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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

**BIOTA OF PHYTOHELMINTHS (NEMATODA)
OF WHEAT PLANT ON THE MUGAN PLAIN OF
AZERBAIJAN**

Specialty: 2429.01 – Parasitology

Field of science: Biology

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INTRODUCTION

Relevance of the topic and degree of development. Phytohelminthology is an important area in agricultural science that studies plant-parasitic nematodes that have a significant impact on the health and productivity of agricultural crops. Nematodes, especially phyto-parasitic species, are among the most dangerous biotic factors that reduce crop yields and product quality, causing serious economic losses in crop production. Wheat (*Triticum*), being a strategically important food crop, is especially sensitive to damage to the root system and vegetative organs by various types of nematodes.

The Mugan Plain, as one of the key agricultural regions of Azerbaijan, has favorable soil and climatic conditions for intensive farming, including wheat cultivation. However, the same conditions also contribute to the active spread of nematodes, which increases the relevance of their study in this region. Particular attention is paid to the distribution of trophic groups (mycotrophs, bacteriotrophs, phytoparasites, etc.), the interaction of nematodes with the detrital food web and the assessment of the degree of their harmfulness to agriculture. The relevance of the work is due to the need for a scientific justification for phytosanitary and agrotechnical measures to control the number of nematodes, as well as the need to replenish regional scientific data on the composition and biology of wheat phytohelminths in the conditions of Southern Azerbaijan. Thus, the topic of the dissertation has both theoretical and applied significance for the sustainable development of agriculture in the region.

Phytoparasitic nematodes are one of the most dangerous biotic factors that negatively affect the yield and quality of agricultural crops, in particular wheat (*Triticum*). Their widespread distribution and ability to cause significant economic losses make the problem particularly relevant. The Mugan Plain is one of the most important agricultural regions of Azerbaijan, with favorable soil and climatic conditions for wheat cultivation. However, these same conditions are also favorable for the development of phytohelminths. In this regard, there is an increasing need to study the species composition, biology, trophic groups and epiphytotic potential of nematodes in this zone, which makes the research topic relevant from both a scientific and

practical point of view.

Object and subject of research. Phytohelminths parasitizing on wheat grown in the conditions of the Mugan Plain of Azerbaijan are the object of the research. Systematic structure, bioecological features, trophic groups, distribution and quarantine significance of phytoparasitic nematodes affecting wheat crops are the subject of the work.

Purpose and objectives of the research. The purpose of the research is a comprehensive study of phytohelminths of wheat grown on the Mugan Plain, their systematics, ecology, trophic affiliation and economic significance.

Main objectives:

- to determine the taxonomic composition of phytohelminths in the study region;
- to study the morphological and biological characteristics of dominant species;
- to classify nematodes by trophic groups;
- to identify the relationship between soil and climatic conditions and species diversity;
- to determine quarantine-significant species and propose control and prevention measures.

Research methods. Research conducted in the main wheat-growing regions of the Mugan Plain - in the Sabirabad, Saatli, Imishli districts in 2017-2024. They include field, laboratory and analytical work based on multidisciplinary methods. 3 standard methods were used to identify nematodes:

1. The Baerman method (funnel method)
2. The method of washing soil through sieves
3. The method of centrifugation in a saturated solution of $MgSO_4 \cdot 7H_2O$

Fixed nematodes identified to species level using light microscopy (LEICA 1000). Photographs of nematode species reflecting the morphological structure are provided.

The main provisions presented for defense:

1. The composition of wheat phytohelminths in the Mugan Plain is represented by 36 species.

2. The number and composition of nematode communities depend on the type of soil, fertile soils are characterized by high biodiversity, while saline, and degraded soils have low rates.

3. Bacteriophages dominate in the agrocenoses of the Mugan Plain, the proportion of predatory and omnivorous forms does not exceed 5%, which reduces the stability of ecosystems

4. Zonal and seasonal dynamics of phytonematodes were characterized and their impact on wheat yields was established depending on agricultural practices.

