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Research Paper

Lesion nematode (*Pratylenchus* spp): 'Emerging threats' in Horticulture and Agriculture, a review

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Abstract
Pratylenchus, also known as lesion or "meadows," is a harmful root lesion nematode found in temperate, subtropical, and tropical climates. It infects all most all economic plants and causes stunting, nutritional and water deficits, and dieback. P. brachyurus; P. coffeae; P. crenatus; P. delattrei; P. goodeyi; P. loosi; P. neglectus, P. penetrans, P. pratensis; P. scribneri; P. thornei; P. vulnus; P. vulnus and P. zeae are most prevalent species predominant in temperate, subtropical, and tropical climates.Symptoms include small patches of yellow and diminished development on leaves, loss of primary root, wilting, and eventually death. Root lesion nematodes are migratory endoparasites that obstruct the absorption of water and nutrients from the soil. Identifying species is challenging due to weak diagnostic traits and morphological variability. Research has shown that reducing the nematode population can help reduce the population of these nematodes. Pratylenchus thornei, a pest with weak diagnostic traits and morphological variability, has been found to exacerbate chickpea wilt, maize root rot, and potato wilts in Sri Lanka. Pratylenchus molecular research has thoroughly investigated ITS, rDNA, 18S rDNA, D2-D3 of the 28S rDNA, and mitochondrial genes. A tomato seedling infested with P. penetrans was significantly reduced in nematode population after being coated with 0.25% maize oil. Cotton roots colonised with Gigaspora margarita produced significantly less P. brachyurus per g. root compared to nonmycorrhizal plants. The symbiotic microorganisms reduced nematode reproduction by altering the cortex, making it unsuitable for worm nourishment, or by competing with the nematode for space. Continuous exposure to carbofuran or phenamiphos doses of 0.05 mM and 0.003 mM completely prevented P.vulnus penetration of Phaseolus vulgaris roots.

Key words: *Pratylenchus, life cycle, distribution, lesion, symptoms, interaction, losses, molecular, botanicals, management*

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I. Introcuction

In 1929, Godfrey recorded the root lesion nematode under the generic name *Tylenchus brachyurus*. In 1936, Filipjev classified the worm as a new species, *Pratylenchus*. Because of their extensive host ranges, global distribution, and migratory endoparasitic activity. The second most common plant pathogenic worm is root lesion nematode, after root knot and cyst nematodes (Castillo and Vovlas, 2007). Lesions, or "meadows," are common plant parasitic nematodes that mostly feed on ornamentals, coffee, peanuts, ramie, vegetables, grains, legumes, and fruit trees (Handoo et al, 2008). A total of 97 legitimate species of root lesion nematodes have been discovered in nearly every cool, temperate, and tropical climate (Yu, Y. et. al, 2021). The most prevalent and damaging species of root lesion nematodes are confined to temperate, sub-tropical and tropical climates of the world are *P. arlingtoni* (Handoo, Carta and Skantar, 2001); *P. artemisiae* (Zheng and Chen,1994); *P. angulatus* (Siddiqi, 1994); *P. andinus* (Lordello, Zamith and Boock,1961); *P. acuticaudatus* (Braasch and Decker, 1988); *P. bhattii* (Siddiqi, Dabur and Bajaj, 1991); *P. bolivianus* (Corbett, 1983); *P. brachyurus* (Godfrey, 1929; Filipjev and Schuurmans Stekhoven, 1941); *P. brzeskii* (Karssen, Waeyenberge and Moens, 2000); *P. coffeae* (Zimmermann, 1898; Filipjev and Schuurmans Stekhoven, 1941); *P. convallariae* (Seinhorst, 1959); *P. crassi* (Das and Sultana, 1979); *P. crenatus* (Loof, 1960); *P. cruciferus* (Bajaj and Bhatti, 1984); *P. curvicauda* (Siddiqi, Dabur and Bajaj, 1991); *P. delattrei* (Luc, 1958); *P. pratensis* (de Man, 1880;

Filipjev, 1936); *P. dunensis* (de la Peña, Moens, van Aelst and Karssen, 2006); *P. ekrami* (Bajaj and Bhatti, 1984); *P. elamini* (Zeidan and Geraert, 1991); *P. estoniensis* (Ryss, 1982); *P. fallax* (Seinhorst 1977); *P. flakkensis* (Seinhorst, 1968); *P. gibbicaudatus* (Minagawa, 1982); *P. goodeyi* (Sher and Allen, 1953); *P. hippeastri* (Inserra et al., 2007); *P. hexincisus* (Taylor and Jenkins, 1957*); P. jaehni* (Inserra, Duncan, Troccoli, Dunn, dos Santos, Kaplan and Vovlas, 2001); *P. kasari* (Ryss, 1982); *P. japonicus* (Ryss, 1988); *P. kralli* (Ryss, 1982); *P. kumaoensis* (Lal and Khan, 1989); *P. penetrans, P. thornei, P. neglectus, P. scribneri* (Steiner, 1943), *P. loosi, P. crenatus, P. vulnus* (Loof, 1960); *P. macrostylus* (Wu, 1971); *P. manaliensis* (Khan and Sharma, 1992); *P. microstylus* (Bajaj and Bhatti, 1984); *P. morettoi* (Luc, Baldwin and Bell, 1986); *P. mulchandi* (Nandakumar and Khera, 1970); *P. neglectus* (Rensch, 1924) Filipjev and Schuurmans Stekhoven, 1941); *P. neobrachyurus* (Siddiqi, 1994); *P. okinawaensis* (Minagawa, 1991); *P. panamaensis* (Siddiqi, Dabur and Bajaj, 1991); *P. penetrans* (Cobb, 1917) Filipjev and Schuurmans Stekhoven, 1941); *P. pinguicaudatus* (Corbett, 1969); *P. pratensisobrinus* (Bernard, 1984); *P. pseudocoffeae* (Mizukubo, 1992); *P. pseudofallax* (Café-Filho and Huang, 1989); *P. pseudopratensis* (Seinhorst, 1968); *P. roseus* (Zarina and Maqbool, 1998); *P. scribneri* (Steiner in Sherbakoff and Stanley, 1943); *P. sefaensis* (Fortuner, 1973); *P. sensillatus* (Anderson and Townshend, 1985); *P. silvaticus* (Brzeski, 1998); *P. subpenetrans* (Taylor and Jenkins, 1957); *P. subranjani* (Mizukubo, Toida, Keereewan and Yoshida, 1990); *P. sudanensis* (Loof and Yassin, 1971); *P. tenuis* (Thorne and Malek, 1968) *P. teres* (Khan and Singh, 1974); *P. thornei* (Sher and Allen, 1953); *P. typicus* (Rashid, 1974); *P. unzenensis* (Mizukubo, 1992) ; *P. ventroprojectus* (Bernard, 1984); *P. vulnus* (Allen and Jensen, 1951); *P. wescolagricus* (Corbett, 1983); *P. yamagutii* (Minagawa, 1991); *P. yassini* (Zeidan and Geraert, 1991); and *P. zeae* (Graham, 1951). *Pratylenchus penetrans* and *P. thornei* tends to occur in raspberry, strawberry and chickpea fields, temperate and tropical orchards, and nurseries of some economic crops; it was probably introduced to most of countries by outsiders. *P. penetrans* has caused significant decline and numerous replanting failures in cherry, apple, and peach orchards of temperate climate. Maize, barley, and wheat, are the primary food crops, and eight root lesion nematodes, including *P. thornei* and *P. neglectus*, have been documented to infect them (Yu, Y. et. al,2021, Smiley, 2010 ; Vanstone et. al, 1998 ; Taylor et. al, 1999). *Pratylenchus coffeae* (Mayne and Subramaniyan (1933), (Siddiqi 1964), in India and (Yokoo and Ikegami (1966), Radewald et al. (1971), and Bridge et al. (1997) Japan and various countries. It was once considered a significant wheat pest in Utah (Pervez et al., 1970), Arizona, Yugoslavia, India, Italy, Mexico, Israel, Galicia, and Cantabrico (Ariasa and Romera, 1975) and Australia (Colbran and McCulloh, 1965).

