THE NEMATODES OF CHILLI PLANTS OF SINDH: ABUNDANCE, DIVERSITY AND THE ASSEMBLAGE

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Abstract

Fifteen chilli growing areas of Sindh (University of Karachi, Malir I, Malir II, Asoo Goth, Memon Goth I, Haji Ghafoor Goth, Memon Goth II, Gulshan-e-Iqbal, New Karachi, National Nematological Research Centre (NNRC, Univ. Karachi), Gadap, Ghotki, Khairpur, Larkana and Sukkur) were studied for soil and plant nematodes. Fifty two species (33 genera) of nematodes, including three new species (*Helicotylenchus Siddiqii* n. sp., *Paratylenchus (P) karachiensis* n.sp. and *Bitylenchus. capsicumi* n. sp.), were encountered during this survey. As evident from the literature survey, some 34 species were migratory ectoparasite. There were four endoparasite species. Bacteria / fungi feeders were five. There was one predatory carnivorous species (*Mylonchulus* sp.). There were three saprophytic species. Several of the ectoparasitic species were endoparasitic at their later stages of life. All *Helicotylenchus* spp. were obligatory parasites, *Hemicriconemoides* and *Hoplolaimus* species were obligatory root parasites. Ten species viz. *Aporcelaimellus paracentrocercus*, *Acrobeloides* sp., *Cephalobus* sp., *Dorylaimus* sp., *Discolaimus* sp., *Ecuminicus monohystera*, *Geomonhystera* sp. *Moshajia* sp. *Mylonchulus* sp. and *Rhabditis* sp. appeared to be free living bacteria. *Rhabditis* sp. was also entomopathogenic and *Tylenchulus semipenetrans*, a semi-endo-parasitic species. Frequency and density (abundance) of nematode species was highly variable from field to field and within a field. A substantial number of species (15 in number; c 29 % of the total species) occurred in one sample site each. *Cephalobus* sp. and *Dorylaimus* sp. occurred in 11 and 10 sites, respectively. By count, 48 species had less than 50% frequency in the sample sites. The mean density of a nematode species amounted to 15.93 ± 1.794 individuals varying by 81.74%. The nematode assemblage size of a site averaged to 200.67 ± 29.67 individuals per site. The population size varied greatly among the sites by 57.25%. The largest assemblage size build up was observed in Ghotki (415 individuals per 100g soil) followed by Sukkur (346). The population size was the lowest at Memon Goth (II). In other sites it ranged from 123 to 263 individuals per site. The number of nematode species recorded from various sites varied from 5 (Haji Ghaffor Goth of Malir) to 20 in another Malir field. The number of species per site averaged to 11.67 ± 1.18 varying substantially (CV= 39.22%). Different species were differentially successful. In 15 sites studied, on the basis of density, nine species of nematodes attained the rank of leading dominant, 12 species were second dominant and 11 species attained the status of the third dominant. *Longidorus elongatus*, was first dominant in two sites (University of Karachi and Ghotki), *Acrobeles* sp., a free living nematode was leading dominant in Malir, Memon Goth I and Gadap. And *Cephalobus* sp, another free-living nematode, was leading dominant in Haji Ghafoor Goth, Memon Goth II and Larkana chilli fields. *Helicotylenchus siddiqii* predominated in Malir, *Tylenchorhynchus annulatus* dominated in Gulshan-e-Iqbal, *Rotylenchus reniformis* in New Karachi and *Xiphinema* basiri and *Acrobeloides* sp. predominated in Asoo Goth (Malir) and Khairpur, respectively. *Meloidogyne javanica* was the leading dominant of chilli plants of NNRC (Karachi) and Sukkur. The structure and organization of the assemblages of different sites was simple as species diversity of the sites was low and the dominance concentration was high. On the basis of information theory function (H'), species diversity was comparatively higher in Sukkur, Ghotki, Gadap, Memon Goth and Malir I. Equitability was lower in Khairpur and maximum in Sukkur. The relative abundance pattern of the species in sample sites was geometric as was evident by the linear plots of densities on log scale. In present studies, Species richness appeared to control diversity relatively more than the equitability. The cluster analysis of the data indicated five discrete groups of the sites, on the basis of compositional similarity: Group A.: an agglomeration product of nine sites and comprised of four sites dominated by free-living *Acrobeles* sp., *Cephalobus* sp. with subordinates such as free-living *Dorylaimus* sp. or parasitic subordinates such as *Tylenchorhynchus brassicae, Filenchus butteus* in varying proportions. The other five sites were dominated by *Longidorus elongatus* in association of subordinate free-living *Aphelenchoides* sp., *Helicotylenchus siddiqii, Tylenchorhynchus annulatus, T. brassicae, Rotylenchus reniformis or Filenchus filiformis*. Group B: comprised of sites from NNRC (Karachi) and Sukkur. The dominant nematode species was *Meloidogyne javanica* in the two sites sub-ordinated by *Tylenchorhynchus annulatus, Helicotylenchus pseudorobustus* and a free-living species, *Ecuminicus monohystera*. Group C: comprised of two sites – Asoo Goth and Gadap dominated by *Xiphinema basiri* sub-ordinated by *Meloidogyne incognita, Longidorus elongatus, Rotylenchulus reniformis* and a free-living nematode, *Acrobeloides* sp. Group D: This was solely represented by the Khairpur site predominated by *Acrobeloides* sp, a free living species . *Tylenchorhynchus tuberosus* and *Tylenchulus semi-*

penetrans were the second and the third dominant species. Group E: represented by Ghotki site was predominated by three parasitic species – *Longidorus elongatus, Aphelenchus avenae* and *Tylenchulus semipenetrans.*

Introduction

Chillies (*Capsicum annuum* L. and *C. frutescens* L. and their several cultivars) constitute a very important cash crop of Pakistan and cultivated in this region for hundreds of years. The average yield of chillies in Pakistan, however, remains low due to leaf and roots pathogens - fungi and nematodes (Khan *et al.*, 2000). Many studies on management and control of chilli pathogens have been undertaken (to cite a few - Brown, 1962; Qamar et al., 1985; Khan and Bilqees, 1989; Khan *et al.*, 1991; Ehteshamul-Haque *et al.*, 1996; Abid, 1997; Ata-ur-Rahman *et al.*, 1997; Hussain *et al.*, 1998; Siddiqui *et al.*, 1999; Zaki *et al.*, 2004; Abid *et al.*, 2004, 2005, 2006). The control and management studies of root knot nematodes associated with chillies in Pakistan have been briefly summarized by Zarina and Shahina (2010). Gul and Saeed (1987, 1990) and Gul and Saifullah (1991) conducted survey in Khyber Pakhtunkhwa with reference to the *Meloidogyne* spp. No comprehensive survey of nematodes of chilli growing areas of Sindh has been undertaken except few publications such as Khan *et al.*, (2000; 2006) and Anwar *et al.* (2013). Ahmad *et al.*, (1998) observed the effect of *Meloidogyne* species on six chilli cultivars i.e. Sweet Pepper, Koria, Yellow, Wonder, Sinha and Cluster. Khan *et al.* (1987) detected the population of *Tylenchus filiformis* in soil under six different crops and found decrease in the population of *Tylenchus filiformis* with chilli plants. Maqbool and Ghazala (1988) identified three species viz., *Hoplolaimus columbus, H. indicus* and *H. seinhorsti* around the roots of *Capsicum annuum* from different localities of Sindh. Khan *et al*. (2000) reported 8 nematode species from 8 chilli growing localities of Sindh (e.g., Goth Ludan Chandio, Karimabad, Kunri, Nasimabad, Nasirabad, Nusratabad and New Kot). Two main groups were identified – a small group with large populations of *Meloidogyne* sp. larvae and a large group comprising communities with saprophytic nematodes and parasitic species such as *Helicotylenchus indicus*, *Tylenchorhynchus annularis*, and *Pratylenchus* spp. with variable densities. Maqbool and Shahina (2001), summing up the work done in Pakistan on chilli nematodes, have enlisted 26 nematode species from *C. annuum* and 5 from *C. frutescens*. Khan *et al*. (2005) reported nine plant parasitic nematodes on chilli from Balochistan province. Khan *et al.* (2006) surveyed ten chilli growing localities of Hyderabad and Karachi Districts in 2005 and reported 11 stylet bearing genera of nematodes and 12 species. They reported highest density of *Psilenchus* spp. (132 per 200 cm^3 of soil) followed by *Hiplolaimus indicus* (62 per 200cm^3) and *Pratylenchus spp.* (52 per 200 cm^3). Shaukat and Khan (1993) investigated spatial pattern of 3 nematodes viz. *Quinisulcius curvus*, *Pratylenchus thornei* and *Aphelenchus avenae*. Recently, Anwar *et al.* (2013) have reported nine nematode species from four vegetables (tomato, chilli, cucumber and bell pepper) cultivated in tunnels at Faisalabad, Jhang, Kasur, Lahore, N-Sahab, Sargodha, T.T. Singh and Shaikhpur.

In the present studies, we have undertaken survey of nematode species from 15 chilli growing localities of Sindh during 2011-2012. These localities included several areas of Karachi (University of Karachi, Malir I, Malir II, Asoo Goth, Memon Goth I, Haji Ghafoor Goth, Memon Goth II, Gulshan-e-Iqbal, New Karachi, National Nematological Research Centre (NNRC, Univ. Karachi) and Gadap) and that of Ghotki, Khairpur, Larkana and Sukkur.

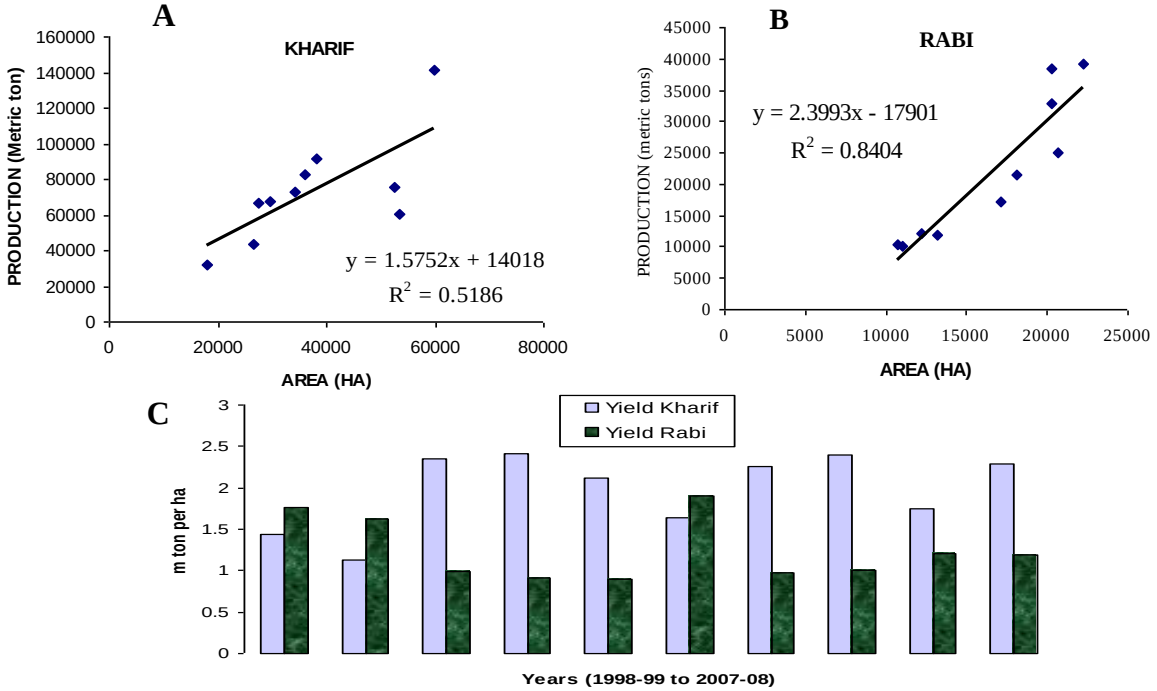

Fig. 1. Production of chillies (m ton) in Sindh during 1998-99 to 2007-08 as function of area under cultivation in Kharif and Rabi (A and B). The yields for Kharif and Rabi are shown in C. (The data of Directorate General of Agriculture Extension, Hyderabad, Sindh in (Govt. of Sindh, 2009) was calculated by us for this paper.