Scientific novelty of the study. For the first time on the Mugan Plain, a comprehensive analysis of the phytohelminth fauna of wheat was carried out taking into account various agrocenoses and seasonal dynamics of nematodes. Trophic groups were determined – endoparasites, migrating endoparasites, phyto-mycophages and free-living saprophytes - which allows us to characterize the structure of nematode communities in the region.

New nematode species, including Heterodera, Pratylenchus and Ditylenchus, have been identified for the region for the first time, patterns of their distribution have been established depending on soil type, humidity, salinity and agricultural practices. These data make it possible to predict the phytosanitary condition of crops and develop effective plant protection measures.

The results of the study enrich the scientific base of Azerbaijan on agrohelminthology and create a basis for further research of the biota of agricultural crops.

Theoretical and practical value of the work. The results of the study deepen scientific understanding of the composition and biology of phytohelminths, expand knowledge of the ecological and trophic classification of nematodes, and contribute to the formation of a scientific basis for phytosanitary and agroecological research.

The obtained data can be used in the development of biomonitoring systems, assessment of the phytosanitary condition of wheat crops, as well as in the implementation of effective agrotechnical and biological methods of combating harmful nematodes.

Approbation and application of the dissertation. The main provisions of the dissertation work were heard and discussed at the

meetings of the Parasitology laboratory of the Institute of Zoology of the Ministry of Science and Education of the Republic of Azerbaijan, annual reporting sessions of the Scientific Council of the Institute, as well as at the scientific seminar of the Institute. In addition, the results of the study were presented and discussed at the following national and international scientific and practical conferences:

Conference of young scientists and students. "Innovation in biology and agriculture to solve global challenges" (Baku, 2018)

XXI International Scientific Conference "Biological Diversity of the Caucasus and Southern Russia" (Magas, 2019)

XII International Scientific and Practical Conference "Biodiversity and Rational Use of Natural Resources" (Makhachkala, 2024)

"Disruptions in the functioning of ecosystems due to global climate change and ways to eliminate them" (Baku, 2024)

The conference is dedicated to the 102nd anniversary of the birth of the National Leader Heydar Aliyev. International Scientific Conference on Global Challenges in Natural and Social Sciences (Ganja, 2025)

"MacroFrontiers 2025: 3rd International Conference on Macromolecular Compounds" (Baku, 2025)

Based on the research materials, 7 scientific articles (4 abroad), 5 conference materials (2 abroad) and 3 theses (1 abroad) reflecting the main content of the dissertation were published.

Names of institutions where the dissertation work was carried out. The research work was carried out in the Parasitology laboratory of the Institute of Zoology of the Ministry of Science and Education of the Republic of Azerbaijan. Molecular analyses, part of the identification of phytohelminth species are carried out at the Institute of Zoology of the Russian Academy of Sciences (St. Petersburg).

The structure and volume of the dissertation. The dissertation work (in the volume of 205710 characters) consists of an Introduction (7372 characters), Chapter I (11041), Chapter II (27253), Chapter III (7867), Chapter IV (10528), Chapter V (19500), Chapter VI (12685), Chapter VII (17360), Chapter VIII (17148), Chapter IX (25319), Chapter X (21134), Chapter XI (18869), Practical recommendations

(1285), Conclusion (5054), Findings (3295), 24 figures, 8 graphs, 17 tables and 197 lists of literature, including Azerbaijani, Russian and other foreign languages.

CHAPTER I LITERATURE REVIEW

The first chapter provides an analysis of the current state of research on phytohelminths of agricultural crops. It is noted that phyto-parasitic nematodes are the third most important group of plant pathogens after fungi and bacteria. In world literature, the main emphasis is placed on the genera *Heterodera*, *Pratylenchus*, *Meloidogyne*, *Ditylenchus* and *Anguina*.^{1,2,3}

The issues of classification of phytohelminths, their morphology, pathogenesis, methods of penetration into plant tissues and development cycles are considered in detail. Particular attention is paid to the mechanism of formation of cysts in *Heterodera* and galls in *Meloidogyne*. It is indicated that most economically significant nematodes are characterized by high adaptability, multi-host nature and resistance to unfavorable conditions.⁴

The analysis shows that for most regions of the Transcaucasus, the tasks of local study of fauna, clarification of species composition and development of phytosanitary measures that take into account regional specifics remain relevant.