Pratylenchus zeae appears to be an issue in tropical regions and has a fairly broad host range in Nigeria (Babatola 1984), Queensland (Blair et al, 1999), Pakistan (Khan et al, 1997), Brazil (Carnerio et al, 1982), Japan (Mitsui and Okamoto, 1973, Fukudome 1978), India (Singh, 1966, Pall and Chand, 1971, Yadav and Verma, 1971, Sitaramaiah, 1984); yet, infestation has been found to be more favourable for sugarcane and sorghum (Tikyani et al., 1969). *P. vulnus* and *P.penetrans* are parasite of other millets reported worldwide. *P. penetrans* have been reported from South Western and Central Ontario (Potter and Townshend, 1973), Japan (), USA (Bird, 1981, Wheeler *et al*, 1994), Cyprus (Philis, 1995), Korea (Park *et al*, 1998), Canada (Columbia, Forge *et al*, 1998) and Brazil (Rossi and Monteiro 2001).

P. scribneri is a species of great commercial importance in temperate fruit and ornamental plants found in Europe, Japan, Korea, Brazil, and the US,. Sethi et.al. (1971) reported *P. penetrans* in India. It is known that *P. brachyurus* is crucial in tobacco Mountain's brown rot (1954). The nematode has also been noticed in Pakistan (Khan *et al* 1997), Sultanate of Oman (Waller and Bridge, 1978), Kyushu (Gotch, 1964), Utah (Bernand et. al. 1979), Nigeria (Babatola, 1984), Brazil (Souza *et al.*, 1999, Sharma and Amabile, 1998), Cuba (Fernandez *et al.*, 1998), Australia (Broadley, 1981) and India (Rama and Das Gupta, 2000). Lesion nematode *P. pratensis* is well distributed in Uzbekistan (Mavlyanov, 1972), India (Rashid, 1997) and USSR (Nesterov and Lizogubova 1972,). *P. neglectus* India, (Mehta and Sundararaju, 1990), Ontario (Qing-yu et al.,1998), Japan (Orui and mizukubo, 1999), Netherlands (Molendijk, 1999), Argentina (Torres and Chaves 1999). *P. delattrei* India (Poornima and Vadivelu 1999 and Mehta and Sundararaju 1990); *P. loosi* Korea (Park *et al* 2002), West Indies (Berg *et al* 2000); *P. crenatus* USA (Wheeler *et al* 1994), Argentina (Torres and Chaves 1999), *P. bolivianus* Israel (Orion *et al* 1979), India (Haseeb and Shukla 1994), England and Wales (Cotton *et al* 1991); *P. agilis* (Yin 1994), *P. vulnus* (Yin 1994), Srilanka, (Mohotti el.al. 1997), Japan (Orui and Mizukubo 1999), *P .indicus* (Rahid 1997), *P. veruculatus*, China (Liu-Guokun and Zhang shaosheng 1999) and West Indies (Van den Berg *et.al*. 2014*), P. andinus* Argentina (Torres and Chaves 1999), *P. fallax*, Ontario (Yu *et al* 1997,1998), Belgium, Britain, France, Italy, Netherlands (Seinhorst 197; Willis et al., 1976), Canada and Japan (Seinhorst,1977; Willis et al.,1976), *P. thornei* from Galicia, Cantabrico (Arias and Romera 1975) and India (Tiwari et al 1992). The distribution of *Pratylenchus* species associated with wheat crops was investigated in Bohemian region of the Czech Republic (Kumari, 2015). In warmer groundnut-growing regions, such as South America, North Central Africa, Nigeria, Brazil, and Australia, it poses significant problems. Several Indian states have reported it (Singh et al., 1964; Rama and DasGupta, 2000). Sugarcane was shown to be related with *P. pratensis* (Prasad, 1960 and Prasad et al., 1964), Singh and Misra (1975) and Rashid (1997) later reported on

it (Singh 1969). Turf grass in Ontario was parasitized by *P. fallax* (Yu et al. 1997), while in China *P. veruculatus* was also reported (Liu-Guokun and Zhang Shaosheng 1999).

