 1976). Celery roots developed many lateral roots and some necrosis appeared which might eventually destroy the whole root system. The tolerance limit of celery was about 70 nematodes in 100cm^3 of soil and the minimum yield was about 60% of that of non-infested treatments (Brzeski, 1975).

Brzeski (1976) noted that females, second and third stage juveniles (J2s and J3s) of *P. bukowinensis*, the only stages that feed, are found feeding mainly on the epidermal cells, and sometimes on cells two layers deeper in the root parenchyma of parsley and cabbage. The fourth stage juveniles (J4s), have thin, short stylet and a reduced pharynx and do not feed. The root diffusates stimulate the molting of J4s to adults; although some molting occurs in the spring in the absence of root exudates. Population increase of 700% in one season on parsley has been recorded.

***Paratylenchus dianthus* Jenkins & Taylor, 1956**

P. dianthus has been reported to retard growth of carnation (*Dianthus caryophyllus* L.) in USA (Jenkins and Taylor, 1956). Root and soil samples were collected in three commercial greenhouses from carnations exhibiting poor growth. Each of four pots containing three plants were inoculated with approximately one thousand individuals of this species. After 50 days, examination of the soil and roots from each pot revealed a population increase of 700 percent. The nematodes inoculated into fallow pots failed to survive, indicating the host preference of the species. It seems probable that this species was one of the contributing factors to poor growth in the three greenhouses sampled.

In another study, *P. dianthus* was determined to be an important pest of carnation in the Naples province, Italy. Fumigation prior to planting prevented damage until the second growing year when nematode populations built up to damaging levels (Pennacchio *et al.*, 1985). Under greenhouse conditions and during a105-days period, *P. dianthus* increased from 100 to 37000 with carnation, to 1509000 with celery, and to 820000 with jasmine tobacco as host plants (Rhodes and Linford, 1961).

***Paratylenchus epacris* (Allen & Jensen, 1950) Goodey, 1963**

P. epacris was found attacking black walnut roots in California, USA. Although trees were also infected with a root-lesion nematode, and an accurate estimation of the damage was not possible, but some evidences indicated that *P. epacris* might contribute to the disease symptoms observed in the infected trees. Numerous colonies of adult females and juveniles were observed with their stylet imbedded in the root tissues, and eggs were observed attached to the debris usually present around the colonies, and males were obtained by washing infested soil through a series of graded screens and from scrapings made from the bark of infected roots (Allen and Jensen, 1950). This is especially interesting, considering that black walnut roots appear to be immune to the closely related genus, *Cacopaurus pestis*. Thorne (1943) was unable to find any evidence that *C. pestis* could attack the roots of black walnut. However, it remains to be determined if *P. epacris* could attack English walnut roots (Allen and Jensen, 1950).

***Paratylenchus hamatus* Thorne & Allen, 1950**

P. hamatus has been reported as a contributing factor to, if not the primary cause of, the fig tree decline (leaf drop) in some fig *Ficus carica* L. orchards in California, USA. In the affected trees, the first observed symptom is the lighter color of the leaves, which gradually becomes more pronounced until the leaves die and fall. Fruits on these trees are undersized and generally fall along with the leaves. A slow decline of the entire tree takes place, culminating the dieback of twigs and small limbs. However, conditions in the observed orchards may have been aggravated by inadequate irrigation during the hot summer months. Populations of *P. hamatus* in the infected orchards ranged from 6 to 3000 per 400 gram of soil. Many specimens of *P. hamatus* were observed attached by their stylets to the rootlets (Thorne and Allen, 1950). Some years later, the deterioration of the condition of pear orchards in California was correlated with the concomitant infection of *P. hamatus* and pythiaceous fungi (French *et al.*, 1964). This nematode was found in 116 out of the 121 orchards investigated, and in 85 orchards large populations were found. The density reached up to 2500 individuals in 250cm^3 of soil. However, the number of *Paratylenchus* in the roots was very low and only in one case, 143 individuals were found in one gram of roots.