Description of the area: Sindh, lower Indus Basin, may be divided into four distinct areas – Kirthar Mountain region in the West, central alluvial plain bisected by the River Indus in the mid, desert belt of Tharparkar in the East and Indus delta in the South. Sindh lies between $23^{o}35'$ – $28^{o}30'$ N latitude (near tropic of Cancer) and $66^{o}42'$ – $71^{o}1'$ E (longitude). It is 579 km long and 442 km broad (in extreme; average 281 km) and encompasses an area of 1, 40,415 km^2 as large as England. The soil in the plains of Sindh is plastic clay – combined with water it turns into mould and when dry it degenerate into desert. Sindh soils are invariably deficient in N (90% of the cases). Eighty percent of the soils are deficient in P and 40% of the soils are deficient in K. Organic matter is low (0.5-1.0%). Climatically, Sindh is arid, hot and dry. Summer is very hot, hazy and dry. Monsoon not very wet. May June and July are the hottest months (SLGO, 2001). Highest temperature ever recorded in Sindh is from Moenjodaro on 26th May, 2010 to be 53.5 ^{o}C. This temperature is considered to be the highest in Pakistan and Asia and 4th highest on the Earth. (http://en.wikipedia.org). Average rainfall is 15-18 cm. Rains mostly occur in monsoon but sometimes rains are torrential.

Agriculture is mainly concentrated in plains. Total cropped area is 3.875 x 1000 Ha (2007-08) as reported by GOS (2009). Chillies are cultivated throughout Sindh. There are around 400 varieties of chilli around the World (www.chilly.in/...). The varieties grown in Sindh are Longi, Talhar, Ghotki and Sanam. Total area under chilli cultivation in 2007-08 has been reported to be 36,075 Ha in Kharif and 18,079 Ha in Rabi (Govt. of Sindh, 2009 (Agriculture Statistics of Sindh, 2009) with corresponding production of 82,726 and 21464 m ton, respectively. The area under chilli cultivation in Sindh is around 50% of the country (*sindhagri.com.pk*). The production of chillies is linearly dependent upon area of cultivation in both seasons (Fig. 1 A and B). The area under cultivation has been higher in Kharif than that in Rabi but increase in production is steeper in Rabi (b = 2.3993) than that in Kharif (b = 1.5752). The yield per Ha during 1988-99 to 2007-08 has averaged to 1.9798 ± 0.1444 m tons.Ha^{-1} (1.134 to 2.415 m tons.Ha^{-1}) in Kharif and 1.2459 ± 0.1189 90m ton.Ha^{-1} in Rabi (0.8918 to 1.90m ton.Ha^{-1}). The yield with few exceptions was higher in Kharif (Fig. C). Yield during the 10-year period varied more during Rabi season (CV = 30.18%) than in Kharif (CV = 23.06%).

Materials and Methods

An extensive survey was carried out during (2011-2012) for the isolation of plant parasitic and soil nematodes associated with chili plants from different areas of Sindh (viz., Khairpur Nathanshah, Larkana, Sukkar, Ghotki, and Karachi), Pakistan .

Collection and storage of root and soil samples: Soil samples were taken from the root zone of plants at a depth of 15-20cm along with some root system of the chilli plant. To obtain a reliable estimate of the nematode species, random sampling of large area was done. Depth of sample core collection is dependent on the host, soil type and nematode species. Generally, collection was made from the upper 15-20 cm soil which is considered adequate in herbaceous crops. One kg soil sample was taken from a plant and kept in polyethylene bag. Plant and root samples were placed in separate polyethylene bags, sealed tightly and labeled with details of host, locality & date of collection and symptoms. Samples were stored at 5-10 °C. Nematodes were processed and followed procedure given by Southey (1986), Siddiqi (2000) and Hooper (1986a, 1986b).

Isolation and extraction of nematodes from soil: Soil samples were processed by modified Baermann funnel method& Cobb's decanting and sieving method (Schindler, 1961).

Qualitative and Quantitative analysis: Qualitative and quantitative analyses of nematodes associated with rhizosphere and rhizoplane of chilli plants were carried out to estimate nematode population per 100g soil and to identify and record the presence of nematode genera in the nematodes population (Southey, 1986; Siddiqui, 2000).

Identification of nematodes: Nematodes were identified on the basis of their morphological characters. Siddiqui (1986, 2000), Dasgupta and Swarup (1986), Nickle (1991), Jairajpuri and Ahmad (1992), Hunt (1998), Luc *et al.* (2005), Andrassy, 2005, 2007; Garaet (2008), Sharma (2011), Fortune (2013) were the important references. The perineal patterns on cuticular surface of perineum were the basis for the identification of *Meloidogyne* species. Young egg-laying females dissected from roots were placed in a drop of 45% Lactic acid in a plastic Petri dish. The posterior half of the body cut off with a scalpel ; the lower pieces of the cuticle heaving perineal patterns were further trimmed to square and inner tissue were completely removed by flexible bristle. Perineal patterns were transferred into a drop of glycerin on glass slide. The cover glass was gently placed & sealed with zut (Eisenback *et al*., 1980).

Treatment to the data: The parameters of frequency and abundance of nematode species were calculated after Adamou *et al.* (2013). % Frequency = e / N * 100; where e is the number of sample sites containing a species and n is the total number of sites studied. The abundance of the species was calculated as:

Abundance = A = ∑ Xi /b;

Where, Xi is the number of nematodes of a species per 100 g soil for a sample site and b is the number sites the species occurred. This parameter by its virtue may be referred to as absolute density of a species. The composite parameter of importance value index (% IVI) of the constituent species was calculated by direct summation of relative frequency and relative density of the species. The dominance-diversity curves (Whittaker, 1965) were, however, plotted on the basis of density of constituent nematode species per 100g soil to portray the underlying relative abundance pattern.

There has been some discussion on the superiority of diversity indices (McIntosh, 1967; Shaukat and Khan, 1979; Shaukat *et al.,* 1981; Dhanmoanonda and Sahunalu, 1988; Heip *et al.,* 1998; Magurran, 2004). The dominance and diversity and its components (species richness and evenness) were calculated using the following formulae given in Ludwig and Reynolds (1988). The data was analyzed statistically. In moderately diverse situation information theory function H' (Shannon and Weaver, 1963) measures diversity very well (Shaukat and Khan, 1979). Diversity indices N1 and N2 have been rated to be intuitively appealing to ecologists (Peet, 1974). The two measures of species richness R1 (Margalef, 1958) and R2 (Menhinick, 1964) behave similarly statistically (Shaukat and Khan, 1979). We followed equitability measures E1 (Pielou, 1975, 1977) and E2 (Sheldon, 1969) as they have commonly been used in ecological studies. Besides, the modified Hill evenness measure was also followed because it reaches progressively to zero as a species become more and more dominant in a community. These indices have recently been used successfully to elucidate diversity in crustacean assemblages of Karachi sandy beach of Clifton (Imran *et al.,* 2014).

Species Richness, R1 = S-1 / Ln (N) ….. .(Margalef, 1958)
Species Richness, R2= S' = S / √ N ….. . (Menhinick, 1964)
Diversity = H' = -∑ pi. Lnpi, ….. i = 1, …S…..(Shannon-Wiener Index)
c =-∑ $pi.^2$, ……i = 1,….S … (Simpson, 1949)
N1 = $e^{H'}$ ….. (Peet, 1974)
N2 = 1/c ….. (Peet, 1974).
Evenness = E1 = H' / H_{max} = H' / Ln S …..(Pielou, 1975, 1977)
Evenness E2 = $e^{H'}$ / S …… (Sheldon, 1969)
Evenness E5 = (1-c) -1 / $e^{H'}$ -1) …..(Modified Hill Ratio; Hill, 1973)

Here, S = Number of species; ni = number of individuals of a species in a site; N = Number of individuals of all species in the site and pi = ni / N.

The data was calculated on Computer package SPSS v. 12 and software provided by Ludwig and Reynolds (1988) along with their book – "*Statistical Ecology: A Primer on Methods and Computing*." The group structure was determined by agglomerative cluster analysis of the data on the basis of density-based Euclidean distances by following Ward's (1963) method. This method has been successfully used in several ecological studies. (Orloci and Kenkel, 1985; Khan et al., 2000). The data was analyzed on SPSS version. 12.

Results and Discussion

A survey of fifteen chilli growing areas of Sindh viz. cultivated fields of Karachi University, Malir I, Malir II, Asoo Goth, Memon Goth I, Memon Goth II, Haji Ghafoor Goth, Gulshan-e-Iqbal (Karachi), NNRC, Gadap, Ghotki, Khairpur, Larkana, and Sukkur was conducted to identify soil nematodes in the chilli roots and the rhizospheric soil and determine their population through conventional methods.