Yield Loss

The losses caused by *Pratylenchus* spp. vary with species, nematode population, crop region and environmental factors. *P. coffeae* is serious problem of coffee plantation in Karnataka. According to Van Berkum and Seshadri, (1971), the nematode cause annual loss of Rs. 20 million to coffee production in Karnataka. *P. zeae* reduces 25 percent yield of sugarcane in Panama (Tarte *et al*, 1977). Similarly, sugarcane yield declined in Australia (Stirling *et al*, 2001). In maize crop, 50 to 100 percent reduction was recorded in Brazil and India (Lordello, 1974, Patel and Patel, 2000). *P. thornei* is an obnoxious pest and is reported to be associated with wide range of hosts, but it is considered important on wheat and chickpea. It causes 27 percent yield loss in Australian wheat (Nicol. *et al* 1999), while in chickpea 27 to 58 percent loss was recorded. (Greco *et al*, 1994, Divito *et al*, 1992 Tiwari et al.1992 and Haseeb *et al*, 2000). The yield of *Mentha piperita* due to *P. penetrans* reduced up to 34 to 66 percent (Bergeson 1963, Bergeson and Green 1979 and Pinkerson 1984). In chickpea, the loss was up to 50 percent (Greco et al 1994) and in tobacco 0.4% loss was reported (Gayed and Watson 1975). Prasad and Rao (1978) evaluated the loss of grain yield of upland rice due to *P. indicus* to the tune of 33 percent while *P. vulnus* cause 80 percent yield loss in strawberry in Srilanka (Mohotti *et al*, 1997).

Symptoms

Nematodes cause root stress, yellowing, leaf loss, weak new growth flushes, and stunted leaves in plants. Drought or limited water availability increases wilting.

Important symptoms of an infected plant include stunting, chlorosis of foliage, the formation of lesions on the roots, as well as diminished plant vigour. Nematodes migrate throughout intercellular and intracellular cortical tissues, feeding on nearby cells to cause necrosis and cell death. As migratory endoparasites, lesion nematodes freely move through the root tissues of their hosts after penetration of the root for feeding and reproduction. The cortical tissue of host is preferred feeding site. The central regions of each of these areas are typically the most severely affected; despite damage to normal-appearing plants lessening when one approach the outer edges. Severely infected plants experience a decrease in leaf size and frequency, leading to significantly lower yields. High nematode populations can combine with other soil-borne infections to kill weak plants, causing a field to become desolate. (Dropkin, 1980). As the season progresses, affected areas may increase, with widespread signs of plant root stress. Low-density nematodes may not show signs above ground, leading to stunting, water and nutrient deficiency (Evans et al., 1993). The most common symptom is the formation of small, elongated, light brown lesions on the root system, which later spread to fine or supporting roots. Initially lesions are tiny, elongated, light brown coloured spot on tap root system which later spread on fine/supporting roots. The lesion enlarges gradually turn black, coalesce and ultimately may girdle the root giving an impression of constriction. Root lesion nematodes are migratory endoparasites that infect and develop mostly in the cortical parenchyma, obstructing the absorption of water and nutrients from the soil, resulting in severe root injury and impaired plant development **(**Yu, Y. et. al,2021**).** Symptoms of infestation in coffee plants include stunted growth, leaf yellowing, root loss, wilting, and death, resembling malnutrition or water deficiency due to *P. coffeae* (Mayne and Subramaniyan ,1933). *P. coffeae* appears to be the most pathogenic species and is responsible for citrus slump disease in Florida. Siddiqui (1964) attributed *P. coffeae* to be a principal cause of soft root rot of citrus causing brownish-black lesion on the rootlets. Rashid and Khan (1975) reported that *P. coffeae* is responsible heavy root damage which subsequently leads to poor growth of chrysanthemum. Plant stunting, premature yellowing, and leaf drying are common above ground symptoms, resulting in decreased flower size.

Moura *et al*, (2001) reported that *P. coffeae* induces symptoms similar to those of the dry rot in yam. Severe shrinkage in grains of wheat due to *P. thornei* was reported by Thorne (1961) from Utah State of U.S.A. From India, Sethi and Swarup (1971); Tiwari et al.(2008) and Tiwari et al. (2011) observed that the infested plant had a sickly appearance with poor patchy growth. Infested root showed brown lesion, stunting, chlorosis, leaf tip necrosis, reduced tillering, and ear size/number reduction, with ear sterility in Yugoslavia causing heavy losses (Grujicic, 1969). Infested plant of chickpea shows general stunting, chlorosis and lack of vigor. On root, infection is characterized by brown to black lesion (Greco *et al*, 1992, Di vito *et al*, 1992). In mint plant, *P. thornei* caused severe wilting, chlorosis of the leaves and lesion on the root system (Haseeb 1992). Maize plant infested with *P. zeae* with very poor growth, stunted and yellowing of the leaves (Pall and Chand, 1971). Similarly infected rose plant showed chlorotic, poor and stunted growth with necrotic lesion on roots (Sunderababu and Vadivelu 1988a).

Pratylenchus delattrei reduces the vigor of chilies and okra, produce downward cuping and crinkling of leaves (Ahmed 1970). Crossandra crop showed chlorosis, wilting, mottled leaves, brown and pinkish hues, and reduced flower yield due to infested plants not producing tertiary spike (Srinivasan and Muthukrishnan, 1975).

P. brachyurus was a major problem on patechouli and hessararghatta in Annamalai hills of Tamil Nadu and Karnataka. The infested plants exhibited wilting symptoms (Khan and Reddy, 1993). *P. penetrans* exhibit necrotic lesions on burdock roots, damage to tap roots, small horizontal scratches, and vertical cracks appear, with scratches correlated with nematode density (Itou *et al*, 2004*).*

II. Morphology

The Pratylenchus (<0.7 mm) is a small, vermiform to obese bird with a small size, rounded cephalic regions, and a variety of tail shapes. Its appearance can be ornamented or otherwise, and its diagnostic features are less commonly used for identification than for juveniles and males. The bird's pharynges have well-developed valves, secretory-excretory holes, and a brief post-vulval uterine sac (Singh et al., 2021).

