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RESEARCH ARTICLE

Beneath the Soil: Exploring Nematode Fauna Dynamics and Crop Infection Patterns in Bareilly, Uttar Pradesh, India

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ABSTRACT

Background: This study looks into how nematodes change over time and how often they infect different crops in and around the Bareilly district in Uttar Pradesh, India. These crops include tubers, roots, bulbous plants, and cole crops. **Main Body**: Nematodes, diminutive worm-like organisms, possess the potential to inflict substantial harm upon agricultural crops, resulting in yield reductions and significant economic repercussions for farmers. Grasping the extent and dynamics of nematode infestations is paramount in formulating effective management strategies. The survey will involve collecting soil and crop samples from various locations in the Bareilly district and neighboring regions. These samples will be analyzed using conventional techniques to identify and quantify nematode species. This will allow for the determination of infection rates in different crop categories**.** **Conclusion:** The findings will yield invaluable insights into nematode fauna dynamics, species diversity, and region-specific infection trends, thereby informing the development of precise control measures aimed at mitigating crop losses and fostering enhanced agricultural productivity.

Keywords: Nematodes, Infections, Agricultural crops, Tubers, Roots.

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INTRODUCTION

Nematodes are microscopic, worm-like organisms that can cause significant damage to agricultural crops, leading to yield losses and economic implications worldwide for farmers. Cole crops refer to vegetables such as cabbage, broccoli, and cauliflower. They belong to the phylum Nematodea, which comprises a diverse group of organisms that play significant roles in nutrient cycling, decomposition, and soil health. While many nematodes are beneficial, contributing to soil fertility and ecosystem functioning, others are parasitic and can cause substantial damage to crop plants. Koenning *et al.*, [1]; Abad *et al.*, [2]; Nicol *et al.* [3] estimates that average crop losses triggered by plant-parasitic nematodes are between 100 and 157 billion USD worldwide.

The 25 genera of plant parasitic nematodes currently known all contain species economically important as plant pests. *Helicotylenchus, Pratylenchus, Heterodera, Ditylenchus, Globodera, Tylenchulus, Xiphinema, Radopholus,* and *Heterodera* are the ten most important genera of nematodes in the world [4]. Root-knot nematodes (*Meloidogyne spp.*) are found all over the world. The most harmful species are *Meloidogyne incognita, javanica, arenaria*, and *Meloidogyne hapla*. The root-knot nematode's giant cell's major feeding site develops at the node's base [5-6]. The absence of cytokinesis results in the induction of a multinucleated giant cell within the host cell. Without cell division, the host cell can form a giant cell with multiple nuclei. Eggs from the female cyst body of nematodes (*Heterodera and Globodera spp.*), which are released as larvae (J2), infect the host and mature into adults within the host's tissue. Cyst worms get into the root tips and cause syncytia, which are special feeding structures [6-12]. Nematodes that cause root lesions, known scientifically as *Pratylenchus species*, can infect a wide variety of plant species and can be found all over the world [13]. *Migrating endoparasites*, known as lesion nematodes, feed mostly on the cortex of the root. Usually, lesions form on the roots, and the leaves turn green above the ground [14]. The burrowing nematode, or *Radopholus*

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similis, is a migratory plant-parasitic worm that produces significant economic losses in yields and is a quarantine plant pest all over the world [6, 15].

In agricultural systems, nematode infestations significantly threaten crop productivity, leading to substantial economic losses for farmers. Their ability to infect a wide range of crops, including tubers, roots, bulbous plants, and Cole crops, makes them a persistent concern for agricultural communities. These pests can invade and feed on the roots, leading to reduced nutrient uptake, stunted growth, and ultimately lower yields [1-2, 16].

Agriculture, which uses 25% of the Earth's land surface, is one of many factors that affect the health of ecosystems around the world [17]. Modern conventional farming methods emerged as a result of agricultural reforms following World War II. More and more proof is coming in that conventional farming doesn't make crops as productive as they could be [18], but the damage this farming does to the environment has been greatly underestimated, if not ignored. Numerous laws have been enacted to reduce the use of wide-spectrum insecticides to protect environmental and human health in a world where three billion kilograms of pesticides are applied annually and are suspected to result in 220,000 deaths per year [19]. More work is needed in this area [20]. The Bareilly district in Uttar Pradesh, India, is an agriculturally rich region with diverse cropping systems. It encompasses a wide variety of crops, including potatoes, carrots, onions, and cabbage, which are vital for both local consumption and commercial markets. However, nematode infestations have been reported to have a detrimental impact on the productivity of these crops in the district, leading to significant losses for farmers. In addition, understanding the dynamics of nematode populations and infection rates is crucial for developing effective management strategies that can mitigate their negative impact on crop production. By assessing the nematode fauna dynamics and infection rates on tuber, root, bulbous, and cole crops in the Bareilly district, this research aims to provide valuable insights into the prevalence and severity of nematode infestations in the region [16, 21-22]. According to Verdejo-Lucas *et al.* [23], the presence of an initial nematode population density of 4,750 juveniles of the species *M. javanica* per 250 cm^3 of soil resulted in a yield drop of up to 61% in tomato plants.