Faunistic description: Fifty two species of nematodes, including three new species (*Helicotylenchus Siddiqii* n. sp., *Paratylenchus (P) karachiensis* n.sp. and *Bitylenchus. capsicumi* n. sp.) and one new record (*Aphelenchus isomerus*) for Pakistan (*Aphelenchus isomerus*) were encountered during this survey (Table 1 and 2; Plate 1). The species belonged to 33 genera including genus *Helicotylenchus* (7 species), genus *Pratylenchus* (5 spp.) genus *Tylenchorhynchus* (5 species), Genus *Hoplolaimus* (3 spp.), genus *Meloidogyne* (2 spp.), *Bitylenchus* (2 spp.), genus *Filenchus* (2 spp.), genus *Aphelenchus* (2 spp.) and remaining 25 genera viz. *Acrobelus, Aporcelaimellus, Acrobeloides, Aphelenchoides, Basiria, Boleodorus, Cephalobus, Ditylenchus, Discolaimus, Dorylaimus, Ecuminicus, Geomonhystera, Moshajia, Hemicriconemoides, Longidorus, Mylenchulus, Paratylenchus, Pararichodorous, Psilenchus, Rhabditis, Rotylenchulus, Rotylenchus, Tylenchorhynchus, Tylenchulus,* and *Xiphinema* (Table 1 and 2) had one species each. Many of these species have already been reported e.g., Brown (1962) described *Aphelenchus* sp., *Meloidogyne javanica*, and *Tylenchorhynchus* sp, on chilli from Malir, Karachi. Anwar *et al*. (1973) detected *Pratylenchus* sp., *Radopholus* sp., *Tylenchus* sp. and free living *Acrobeles* sp., *Cephalobus* sp., *Chiloplacus* sp., *Discolaimus* sp., *Dorylaimus* sp., *Eucephalobus* sp, *Odontolaimus* sp., *Metaphelenchus* sp. around the roots of chilli from Faisalabad, Punjab. *Hemicriconemoides mangiferae* was found from *Capsicum frutescens* in Karachi (Saeed & Ghaffar, 1979). Maqbool (1981) reported

Meloidogyne incognita on chilli from different parts of Pakistan. Maqbool and Saeed (1981) reported *M. hapla* on chilli from Sindh, Punjab & Khyber Pukhtoonkhwa on *Capsicum frutescens*. We, however, couldn't detect *M. hapla* in the present studies. Maqbool & Hashmi (1984) reported *Heterodera zeae* on *Capsicum annuum* from RahimYar Khan. Maqbool (1986) reported *Helicotylencus indicus* around the roots of chilli from different parts of Pakistan. Maqbool & Ghazala (1988) identified three species viz., *Hoplolaimus columbus, H. indicus* and *H. seinhorsti* around the roots of *Capsicum annuum* from different localities of Sindh. Anwar (1989) detected plant parasitic nematodes viz., *Criconemoides* sp, *Ditylenchus dipsaci, Hoplolaimus* sp., *Meloidogyne* sp. *Paratrichodorus* sp., *Radopholus similes* and *Xiphinema* sp. on chilli from different localities of Punjab. Firoza & Maqbool (1991) described *Rotylenchus capsicumi* new species from Quetta, Baluchistan. Nasira & Maqbool (1995) detected the *Longidorus elongatus* from Karachi. Zarina & Maqbool (1998) described *Pratylenchus roseus* new species from Umerkot. Anwar & Mckenry (2012) described *Belonolaimus longicaudatus, Helicotylenchus* sp., *Paratrichodorus minor from* Punjab.

As evident from the literature survey, some 34 species (Table 1) were migratory ectoparasite. There were four endoparasite species. Bacteria / fungi feeders were five. There was one (*Mylonchulus* sp.) predatory carnivorous species. There were three saprophytic species. Several of the ectoparasitic species are known to be endoparasitic at their later stages of life. All *Helicotylenchus* spp. were obligatory parasites, *Hemicriconemoides* and *Hoplolaimus* species are obligatory root parasites. Ten species viz. *Aporcelaimellus paracentrocercus, Acrobeloides* sp., *Cephalobus* sp., *Dorylaimus* sp., *Discolaimus* sp., *Ecuminicus monohystera, Geomonhystera* sp. *Moshajia* sp. *Mylenchulus* sp. and *Rhabditis* sp. appeared to be free living. *Rhabditis* sp. also appeared to be entomopathogenic and *Tylenchulus semipenetrans* a semi-endoparasitic species (Table 1). Of the above given 52 species (Table 2) few nematodes such as *Meloidogyne* sp. *Tylenchus* sp., *Helicotylenchus indicus, Pratylenchus penetrans, Tylenchorhynchus annulatus, Psilenchus hilarious, Pratylenchus thornei, Hoplolaimus indicus*, and *Aphelenchus avenae* have already been reported by Khan *et al.* (2000) from chilli (*C. frutescens*) from some localities of Sindh (Kunri, New Kot, Nusratabad,, Karimabad, Nasirabad, and Nasimabad, etc.). Moreover, Khan *et al.* (2006) also reported *Hoplolaimus indicus, Helicotylenchus indicus, Meloidogyne incognita, M. javanica, Pratylenchus* sp. and *Psilenchus* spp. from Hyderabad and Karachi. Some species of Table 2, such as *Aphelenchus avenae, Helicotylenchus dihystera, M. javanica, M. incognita, Pratylenchus penetrans* have been reported from some vegetables (tomato, cucumber, chillies and bell peppers) from Faisalabad, Kasur, Jhang, Lahore, N. Sahab, T.T. Singh, Sargodha and Shaikhpur while grown in tunnels. However, species like *Radopholus smiles* and *Tylenchorhynchus claytoni* were exclusive to Punjab and were not found in Sindh. Similarly, *Tylenchus* sp (larvae) reported in chilli association from Sindh by Khan *et al.* (2000) was not observed by us in the present survey of Sindh. Some of the species (Table 2) such as *Basiria graminophila, Boleodorus acutus, Filenchus filiformis, Helicotylenchus dihystera, Hemicriconemoides mangiferae, and Rotylenchus reniformis* have been reported in association of Jamun (*Syzygium cumini* L) in Sindh by Khan *et al.* (2013). The genera like *Helicotylenchus, Pratylenchus, Rotylenchus and Meloidogyne* are indeed wide spread and have been reported from three chili growing areas of Ranga Reddy district of Telangana by Zareena and Das (2012). Parasitic nematodes – *Meloidogyne* sp. *Tylenchorhynchus indicus, Helicotylenchus dihystera, Rotylenchus reniformis, Pratylenchus* sp. and *Xiphinema* eggs are also reported from association of vegetables (tomato, eggplant, and pepper) in Niger (Adamou *et al.*, 2013).

Density and frequency: Frequency and density (abundance) of nematode species was highly variable from field to field and within a field. The parameter of mean density per 100g soil of the sample fields of occurrence distributed more or less normally (Table 3 and 4). Most of the species (45 in number; 86.5% of the total species) had density below 25 individuals per 100g soil. High density or abundant species were quite low in number. Only two species viz. *Meloidogyne javanica* (66.66 ± 7.27), *Longidorus elongatus* (50.50 ± 19.39) had mean density > 50.0. *Acrobeloides* sp. occurred in three sites but with highly varying density (48.33 ± 41.84 individuals per 100g soil). Four species viz. *Helicotylenchus pseudorobustus* (29.67 ± 8.29), *Meloidogyne incognita* (28.0 ± 22.0), *Tylenchulus semipenetrans* (42) and *Acrobeles* sp. (33.71 ± 0.74) had moderately higher density (25 - 45 individuals per 100g soil) (Table 3; Fig. 2). The mean density of a species amounted to 15.93 individuals varying by 81.74% (Table 4). Khan et al. (2006) have reported densities of few nematodes in their studies of chilli nematodes of some sites of Sindh to be highest for *Psilenchus* spp. (132 per 200 cm^3) followed by *Hiplolaimus indicus* (62 per 200cm^3) and *Pratylenchus spp.* (52 per 200 cm^3 of soil). Since density of soil per mL is 2.56g. The density of the three nematodes (*Psilenchus* spp., *Hoplolaimus indicus* and *Pratylenchus* spp) thus corresponded to 26, 12 and 10 individuals per 100 g soil, respectively. In present, their densities were 6.67, 15 and 0.67-26.67, respectively.

A substantial number of species (15 in number; 28.8 % of the total species), represented only one sample site (Table 2). *Cephalobus* sp. and *Dorylaimus* sp., however, occurred in 11 and 10 sites, respectively. By count, 48 species had frequency less than 50% in the sample sites. Only four nematode species viz. *Cephalobus* sp. (73.33%), *Dorylaimus* sp. (66.67%), *Aphelenchus avenae* (60%) and *Filenchus butteus* (53.33%) were the species with frequency greater than 50%. None of the species was ubiquitous (Table 3; Fig. 3). Twenty nine species had frequency varying from little more than 10 to less than 40%. The mean frequency for a species was 22.56 ± 2.32 varying by 74.04% (Table4).

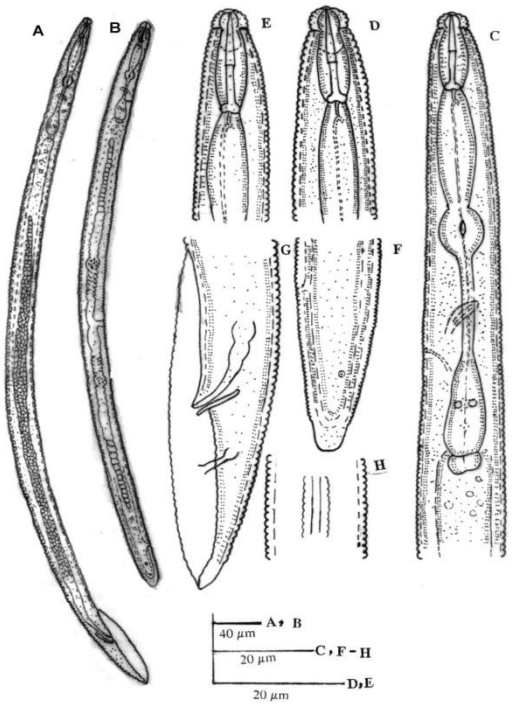

Plate 1A. (A-H). *Bitylenchus capsicumi* n.sp., B .Entire female; C. Oesophageal region; D. Head region; F. Tail end; H. Lateral field; (A, E & G. male). A. Entire body; E. Head region, G. Tail end.

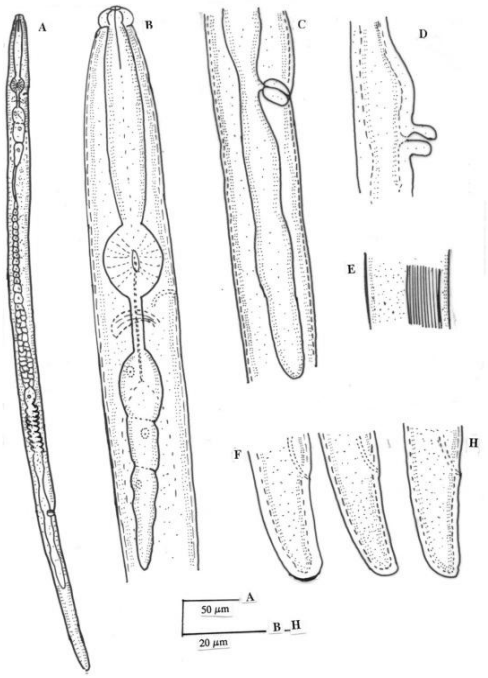

Plate 1B. (A-H): *Aphelenchus isomerus* Anderson & Hooper, 1980 (Ebsary, 1991).A. Entire female; B.Oesophageal region; C. Vulval region with post uterine sac; D. Vulval region; E. Lateral field; F-H. Tail ends.

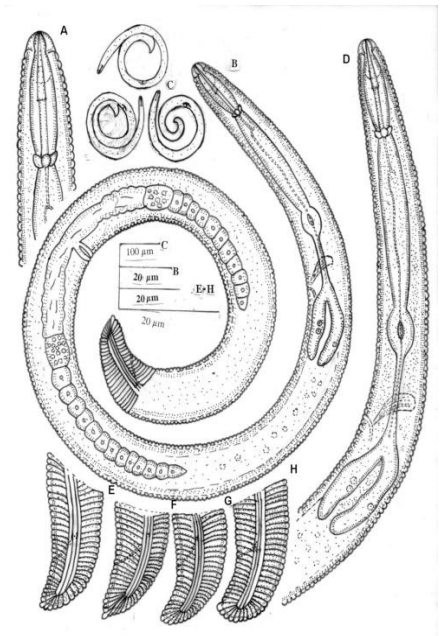

Plate 1C. (A-H). *Helicotylenchus siddiqii* n.sp. A. Head region; B.Entier body; C. Posture of adults; D.Oesophageal region; E-H.Tail end.