Life Cycle

The temperature, humidity, host and soil types are related in completion of the life cycle of *Pratylenchus* species. *P. goodeyi* took 24 days to finish the life cycle in susceptible cultivar (Nakyetengu) of banana and 30 days in resistant (Sukalindizi) cultivar (Prasad *et al*, 1999). In potato tubers in Japan, adult *Pratylenchus coffeae* has an average life span of about 27 days at 25-30^{0}C (Gotoh and Ohshima, 1963). The embryonic development of *P. indicus* completes in 5-6 days at 28^{0}C and the post embryonic development to gravid female takes 28 days in rice root. One life cycle on rice was completed at 30^{0}C (Prasad and Rao 1981). Nandakumar and Khera (1974) studied the life cycle and post-embryonic development of *P. mulchandi in vitro* cultures with plant callus tissues and pearl millet seedlings. They reported that the life cycle takes about 24-36 days at room temperature (25-30^{0}C). There were four moults, the first occur inside the egg. It required 6 to 10 days for the egg to hatch, 15 to 20 days for second stage larvae to reach the adult stage and 3 to 6 days from maturation to egg laying. *Pratylenchus medittraneus* feed ecto-parasitically with endo-parasitic feeding and finishes the life cycle in about 8-10 weeks on potato root tips under laboratory condition (Orion *et al*, 1995). *Pratylenchus thornei* took 25-35 days to complete off the life cycle at 20-25^{0}C on carrot disk culture (Castillo *et al*, 1995), while in maize, *P. thornei* completed the life cycle in 25-29 days under laboratory condition at 30-32^{0}C with 4 moults, the first being inside the egg (Siyanand *et al*, 1982). The genus *Paratylenchoides* (Raski, 1973) was assigned to *Pratylenchus* species with stronger cephalic sclerotisations, dorso-ventrally narrower heads and small narrow rounded protrusions on the anterior surface of conoid lip region. In pigeon pea, *P. sudanensis* took 28 days to complete the life cycle from newly hatched juveniles to gravid female at 26-31^{0}C (Yassin and Mohamed 1980).

Host Range

Lesion nematodes are adapted to a large variety of environmental conditions and have a wide host range. Wheat, barley, maize, sorghum, bean, chickpea, soybean, lentil, pea, sunbeam, urdbean, frenchbean, fababean and pigeonpea were reported to be good hosts while sunflowers serve as poor hosts for *P. thornei* (O' Brien, 1982, 1983, Greco and Sharma, 1990 and Ali, 1991). Grasspea, *lathyrus sativus*, lettuce, potato, cauliflower and cereals were good host while parsley, turnip, rashad and kumboz were reported to be non-host from Syria. (Greco *et al*, 1988).

Pratylenchus zeae appears to be widely distributed in tropical areas and has wide host range. Sorghum, maize, chickpea, *Phaseolus vulgaris*, soybean, aubergine, cabbage, *Setaria italica* were most favorable hosts, turnips, pigeonpea, okra and *Pennisetum glaucum* were moderately favorable while sunhemp was non-host. (Sunderaraju and Mehta, 1990 ; Jones and Hillock, 1995). Coffee is most important host of *P.coffeae* in India, beside coffee, citrus, groundnut, maize, rice millet, okra melon, aubergine, lettuce, sesamum, soybean, millet, frenchbean, cotton, onion sweetpepper are good hosts while French marigold, rangpur lime, sesame, sunflower, cotton are poor host (Silva and Innmoto 2002; Chhabra and Majan 1976).

Pratylenchus brachyurus has been commonly associated with tobacco in Gujarat, Karnataka and Uttar Pradesh. Cucumber, okra, tomato and cantaloupe were considered to be good hosts while population decline occured in onion, cabbage, sweet pepper, carrot and lettuce (Machado and Innmoto 2001). In Brazil, tomato, *Cucumis melo*, sachharum hybrid, oats, wheat, barley, sorghum, jaragua grass, rice, napies, grass, maize, sigual grass, pongola grass, cucumber, okra, tobacco, *Centrosema pubescens* and lima bean were considered to be good hosts while rye grass, *Capsicum annum*, garlic, onion, cauliflower, cabbage, carrot were non host crops (Charchar and Huang 1980, 1981). *P. goodeyi* possesses a wide host range including *Commelina benghalensis*, *Hyperrhenia rufa*, Musa sp cv Nyova, *Plectranthus barbatus*, *Tripsacum laxam*. Some of weed species viz. *Ageratum conyzoides*, *Bidens pislosa*, *Crassocephalum crepidioides cassava* and groundnut did not harbour the development of *P. goodeyi* (Mbwana *et al*, 1995, Namaganda *et al*, 2000). *P. vulnus* was found to be associated with almond, apple, avocado, cherry, grape, plum, walnut while citrus and olive were non host crops in Spain (Pinochet *et al*, 1992). Tomato, garden pea, maize and soybean were good host for *P. hexincisus* (Zirakpavar, 1980).