The research results will not only add to what is known about nematode ecology, but they will also help come up with integrated pest management plans to reduce crop losses caused by nematodes. Farmers can take targeted steps to control nematodes by learning about the species that attack different crops and their commonalities. These steps include crop rotation, using resistant cultivars, biological control agents, and long-term soil management.

The main goal of this study is to understand how nematode populations change and their infection rates in tuber root, bulbous, and Cole crops in the Bareilly district of Uttar Pradesh. The findings will contribute to the development of effective strategies to control nematode infestations. This will help farmers in the region get higher crop yields and more stable economies [24-25]. Many nematodes are beneficial and contribute to soil fertility and ecosystem functioning; others are parasitic and can cause significant damage to crops. In agricultural systems, nematode infestation seriously threatens crop productivity and results in significant economic losses for farmers. Their ability to infect a variety of crops, including tubers, roots, bulbs, and cabbages, makes them a constant concern for farming communities [24, 26]. These pests can attack and feed on the roots, resulting in reduced nutrient uptake, stunted growth, and ultimately reduced yields. The district of Bareilly in Uttar Pradesh, India, is a rich agricultural region with diverse cropping systems. It covers a wide range of crops, including potatoes, carrots, onions, and cabbage, which are essential for both local consumption and commercial markets. However, nematode infestation has been reported to negatively impact the productivity of these crops in the county and result in significant losses to farmers [6]. Understanding nematode population dynamics and infection rates is crucial to developing effective management strategies that can mitigate their negative impact on agricultural production. This study looks at the nematode fauna dynamics and infection rates of tuber, root, tuber, and cabbage crops in the Borough of Bareilly. The goal is to give useful information about common and bad nematode infestations in the area. The research results will not only help us learn more about nematode ecology, but they will also help us come up with integrated pest management plans to stop nematodes from destroying crops [26-27]. Farmers can use targeted control methods like crop rotation, resistant cultivars, biological control agents, and sustainable soil management practices if they know the specific nematode species and where they live in different crops. This study aims to fill the knowledge gap on nematode fauna dynamics and infection rates in Bareilly District, Uttar Pradesh in tuber, root tuber, and cabbage crops. The insights gained from this study will help to develop sustainable and effective strategies to control nematode infestations and offer higher yields and economic stability to farmers in the region.

MATERIALS AND METHODS

Cobb's Technique Modified by Barker

"Cobb's sieving and decanting method" extracted the nematodes from soil or roots. Mixed soil with water in a trough, passing the supernatant through 100, 200, and 400 mesh sieves. Thus, Nematode suspensions were collected to study the population dynamics and infection rate [28]. Calculations for population dynamics and rate of infection have been done using the following formulas:

Norton's Formulas (1978)

Relative Abundance (RA): Number of samples containing different species

$$RA = \frac{Number\ of\ samples\ containg\ different\ species}{Number\ of\ samples\ collected} X100$$

Relative Density (RD):

$$RD = \frac{Number\ of\ individuals\ of\ a\ species\ in\ a\ sample}{Total\ number\ of\ all\ individuals\ in\ a\ sample}\ X100$$

Relative Frequency (RF):

$$RF = \frac{Frequency\ of\ one\ species}{Total\ number\ of\ all\ individuals\ in\ a\ sample}\ X100$$

Dominance Value Index (DVI):

$$DVI = \frac{RA + RF + RD}{3}\ X100$$

Analysis of the Soil Samples:

pH

The pH of the soil samples was measured with the help of a pen pH meter by dissolving 10 g of soil in 100 mL of distilled water.

Moisture Content

10 grams of each soil sample (W_1) were taken and kept in an oven at 60°C for 45 to 60 minutes. After complete drying, the sample was weighed again (W_2), and the percent moisture content was calculated by following the formula:

Percent moisture content

$$Percent\ moisture\ content = \frac{W1 + W2}{W1}\ X100$$

Southey's method (1970)

Hot water (60-70°C) killed the extracted nematodes and fixed with 4% formalin for 24 hours. Nematodes were then dehydrated properly in Seinhorst's mixtures I and II, mounted on a drop of glycerine, and finally sealed with nail enamel.

All the slides as well as vials containing nematode suspensions, were sent to experts.

Sasser and Carter (1985)

Based on Sasser and Carter, morphological descriptions of Meloidogyne incognita males, females, juveniles, and egg masses were given.