P. hamatus was also found to be associated with 60 declined citrus trees in Shiraz, Iran (Abivardi, 1970). Populations from various samples ranged from 225 to over 300 nematodes per 100cc soil, but no direct evidence of feeding on the roots of sour orange and lime seedlings was observed under the microscope. However, second stage juveniles (J2s) of the citrus nematode were also present in higher

populations, which ranged from 420 to 650 nematodes per 100cc soil, thus the observed decline cannot be attributed only to *P. hamatus*. It has also been shown that high populations of *P. hamatus* can reduce flower production and quality of roses (MacDonald, 1976). This species seems to be also damaging to grapevine orchards (Raski and Lider, 1959; Philis, 2003). In an established vineyard, the nematicides cadusafos and carbofuran controlled *Xiphinema index* Thorne & Allen, 1950*, Mesocriconemax enoplax* (Raski, 1952) Loof & de Grisse, 1989 and *P. hamatus*, and subsequently increased yields (Philis, 2003); however, the exact role of *P. hamatus* cannot be determined as the observed yield loss may have been related to the other two nematodes which are considered as important parasites of grapevine in literature.

There are also cases in which *P. hamatus* has considerably reduced the yield of vegetable crops. According to Lownsbery *et al.* (1952), this nematode severely infected celery in Connecticut, USA, and under greenhouse conditions it showed marked pathogenicity. Methyl bromide treatment of soils infested with this nematode increased the weight of pot-grown celery by four times when compared with the control. Rich (1955) reported *P. hamatus* attacking the roots of celery in New Hampshire, USA and causing severe stunting and chlorosis. In the Federal Republic of Germany, this species caused heavy damage to carrots (Weischcr, 1957). According to the results, the critical number of *P. hamatus* in 500cm^3 of soil, causing damage to carrot, was 3000 to 4000 nematodes. The extent of damage depended also on the phase of development of the plants; and younger plants were damaged more readily than older ones. At the end of the vegetative period, even a few thousand s of *Paratylenchus* cannot cause perceivable damage to carrot (Weischer, 1964). In the Wisconsin State, USA, *P. hamatus* was found to be a parasite of peppermint (Faulkner, 1964). In highly infested fields, the plant growth was retarded, flowering delayed, the root system was weaker than that of the healthy plants and the plants showed symptoms of withering. Experiments indicated that the nematode population increases rapidly up to the beginning of flowering, it then decreases during flowering, and increases again after flowering, reaching up to 100000 individuals on a single plant. At the end of the experiment, with the decrease in the fresh\dry weight of plant, population of the nematode was considerably reduced. It is presumed that *P. hamatus* reduces the yield of peppermint and adversely affects the quality of the essential volatile oil (Faulkner, 1964). In the USSR, *P. hamatus* was also found constantly in large numbers (up to 1000 individuals in 15 gram of soil) in the subsoil of peppermint fields in Moldavia (Lisetskaya, 1968; 1969).

***Paratylenchus microdorus* Andrassy, 1959**

Andrassy (1985) observed a heavy infestation of *P. microdorus* in Hungary which could delay growth of red clover and lettuce. The leaves of affected plants were smaller and their lateral roots were fewer in number than healthy plants. Some other reports further proved the damage of this species to monocotyledons, especially grasses). Brzeski (1998) reported *P. microdorus* as a common species in meadows, sometimes also found in the rhizosphere of corn plants. He suggested that Poacae are probably the main host. Ciobanu *et al.* (2003) also noted that this species prefers grasses. Talavera and Navas (2002) found some *Paratylenchus* species (*P. microdorus*, *P. similis*, *P. nanus* and *P. ciccaronei*) were the most abundant (98% frequency) and prevalent (average 146 nematodes per 100cm^3 soil) plant-parasitic nematodes associated with pastures and grassland s in southern Spain. They also noted that *P. microdorus* populations were maintained or increased by all grasses or legumes tested in a pot experiment. They concluded that *Paratylenchus* spp. well exploit the summer drought in semi-arid grassland s for their survival in better competition with other nematodes and thus, they are predominant in the region. Dominance of *Paratylenchus* in dry l and pastures has also been reported by Yeates (1984) and Nombela *et al.* (1999).

***Paratylenchus minutus* Linford in Linford, Oliveira & Ishii, 1949**

It seems that pineapple plantation environment is especially favorable to *P. minutus* (Linford, 1942; Linford *et al.*, 1949). Linford (1942) found large numbers of this nematode attached to pineapple rootlets. Furthermore, Linford *et al.* (1949) observed that the old plantations of pineapple in Hawaiian region frequently contained 100 to over 900 nematodes per gram of soil, and up to 23800 nematodes per gram of root. They also stated that *P. minutus* might be able to feed and reproduce on roots of 24 other plants including weeds, crop plants, and ornamentals, when they were grown in miniature root-observation boxes of infested soil. Although the lack of visible pathological symptoms in cells fed on, and the occurrence of large populations on roots of apparently normal pineapple plants, tend to indicate that *P. minutus*is non-pathogenic, the authors finally noted that such a conclusion would be premature and needs further confirmations.