Sugarcane was preferred as a good host for various *Pratylenchus* sp. viz., *P. brachyurus, P.coffeae, P. zeae, P. pratensis, P. delattrei, P. neglectus, P. scribneri, P. indicus* (Gotoh 1965; Mehta *et al* 1992 and Mehta and Sunderaraju 1990). Tobacco was considered a good host for *P. penetrans, P. zeae, P. coffeae, P. impar, P. thornei, P. brachyurus, P. vulnus* (Khan and Singh 1974; Potter and Townshend 1973; Fukudome 1978 and Lucas 1965) ; Tomato for *P. penetrans and P. hapla* (Mitsui and Okamoto 1973); Potato for *P. penetrans, P. thornei, P. brachyurus, P.coffeae, P. crenatus, P. scribneri, P. neglectus, P. teres, P. thornei* (Orion *et al* 1979; Bird 1981; Koen 1967; Wheeler *et al* 1994 and Khan and Singh 1974) ; Rice for *P. zeae, P. brachyurus* (Thames 1982) ; Coffee for *P. coffeae, P. brachyurus, P. zeae* (Souza *et al* 1999) ;Banana for *P.* goodeyi, *P. coffeae, P. pratensis, P. brachyurus,* (Ploetz *et al* 2003; Bridge *et al* 1997; Wanda *et al* 1998 and Pinochet *et al* 1998) ; Tea for *P. loosi, P. bract, P. coffeae* (Park *et al* 2002 and Souza *et al* 1999). Oat, barley, rice wheat were considered good hosts for *P. neglectus, P. thornei, P. crenatus, P .neocapitalus* (Orion *et al* 1979 and Khan and Sigh 1997); Soybean was a good host for *P. coffeae, P. neglectus, P. vulnus, P. penetrans, P. scribneri, P. brachyurus, P. coffeae, P .crenatus, P. zeae, P. hexincisus* (Orui and Mizukubo 1999; Taylor et.al. 1968; Lindsey 1971 and Zirakparvas 1980); Sweet potato for *P. coffeae, P . zeae, P. brachyurus, P. pratensis* (Iwahar *et al* 2001; Kikukawal and Sakai 1969 and Birchfield *et al* 1978) ; Ginger, Mango, Peanut, Lucerne and Plum were considered good hosts to *P. coffeae, P. brachyurus (*Rama and Das Gupta 2000) ; *P. agilis, P. coffeae, P. Vulnus (*Yin 1994) ; *P. brachyurus, P.coffeae, P.hexinicisus (*Bernard 1980 and Charchar and Huang 1981) ; *P. brachyurus, P. penetrans P.thornei (*Waller and Bridge 1978 and Orion *et al* 1979) and *P. penetrans (*Sharma 1998) respectively. Turmeric and raspberry were considered a good host for *P. delattrei (*Poornima and Vedivelu 1999) and *P. penetrans (*Vrain *et al* 1997 and Forge *et al* 1998) respectively. Sesame and sunflower was found to be a good host for *P. brachyurus* (Sharma and Amabile 1998); Cotton for *P. sudanensis, P brachyurus (*Yassin 1979; Charchar and Huang 1981) and Citrus and Grape for *P. vulnus (*Pinochet *et al* 1992).

Interaction

Pratylenchus thornei has been reported to increase the severity of chickpea wilt and corn root rot of maize in the association of *Fusarium* spp. and potato wilts in presence of *Verticillium dahliae* (Smiljakovic *et al,* 1975, Krikun and Orion 1977, Devi 1993).The interaction *of verticillium albo-atrum* and *verticillium dahliae* with *P. penetrans* causes early dying, affecting plant height, shoot weight and yield loss in potato, flax, pepper and egg plant (Burpee and Bloon, 1978 ; Martin, 1981 ; Cooseman, 1977 ; Mckeen and Mountain, 1960 and Olthof, 1969). In strawberry and Pea, *P. penetrans* interact with *Rhizoctonia fragariae* and *Fusarium oxysporum* and as a result, the incidence of black rot and wilt disease increased, it also increased the severity of club root disease caused by *Plasmodiphora brassicae*. Additive interaction with *Phytophthora erythroseptica* was recorded due to aggressiveness of fungus (Vrain and Pepin 1989, Lamondia 2003, Jensen and Vaughan 1973 and Mitchell 1971). *P. vulnus,* in presence of *Fusarium oxysporum* and *Verticillium dahliae* showed additive effect, on reduction in growth of peach, while in map seedling and Laccina, the nematode population was suppressed (Wehunt and Weave 1972, Lamberte *et al,* 2002, Kheire *et al,* 2002).

Combination of *Pratylenchus zeae* with *Curvularia* spp., *Fusarium monoliforme, Rhizoctonia solani,* and *Pythium graminicola* retarded the top growth and caused severe root necrosis of sorghum and sugarcane, but in case of maize the population of nematode decreased due to toxic effect of fungus (Santo and Holtzmann 1970, Rodriquez and Ayala 1977, Patel *et al,* 2002). Faulkner and Scotland, 1965 observed synergistic interaction between *Verticillium dahliae* f. sp. *menthae* and *P. menyus* in causation of *Verticillium* wilt of *Mentha piperita*. The presence of nematode increased the incidence and severity of disease. The period for development of *Verticillium* wilt was reduced to 2 to 3 weeks by the presence of nematode, while with *Rhizoctonia solani* it caused heavy loss in wheat, both the organism were essential for full expression of disease (Benedict and Mountain 1956). While working with carrot, potato, red clover, tomato and spinach Slootweg (1956) reported that the root rot caused by *Cylindrocarpon radicola* was more severe in presence of *P. pratensis*. Palmer *et al,* (1967) reported that drastic reduction on fresh weight of corn occured when *P. scribneri* and *Fusarium monoliforme* were present together.

Molecular

In *Pratylenchus*, species boundaries are frequently challenging to draw simply based on morphology due to the variability of morphology and scarcity of diagnostic characteristics. As of December 2020, the Gene Bank contains numerous sequences, but only 40 Pratylenchus sensu lato species have been linked to genetic data (Singh et al., 2021). These erroneously accepted sequences could lead to a series of incorrect interpretations, including morphological identification gone wrong (Janssen et al., 2017) and incorrect species identity interpretations based on relationships in phylogenetic trees. It is also possible that some species in the Pratylenchus genus are cryptic (Van den Berg E., 2014). The distinction between agricultural nematode pest species and their sibling species has become increasingly important due to factors like food security, quarantine laws, and non-chemical pest management methods (Palomares-Rius et.al. 2014). The Sequence analysis of 18S

and D2/D3 of *P. crenatus* reveal no variation in samples examined, while five populations of *P. neglectus* differ by 0 to 0.14 % (18S) and 0.17 to 0.50 % (D2/D3) in Bohemian region of the Czech Republic (Kumari, 2015). Employing rDNA is a better approach in diagnosis of nematodes. It was observed that the structure of ribosomal DNA (rDNA) sequence constitutes a trustworthy genetic marker for identification besides being a potent instrument towards analyzing genetic diversity. *Pratylenchus* populations have been extensively characterized employing the 28S D2/D3 rDNA segment on a regular schedule (Handoo et al., 2001; Al-Banna et al., 2004; De Luca et al., 2004; Inserra et al., 2007; Subbotin et al., 2008). *P. neglectus* primers set PNEG+D3B and *P. crenatus* primer set PCR22_F+PCR22_R were employed for the specific amplification of *P. neglectus* includes primer sequences alongside primer references. A quick method was implemented to extract whole genomic DNA (Stanton et al., 1998). *Pratylenchus dakotaensis* is a new and unidentified species of *Pratylenchus* differs from closely related species such as *P. convallariae, P. pratensis, P. fallax,* and *P. flakkensis,* based on molecular characteristics. The North Dakota isolate on soybeans seems to be a new species of root-lesion nematode, which has been designated and described as *P. dakotaensis* n. sp. depending on both morphological and molecular data (Handoo et.al, 2021). *Dioscoria. rotundata* Poir., *D. cayenensis* Lam., *D. alata* L., *D. dumetorum* (Kunth) Pax., *D. bulbifera* L., and *D. esculenta* (Lour.) are common yam species. Additionally, yams have a significant socio-cultural role in communities, and for those who live in yam-producing areas, growing and selling them is a substantial source of revenue.