Reddy *et al.*, 1997: It is used for the mean Gall Index Value (MGI).

Scale

1 = 1 to 25 galls without egg masses

2 = 1 to 25 galls with egg masses

3 = 26 to 50 galls with egg masses

4 = with numerous egg masses

$$MGI = \frac{Number\ of\ total\ galls\ count\ in\ each\ replicate}{3}$$

Statistical Calculation

Statistical calculations like minimum value, maximum value, average, median value, standard deviation, correlation coefficient, and root squared value were taken with the help of the computer package.

RESULTS AND DISCUSSION

Geographical Position

Bareilly is situated in the middle of the Rohilkhand commissionary. It is one of the most fertile regions of Uttar Pradesh, India. Bareilly covers an area of 4, 120 km. It is a Tarai-Bhabar region between 150 km in the North-South and 110 km in the East-West. This district lies between latitudes 28.19 and 58.54° and longitudes 78.58 and 79.870°. It is 250 km from Lucknow, the capital of the state. Several rivers like Ramganga, Shankha, Kicha, Nakatiya, Devrania, Behgul, and some other small rivers flow, providing a perennial water supply.

Loam, sandy loam, silt, and at very few places sandy soils are found with 8-36% moisture content and 7.2 to 7.9 soil pH (Table 1). Hence, these factors make it a fertile area that is highly suitable for agriculture.

During 2020-21, a survey of potato, sweet potato, turnip, beet root, radish, carrot, onion, garlic, cabbage, and cauliflower was conducted in 20 localities in and around Bareilly region. A total of 352 soil samples were collected to study nematode fauna, population dynamics, and rate of infection (Figure 1).

Nematode Fauna:

During the survey, many plants parasitic nematodes were encountered viz. *Meloidogyne incognita*, *Helicotylenchus indicus*, *Helicotylenchus dihystra*, *Tylenchorhynchus nudus*, *Rotylenchulus reniformis*, *Xiphinema basiri*, *Dorylimids*, *Tylenchus mashoodi*, *Rhabdites*, *Aphelenchus costasus*, *Heterodera avenae*, *Basiliophora similis*, *Discolaimus species*, *Pratylenchus zeae* and *Tylenchus spec*ies (Table 1).

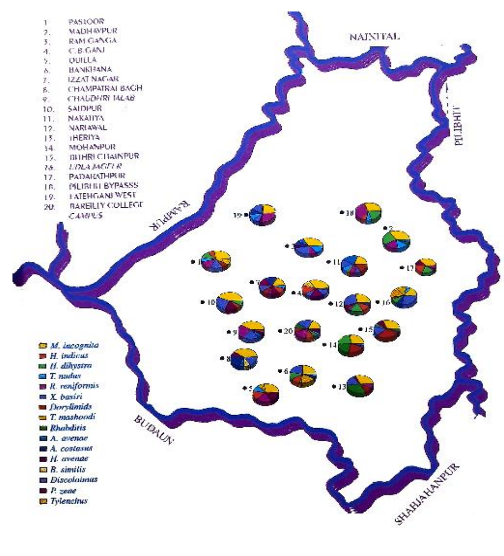

Figure 1: Map representing the dominance value index of the localities studied in the Bareilly region

Meloidogyne was found in all the samples from all the 20 localities. *Tylenchorhynchus, Helicotylenchus, Xiphinema* and *Rotylenchulus* species were found in most of the samples studied.

Though *Tylenchorhynchus* species was also found to be associated with almost all the crops studied in all the localities, but its frequency was very high in the fields dominated by cabbage and cauliflower-growing area. The plants of cabbage and cauliflower in such fields appeared unhealthy.

It has also been observed that the occurrence of incognita species of Meloidogyne was highest in relation to other

Table 1: Survey of Tuber, Root, Bulbous, and Cole Crops in and around Bareilly Region