***Paratylenchus nanus* Cobb, 1923**

Populations of *P. nanus* were for the first time recovered from the rhizosphere of apparently healthy roots of the Californian laurel tree (Cobb, 1923) and the necrotic parts of the roots of elegant zinnia (Steiner, 1924). Raski (1975) listed alfalfa and several other plants as possible hosts from the USA and Canada. Corbett (1978) stated that it is possible to find an enormous population up to 250 thousand of *P. nanus* per a litre of soil in the rhizosphere of perennial plants, particularly orchards. It appears that grasses are good hosts of *P. nanus*, as confirmed by Viketoft *et al.* (2005) and Viketoft (2008) who found orchard grass *Dactylis glomerata* L. and timothy-grass *Phleum pretense* L. as the best hosts for this species. In glasshouse tests of 15 pasture plants, common in New Zeal and, Bell and Watson (2001) indicated that all good hosts (reproduction factor > 1) of *P. nanus* were grasses, namely orchard grass *D. glomerata*, Italian ryegrass *Lolium multiflorum* Lam. and perineal ryegrass *L. perenne* L.. Annual bluegrass *Poa annua* L. was considered as a poor host and the two C4 grasses, paspalum *Paspalum dilatatum* Poir. and summer grass *Digitarias anguinalis* (L.) Scop. were non host plants. There was no significant difference in the proportion of life stages between good and poor hosts of the nematode. Furthermore, they considered apple, cherry, grapevine, potato, carrot, celery, corn and also 35 woody and bushy plants as other hosts of this species. Brzeski (1998) also reported *P. nanus*as a common species in meadow soils, and the rhizosphere of cereals. However, Ciobanu *et al.* (2003) found this species in forests on brown acid soils located at high altitudes and therefore, they suggested that this species is not restricted to lowland habitats and grass vegetation.

The effects of the host on reproduction or morphometric characters of *P. nanus* has been studied in few works. In an infection of the garden balsam *Impatiens balsamina* L. by 4000 individuals, the number of nematodes increased by 23 times during two months (Odihirin and Jenkins, 1965). The symptoms of infection on plants were: growth arrest, yellowing, late flowering and reduction in the weight of shoots (by 19 to 30%) and roots (by 2.3 times). In the another study (Fisher, 1965), approximately 1000 adults and fourth-stage juveniles of this species were added to each pot with apple and apricot seedlings as host plants and allowed to develop for four months. The two hosts had no effect on the morphometric characters of females but apricot seedlings allowed the development of longer males.

***Paratylenchus neoamblycephalus* Geraert, 1965**

There is a well-documented and helpful piece of information on the pathogenicity of *P. neoamblycephalus* by Braun and Lownsberry (1975). They indicated that elimination of the nematode from soil by fumigation with 1,2-dibromoethane, stimulated the growth of Myrobalan plum seedlings. Addition of a suspension of *P. neoamblycephalus* to Myrobalan seedlings inhibited their growth

compared to non-inoculated control treatments. Roots of Myrobalan seedlings inoculated with the nematode were smaller, darker, and had fewer feeder roots compared to those of control plants. Nematodes were observed feeding ectoparasitically, but their head was embedded in root cortex. They were associated with small lesions and dead lateral roots. Clusters of nematodes were common at ruptures in the epidermis, and where lateral roots emerged. Inhibition of Myrobalan growth by *P. neoamblycephalus* was greater at 20 and 27 ºC than at 30 ºC, and was not affected by pH over the range 4.5 to 6.5. Rose, apricot, peach, and all varieties and hybrids of cherry (*Prunus cerasifera* Ehrh.) tested, were hosts for this species. None of the herbaceous plants examined were hosts for the nematode, and some trees (*e. g.*, walnut and fig) were either non or very poor hosts. However, the authors did not obtain any success in culturing the nematode on various herbaceous plants or Myrobalan callus tissue. Reuver (1959), Geraert (1965) and Fisher (1967) reported apple as a host for *P. neoamblycephalus* in Europe and Australia, but Braun and Lownsberry (1975) noted that apple does not seem to be a host for Californian population of *P. neoamblycephalus*. They argued that this may indicate the existence of races for this species.