ITS, rDNA, 18S rDNA, D2-D3 of the 28S rDNA, and mitochondrial genes have all been extensively analyzed in *Pratylenchus* molecular investigations (Castillo and Vovlas, 2007; De Luca et al., 2012; Janssen, Karssen, Couvreur et al., 2017; Orui and Mizukubo, 1999). In accordance with Subbotin et al. (2008), the 28S rDNA region D2-D3 of *Pratylenchus* is a more accurate molecular marker for species identification within the genus than the 18S rDNA. For the molecular identification of *Pratylenchus* species, the D3 subunit fragment of the 28S-rDNA gene located inside the genome area is being extensively used (Hodda et al., 2014). Molecular approaches were utilized for the study of *P. coffeae* and *P. brachyurus* (Humphreys-Pereira et al., 2017), molecular techniques were performed to determine *P. bolivianus, P. gutierrezi, P. pseudocoffeae*, and *P. zeae* (Zamora-Araya et al., 2016).

PCR-based molecular biotechnologies were used to identify and differentiate plant parasitic nematodes, replacing previous methods that involved hybridization with a sequence-specific DNA probe.Considering the ITS sequences of *P. coffeae, P. loosi,* and *P. penetrans* provided an example, distinctive primers and identification schemes for RLNs (Uehara et. al, 1998 a,b). *Pratylenchus agilis, P. bolivianus, P. mediterraneus, P. pratensis, P. pseudocoffeae, P. fallax, P. neglectus, P. thornei, P. coffeae, P. penetrans, P. scribneri, P. brachyurus, P. vulnus, P. crenatus, P. loosi, P. goodeyi, P. pratensis* and *P. zeae* were within the eighteen *Pratylenchus* species, in which a dependable diagnostic procedure had been developed. (Waeyenberge et al., 2000).

Five restriction enzymes (CfoI, DdeI, HindIII, HpaII, and PstI) were used to digest the rDNA segments. Combining at least two distinct enzymes allows for the differentiation of all *Pratylenchus* species from one another. Most of nematode species were distinguished by CfoI, with an exception of *P. fallax, P. penetrans, and P. pseudocoffeae*. A PstI digestion was applied to further differentiate *P. fallax* and *P. pseudocoffeae*. RFLP within species were recorded to separate each of the three *P. coffeae* populations from one another by digestion using CfoI, DdeI, HindIII, or HpaII (Waeyenberge et al., 2000). Likewise, generic diagnostic protein biomarkers, has been identified by applying an efficient and speedy production technique. *Pratylenchus* at the level of species, such as *P. thornei, P. penetrans, P. neglectus* and *P. zeae*, were capable of being distinguished from one another using particular biomarkers with varying mass-to-charge (m/z) ratios (Tan, 2012).

Pratylenchus sequences with no known function

According to Nicol et al. (2011), 57% of the high-quality contigs created from the Pratylenchus thornei transcriptome readings matched no protein in any database. Similar to this (Haegeman et al., 2011), only 10,000 of the 56 325 contigs and singletons from the *P. coffeae* transcriptome that were chosen for analysis were effectively annotated non-coded protein (Fire et al., 1998). Similar to this (Haegeman et al., 2011), only 10,000 of the 56 - 325 contigs and singletons chosen for study from the *P. coffeae* transcriptome were effectively identified as non-coded proteins. Analysis of these contigs revealed that many of them might really include coding sequences. Two-thirds of *P. thornei* unannotated contigs displayed an open reading frame distribution like that of annotated sequences (Nicol et al., 2011). Uncharacterized sequences of *P. coffeae* may be sequenced uniquely to the *Pratylenchus* genus, or they may be non-coding RNAs (ncRNAs; Backofen et al., 2010; Langenberger et al., 2010). Kapranov et al. examined coding sequences and ncRNAs in 2007.

RNA interference and root lesion nematodes

RNA interference (RNAi) is a molecular technique used to study gene functioning in eukaryotes, where double-stranded RNA degrades mRNA, preventing protein synthesis. According to Fire et al. (1998), this is a conserved, natural post transcriptional process that regulates gene expression.

Transgenic control of *Pratylenchus*

In order to confer resistance against *P. penetrans*, Samac and Smigocki (2003) employed a transgenic technique to express phytocystatins, which are inhibitors of the digestive enzymes of nematodes, including cysteine proteases. Using *Medicago sativa* plants, the effectiveness of transgenic production of two rice cystatins were investigated: oryzacystatin I (OC-I), which inhibited papain activity, and oryzacystatin II (OC-II), which inhibited cathepsins. The reduction in the number of nematodes feeding on transgenic lines expressing both OC-I (29% reduction) and OC-II (32% reduction) constitutive expression of protease inhibitors in host cells has a deleterious effect on *P. penetrans* capacity to eat, live, and develop. Plants expressing various forms of oryzacystatin shown increased resistance to other nematodes, in contrast to information published for *P. pen*etrans (Urwin et al., 1995, 1997, 2000; Vain et al., 1998). Tan et al. (2013) suggest that migratory nematodes such as *Pratylenchus* might respond more favourably to transgenic control through the use of an in planta RNAi technique. Yadav et al. (2006) explores the impact of RNA interference (RNAi)-mediated gene silencing on planta nematodes. Transgenic plants are created using an RNAi vector, which transforms a target gene into a silencing trigger.

Susceptibility, tolerance and resistance to *Pratylenchus* spp.