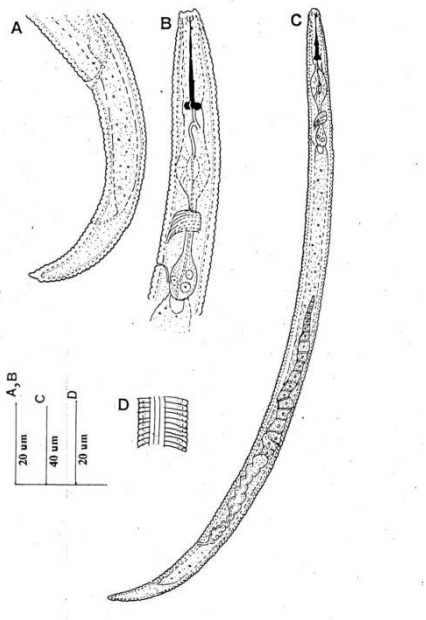

Plate 1D. (A-D). *Paratylenchus(P) karachiensis* n.sp., A. Female tail, B. Oesophageal rtegion, C. Entire female; D. Lateral view at mid Body.

Table 1. Taxonomic details and biological types of nematodes identified from soils of some fields of chillies.

Nematodes	Authority	Biological Types / Physiotypes
Aphelenchoides besseyi	Christie,1942	*Rice nematode, white tip of disease of rice, facultative ectoparasite and endo parasites of plant*
Aphelenchus avenae	Bastian 1865	*mycetophagous, phytoparasitic, entomoparasites, ectoparasite or endoparasites of insect*
Aphelenchus isomerous (New record)	Anderson and Hooper, 1980 (Ebsary,1991)	*mycetophagous, phytoparasitic, entomoparasites, ectoparasite or endoparasites of insect*
Bitylenchus brevelinatus	(Williams,1960) Jairajpuri,1982	*stunt nematodes Migratory ectoparasite of roots*
B. capsicumi n.sp..	Akhter & Zarina, (2014)	*stunt nematodes Migratory ectoparasite of roots*
Basiria graminophila	Siddiqi,1959	*Migratory ectoparasite of roots Algae ,moss, lichen and plant feeders*
Boleodorus acutus	Thorne & Malek,1968	*Migratory ectoparasite of plant roots Algae, moss, lichen*
Ditylenchus dipsaci	(Kuhn,1857) Filipjev,1936	*Migratory ectoparasite, fungivorous,, plant feeder on roots and aerial parts of plants.*
Filenchus filiformis	(Bütschli,1873) Meyl, 1961	*Migratory ectoparasite algae, moss ,lichen and plant roots feeders*
Filenchus butteus	(Thorne and Malek,1968) Raski & Geraert,1987	*Migratory ectoparasite algae, moss, lichen and plant roots feeders*
Helicotylenchus digonicus	Perry in Perry, Darling and Thorne,1959	*Migratory ectoparasite obligate parasites of roots spiral nematodes*
H. dihystera	(Cobb,1893) Sher,1961	*Migratory ectoparasite obligate parasites of roots spiral nematodes*
H. indicus	Siddiqi,1963	*Migratory ectoparasite obligate parasites of roots spiral nematodes*
H. mucronatus	Siddiqi,1964	*Migratory ectoparasite obligate parasites of roots spiral nematodes,*
H. multicinctus	(Cobb,1893) Golden,1956	*Migratory ectoparasite obligate parasites of roots spiral nematodes ,parasites of banana reported from banana production of the world*
H. pseudorobustus	(Steiner,1914)Golden,1956	*Migratoy ectoparasite obligate parasites of roots spiral nematodes*
Helicotylenchus Siddiqii n. sp.	Akhter and Zarina (in press)	*Migratoy ectoparasite obligate parasites of roots spiral nematodes*
Hemicriconemoides mangiferae	Siddiqi,1961	*Migratory ectoparasite phytoparasite on root cortex ,ring nematode*
Hoplolaimus (B.) columbus	Sher,1963	*Migratory ectoparasite , obligate phytoparasite on cortical & vascular tissue, lance nematode*
H. (B.) indicus	Sher,1963	*Migratory ectoparasite, obligate phytoparasite on cortical & vascular tissue, lance nematode*
H.(H.) galeatus	(Cobb, 1913) Thorne,1935	*Migratory ectoparasite , obligate phytoparasite on cortical & vascular tissue, lance nematode*
Longidorus elongatus	(DeMan,1876) Thorne and Swanger,1936	*Migratory ectoparasite, polyphagous on roots & transmit RRV & BRV virus*
Meloidogyne incognita	(Kofoid & White,1919) Chitwood,1949	*obligate endoparasite on root, root-knot nematode, root-gall inciting male vermiform, female sedentary*
M . javanica	(Treub, 1885) Chitwood,1949	*obligate endoparasite on root, root-knot nematode, root-gall inciting male vermiform, female sedentary*
Paratylenchus (P) karachiensis n.sp.	Zarina and Akhtar (in press)	*obligate root ectoparasite Migratory, pin nematode*
Pararichodorous	(Colbran, 1956)	*ectoparasite Migratory, polyphagous feeding TRV & PRV*

minor	Siddiqi,1974	*transmit the virus, stubby root virus*
Pratylenchus coffea	(Zimmerman,1898) Filipjev and Schuurmans Stekhoven, 1941	*Migratory endoparasite on root, obligate parasite, root lesion nematode*
P. neglectus	(Rensch,1924) Filipjev and Schuurmans Stekhoven,1941	*Migratory endoparasite on root, obligate parasite, root lesion nematode*
P. penetrans	(Cobb,1917) Filipjev and Schuurmans Stekhoven, 1941	*feed ectoparasitically and moved into the root cortex feed endoparasitically on tobacco, potato & radish*
P.roseus	Zarina and Maqbool, 1998	*Migratory ectoparasite then endoparasite*
P. thornei	Sher & Allen, 1953	*Migratory ectoparasite plant roots then endoparasite Reported wheat growing areas*
Psilenchus hilarulus	de Man, 1921	*Migratory ectoparasite on plant root*
Rotylenchulus reniformis	Linford and Olivira,1940	*ectoparasite on root transitional stage between Migratory endoparsite & saccate, sedentary endoparasite*
Rotylenchus capsicumi	Firoza and Maqbool,1991	*Migratory ectoparasite plant roots, stunt nematode*
Tylenchorhynchus annulatus	(Cassidy,1930) Golden,1971	*Migratory ectoparasite plant roots, stunt nematode*
T.brassicae	Siddiqi,1961	*Migratory ectoparasite plant roots, stunt nematode*
T. elegans	Siddiqi,1961	*Migratory ectoparasite plant roots, stunt nematode*
T.mashhoodi	Siddiqi and Basir,1959	*Migratory ectoparasite plant roots, stunt nematode*
T. tuberosus	Zarina and Maqbool,1994	*Migratory ectoparasite plant roots, stunt nematode*
Tylenchulus semipenetrans	Cobb,1913	*obligate root parasite, causing slow decline ,citrus nematode*
Xiphinema basiri	Siddiqi,1959	*ectoparasite Migratory on root nepo virus vector & dagger nematode*
Acrobelus sp.	Linstow,1877	*common in soil saprophagous or microbivorus*
Aporcelaimellus paracentrocercus	(deConinck,1935) Baqri & Coomans, 1973	*free living soil nematode, bacteria fungi feeder recycling organic matter*
Acrobeloides sp.	Cobb, 1924	*common in soil saprophagous or microbivorus*
Cephalobus sp.	Bastian, 1865	*common in soil saprophagous or microbivorus*
Dorylaimus sp.	Dujardin, 1845	*free living soil nematode, bacteria fungi feeder recycling organic matter*
Discolaimus sp.	Cobb, 1913	*free living soil nematode, bacteria fungi feeder recycling organic matter*
Ecuminicus monohystera	(de Man, 1880) Thorne, 1974	*free living soil nematode, bacteria , fungi feeder recycling organic matter*
Geomonhystera sp.	Andrassy, 1981	*dry mosses, soil, under the bark trees, phytoparasite, Migratory*
Moshajia sp.	Siddiqi, 1982	*free living soil nematode ,bacteria fungi feeder recycling organic matter*
Mylonchulus sp.	(Cobb, 1916) Altherr, 1953	*carnivorous, predatory nematode*
Rhabditis sp.	Dujardin,1845	*bacteria feeders, entomopathogenic nematodes*

Table 2. Occurrence of nematodes in association of Chilli crop in Sindh.

Nematode	No. of Sites	Sites of occurrence
Aphelenchoides besseyi	7	1, 6, 9, 11, 13, 14, 15
Aphelenchus avenae	9	2, 4, 5, 9, 10, 11, 12, 14, 15
Aphelenchus isomerous	4	1, 5, 10, 12
Bitylenchus brevelinatus	2	4,11
B. capsicumi n. sp.	2	1, 5
Basiria graminophila	2	4, 13
Boleodorus acutus	1	6
Ditylenchus dipsaci	6	2, 5, 7, 10, 11, 14
Filenchus filiformis	4	2,9,10,13
Filenchus butteus	8	2,4,6,7,8,12,13,15
Helicotylenchus digonicus	4	4,9,11,12
H. dihystera	5	2,5,9,11,12
H. indicus	4	1,11,12,15
H .mucronatus	1	5
H. multicinctus	2	5,15
H. pseudorobustus	3	2,12
Helicotylenchus siddiqii n.sp	2	2,5
Hemicriconemoides mangiferae	1	14
Hoplolaimus (B.) columbus	4	1,9,12,15
H. (H.) galeatus	2	12,14
H. (B.) indicus	1	15
Longidorus elongatus	4	1,10,12,14
Meloidogyne incognita larvae	2	4,14
M . javanica larvae	3	4,10,15
Paratylenchus (P) karachiensis n.sp.	1	2
Pararichodorous minor	1	3
Pratylenchus coffea	4	2,8,10,12
P. neglectus	3	4,11,12
P. penetrans	4	3,5,11,12
P.roseus	1	5
P. thornei	3	1,2,15
Psilenchus hilarulus	1	10
Rotylenchulus reniformis	5	21,4,9,11,15
Rotylenchus capsicumi	2	3,4
Tylenchorhynchus annulatus	6	2,5,8,10,11,12
T. brassicae	5	3,7,8,11,12
T. ewingi	1	7
T. mashhoodi	4	5,12,14,15
T. tuberosus	2	9,13
Tylenchulus semipenetrans	1	12
Xiphinema basiri	1	4
Acrobeles sp.	7	2,3,4,5,8,11,13
Aporcelaimellus paracentrocercus	1	2
Acrobeloides sp.	3	2,8,13
Cephalobus sp.	11	1,2,3,5,6,7,8,9,10,11,15
Dorylaimus sp.	10	1,2,5,6,7,8,10,11,13,14
Discolaimus sp.	2	5,10
Ecuminicus monohystera	1	10
Geomonhystera sp.	1	2
Moshajia sp.	6	1,2,5,8,9,12
Mylonchulus sp.	5	2,7,8,9,10

Nematode	No. of Sites	Sites of occurrence
Rhabditis sp.	1	5

*, Number of sites of occurrence (out of 15)

Sites 1, University of Karachi; 2, Malir I; 3, Malir II; 4, Asoo Goth; 5, Memon Goth I; 6, Haji Ghafoor; 7, Memon Goth II; 8, Gulshan-e-Iqbal; 9, New Karachi; 10, National Nematological Research Centre (NNRC, Univ. Karachi); 11, Gadap; 12, Ghotki; 13, Khairpur; 14, Larkana and 15, Sukkur.