***Paratylenchus projectus* Jenkins, 1956**

The pathogenicity of this species has been investigated more than any other species of the pin nematodes. A large number of studies were conducted on grasses and legumes, although information is available on the pathogenicity of *P. projectus* to some other plants including tobacco, bean and sunflower. Some of the conducted researches are reviewed in Loof (1975).

Coursen *et al.* (1958) provided a list of 10 non-hosts and 42 host species. Coursen and Jenkins (1958) carried out pot experiments with tobacco and tall fescue *Festuca elatior* L. They found that inoculated tobacco plants were shorter than the control plants, and had stunted top growth and reduced internode length. The root systems were unusually clean and white, with less developed lateral roots, and maximum population in pots reached about 40000 nematodes per root system. The symptoms on tall fescue were slight stunting, increase in root weight and the number of tillers. In agreement with the suitability of tobacco as a host for this species, Loof (1975) noted that in the field where the type population of *P. projectus* was found, tobacco culture had been abandoned because of low yields. In another study (Olthof, 1979), common bean was recommended for rearing large numbers of *P. projectus* under greenhouse condition.

Smolik *et al.* (1983) indicated that the most dominant species of nematodes in sunflower fields of South Dakota, USA, was *P. projectus*; late-season populations frequently ranged from 1500 to 4000 per 100cm^3 of soil. Smolik and Walgenbach (1984) noticed that sunflower appears to be an excellent host for *P. projectus*, and it is probable that *P. projectus* control was in part responsible for the yield increases observed in the nematicide application treatment. However, Smolik (1987) concluded that *P. projectus* is was only a mild parasite of sunflower in his greenhouse study, and large populations would be necessary for substantial plant growth reduction. *P. projectus* significantly ($P < 0.05$) reduced sunflower seed yields in this study. Yield reductions occurred in both fertilized and unfertilized treatments and ranged from 12 to 33%. Application of fertilizer did not affect *P. projectus* damage to sunflower. Populations of the nematode increased 20 to 126 fold over 14 weeks. Population increase of the nematode on sunflower was highest at 20 and 25 ºC, and populations did not increase above initial inoculum levels at 10, 15, or 35 ºC. Both seed yield and final populations of *P. projectus* were significantly ($P < 0.01$) greater in the fertilized treatments. He also noted that early planting (mid-April to early May) of sunflower may reduce *P. projectus* damage to this crop (Smolik, 1987).

Excluding the above-mentioned studies, other investigations are mainly focused on the

effects of *P. projectus* on legumes or grasses. Rhoades and Linford (1961) inoculated 100 *Paratylenchus projectus* of mixed stages to 4-inch pots in which various plants were growing in sterilized potting mixture. After 105 days, the number of nematodes were 38000 with red clover *Trifolium pretense* L., 147000 with timothy-grass *Phleum pretense* L., 181000 with celery *Apium graveolens* var. *dulce* pers., and 2637000 with jasmine tobacco *Nicotiana alata*var.*gr* and *iflora,* Link and Otto. In North Carolina, McGlohon *et al.* (1961) found that *P. projectus* causes significant decrease in top weight of a legume, *Lespedeza stipulacea* Maxim., and damages the root system severely, but yield reduction was not observed in this poor host. Shesteperov (1971) observed that in the Moscow region of the USSR a complex of plant-parasitic nematodes, among them *P. projectus,* delays growth and development of red clover. In addition, the number of plants and of the leaves per plant were reduced. Furthermore, the leaves were reduced in size and dry weight and winter hardiness were decreased. The susceptibility to pathogenic organisms was also increased.