CHAPTER II PHYTOHELMINTHOLOGICAL RESEARCH IN AZERBAIJAN AND ADJACENT REGIONS

The chapter is devoted to the historical and current state of phytohelminth research in Azerbaijan, as well as in neighboring

¹ Decker, H. Plant-parasitic nematodes of cereals // *Nematology Reviews*, - 1989. - vol. 2. - p. 45–67.

² Dababat, A.A. Prevalence of *Heterodera filipjevi* in Turkey and screening for resistant wheat genotypes // *Phytoparasitica*, - 2014. - vol. 42. № 5, - p. 641–649.

³ Nicol, J.M. et al. Biology of *Heterodera avenae* // *Nematology*, - 2007. - vol. 9. № 5, - p. 645–656.

⁴ Evans, K., Perry, R.N. Traditional methods for nematode diagnosis // *Nematology*, - 2001. - vol. 3, № 1, - p. 1–12.

countries – Iran, Turkey, Georgia, Russia and Uzbekistan. It is shown that in Azerbaijan, the approach focused on morphological diagnostics and control of individual quarantine species *Anguina tritici*, *Heterodera avenae* was previously dominant.⁵

It is noted that the work of recent years (2020–2023) has significantly expanded the understanding of the biodiversity of phytone-matodes. For the first time, species such as *Heterodera mothi* and *Pratylenchus thornei* recorded. In neighboring Iran, molecular methods are actively used, which has led to a refinement of the taxonomy of Meloidogyne and Heterodera.

CHAPTER III

SOIL AND CLIMATIC FEATURES OF THE MUGAN PLAIN

This chapter provides characteristics of the agroecological research environment. The Mugan Plain is located in the southeastern part of Azerbaijan and is characterized by an arid climate with moderately hot summers and short, mild winters. The average annual temperature is +14.4°C, the annual precipitation is 250–300 mm, which, with intensive irrigation, creates favorable conditions for the development of nematodes.

The soil cover is represented by serozems, meadow-serozem and alluvial soils. In irrigated fields, a decrease in humus, compaction of the upper horizon, and deterioration of the structure are observed, which contributes to the accumulation of nematodes.

Particular attention is paid to degraded areas and zones of wheat monoculture - this is where the most active foci of root damage by phytohelminths are observed.

CHAPTER IV

MATERIAL AND METHODOLOGY

The material used is the long-term collections of the dissertation candidate from 2017 to 2024 in order to study the phytone-matode

⁵ Huseynova, G.T. Regional phytohelminthological studies on wheat in Azerbaijan and Neighboring countries: // - Ankara: Munis Entomology & Zoology, - 2025. - vol. 20. - p. 3808-3813

complexes of agrocenoses. During this time, planned sampling of soil and plant material was carried out in the southeastern part of the Mugan Plain, covering the areas of Imishli, Sabirabad, Saatli and partially Gadzhigabul. A total of 440 samples were collected during this period. The distribution of samples by year is presented as follows: in 2017-2019, 45 and 55 samples were collected, respectively, in 2020 - 73 samples, in 2021 - 85 samples, in 2022 - 73 samples, in 2023 - 67 samples and in 2024 - 42 samples.

In order to comprehensively assess the state of the soil ecosystem, the level of fertility, and to identify signs of degradation and erosion, the present study used the method of functional analysis of nematode communities developed by Ferris H., Bongers T., Goede R.G.M. This approach is based on the classification of nematodes by trophic groups and a stress resistance scale (colonization-persistence scale - c-p scale), with subsequent calculation of indices reflecting the structure and functioning of the soil food net.⁶

Sampling and sample preparation. Soil samples were collected from a depth of 0–20 cm using the five-replication method, followed by combining into a mixed sample weighing 500 g. Nematodes were isolated from each sample using the standard Berman funnel method. Sampling was carried out in compliance with the coordinate reference and agroecological characteristics of the sites.