S.No.	*Locality*		*Nematodes*	*RA %*	*RD%*	*RF%*	*DVI%*
1.	Pastoor		*M. incognita*	100	45.75	27.77	57.17
	pH	7.2–7.5	*H. indicus*	35	5.85	9.1	17.48
	Soil Type	Sandy Loan	*H. dihystra*	52	8.77	12.12	23.63
	Moisture Content	16–30	*T. nudus*	20	18.05	9.52	15.86
			R. reniformis	55.14	22.22	19.45	32.27
			X. basiri	57.14	10.64	20.40	29.39
			Dorylimids	30	5.2	9.09	14.76
			T. mashoodi	50	5.85	12.12	22.66
2.	Madhavpur		*M. incognita*	80	47.03	25.86	50.96
	pH	7.6–7.9	*H. dihystra*	75	22.64	20	39.21
	Soil Type	Sandy Loan	*R. reniformis*	62.5	3.77	16.67	27.64
	Moisture Content	18–32	*T. nudus*	37.7	7.36	15.86	20.31
			Rhabditis	12.5	6	4.25	7.68
			A. avenae	14.28	6.25	4.76	8.43
3.	Ramganga		*M. incognita*	90	40.49	34.61	55.03
	pH	7.5–7.8	*A. avenae*	20	10.4	6.06	12.15
	Soil Type	Silt	*A. costasus*	25	8.95	11.11	15.06
	Moisture Content	10–20	*H. avenae*	20	7.97	7.69	11.89
			R. reniformis	60	11.04	23.08	36.76
			X. basiri	50	25.76	19.23	16.71
			T. nudus	50	9.75	22.22	27.32
4.	Clutter Buck Ganj		*M. incognita*	100	47.62	33.34	60.32
	pH	7.4–7.8	*B. similis*	42.85	10.62	11.28	22.18
	Soil Type	Sandy Loan	*T. nudus*	62.5	17.11	19.28	32.95
	Moisture Content	18–22	*Discolaimus species*	30	2.52	11.11	14.54
			P. zeae	57.14	17.46	19.14	31.25
			X. basiri	37.5	7.89	11.54	18.98
			A. costasus	10	13.39	4.35	9.25
5.	Quilla		*M. incognita*	80	47.03	25.86	50.96
	pH	7.2–7.5	*T. mashoodi*	28.57	4.26	10.2	14.34
	Soil Type	Silt	*T. nudus*	40	8.22	13.33	20.52
	Moisture Content	10–15	*H. indicus*	57.14	12.77	20.4	30.1
			R. reniformis	62.5	23.33	2.73	36.19
			H. avenae	75	7.55	20	34.18
6.	Bankhana		*M. incognita*	100	42.47	33.32	58.6

	pH	7.4–7.5	*X. basiri*	100	25.55	33.33	51.29
	Soil Type	Loan	*H. dihystra*	57.14	12.77	20.4	30.1
	Moisture Content	12–18	*H. indicus*	50	9.75	22.22	27.32
			Tylenchus species	10	6.13	3.84	6.66
			T. mashoodi	12.5	12.19	5.56	43.11
			A. costasus	20	9.6	8.34	12.65
			T. nudus	10	8.23	5.56	7.93
7.	Izzatnagar		*M.incognita*	80	12.5	22.22	38.24
	pH	7.5–7.7	*A.costasus*	60	26.87	16.67	34.51
	Soil Type	Loam	*P.zeae*	75	9.35	18.18	34.51
	Moisture Content	10–22	*Discolaimus* species	50	8.77	12.12	23.63
			Dorylimids	40	7.5	11.11	19.54
			R. reniformis	20	3.75	5.56	9.77
			H. avenae	37.5	12.24	11.54	20.43
			H. indicus	42.8	12.5	14.27	23.19
			T. nudus	20	7.97	7.69	11.89
8.	Champatrai Bagh		*M. incognita*	100	48.3	30.77	59.69
	pH	7.4	*P. zeae*	75	8.16	23.08	35.41
	Soil type	Sandy loam	*A. costasus*	25	4.08	7.69	12.26
	Moisture content	15–21	*A. avenae*	14.28	6.25	4.76	8.43
			B. similis	25	4.08	7.69	12.26
			X. basiri	60	12.24	15.38	25.87
9.	Chaudhri Talab		*M. incognita*	100	60.97	44.44	68.47
	pH	7.5	*R. reniformis*	80	56.8	33.33	43.11
	Soil type	Sandy loam	*X. basiri*	60	17.6	25	34.2
	Moisture content	12	*A. avenae*	12.5	12.19	5.56	10.08
			H. avenae	20	3.75	5.56	9.77
			H. indicus	10	8.23	5.56	7.93
10.	Saidpur		*M. incognita*	80	56.8	33.33	56.71
	pH	7.3	*X. basiri*	70	19.08	21.21	36.76
	Soil type	Sandy loam	*H. avenae*	34.51	14.98	1.54	21.34
	Moisture content	8–15	*H. indicus*	14.28	6.25	4.76	8.43
			H. dihystra	20	7.97	7.69	11.89
11.	Nakatiya		*M. incognita*	100	34.38	38.46	57.61
	pH	7.5	*A. avenae*	83.33	63.45	33.33	60.04
	Soil type	Silt	*X. basiri*	75	28.57	26.08	43.22
	Moisture content	10–15	*T. nudus*	50	8.27	20	26.09
			Tylenchus species	16.67	6.9	6.67	10.08
			R. reniformis	50	1071	17.39	26.03