In his greenhouse experiments, Townshend (1972) found an increase from 37 to 3200 nematodes per 25 gram of soil under timothy-grass *Phleum pretense* var. Climax, and from 67 to 866 under trefoil *Lotus corniculatus* var. Viking after seven months. Townshend and Potter (1976) found that legumes are good hosts of *P. projectus* with the exception of alfalfa that was a poor host. Among grasses, timothy-grass *Phleum pretense* L. was a good host, orchard grass *D. glomerata* L. a fair host, and brome grass *Bromus inermis* Leyss. a poor host. Oat and rye were good hosts among the cereals, barley and wheat were fair hosts, and corn was a poor host. In other experiment, Townshend *et al.* (1973) indicated that *P. projectus* increased to much greater numbers under forage crops in the greenhouse than are normally found in the field. Among the grasses, squirrel-tail grass *Hordeum jubatum* L., *Echinochloa pungens* var. Wieg and *ii*, barnyard grass *E. crusgalli* L., quaking grass *Briza maxima* L. and Italian rye-grass *Lolium multiflorum* Lam. were among some of the best hosts of *P. projectus*, but Millet *Panicum capillare* L. and rice cutgrass *Leersia oryzoides* (L.) Sw. were among the poorest hosts. Among the legumes, birdsfoot trefoil *Lotus corniculatus* L. was the best host, and alfalfa *Medicago sativa* L., and red clover *Trifolium pratense* L. were the poorest hosts. Although *P. projectus* appears to multiply on many plants, the best grass hosts supported higher nematode populations than the best legumes (Townshend and Davidson, 1989).

In a pot experiment, populations of *P. projectus* became established on 10 grasses and two legumes (Wood, 1973).Reproduction occurred on all of the hosts examined. Non-feeding, preadult fourth stage juveniles comprised about 50% of most populations. In another greenhouse study (Sohlenius *et al.*, 2011), *P. projectus* increased with time in all treatments except for timothy-grass *Phleum pretense* L., Alsike clover *Trifolium hybridum* L. and the control treatments. The nematode increased in several treatments, including white clover *T. repens* L., where it reached extremely high numbers. Contrary to this, it was almost totally absent under *T. hybridum* treatment. However, it has already been shown that the nematode population increased markedly in the grass plots in a Swedish study of arable l and (Sohlenius *et al.*, 1987*)*. Ina series of grassland s of different ages, Wasilewska (1997) found a very high abundance of *P. projectus* in permanent grassland with an age of more than 20 years. Korthals *et al.* (2001) also found an increased number of this species in plots changed from monoculture field crops into more permanent or highly diverse plant communities.

It appears that *P. projectus* can be considered as an important plant-parasitic nematode of forage fields in Canada. Webster *et al.* (1972) noticed that the occurrence of *P. projectus* appears to be associated with a widespread disease of alfalfa in in Alberta, Canada, called "alfalfa sickness". Affected plants were stunted, spindly, yellowish-green in color, and poorly nodulated. Amending soil

with macronutrients (NPK) and micronutrients did not significantly improve the growth of affected plants. Beneficial effects with treating "sick" soils with steam and with Metham sodium have been reported. Examined alfalfa plants and soil adhering to their root systems consistently revealed higher counts of *Paratylenchus* in soils from areas of poor growth compared to areas of good growth. Counts of *Paratylenchus* varied from zero to more than 7000 per kg soil. Twenty-three percent of the soils contained more than 4000 *Paratylenchus* per kg of soil (Webster *et al.*, 1972). In another study in Alberta, Canada (Webster and Hown, 1973), sampled locations in the Peace River had low numbers of *P. projectus* with only 25% of the samples showing greater than 1000 and only 4% with more than 10000 nematodes per kg of soil. In contrast, an area in central Alberta had 56% of the counts greater than 1000 and 20% greater than 10000 per kg of soil. In two other surveys conducted in Canada, *P. projectus* was found in 85-90% of the forage fields in the province of Ontario, and in 61-63% in the provinces of Quebec and New Brunswick (Townshend *et al.*, 1973; Willis *et al.*, 1976).

***Paratylenchus shenzhenensis* Wang, Xie, Li, Xu, Yu & Wang, 2013**

High population densities of *P. shenzhenensis* (7600 nematodes per 100cm^3 of soil) were considered to be the cause of severe damage to anthurium *Anthurium and raeanum* in Shenzhen, Guangdong Province, China (Wang *et al.*, 2016). Commercial fields of this plant showed a patchy distribution of chlorotic declining plants that were usually stunted. In pathogenicity tests, obvious disease symptoms were observed as reduced and rotted roots (four months after nematode inoculation) as well as reduced plant growth and height plus reduced rotted roots (eight months after nematode inoculation). Histological observations indicated that *P. shenzhenensis* is an endoparasitic pathogen of anthurium roots. Whole nematode bodies were observed in the outermost epidermal cells and root hairs, and the cell walls and middle lamellae were partially dissolved because of nematode migration and feeding.