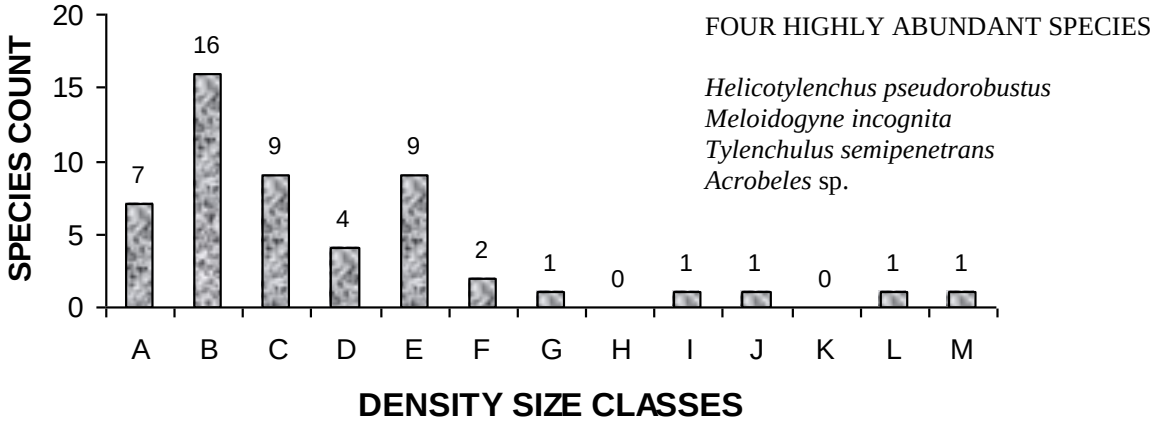

Fig.2. Count of the nematode species in relation to various size classes of density of nematode species in 100g soil. Key to the acronyms: A, ≤ 5; B, 5.1-10; C, 10.1-15; D, 15.1-20; E, 20.1-25; F, 25.1-30; G. 30.1-35, H, 35.1-40; I, 40.1-45; J, 45.1-50, K, 50.1-55; L, 55.1-60 and M, > 60 individuals of a species per 100g of soil of various sites. The classes from A to E consisted of 45 species (86.5% of the total species.

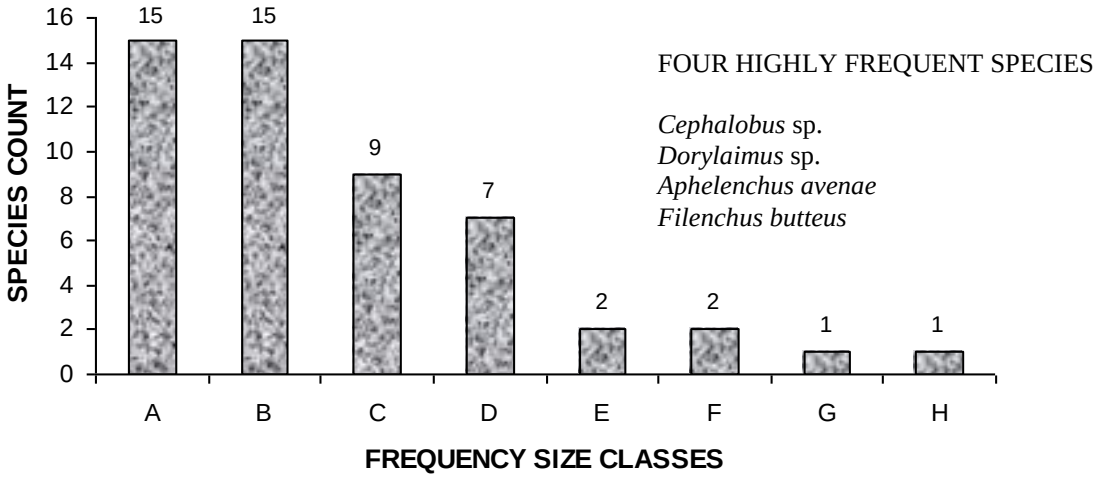

Fig. 3. Count of the nematode species in relation to various size classes of frequency of percent occurrence of nematode species in various sites. Key to the acronyms: A, ≤ 10; B, 11-20; C,21-30; D,31-40; E,41-50; F,50-60; G.61-70 and H,71-80; . The size classes from A to D consisted of 46 species (88.5% of the total species).

Table 3. Density, frequency and IVI of nematodes of Chilli crop in Sindh.

Nematode	Sites *	(F'3)	Density	F3	D3	% IVI
Aphelenchoides besseyi	7	46.67	10.43	3.9776	1.26	2.619
Aphelenchus avenae	9	60.0	24.44	5.1137	2.95	4.032
Aphelenchus isomerous	4	26.67	9.25	2.2730	1.12	1.697
Bitylenchus brevelinatus	2	13.33	24.50	1.1361	2.96	2.048
B. capsicumi	2	13.33	13.00	1.1361	1.57	1.353
Basiria graminophila	2	13.33	6.50	1.1361	0.78	0.958
Boleodorus acutus	1	6.67	6.0	.5685	0.72	0.644
Ditylenchus dipsaci	6	40.0	3.66	3.4091	0.44	1.925
Filenchus filiformis	4	26.67	8.0	2.2730	0.97	1.622
Filenchus butteus	8	53.32	9.25	4.5443	1.12	2.832
Helicotylenchus digonicus	4	26.67	7.0	2.2730	0.85	1.562
H. dihystera	5	33.33	7.8	2.8406	0.94	1.890
H. indicus	4	26.67	15.25	2.2730	1.84	2.057
H . mucronatus	1	6.67	16.0	.5685	1.93	1.249
H. multicinctus	2	13.33	24.0	1.1361	2.90	2.018
H. pseudorobustus	3	20.0	29.67	1.7046	3.58	2.642
Helicotylenchus n.sp	2	13.33	15.0	1.1361	1.81	1.473
Hemicriconemoides mangiferae	1	6.67	15.0	.5685	1.81	1.189
Hoplolaimus (B.) columbus	4	26.67	12.25	2.2730	1.48	1.877
H .(H.) galeatus	2	13.33	7.0	1.1361	0.85	0.993
H. (B.) indicus	1	6.67	15.0	.5685	1.81	1.189
Longidorus elongatus	4	26.67	50.5	2.2730	6.10	4.187
Meloidogyne incognita	2	13.33	28.0	1.1361	3.38	2.258
M. javanica	3	20.0	61.66	1.7046	7.45	4.577
Paratylenchus(P) karachiensis	1	6.67	10.0	.5685	1.21	0.889
Pararichodorous minor	1	6.67	2.0	.5685	0.24	0.404
Pratylenchus coffea	4	26.67	10.75	2.2730	1.30	1.787
P. neglectus	3	20.0	8.67	1.7046	1.05	1.377
P. penetrans	4	26.67	13.5	2.2730	1.63	1.952
P.roseus	1	6.67	4.0	.5685	0.48	0.524
P. thornei	3	20.0	6.67	1.7046	0.81	1.257
Psilenchus hilarulus	1	6.67	2.0	0.5685	0.24	0.404
Rotylenchulus reniformis	5	33.33	20.6	2.8406	2.48	2.660
Rotylenchus capsicumi	2	13.33	5.5	1.1361	0.66	0.898
Tylenchorhynchus annulatus	6	40.0	20.33	3.4091	2.45	2.930
T. brassicae	5	33.33	16.4	2.8406	1.98	2.410
T. elegance	1	6.67	6.0	0.5685	0.72	0.644
T. mashhoodi	4	26.67	19.75	2.2730	2.38	2.327
T. tuberosus	2	13.33	13.0	1.1361	1.57	1.353
Tylenchulus semipenetrans	1	6.67	42.0	0.5685	5.07	2.819
Xiphinema basiri	1	6.66	2.0	0.5676	0.24	0.404
Acrobeles sp.	7	46.67	33.71	3.9776	4.07	4.024
Aporcelaimellus paracentrocercus	1	6.67	5.0	0.5685	0.60	0.584
Acrobeloides sp.	3	20.0	48.33	1.7046	5.84	3.772
Cephalobus sp.	11	73.33	22.09	6.2497	2.67	4.460
Dorylaimus sp.	10	66.66	10.0	5.6813	1.21	3.446
Discolaimus sp.	2	13.33	7.0	1.1361	0.85	0.993
Ecuminicus monohystera	1	6.66	24.0	0.5676	2.89	1.729
Geomonhystera sp.	1	6.67	24.0	.05685	2.89	1.729
Moshajia sp.	6	40.0	5.5	3.4091	0.66	2.035
Mylonchulus sp.	5	33.33	4.2	2.8406	0.51	1.675
Rhabditis sp.	1	6.67	22.0	0.5685	2.66	1.614

*, Number of sites of occurrence (out of 15); F'3, Absolute frequency; F3, Relative frequency; D3, relative density; IVI, Importance value index.

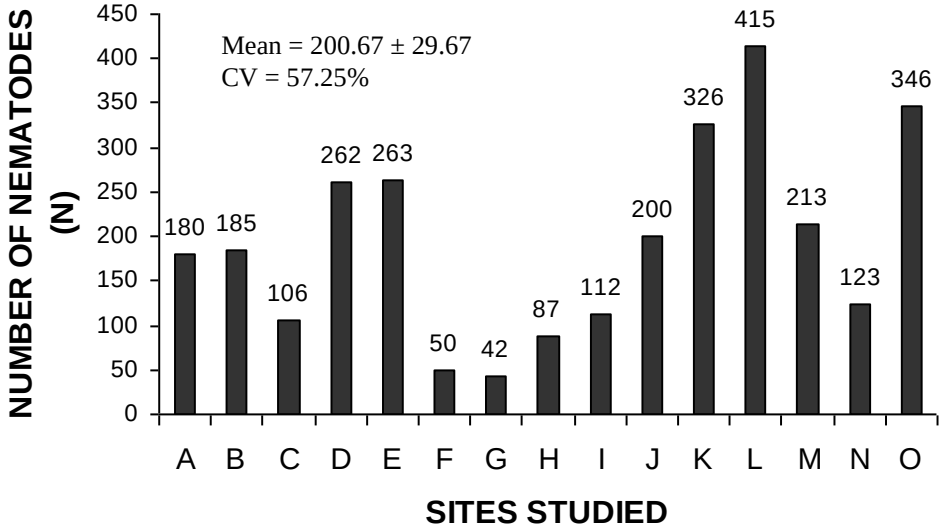

Fig. 4. Total number of nematode individuals (N) isolated per 100g of soil from each of 15 chilli fields of various areas of Sindh. Key to the acronyms: A, University of Karachi; B, Malir; C, Malir (Chilli +Lauki); D, Asoo Goth, E, Memon Goth I; F, Haji Ghafoor (Malir); G, Memon Goth II; H, Gulshan-e-Iqbal; I, Karachi; J. NNRC; K, Gadap; L, Ghotki; M, Khairpur; N, Larkana and O, Sukkur.