			Discolaimus species	30	6.02	14.29	16.77
			Dorylimids	85.7	25.64	30.23	47.19
12.	Nariawal		*M. incognita*	100	42.47	33.33	58.6
	pH	7.5	*X. basiri*	100	52.08	33.34	61.81
	Soil type	Sandy loam	*Dorylimids*	20	6.49	6.45	10.98
	Moisture content	10–15	*R. reniformis*	20	10.81	6.45	12.42
			H. dihystra	75	8.16	23.08	35.41
			H. indicus	60	6.34	18.18	28.17
			A. costasus	25	4.08	7.69	12.26
13.	Theriya		*M. incognita*	100	52.71	33.33	62.01
	pH	7.5	*P. zeae*	12.5	6	4.25	7.68
	Soil type	Sandy loam	*X. basiri*	62.5	19.64	26.29	36.14
	Moisture content	12–18	*Rhabditis* species	100	59.58	35.71	65.09
			Dorylimids	40	9.58	13.34	20.97
			R. reniformis	20	19.18	6.67	15.28
14.	Mohanpur		*M. incognita*	100	60.97	44.44	68.47
	pH	7.4	*H. dihystra*	80	56.8	33.33	56.71
	Soil type	Sandy loam	*Rhabditis*	90	40.49	34.61	55.03
	Moisture content	12–20	*Dorylimids*	90	46.24	27.28	54.51
			Discolaimus	10	6.13	3.84	6.66
			X. basiri	12.5	12.13	5.56	10.08
15.	Bithri chainpur		*M. incognita*	90	40.49	34.61	55.03
	pH	7.5	*H. avenae*	40	7.5	11.11	19.54
	Soil type	Sandy loam	*H. dihystra*	20	3.75	5.56	9.77
	Moisture content	15–25	*X. basiri*	60	18.11	26.09	33.28
			Dorylimids	100	43.75	27.77	57.17
			R. reniformis	10	3.15	4.35	5.83
			Rhabditis	20	3.75	5.56	9.77
16.	Udla Jageer		*M. incognita*	80	18.89	10	32.96
	pH	7.3	*T. nudus*	62.5	17.65	21.81	11.65
	Soil type	Sandy loam	*T. mashoodi*	50	12	18.18	26.73
	Moisture content	20–30	*Tylenchus* species	62.5	19.64	26.29	36.14
			H. indicus	12.5	6	4.25	7.68
			H. dihystra	37.7	7.36	15.86	20.31
			A. costasus	28.57	4.26	10.2	14.34
			X. basiri	87.5	50.58	33.33	57.14
17.	Padarathpur		*M. incognita*	100	48.3	30.77	59.69
	pH	7.2	*H. avenae*	42.8	12.5	14.27	23.19
	Soil type	Loam	*H. indicus*	70	19.08	21.21	36.76
	Moisture content	10–22	*H. dihystra*	50	25.76	19.23	31,66
			P. zeae	10	6.13	3.84	6.66
			R. reniformis	25	8.94	11.11	15.02

18.	Pilibhit by pass		*M. incognita*	100	52.08	33.34	61.81
	pH	7.5	*R. reniformis*	100	60.97	44.44	68.47
	Soil type	Sandy loam	*H. indicus*	25	8.94	11.11	15.02
	Moisture content	22–30	*T. nudus*	20	9.6	5.34	12.65
			H. dihystra	80	16	33.33	43.11
19.	Fatehgunj (west)		*M. incognita*	70	48.03	30.43	50.49
	pH	7.6	*X. basiri*	60	18.11	26.09	33.28
	Soil type	Sandy loam	*A. costasus*	40	8.4	14.82	21.07
	Moisture content	18–32	*T. nudus*	30	11.76	16.66	19.47
			Discolaimus	30	7.56	11.11	16.22
			P. zeae	10	5.88	5.56	7.15
			R. reniformis	100	23.03	30.77	51.27
20.	Bareilly college campus		*M. incognita*	100	48.2	28.58	58.93
	pH	7.5	*X. basiri*	90	58.82	50	66.27
	Soil type	Sandy loam	*Rhabditis*	57.14	17.46	19.44	31.25
	Moisture content	18–36	*Dorylimids*	42.85	10.32	11.28	22.38
			R. reniformis	100	50	30.77	60.26
			H. indicus	62.5	17.11	19.23	32.95
			H. dihystra	37.5	7.89	11.54	18.98
			T. nudus	25	1.97	7.69	11.55
			H. avenae	40	8.77	22.22	23.66

species like *javanica*, *acrita*, *arenaria* or *hapla*. Whereas *Helicotylenchus indicus*, *H.dihystra*, *Tylenchorhynchus mashoodi*, *T. nudus*, *Aphelenchus avenae* and *A. costasus* each were observed with two species *Rotylenchulus reniformis* had also been screened from most of the samples with low frequency whereas; *B. similis* was present only in two localities (Table 1 and Figure 1).