Other species

Some information is available on the damage potential of other *Paratylenchus* species, although usually there is no direct evidence on the pathogenicity or damage level of these nematodes to the associated plants. High populations of *P. besokianus* Bally & Reydon, 1931 were recovered in the necrotic parts of the roots of coffee tree (Bally and Reydon, 1931). Boag (1974) observed high population densities of an unknown species of *Paratylenchus* in the *Quercus* spp. rhizosphere in Scotland. Wu and Hown (1975) noticed that rhubarb *Rheum rhabarbarum* L. plants grown in a small pot, containing soil infested with *P. neoprojectus* Wu & Hown, 1975, were not vigorous and appeared to become unhealthy as they grew older. Furthermore, the nematode population was extremely heavy and countless thous and s of nematodes at different stages were present. The authors concluded that this crowded environment and declining condition of the plants might affect the development of the nematode ovary, which was usually shorter.

Microscopic observations were made on feeder roots collected from an olive orchard in Italy naturally infected with *P. peraticus* (Raski, 1962) Siddiqi & Goodey, 1964. During the observations, active vermiform juveniles, immature females, and males were detected only in the soil, while mature females were found attached to the roots. This species induced feeding tubes in the host root tissues (Inserra and Vovlas, 1977). In another study (cid del prado Vera and Maggenti, 1988), colonies of juveniles and females of *P. hamicaudatus* ciddel prado Vera & Maggenti, 1988 induced specialized feeding site in the cortex of the roots of the Coast Redwood *Sequoia sempervirens* (D. Don) Endl

Brzeski *et al.* (1999) found the species *P. arculatus* Luc & Guiran, 1962 in a soil sample from olive tree nursery in the south of Spain. The population density varied from 0.03 to 2.49 of

nematode per cm^3 of soil. During the examination of olive roots, the author found many females on roots. As stated by Háněl (2000), the species *P. straeleni* (de Coninck, 1931) Oostenbrink, 1960 is probably a typical species of soil fauna under silver birch *Betula pendula* Roth. culture, because it occurs numerously in birch rhizosphere of wet as well as dry soils in South Bohemia. Čermák and Renčo (2010) also noticed that *P. Straeleni* was dominant species of plant-parasitic nematodes in the wet birch wood of Slovak and the Czech Republic.

Feeding habits of *P. latescens* (Raski, 1976) Siddiqi, 1986 was well discussed in detail by two separate studies (Troccoli *et al.*, 2002; Inserra *et al.*, 2003). These studies indicated that mature females of *P. latescens* remain as sedentary ectoparasites attached by the stylet to the surface of timber bamboo roots (*Phyllostachys bambusoides* Siebold &Zucc.) for their entire life. Troccoli *et al.* (2002) indicated that slender females initiate root infection. These slender females remain attached to the root surface by the stylet. Soil particles and cell debris accumulate around the anterior portion of the female body outside the root. As females reach sexual maturity, they become swollen and secrete a gelatinous matrix, which covers and protects their body. The gelatinous matrix hardens around females, males, newly hatched J2s, and eggs. Multiple infections by four or five females packed together in the same gelatinous matrix were common. J2s leave the gelatinous matrix and move to the soil and molt to initiate another cycle. Inserra *et al.*, (2003) pointed out that vermiform females insert their long stylet into root tissues and remain attached to the root surface, where they mature and swell. Penetration of the nematode body to the root tissue does not occur and thus, no anchorage can be seen at the feeding site. The electron-dense deposit, probably produced by the root cell walls, appears to cement and thus anchor the stylet to the roots, allowing a sophisticated form of parasitism involving feeding site formation similar to that of other sedentary tylenchulids and cyst-forming nematodes.

P. curvitatus van der Linde, 1938 suppressed plant height, stem sturdiness, root length and to a little extent flower size on carnation at the initial inoculum level of 500 individuals per pot. The severity of the damage increased with the corresponding increase of the inoculum level. Plants affected by this species were stunted, and their leaves turned yellow. Floral stalks of such plants were weak leading to poor quality of flowers. This study indicated that *P. curvitatus*is a potential threat to profitable cultivation of carnation in the infested areas (Khanna and Jyot, 2002).

The findings of Masdek *et al.* (2007) indicated that infestation by *Paratylenchus* sp. is the most probable cause of yield decline of pineapple on peat in Johor, India. Foliar analysis of the pineapple plants showed decreased content of potassium in the leaf. After the parent crop was sprayed with herbicide and burned later, the nematode population decreased, but the population in the root and soil still could affect the next crop.