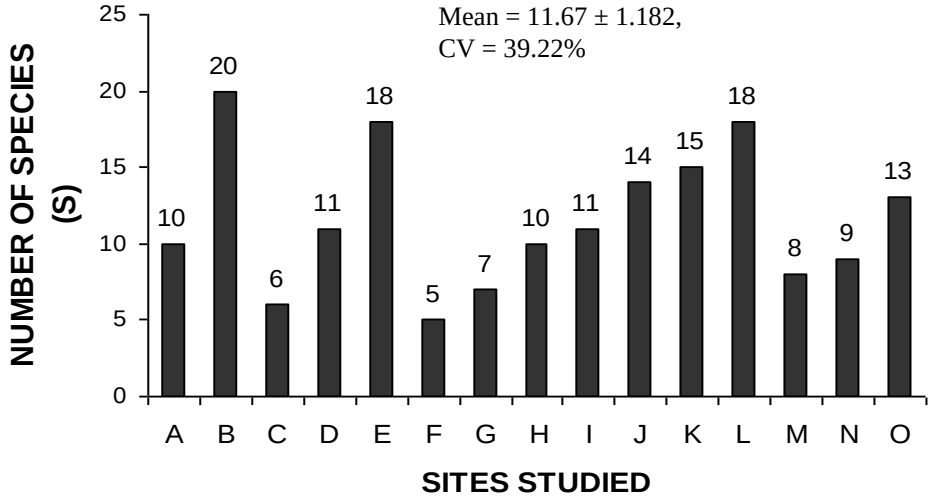

Fig.5. Total number of nematode species (S) isolated per 100g of soil of 15 chilli fields of various areas of Sindh. Key to the acronyms: A, University of Karachi; B, Malir; C, Malir (Chilli +Lauki); D, Asoo Goth, E, Memon Goth I; F, Haji Ghafoor (Malir); G, Memon Goth II; H, Gulshan-e-Iqbal; I, Karachi; J. NNRC; K, Gadap; L, Ghotki; M, Khairpur; N, Larkana and O, Sukkur.

Nematode assemblage-size of various sites: The population of nematodes recovered from 100g soil from each of the sample sites is presented in Fig. 3. The nematode assemblage size of a site averaged to 200.67 ± 29.67 individuals per site. The population size varied greatly among the sites by 57.25% (Fig. 4). The largest nematode assemblage build up was observed in Ghotki (415 individuals per 100g soil) followed by Sukkur (346). The assemblage size was the lowest at Memon Goth. (II). In other sites it ranged from 123 to 263 individuals per site.

The number of nematode species recorded from various sites varied from 5 (Haji Ghaffor Goth of Malir) to 20 in another Malir field. The number of species per site averaged to 11.67 ± 1.18 varying substantially from 5 to 20 (CV= 39.22%) (Fig. 5). The number of species in Malir I and Ghotki were similar – each with 18 species.

Table 4. Dispersion and location parameters of frequency, density and IVI of nematodes.

Statistical parameters	Absolute frequency	Absolute density	IVI (%)
N	52	52	52
Mean	22.564	15.926	1.9229
Std. Error of Mean	2.3167	1.794	0.1508
Median	20.0	12.625	1.7290
CV (%)	74.04	81.24	56.56
Skewness	1.222	1.665	0.829
Std. Error of Skewness	0.330	0.330	0.330
Kurtosis	1.153	2.985	0.145
Std. Error of Kurtosis	0.650	0.650	0.650
Minimum	6.660	2.0	0.404
Maximum	73.330	61.660	4.577
KS-z	1.374	1.143	1.034
p	0.046	0.147	0.235

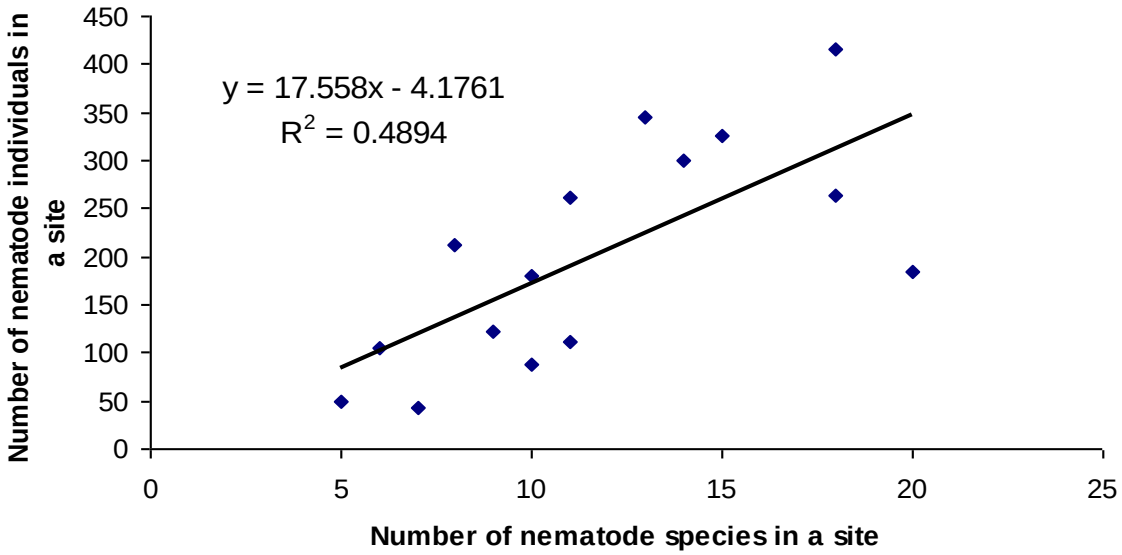

Fig. 6. Relationship of number of nematode species in a site with total assemblage size of nematodes in the site (number per 100g soil).

Relationship of nematode assemblage size and number of species: The nematode assemblage size of a sample site exhibited significantly positive correlation ($r = 0.6996$; $p < 0.01$) with number of species colonizing the site (Fig. 6). This relationship was given by following linear equation indicating that 49% of the assemblage size variation was control by the number of species present in the site ($r^2 = 0.4894$),

Nematode assemblage size of a Site = -4.1781 + 17.588 Number of species in the site

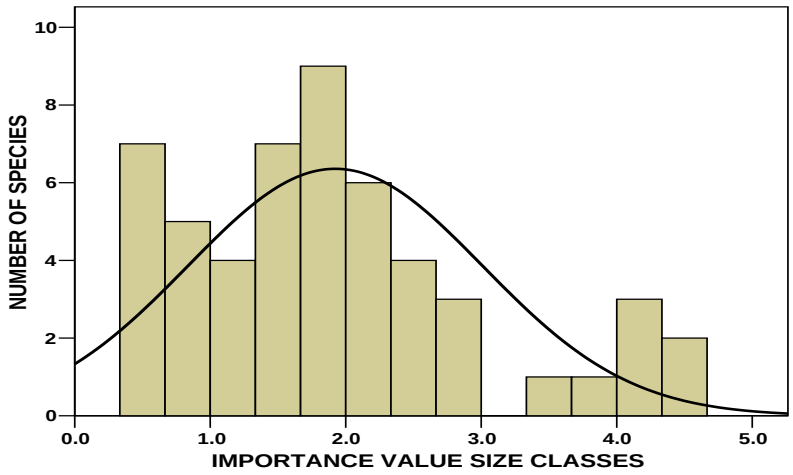

Fig. 7. Frequency distribution of number of nematode species in various size classes of % importance value.

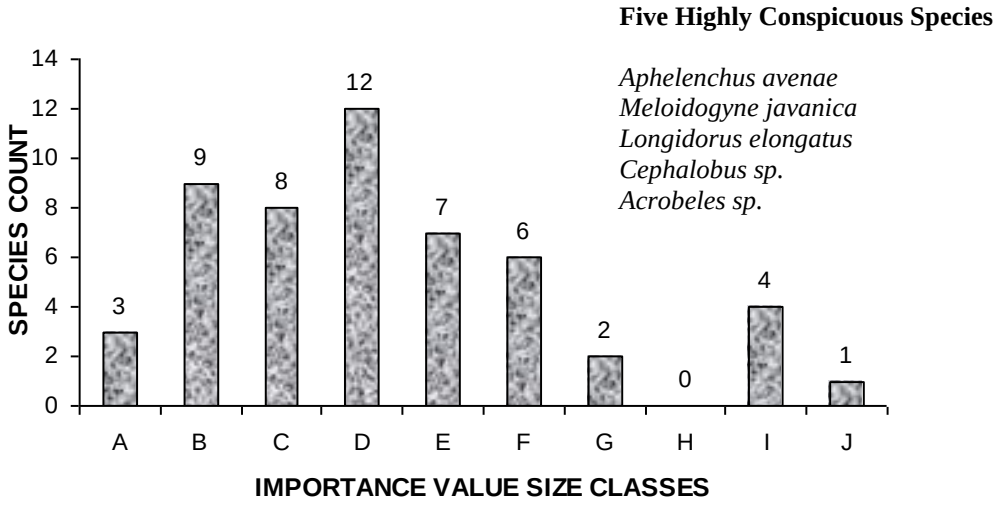

Fig. 8. Count of the total nematode species in relation to various size classes of their percent importance value index in various chilli-growing sites. Key to the acronyms: A, ≤ 0.5; B, 0.51-1.0; C,1.1-1.5; D,1.51-2.0; E,2.1-2.5; F, 2.51-3.0; G.3.1-3.5, H,3.51-4.0 and I, 4.1-4.5. The classes from B to F occupied a greater number of species (42).

Species conspicuousness: To determine conspicuousness of nematode species encountered during present survey objectively, a composite parameter of Importance Value Index was calculated by summing relative density and relative frequency of the species. The value of this index (% IVI) for various species is presented in Table 3. The % IVI varied greatly among species (56.56%) and distributed in positively skewed manner (Table 4; Fig. 7). The IVI of species averaged to 1.923 ± 0.151. Some 32 species had % IVI lower than the average value of the index (Fig. 7). None of the species had % IVI greater than 5. Five species viz. *Aphelenchus avenae, M. javanica, Longidorus elongatus, Cephalobus* sp. and Acrobeles sp. had % IVI ranging between 4 and 5 (Fig. 8). Of these highly conspicuous species, *Cephalobus* sp. and *Acrobeles* sp. are free-living ones. Some 39 species (75%) of the total species had % IVI ranging from 0.5 to 2.5. and 8 species had % IVI greater than 2.5 to 4.0 (Table 3). On the basis IVI, *Aphelenchus avenae, Aphelenchoides besseyi, Bitylenchus brevelinatus, Filenchus butteus, Helicotylenchus indicus, H. multicinctus, H. pseudorobustus, Longidorus elongatus, Meloidogyne javanica, M. incognita, Rotylenchus reniformis, Tylenchorhynchus annulatus, T. brassicae, T. mashoodi, Tylenchulus semipenetrans, Cephalobus sp., Acrobeles sp. Dorylaimus* sp. are very important species of chilli crop of Sindh. Of these species, the last three are, however free-living nematodes; the others being parasitic are of concern.

Table 5. The nematodes assemblages of chilli field soils of Sindh.