Population Dynamics

Overall screening of 352 soil samples revealed the presence of 16 species or genera of plant parasitic nematodes. Relative abundance (RA) of *M. incognita* was highest (92.5%) in all the 20 localities which were followed by dagger nematode, *Xiphinema basiri* (49.10%). Other nematodes percentage were *R. reniformis* (38.25%), *H. dihystra* (29.21%), *H. indicus* (25.08%), *Dorylimids* (22.42%), *T. nudus* (18.26%), *H. avenae* (15.64%), *Rhabdities* (13.98%), *P. zeae* (11.98%), *A. costasus* (11.67%), while, *Tylenchus spp*., *Discolaimus spp*., *T. mashoodi* and *A. avenae* were only 4.45 to 7.21% (Tables 1 & 3 & Figure 2). Relative density (RD) of *M. incognita* was highest (44.67%) and lowest (0.72%) was of *B. similis*. Whereas (5.44 to 18.84%) density was found of *T. nudus*, *H. indicus*, *Rhabdities, Dorylimids*, *R. reniformis* and *X. basiri*. (1.55 to 4.92%) the density of *Discolaimus spp., Tylenchus spp., T. mashoodi, P. zeae*, *A. costasus*, *H. avenae* and *A. avenae* were observed (Tables 1 and 3 & Figure 2).

The highest relative frequency (RF) of *Meloidogyne* (31.44%) was followed by *X. basiri* (18.64%), *R. reniformis* (12.63%) and *H. dihystra* (10.10%). Although these species were almost omnipresent (6.82%) *Dorylimids,* (7.01%) *T.nudus* and (8.47%) *H. indicus* frequencies were observed. Almost equal frequency had been noticed for *A. costasus* (4.04%). *H. avenae* (4.69%), *Rhabdities* (4.97%). The relative frequency of *Tylenchus spp. T. mashoodi*, *Discolaimus spp*. and *P. zeae* were found to be (1.84–3.70%) whereas lowest was (0.94%) of *B. similis* (Tables 1 and 3 & Figure 2).

Rate of Infection

Rate of infection was highest 56.20% in case of *M. incognita* in all the crops studied. *R. reniformis* and *X. basiri* were also present in most of the samples but the rate of infection was 28.86 and 22.08% respectively. All the varieties of carrot, Desi or Vilaytee grown in fields of Bareilly studied, South East and South North regions were found to be highly susceptible to *M. incognita* followed by *Xiphinema basiri* and *Helicotylenchus dihystra* as rate of infection of these nematodes were found much higher in these fields. Interestingly, when carrots were sown under mixed cropping systems in a few fields' number, galls were found more on other vegetables adjacent to carrot. This is also borne out during the survey that although onion was grown in this region in very small scale but, *Meloidogyne* appears to be host specific in onion fields with higher rate of infection specially in Eastern region. In fields which have been geographically contiguous, the rate of infection was found comparatively much higher. The infection caused by *T.nudus, Dorylimids*, *H.indicus* and *H. dihystra* ranged between 10.23 to 16.06%. 6.10 to 8.43% infection rate was observed due to

P. zeae, A. costasus, H. avenae and *Rhabdities* while, only 2.64 to 3.89% infection was observed due to *Tylenchus spp. Discolaimus and T. mashoodi*. The occurrence of *B. similis* was minimal i.e. with 1.68% rate of infection only (Table 1 & Figure 1).

Seasonal Variation

Highest increase in population of plant parasitic nematode was in December (13,620) followed by October (12,478) and January (11,970) in 250 gms soil each during the course of survey (2020-21) in Nakatiya area, which is situated South East in Bareilly District, whereas lowest population of only 965 were observed in the month of May in this area (Table 2 & Figure 3).

Further the bulk of the population was confined to the root zone area (0–30 cm) following a fallow field, a rapid decline in population occurred and in extreme cases the population was reduced to 1/23. In the presence of suitable host crops more larvae were encountered than females in the samples studied. In the remaining months the population of nematodes fluctuates from one thousand to more than four thousand except October (Table 2). The highest (21.4%) nematode occurred in screening of the soil samples in the month of December but in May it was found to be only (1.5%) whereas, (5.6–19.6%) were found during other months of the year (Figure 3). The population increases, with the rise in temperature from 12 to 18°C and at (18–25%) moisture level while at the temperature of 34 to 40°C perhaps they go deep or do not survive (Table 2).

These observations also indicate that plant parasitic nematodes have the widest range of occurrence in all the types of tubers, bulbous, root and cole crops with ubiquitous presence throughout the region due to the moderate type of climate and suitable host range.