Nematodes were identified under a microscope to the genus or functional group and classified according to trophic specialization and c-p value, which made it possible to compile a table of their quantitative distribution by functional groups.⁷

Calculation of functional indices. According to the Ferris H, Bongers T. methods, the following indices calculated based on the data

⁶ Ferris, H., Bongers, T., de Goede, R.G.M. A framework for soil food web diagnostics: Extension of the nematode faunal analysis concept // *Applied Soil Ecology*, - 2001. - vol. 18. № 1, - p. 13–29

⁷ Bongers, T. The maturity index: An ecological measure of environmental disturbance based on nematode species composition // *Oecologia*, - 1990. - vol. 83. № 1, - p. 14–19.

on the number of individuals in each functional group:^{8,9}

1. Enrichment Index (*EI*): reflects the community's response to available resources.

Calculated using the formula:

$$EI = 100 \times \frac{e}{e+b} \quad (1)$$

where *e* are enrichment groups (for example, bacteria-eating c-p 1), *b* are basal groups (bacteriophages and fungivores c-p 2)

2. Structure Index, *SI*. Characterizes the degree of development of trophic links and the maturity of the community:

$$SI = 100 \times \frac{s}{s+b} \quad (2)$$

where *s* are forms sensitive to disturbances (phytophages c-p 4–5, predators and omnivores c-p 4–5).

3. Basal Index, *BI*. Shows the degree of degradation and stress load on the soil:

$$BI = 100 \times \frac{b}{b+s+e} \quad (3)$$

The results of the index calculations are interpreted in the context of the state of the soil ecosystem:

High *SI* and moderate *EI* values indicate a stable, slightly disturbed ecosystem.

High *EI* with low *SI* indicates the supply of fresh organic matter and possible agronomic intervention (e.g. manure, compost).

High *BI* and low *SI* are typical of degraded, eroded or anthropogenically disturbed soils.

Molecular and phylogenetic studies. DNA was extracted from the second larval stage (J2) using proteinase K according to the method of Tanha Maafi. Primers for amplification were ITS-rRNA (TW81/AB28)

⁸ Ferris, H., Bongers, T., de Goede, R.G.M. A framework for soil food web diagnostics: Extension of the nematode faunal analysis concept // Applied Soil Ecology, - 2001. - vol. 18. № 1, - p. 13–29.

⁹ Bongers, T. The maturity index: An ecological measure of environmental disturbance based on nematode species composition // Oecologia, - 1990. - vol. 83. № 1, - p. 14–19.

and mitochondrial COI gene (Het-coxiF/Het-coxiR).^{10,11}

Sequencing was performed in the Quintara Biosciences laboratory (USA), new sequences are deposited in GenBank (MH144206–MH144209).

CHAPTER V SYSTEMATIC REVIEW OF WHEAT NEMATODE FAUNA IN THE MUGAN PLAIN OF AZERBAIJAN

Based on comprehensive surveys of agrocenoses of the Mugan Plain of Azerbaijan, where wheat (*Triticum*) is the leading agricultural crop, a high level of taxonomic and trophic diversity of the rhizosphere nematode fauna was established. A total of 36 species were identified, belonging to 20 genera and 13 families from two classes - Secernentea and Adenophorea. The dominant ones are representatives of the genera Panagrolaimus, Cephalobus, Pratylenchus and Aphelenchoides, which reflects a combination of both saprophytic and phytoparasitic forms.

5.1. Trophic groups of nematodes. Nematodes associated with the detrital food web: mycotrophic nematodes, bacteriotrophic nematodes. Mixed-trophic nematodes (phytomycophages)

Nematodes divided into five trophic groups: bacteriotrophic, mycotrophic, phytoparasitic, phyto-mycophagous and omnivorous. Phytopathogenic species causing root suppression and reduced yields are important, including the quarantine *Ditylenchus dipsaci* and *Heterodera avenae*. Their mouthparts reflect trophic adaptations, and phyto-mycophages participate in the transfer of microorganisms and stimulation of plant immunity.