A hybrid between wheat cv. Janz and a hexaploid wheat line that has been an efficient resilent to *P. th*ornei and *P. neglectus*, revealed quantitative trait loci (QTLs) linked to resistance (Zwart et al., 2005). *P. thornei* resistance was discovered in *Aegilops tauschii*, the ancestor of D-genome. Chromosomes 2BS, 6DS, and 6DL included three substantial QTLs for *P. thornei* resistance (Zwart et al, 2010) and two significant QTLs for the resistance of *P. neglectus* (Yu, Y. et. al,2021). A total of five QTL loci that have been linked to the resistance against *P. neglectus* in barley germplasm have been identified on chromosomes 3H, 5H, 6H, and 7H; these loci could be useful for marker-assisted selection for barley resistance (Sharma et al., 2011). The wheat cultivars which were both immune and tolerant to the most commercially significant *Pratylenchus* species, would yield the greatest traditional long-term production efficiency (Smiley and Nicol, 2009).

Nematode management

(A) Physical Method

Hot water treatment- This method is widely used for killing nematodes in plants and seeds before planting, effectively treating infested seeds, tubers, bulbs, and roots.Green *et al*, (2000) reported that hot water treatment of suckers at 53-55ºc for 20 minutes significantly reduces the most damaging nematode *P. coffeae* in plantation root, as a result percentage of dead root at flowering, percentage of bunch loss (due to toppling stem breakage failure to flower or premature death) was significantly reduced. Castagnone (1988) and Ascosta and Ayala (1976) reported that dry rot of *Dioscorea rotundata* tuber caused by *P. coffeae* was reduced by hot water dips at 35^0 to 54 °*C* for 15 to 60 minutes while Coates (1977) reported that hot water treatment of tuber of *Dioscorea rotundata* at 51^0C had an adverse physiological effect on the distal portion of the tuber.

(1) **Root dips treatment-**The nematode can be controlled by dipping the bare roots in hot water. Yellow yam (*Dioscorea cayenensis*) material dipped for 30 minutes in 2000 ppm solution of oxamyl for 45 min. in water at 45°C reduce the population of *P. coffeae* and produced 36 percent and 23 percent greater tuber yield (Hutton *et al*, 1982). Root of tomato seedling infested with *P. penetrans* dip in corn oil @ 0.25% substantially reduced the population of the nematode (Miller 1978). Root dip treatment for 8 hours in 0.05 to 0.1% solution of aldicarbs, carbofuran, fensulfothion, fenamiphos or phorate protected crossandra seedlings from *P. delattrei* for 3 days after transplanting (Vadivelu and Muthukrishnan, 1979).

(B) Cultural Method

(1) **Crop rotation-** Cropping the land with same crop may lead to a serious buildup of nematode in soil. To avoid the built up population, crop rotation is must. The success of crop rotation depends on proper selection of crops in sequence. The duration of crop rotation depends upon initial nematode population and rate of decline in population during crop rotation. The population of *P. penetrans* in potato field can be suppressed by growing wheat or rye (Florini and Loria 1984), forage pearlmillet and marigold (Ball *et al*, 2003), *Brassica nigra* and *Tagetes patula* (Trifonova 2003, Alexander and Waldenmaier 2002), Beet and marigold (Oostenbrink 1961).

The effect of rotation of crop on *P. indicus* in rice field were investigated, sesame, mustard, black gram, green gram among dicot, barley and wheat among gramineae were non-host. These were suitable for rotation in rice soil (Prasad and Rao 1978). The population of *P. alleni* was reduced by growing marigold, castor bean and chrysanthemum (Hackney and Dickerson 1975) while, inclusion of wheat or winter legume resulted low population of *P. scribneri* (Rodriquez and Collins 1980). Paddy or green gram (*Phaseolus aureus*) after banana

suppressed the population of *P. coffeae* (Rajendran *et al* 1979). Two successive cropping of cowpea and mungbean grown after rice reduce the population density of *P. zeae* resulting in higher yield (Aung and Prot 1990). Prasad *et al,* (1983) noticed the influence of *P. indicus* population of 6 different crop sequences in rotation with rice, fallowing or planting of *Phaseolus radiatus* decreased the nematode population but increased in rotation involving *Carthamus tinctorius* or *Nicotiana tabacum.*The population of *P. scribneri* in soil and root, in continuing three years rotation scheme of summer crop of corn, soybean and cotton followed respectively by wheat, fallow and mixed common vetch and crimson clover responded to crop development. The inclusion of wheat or winter in the rotation sequence resulted in lower down number of *P. scribneri* (Rodriquez and Collins 1980). Todd (1991) observed the responses of *P. scribneri* populations to 8 cropping regimes (5 continuous: Lucerne, maize, sorghum, soybean and fallowed soil and three rotations: fallow maize, soybean maize and maize soybean). He concluded that with the exception of lucerne, all the crop species examined supported substantial increase in population. He further reported that the population was consistently concentrated in the top 30 cm. of soil.

(2) **Solarization**- Solar heating of moist soil by means of Polythene mulching during peak summer month is effective in controlling soil borne nematode. It is cheaper and environment friendly approach without any toxic residual. Grinstein *et al,* (1979) reported that mulching of infested soil (*P. thornei*) for 31 days with polythene sheet in Israel developed solar heating and resulting 80 to 100 percent reduction in the population of *P. thornei* and an increase in yield of potato by 35 pecent. The soil solarization with double layer of transparent sheet gave 98 pecent reduction in *P. thornei* in chickpea followed by single layer transparent sheet (50mm thick) which resulted 87 pecent decline in the population of nematodes (Akemc *et al,* 2000). *P. penetrans* population was significantly decreased in the top 10 cm soil layer after a carrot field was solarized for four weeks with 0.02mm polythene film mulch in July. The effect of solarization was highest in August and lowest in May and September. (Minagawa *et al,* 2004). Potato field covered with transparent plastic for 8 weeks from mid June to mid August, the temperature of soil was 7-10 degree higher as compared to non-solarized soil. The population of root lesion nematode *P. penetrans* was significantly reduced by 50 pecent in the surface layer. Yield increases raise from 10 to 43 pecent. Solarization is an effective soil disinfestations procedure for top 10 cm of soil (Lazarovits *et al,* 1991).