Based on Growers' Information of Crop Loss Data

During the survey period (2020-21) of fields in and around Bareilly region important pests other than nematodes and diseases of growing crop mainly onion, carrot, cauliflower, cabbage, radish, and potato were identified. The most important pest which cause a drastic loss in Nakatiya area were cabbage or cauliflower root fly (*Delia radicum*), onion neck rot (*Botrytis alii*) and carrot rust fly (*Psila rosae*). The growers employ cultural plant protection methods such as placement and timing of crops, crop selection and field sanitation extensively while, and direct control methods are rarely applied.

Huang *et al.*, [29] and Que *et al.*, [30] reported susceptibility and association of Meloidogyne spp. to carrot. The present result is also supported by Boiteux *et al.*, [31] and Seo *et al.*, [32]. However, Escobar-Avila *et al.*, [33] reported carrot is seriously affected by *Heterodera carotae* in temperate regions. Nagesh and Reddy *et al.* [34] reported *M. incognita* on carrot, besides galling, some other typical symptoms such as forking of tap roots and cracking of roots have also been observed by them. Such symptoms on the root of carrot were also reported by Ali *et al.*, [35] due to root knot nematode. Similar observations had been noticed during survey as well as by inoculation experiment also in the present study.

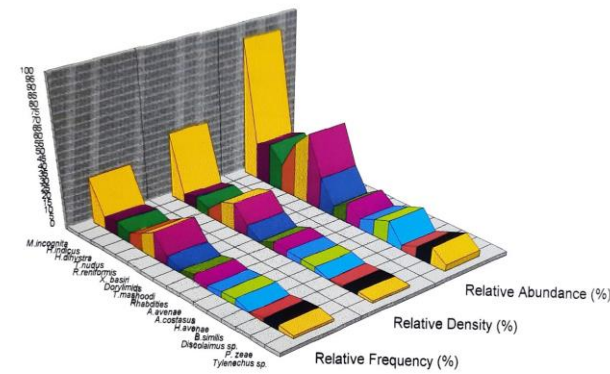

Figure 2: Average nematode population dynamics in total localities studies

Širca *et al.*, [36] observed that *M. arenaria* and *M. incognita* producing small galls on onion roots with reduced root system in field conditions. In the present study too, incidence of root knot nematode, *M. incognita* is observed to produce the same symptoms in onion in various fields of Bareilly region. These reports are also in accordance with those of Quebbeman, [37], Wilson [38] and Rotenber *et al.*, [39]. Some other workers like Yavuzaslanoğlu *et al.*, [40] had reported stem nematode, *Ditylenchus dipsaci, is a* serious pest of onion in many Western countries.

Highest frequency of occurrence of Meloidogyne (92.5%) had been encountered here in total 352 soil samples studied. It was almost parallel with the results of Ladner *et al.*, [41] and Singh et al., [50] who reported (92.33%) occurrence of Meloidogyne in tomato, brinjal and okra. Singh [42] and Janati *et al.*, [21] reported (82.16%) Meloidogyne during the survey of various cucurbetacious plants in Bareilly region. Prior to this, root knot nematodes had been reported by several other workers like Khan and Khan [43] and Wang *et al.*, [44] from this region. The results of present study obtained exhibit a correlation between population build up and host damage. Which further confirms the results of Nelson [45]; Bucki *et al.*, [46] and Chowdhury *et al.*, [47]. Highest increase in the population of nematodes occurred at 18 to 30°C and at (25%-30%) moisture level and pH 7.2 to 7.5 [48-49].

CONCLUSION

In conclusion, our research on nematode fauna dynamics and infection rates on tuber, root, bulbous, and cole crops in Bareilly District, UP, India has provided valuable insights into the prevalence and impact of nematode infestations in agricultural settings. Firstly, we observed that nematode species diversity was relatively high across the studied crops, indicating the presence of a diverse range of nematode species in the region. This finding underscores the need for effective management strategies to control and mitigate nematode infections in these crops. Secondly, our analysis of infection rates revealed that nematode infestations were prevalent in the majority of crops, with root and tuber crops being the most heavily affected. These findings highlight the vulnerability of

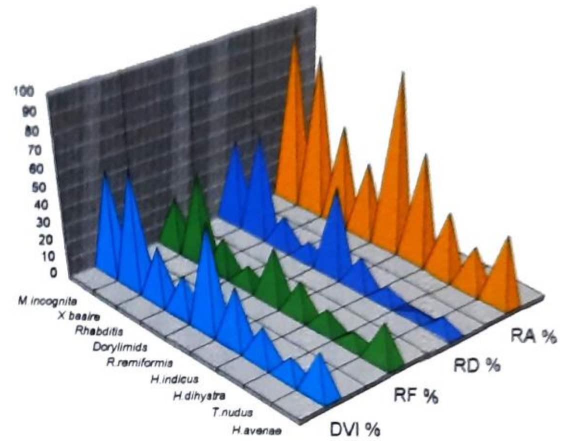

Figure 3: Percent occurrence of Nematode genera in most infected field (nakatiya)