Site	Nematode Assemblage
UOK	*Longidorus elongatus- Aphelenchoides besseyi – Geomonhystera sp.*
Malir I	*Helicotylenchus siddiqii n. sp. – Cephalobobus sp. – Aphelenchus avenae*
Malir II *	*Acrobeles sp. – Cephalobus sp. – Tylenchorynchus brassicae*
Asoo Goth	*Xiphinema basiri – Meloidogyne incognita – Longidorus elongatus*
M G1	*Acrobeles sp. Helichotylenchus multicinctus – Bitylenchus capsicumi*
HGG	*Cephalobus sp. – Dorylaimus sp. - Filenchus butteus = Boleodorus acutus*
M G II	*Cephalobus sp. – Dorylaimus sp. – Tylenchorhynchus brassicae = Tylenchorhynchus elegance*
G I	*Tylenchorhynchus annulatus – Tylenchorhynchus brassicae*
N. Karachi	*Rotylenchus reniformis – Filenchus filiformis*
NNRC	*Meloidogynae javanica – Tylenchorhynchus annulatus – Ecuminicus monohystera*
Gadap	*Acrobeles sp. = Rotylenchulus reniformis*
Ghotki	*Longidorus elongatus – Aphelenchus avenae – Tylenchulus semipenetrans*
Khairpur	*Acrobeloides sp. – Tylenchorhynchus tuberosus – Filenchus butteus*
Larkana	*Cephalobus sp. - Tylenchorhynchus mashoodi*
Sukkur	*Meloidogynae javanica – Helicotylenchus pseudorobustus – Longidorus elongatus*

Acronyms: UOK, University of Karachi; M G I = Memon Goth I; HGG, Haji Ghafoor Goth; MG Ii, Memon Goth II; GI, Gulshan-e-Iqbal; NNRC, National Nematological Research centre. *, *Luffa* was also present along with chilli.

The dominants: Analysis of the assemblages of various sites on the basis of density-based dominants indicated that in 15 sites studied, nine species of nematodes attained the rank of leading dominant, 12 species were second dominant and 11 species attained the status of the third dominant (Table 5). Species such as *Longidorus elongatus*, was first dominant in two sites (University of Karachi and Ghotki), *Acrobeles* sp., a free living nematode was leading dominant in Malir, Memon Goth I and Gadap. *Cephalobus* sp, another free-living nematode was leading dominant pre-dominated in Haji Ghafoor Goth, Memon Goth II and Larkana chilli fields. *Helicotylenchus siddiqii* predominated in Malir, *Tylenchorhynchus annulatus* dominated in Gulshan-e-Iqbal, *Rotylenchus reniformis* in New Karachi, and *Xiphinema* basiri. and a free-living *Acrobeloides* sp. predominated in Asoo Goth (Malir) and Khairpur, respectively. Root knot nematode, Meloidogyne javanica was the leading dominant species of NNRC (Karachi) and Sukkur. This is the most common tropical nematode attacking vegetables. None of the leading dominant species given above had widespread predominance. They generally represented local dominance. Different species were differentially successful. Therefore, to disclose structure and organization of the assemblages of various sites, diversity and dominance analysis was undertaken.

Species diversity, dominance, species richness and relative abundance pattern: The nematode assemblages in hand were simple in structure and organization as indicated by the low values of diversity indices and high values of dominance (Table 6). The species diversity in terms of species, S, averaged to 11.7 ± 1.2 (5 – 20; CV = 60.4%). Species diversity was substantially higher in chilli fields of Malir I, Memon Goth, NNRC fields, Gadap, Ghotki and Sukkur and relatively low in other fields (Malir II, Asoo Goth, Haji Ghafoor Goth, Gulshan-e-Iqbal, Khairpur and Larkana. Also, on the basis of information theory function (H'), species diversity was comparatively higher in Sukkur, Ghotki, Gadap, Memon Goth and Malir I. Species richness indices R1 and R2 and species diversity indices N1 and N2 behaved in similar fashion as H' and S (Table 6). Equitability component of diversity E1 varied little among the sites (CV= 9.44%). E2 and E3 behaved almost similarly and varied around 13%. Equitability was lower in Khairpur and maximum in Sukkur.

There was a great degree of multi-colinearity among diversity and its component and dominance measures (Table 7).The relationship of species diversity with its components (species richness and equitability) was positive but it related negatively with dominance, c, as has been reported earlier (Shuakat *et al.,* 1978; 1981). It was apparent from the correlation studies that species diversity, H', was more controlled by species richness (c. 70%) than equitability (24%) (Table 7).

According to Whittaker (1965) a natural community (assemblage of species) is an admixture of differentially and unequally successful species. The dominant species influences the subordinate species and thus the structure and function of the assemblages. This was indicated by the diversity dominance analysis that structure and organization of the assemblages in hand was quite simple and the relative abundance pattern of the species in sample sites was geometric as was evident by the linear plots of densities on log scale (Fig. 9) for all sample sites. This distribution implied geometric distribution of resources to the species. It indicated that most successful species (dominants) pre-empted a fraction 'k' of the resources, next a fraction of the remainder of the resources and so on (May, 1975, Tokeshi, 1990; 1996; Magurran, 2004). Such a distribution is attributed to

species poor situations where dominance is strongly developed. With the present data in hand, species richness appeared to control diversity more than the equitability does. Tramer (1969) suggested that communities of non-rigorous environment (biologically controlled environment) are more controlled by species richness. The diversity of irrigated - cultivated fields of chilli in Sindh appears to be more controlled biologically. However, a sound control of the environment still remains there since there is no such entity as wholly biologically controlled or wholly physically controlled (Smith, 1980). The community is rather influenced by the two.

Table 6. Species richness, diversity, dominance and equitability of soil nematodes of chilli crop in Sindh.

Site	S	R1	R2	c	H'	N1	N2	E1	E2	E5
UOK	10	1.7465	0.7603	0.16891	1.9647	7.1324	5.920	0.8532	0.7132	0.87024
Malir I	20	3.6396	1.4704	0.07397	2.7301	15.334	13.519	0.9113	0.7667	0.8734
Malir II	6	1.0722	0.5828	0.27097	1.5353	4.643	4.149	0.8569	0.7738	0.8647
Asoo Goth	11	1.7959	0.6796	0.17759	1.9085	6.743	5.631	0.7959	0.6129	0.8064
M G1	18	3.0509	1.099	0.07155	2.7206	15.189	13.977	0.9413	0.8438	0.9146
HGG	5	1.0225	0.7071	0.31755	1.3442	3.835	3.149	0.8352	0.7670	0.7581
M G II	7	1.6053	1.0801	0.20093	1.7155	5.559	4.977	0.8816	0.7942	0.8722
G I	10	2.0153	1.0721	0.17134	1.9703	7.173	5.836	0.8557	0.7173	0.7835
N. Karachi	11	2.1193	1.0394	0.13385	2.1810	8.855	7.471	0.9096	0.8050	0.8280
NNRC	14	2.4536	0.9899	0.21261	1.9394	6.955	4.703	0.7349	0.4968	0.6293
Gadap	15	2.4193	0.8308	0.11707	2.3505	10.491	8.542	0.8680	0.6994	0.7947
Ghotki	18	2.8200	0.8836	0.13054	2.3974	10.995	7.661	0.8294	0.6108	0.6664
Khairpur	8	1.3057	0.5482	0.40996	1.3278	3.773	2.439	0.6385	0.4716	0.5191
Larkana	9	1.6625	0.8115	0.17446	1.8320	6.247	5.143	0.8338	0.6941	0.7896
Sukkur	13	2.0525	0.6989	0.09469	2.4454	11.535	10.559	0.9534	0.8873	0.9074
Mean	11.7	2.052	0.8809	0.1811	2.025	8.3248	5.5785	0.8466	0.7265	0.7870
SE	1.2	0.189	0.063	0.024	0.115	0.962	0.868	0.021	0.026	0.028
CV (%)	60.4	35.67	27.50	50.31	22.02	44.73	39.40	9.44	13.62	13.82

Table. 7. Pearson product moment correlation coefficients among species diversity and its components measures.

S	S									
R1	0.971	R1								
R2	0.601	0.772	R2							
c	-0.744	-0.771	-0.613	c						
H'	0.914	0.912	0.631	-0.929	H'					
N1	0.917	0.917	0.641	-0.855	0.977	N1				
N2	0.832	0.846	0.627	-0.845	0.947	0.982	N2			
E1	0.313	0.377	0.451	-0.781	0.644	0.624	0.707	E1		
E2	0.211	-0.093	0.274	-0.522	0.383	0.401	0.531	0.935	E2	
E5	0.104	0.175	0.313	-0.643	0.452	0.434	0.563	0.905	0.895	E5

Cluster analysis: The dendrogram resulting from the average linkage clustering of 15 sites of chilli crop fields is presented in Fig. 10. Five discrete groups which may be derived from the dendrogram may be discussed as follows:

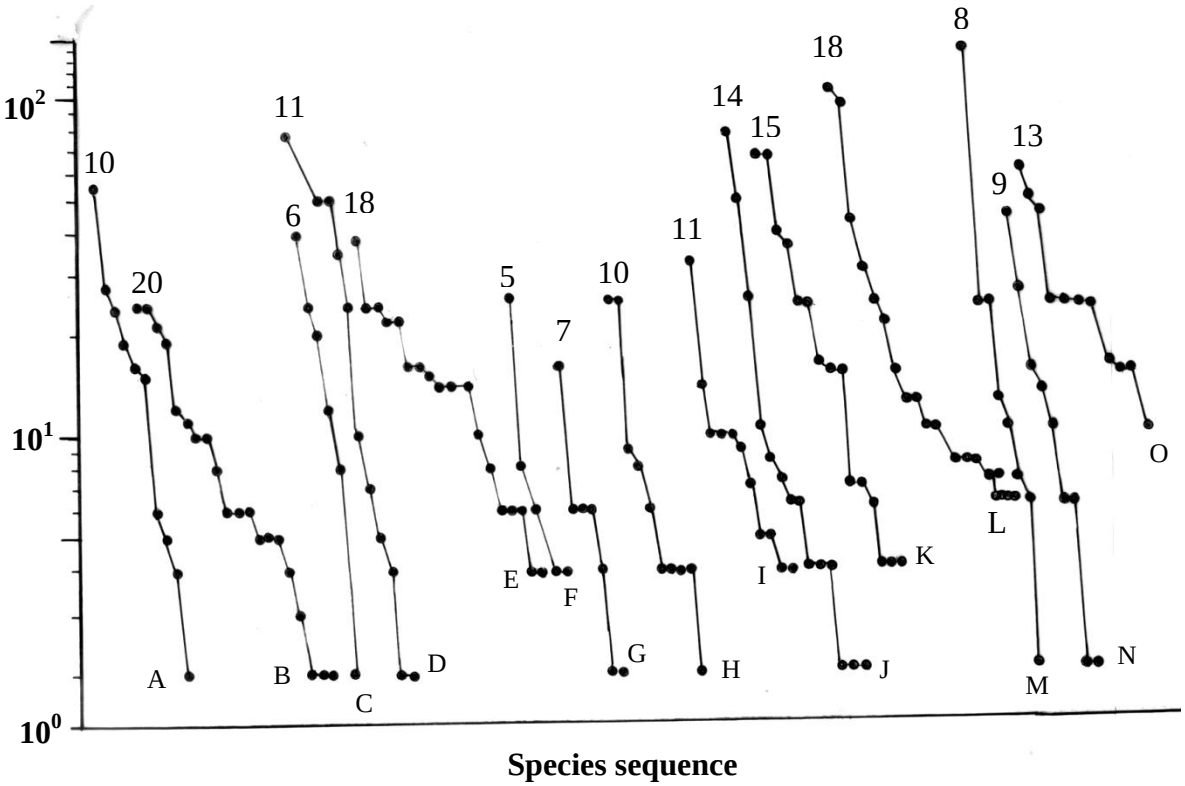

Fig. 9. Relative abundance pattern of nematodes in soils of sites of chilli crops in the province of Sindh. Alphabets (A-O) represent sites as in Table 1. Figures above the curve represent the number of nematode species present in the site.