Concluding remarks

The pin nematodes of the genus *Paratylenchus* occur in the rhizosphere of many plants and feed on a wide range of host plants. *Paratylenchus species* sometimes may produce no specific symptoms in plants, but, it is supposed that large populations reduce the absorption capacity of roots and promote root death; probably they affect the general physiology of the plant (Linford *et al.*, 1949). If a large number of *Paratylenchus* inhabit the subsoil zone, the plants show symptoms of quick death (Jenkins, 1960; Mai *et al.*, 1960; Adams and Eichenmuller, 1962; Corbett, 1966).

Generally, *Paratylenchus* is not considered damaging on most crops unless it occurs in high numbers, more than 500 per $100cm^3$ of soil (Talavera and Navas, 2002). Heavy accumulation of *Paratylenchus* in the rhizosphere of plants and even in the roots is not necessarily conclusive of their parasitic life style. Interestingly, the researchers were often puzzled by the absence of a distinct correlation between the size of populations of

Paratylenchus and visible symptoms of the plant condition, so, very large populations were often found in the rhizosphere of apparently healthy plants (Cobb, 1923; Linford *et al.*, 1949; Reuver, 1959; Mcglohon *et al.*, 1961; Lownsbery *et al.*, 1964). An important note in the pathogenicity of *Paratylenchus* which should be considered in making management decisions, is the ability of its species to increase from low number to damaging levels during a short time (Jenkins and Taylor, 1956; Coursen and Jenkins, 1958; Rhoades and Linford, 1961; Faulkner, 1964; Odihirin and Jinkins, 1965; Townshend, 1972; Townshend *et al.*, 1973; Brzeski, 1976).

According to the literature, studies on the pathogenicity and damage to plants have not been well performed for pin nematodes (as a group having ectoparasitic feeding behavior, and capable for causing damages) compared to sedentary or migratory endoparasites (*e.g.*, root-knot nematodes, cyst nematodes, root-lesion nematodes). However, the difficulties in working with these very small-sized nematodes are well known for plant pathologists. Much of the damage to crops is recorded for certain widespread species including *P. bukowinensis*, *P. dianthus*, *P. hamatus*, *P. nanus*, *P. neoamblycephalus* and *P. projectus*. This means our current knowledge on the damage potential of many species in the genus is very limited. However, more detailed studies encompassing several species of the genus are required to clarify the exact importance and roles of this group of nematodes in agroecosystems. On the other hand, understanding the feeding behavior and corresponding mechanisms, the host plant resistance and nematode virulence are essential to have better insights into the pathogenicity of the pin nematodes.

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پتانسیل بیماریزایی نماتدهای سنجاقی (Nematoda: Tylenchulidae) *Paratylenchus* spp. در گیاهان

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چکیده: جنس *Paratylenchus* در تعریف گسترده خود شامل نماتدهای متعلق به جنس‌های *Paratylenchus* (گونه‌های دارای استایلت به‌طول ۱۰ الی ۴۰ میکرومتر)، *Gracilacus* (گونه‌های دارای استایلت به‌طول ۴۰ الی ۱۲۰ میکرومتر)، *Gracilpaurus* (گونه‌های دارای برجستگی‌های کوتیکولی) و *Paratylenchoides* (گونه‌های دارای شبکه کوتیکولی سر رشدیافته) است. تعدادی از گونه‌های دارای استایلت بلند، از بافت کورتکس ریشه‌های میزبان‌های چوبی تغذیه کرده و متورم می‌شوند، اما اغلب گونه‌ها انگل سطحی ساکن ریشه‌های گیاهان می‌باشند. به‌عبارت دیگر، گونه‌های دارای استایلت کوتاه‌تر از ۴۰ میکرومتر معمولاً از سلول‌های اپیدرمی تغذیه می‌کنند اما گونه‌های دارای استایلت بلندتر قادرند بدون وارد شدن به ریشه، از بافت کورتکس آن تغذیه نمایند. به‌طور کلی نماتدهای سنجاقی جنس *Paratylenchus* انگل‌های گیاهان عالی بوده و بیش‌ترین فراوانی را در فرار یشه‌ی درختان و گیاهان چندساله دارند. مقاله مروری حاضر بیماریزایی و پتانسیل خسارت نماتدهای سنجاقی را در گیاهان مورد بحث قرار داده است.

واژگان کلیدی: *Gracilacus*، خسارت، بیماریزایی، گیاهان چندساله، درختان، نماتدهای سنجاقی، جمعیت