Table 2: Fluctuations in the population of Nematode genera studied during 2022-21 from nakatiya, the highly infected area of Bareilly

Months	*pH*	*Moisture content*	*Temp. of soil °C*	*Population/ 250 gm of soil*
February	7.4-7.5	12-18	17-18	4,950
March	7.2.7.3	12-17	24-26	3,580
April	7.4-7.5	15-19	25-27	2,670
May	7.5	20-24	34-40	965
June	7.3-7.4	20-25	32-38	1,080
July	7.2-7.5	22-35	31-34	1,175
August	7.2	20-36	32-34	1,485
September	7.2	20-28	30-32	2,775
October	7.4	18-25	24-28	6,780
November	7.4-7.5	16-25	23-24	12,478
December	7.2-7.4	16-20	12-18	13,620
January	7.2-7.5	18-20	10-12	11,970

Table 3: Average nematode population dynamics in total localities studied (means ± SEM. $p < 0.05$)

Nematodes	*RA%*	*RD%*	*RF%*	*Minimum value*	*Maximum Value*	*Average %*	*Means ± S.D.*	*C.C.*	*R. Squared*
M. incognita	92.5	44.67	31.44	31.44	92.5	56.2	44.67±26.227	-0.9504	0.9333
H. indicus	25.08	5.75	8.47	5.75	25.08	13.1	8.47±8.543	-0.7936	0.6299
H. dihystra	29.21	8.89	10.1	8.89	29.21	16.06	10.1±9.306	-0.8382	0.7026
T. nudus	18.26	5.44	7.01	5.44	18.26	10.23	7.01±5.709	-0.8044	0.6170
R. reniformis	38.25	15.38	12.63	12.63	38.25	22.08	15.38±11.484	-0.9107	0.8294
X. basiri	49.1	18.84	18.67	18.64	49.01	28.86	18.84±14.312	-0.8688	0.7549
Dorylimids	22.42	7.73	6.82	6.82	22.42	12.32	7.73±7.149	-0.8908	0.7935
T. mashoodi	7.05	1.71	2.3	1.71	7.05	3.68	2.3±2.390	-0.8112	0.6581
Rhabditis	13.98	6.36	4.97	4.97	13.98	8.43	6.36±3.960	-0.9287	0.8625
A avenae	7.21	4.92	2.72	2.72	7.21	4.95	4.92±1.833	-0.9999	0.9998
A costasus	11.67	3.96	4.04	3.98	11.67	6.56	4.04±3.611	-0.8626	0.7441
H. avenae	15.64	3.76	4.69	3.76	15.64	8.03	4.69±5.394	-0.8226	0.6867
B. similis	3.39	0.72	0.94	0.72	3.39	1.68	0.94±1.210	-0.7692	0.6831
Discolaimus species	7.5	1.55	2.62	1.55	7.5	3.89	2.62±2.589	-0.8095	0.5917
P. zeae	11.98	2.64	3.7	2.64	11.98	6.1	3.7±4.175	-0.9297	0.6553
Tylenchus species	4.45	1.63	1.84	1.63	4.45	2.64	1.84±1.282	-0.8306	0.690

these crops to nematode attacks and the potential risks they pose to agricultural productivity in the region. Furthermore, our research demonstrated the significant negative impact of nematode infestations on crop yield and quality. We observed reduced crop growth, stunted plant development, and decreased tuber and bulb size in infested crops compared to their non-infested counterparts. These findings emphasise the importance of identifying and implementing effective nematode control measures to mitigate these losses and ensure better crop productivity. Additionally, our study identified certain nematode species, such as Meloidogyne spp., as major contributors to crop infestations. Understanding the prevalence and biology of specific nematode species is crucial for developing targeted and effective management strategies to combat their impact on crop health. In conclusion, our research underscores the urgent need for integrated pest management strategies that can effectively mitigate nematode infestations in tuber, root, bulbous, and cole crops in Bareilly District, UP, India. Implementing measures like crop rotation, soil sanitation, biological control agents, and resistant cultivars can play a vital role in reducing the incidence and severity of nematode infections. These findings will serve as a helpful resource for farmers, agricultural extension agencies, and researchers in devising sustainable and effective solutions to tackle nematode-related challenges in the region's agriculture.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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AUTHORS' CONTRIBUTIONS

1-BT (Performed experiments, writing draft, Research article and edit) 2- MH (Performed experiments, writing draft, Research article and edit). We confirm that the manuscript has been read and approved for submission by all the authors The manuscript does not report on or involve the use of any animal or human data or tissue.

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