Table 8. Average species richness, diversity, dominance and density per 100 g soil of the major nematode assemblages as defined by the Ward method of clustering.

Diversity indices	Group A	Group B	Group C	Group D	Group E
S	10.66 ± 1.72	13.50 ± 0.50	13.0 ± 2.0	8.0	18.0
R1	1.993 ± 0.288	2.253 ± 0.201	2.108 ± 0.312	1.310	2.820
R2	0.959 ± 0.090	0.844 ± 0.145	0.876 ± 0.076	0.5482	0.8836
H	1.999 ± 0.159	1.693 ± 0.753	2.130 ± 0.221	1.3278	2.3974
N1	8.2186 ± 1.42	9.2449 ± 2.29	8.6167 ± 1.87	3.7727	10.9945
N2	7.1269 ± 1.31	7.6317 ± 2.93	7.0865 ± 1.46	2.4393	7.6605
C	0.1749 ± 0.025	0.154 ± 0.059	0.1943± 0.184	0.4100	0.1305
E1	0.8753 ± 0.013	0.8441 ± 0.109	0.7654 ± 0.031	0.6385	0.8294
E2	0.7639±0.016	0.9275±0.040	0.6562±0.043	0.4716	0.6108
E5	0.8258±0.017	0.9168±0.013	0.8005±0.006	0.5191	0.6604
Average total density *	127.56 ± 23.6	273.0 ± 73.01	204.0 ± 32.05	218	415

*, calculated as total density / number of sites of occurrence.

Group A: It was the agglomeration of nine sites generally around Karachi viz. University of Karachi, Malir I and II, Memon Goth, Haji Ghafoor Goth, Gulshan-e-Iqbal and New Karachi and Larkana. This group was quite heterogeneous and comprised of four sites dominated by free-living *Acrobeles* sp., *Cephalobus* sp. with free-living *Dorylaimus* sp. or parasitic subordinates such as *Tylenchorhynchus brassicae, Filenchus butteus, etc.* in varying proportions. The other five sites dominated by *Longidorus elongatus* in association of subordinate *Aphelenchoides* sp. *Helicotylenchus siddiqii, Tylenchorhynchus annulatus, T. brassicae, Rotylenchus reniformis or Filenchus filiformis*. This group exhibited moderate diversity but low assemblage density of 127.56 ± 23.6 (Table 8).

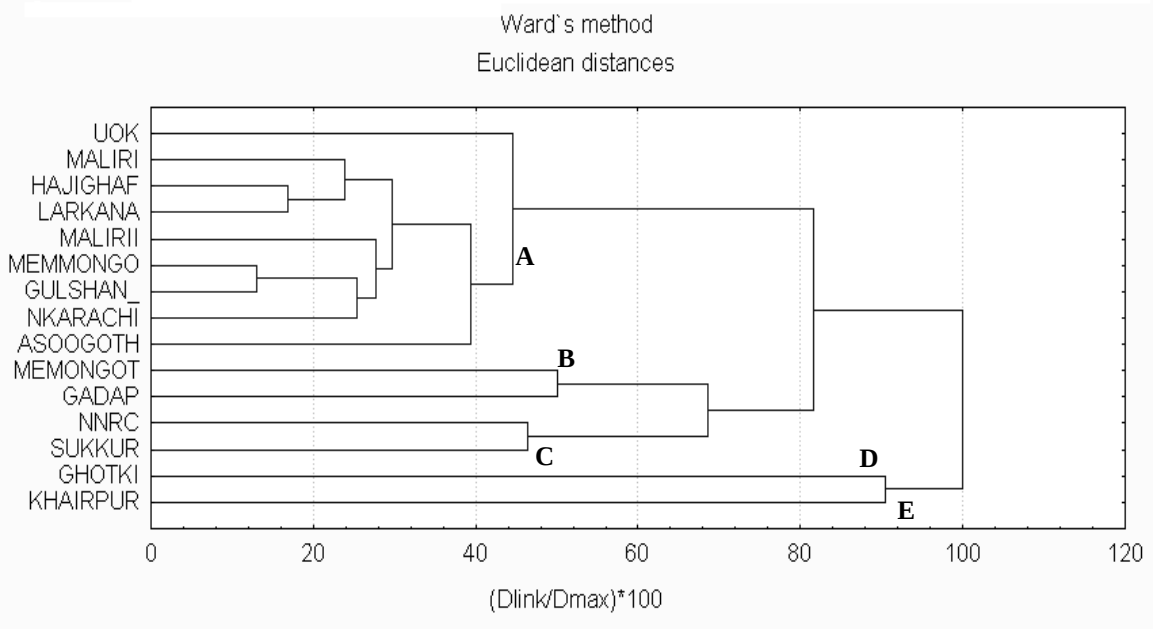

Fig. 10. Cluster dendrogram for various sites studied on the basis of density of 52 nematodes isolated (Table 1) - as given by agglomeration due to Ward Method on the basis of Euclidean distances between the sites. The site studied formed five groups at a scale of cluster distance of 10. The group extraction was made at least at 50% compositional similarity.

GROUP B: This group comprised of sites from NNRC (Karachi) and Sukkur. The dominant nematode species was *Meloidogyne javanica* in the two sites and sub-ordinated by *Tylenchorhynchus annulatus, Helicotylenchus pseudorobustus* and a free-living species, *Ecuminicus monohystera*. This group represented moderate diversity and moderate assemblage density of 273.0 ± 73.01 with comparatively larger variation (Table 8).

GROUP C: This group comprised of two sites – Asoo Goth and Gadap dominated by *Xiphinema basiri* sub-ordinated by *Meloidogyne incognita*, *Longidorus elongatus*, *Rotylenchulus reniformis* and a free-living nematode, *Acrobeloides* sp. This group also had moderate species diversity and assemblage density, 204.0 ± 32.05 (Table 8).

GROUP D: This was solely represented by the Khairpur site predominated by a free living species, *Acrobeloides* p. *Tylenchorhynchus tuberosus* and *Tylenchulus semi-penetrans* were the second and the third dominant species. This group exhibited comparatively low species diversity but moderate assemblage density (218) (Table 8).

GROUP E: It was represented by Ghotki site dominated by three parasitic species – *Longidorus elongatus, Aphelenchus avenae* and *Tylenchulus semipenetrans.* The group showed high diversity and very assemblage density (415) (Table 8).

Khan *et al.* (2006) has performed cluster analysis of 10 chilli growing localities of Sindh where density of nematode species has been the statistical attribute. They recognized two broader groups. Group I comprised of two subgroups separately dominated by *Hoplolaimus indicus* and *Meloidogyne javanica*. The second group was abundantly dominated by *Tylenchorhynchus annulatus* and *Xiphinema* sp. The similarity of their results with ours is quite evident.

Our studies of chilli growing localities of Sindh have indicated that there a number of parasitic species of agricultural concern viz. *A. avenae, A. isomerus, D. dipsaci, F. filiformis, F. butteus, H. digonicus, H. dihystera,, H. indicus, H. pseudorobustus, Hoplolaimus (B.) columbus, Longidorus elongatus, M. javanica, M. incognita, M. javanica, T. brassicae, T. mashhoodi,* etc. The species of potential threat have occurred in various combinations and abundance. Some of them have already been reported from Pakistan to infect chilli plants. Several of them have wide range of hosts but the *M. incognita* and *M. javanica* have the widest range of hosts including chillies in Pakistan (Fig. 11). The simultaneous presence of sedentary endoparasite (*Meloidogyne* spp.) and migratory endoparasite (*Pratylenchus* spp.) appears to be quite alarming. The assemblage of several types of nematodes needs further studies with respect to the interactions that may take place between them. Adamou *et al.* (2013) have opined that endoparasite like *Meloidogyne* and *Pratylenchus* may inhibit the proliferation of *Xiphinema* sp. The structure of the nematode assemblage may be influenced by interaction (competition) among them (Permilla *et al.,* 2004). Sarr and Prot (1985) had shown competition between species of the same genus as that between *Meloidogyne incognita* and *M. javanica* on *Digitalis exilis*.

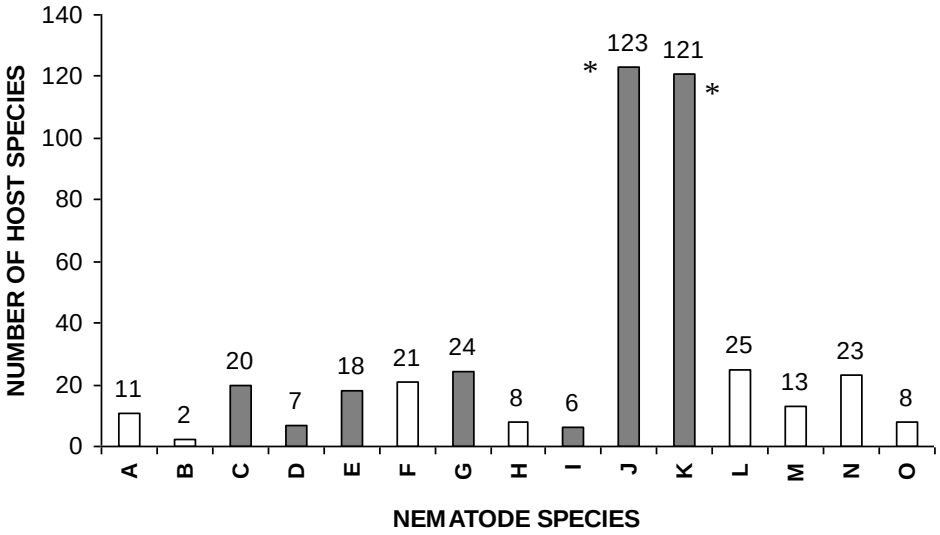

Fig. 11. Host range of plant species recorded to be infected by nematode species (drawn from the country report of biodiversity of nematode fauna by Maqbool and Shahina (2001). *, Host range of *M. incognita* and *M. javanica* is after Shahina *et al* (2009). Key to the nematode name acronyms: A, *A. avenae*; B, *A. besseyi*; C, *D, dipsaci*; D, *F. filiformis*; E, *H. digonicus*; F, *H. dihystera*; G, *H. indicus*; H, *H. pseudorobustus*; I, *L. elongatus*; J, *M. incognita*; K, *M. javanica*; L, *T. annulatus*; M, *T. semipenetrans*; N, *T. brassicae*; O, *T. mashhoodi*. The solid bars indicate the chilli as a host included in previous reports. Open bar species are the new chilli nematodes not reported from chillies previously from Sindh.

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