(3) **Application of fertilizer and organic amendments**- Application of inorganic fertilizers to soil and incorporation of various organic amendments influence the nematode populations. Their application not only decreases the nematode population but on contrary improve the soil structure. According to the findings of Lamberti (1973) and Tacconi *et al,* (1988), the crop relations and mineral fertilizers affect *P. thornei* population in different ways. Low inorganic fertilizer rates increase nematode numbers, improving yield in irrigated wheat infected with P. thornei. However, nitrogen application reduces yield when nematode population exceeds threshold levels. Kurten and Kemper (1974) observed that the application of anhydrous ammonia resulted a slight temporary decline in population of *P. crenatus.* At the end of eight years' period of investigation however, the population of this nematode was no longer lower on anhydrous ammonia plots than on CAN fertilizer control. Three application of half, normal and supernormal dose of nitrogen (50, 100 and 200 kg/ha in 8 organic amendments viz. groundnut, cottonseed, soybean oilcakes, poultry manure, sheep manure, cow dung, raw sewage sludge and cassava peelings. All the amendments brought about a significant decrease in *P. brachyurus* population and corresponding increase in growth and yield of okra (*Abelmoschus esculentus*).

(C) Effect of AM on *Pratylenchus* spp.

Plant parasitic nematodes and AM fungi usually coexist in same root of host, each having a distinct opposing influence on plant's health. Hussey and Roncaderi (1978), identified that cotton roots colonized by *Gigaspora margarita* produced considerably fewer *P. brachyurus* per gram root than nonmycorrhizal plants lower nematode reproduction. Symbionts modifying cortex or competing for space led to enhanced growth in mycorrhizal plants, causing nematode-friendly conditions and affecting their growth. Jothi and Sundarababu (1997) and Sundarababu *et al,* (1998) had the view, that before the inoculation of *G. fasciculatu,* it acted as a shield for nematode entrance hence management of *P. zeae* population in maize. Under micro-plot experiment, Pinochet *et al,* (1995) found that *Glomus mosseae* pre-inoculated peach root exhibited lower population of *P. vulnus* as compared to alone. Samrat (commercial), a commercial formulation based on the egg parasite fungus *Paecilomyces lilacinus,* inhibits *P. thronei* growth and multiplication, resulting in a low population (Bhatt et al., 2015).

(D) Chemical control

Rhoades (1984) found that carbofuran, fenamiphos, oxamyl, and terbuphas significantly reduced *P. scribneri* infesting *M. spicata*. Fenamiphos was the most effective treatment. Ingham et al. (1992) found ethoprop to be highly effective in reducing *P. penetrans* population in spearmint fields. Carbofuran or its analog FMC 35001 also reduced *P. penetrans*. Studies regarding the management of *P. thornei* infesting spearmint by application of neem, mustard and linseed cakes @ 1500 kg/ha and aldicarb, carbofuran, ethoprop @ 4 kg a.i./ha, indicating that neemcake was the most effective being followed by mustard cake, aldicarb, ethoprop, carbofuran and

linseed cake respectively. However, all treatments considerably improved the growth oand yeind of oil in *Mentha spicata* with nematode reduction in soil and root (Shukla and Haseeb, 1996). Infestation in citrus seedlings of *P.* coffeae was eliminated by treating fensulfothion and fenamiphos @ 4.4 kg a.i. /ha and stem diameter of the treated seedling increased by 44 and 46 pecent respectively after 6 months. *P. coffeae* was effectively controlled by applying aldicarb/carbofuran @ 4 Kg a.i. /ha. or aldicarb at 4 kg/ha was proved equally potent against *P. coffeae*. Phensulphothion on *Arachis hypogea* while Dazomet at 4 kg/ha was less effective and was phytotoxic (Chhabra and Mahajan 1976). Maize, groundnut, soybean field infected with *P. brachyurus* had better nematode control and increased yield by the application of Carbofuran 3G at 50 kg/ha or Temik 10 G at 25 kg/ha. Temik was superior to carbofuran (Lordello et al 1983, Boswell and Grichar 1983 and Novaretti et al 1982). The fibrous and coarse roots of corn infested with *P.hexincisus* demonstrated a decrease in the population of nematode with aldicarb and ethoprop at 2.24 Kg a.i./ha while dramatic drop in *P. delattrei* population in maize roots was found with carbofuran or aldicarb @ 25 Kg/ha (Zirakparvar 1980, Naganathan and Sivakumar 1975). Nursery bed treatment with phorate, aldicarb, fensulfothion and carbofuran each at 5 g/m^2 gave good and healthy *P.delattrei* (Vadivelu and Muthukrishnan 1979). Marban et. al, 1980 reported that penetration of roots of *Phaseolus vulgaris* by *P.vulnus* was completely inhibited by continuous exposure of the nematode to carbofuran or phenamiphos at 0.05 mM and 0.003 mM.

(E) Botanical control-

Plant leaf extracts from *Acalypha indica, Casia fistula,* and *Solanum torvum* had the strongest nematicidal effect against adult and juvenile Pratylenchus coffeae. *S. turvum* and *A. indica* leaf extracts had the highest fatality rate (89.7%) at 100% concentration after 24 hours (Sundararaju et al.,2003). Nemate being a neem based formulation, compounds like Azadirachtin and triterpenoid inhibit the development of the pathogen whenapplied as a soil treatment (Bhatt et al.,2015).

III. Conclusions

Nematode control measures like crop rotation, solarization, and genetically resistant cultivars can reduce nematode populations and increase crop yield. Biological agents like AM fungus can be used to control infestations. Cooperation between researchers, extension agents, farmers, and policymakers is crucial for sustainable agriculture and global food security. Genetic resistance breeding and precision agriculture technologies can enhance crop yield and reduce economic losses. A multimodal strategy and innovative crop resistance can manage parasites effectively.Resistance to cultivars in agriculture boosts production and profitability, promoting resilience in food supply chains. Further research is needed for large-scale nematode eradication.

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Authors' contributions

1. Suresh Prasad Tiwari – Design of the work collected the data, wrote the article, interpretation of data
2. Dilshad Masih- Conceived and designed the data, contribution in data and analysis tools
3. Rajbabbar Jatav- Proof reading
4. Gyanendra Tiwari - Proof reading
5. Raja Husain - Proof reading

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