5.2. Nematodes of phytopathogenic significance: ectoparasitic root nematodes, endoparasitic migratory nematodes and isedentary root nematodes

¹⁰ Tanha Maafi Z., Subbotin, S.A., Moens, M. Molecular identification of cyst-forming nematodes (*Heterodera* spp.) from Iran using RFLP of ITS-rDNA // *Nematology*, - 2003. - vol. 5. № 1, - p. 99–108.

¹¹ Subbotin, S.A. Molecular identification of cyst-forming nematodes (*Heterodera* spp.) using mitochondrial COI gene // *Nematology*, - 2015. - vol. 17. № 5, - p. 545–554.

Under the influence of mixed-trophic nematodes and their associated microbes, signaling pathways are activated, the synthesis of protective proteins increases, and the immune response of the root system is enhanced. Thus, mixed-trophic nematodes play an important role in the formation of a balanced, biologically stable rhizosphere environment.

The obtained data confirm that nematode communities of wheat agroecosystems of the Mugan Plain represent a complex dynamic system, including both regulators of biogeochemical processes and dangerous pathogens. The results can be used to develop measures of biomonitoring and phytosanitary control at the level of agrolandscapes.

CHAPTER VI

CHAPTER VI INDICATION OF SOIL FERTILITY AND EROSION USING NEMATODE COMMUNITY PARAMETERS

This chapter presents the results of a study aimed at assessing the ecological state of soils in the Mugan Plain of Azerbaijan based on the structure and functional characteristics of free-living nematode communities.

Field and laboratory studies were carried out in 2021–2023 at 12 stationary sites in the Saatli, Sabirabad and Imishli districts, covering various soil types (meadow-s, alluvial meadow, gley-serozems). Based on the selection and analysis of soil samples from a depth of 0–40 cm, the taxonomic composition and number of nematodes, distribution by trophic groups were studied, and the maturity indices (MI), enrichment (EI) and structural index (SI) were calculated using the Ferris G. method. In addition, the physicochemical parameters of the soil (humus, pH, density, moisture, etc.) were determined and a correlation analysis was carried out with the nematode complex indicators.

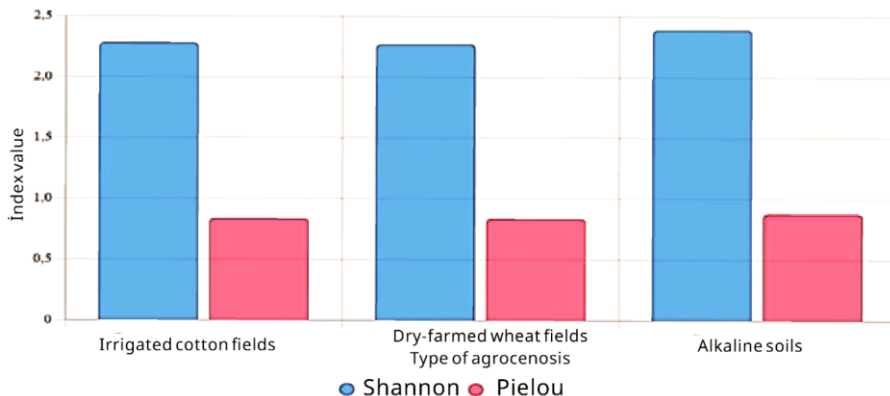
It is shown that on the fertile soils of Saatli, nematode communities are characterized by high maturity and structural complexity: MI – 3.2, SI – 65, EI – 42, with a predominance of K-strategists and bacteriophages. On the alluvial-meadow soils of Sabirabad, moderate signs of degradation were recorded (MI – 2.7, SI – 54), while on the saline and compacted soils of Imishli, a sharp depletion of the community and the dominance of R-strategists were observed

(MI – 1.4-1.6, SI – 21-28, EI – up to 68). Significant correlations between the indices and soil properties were established: MI is positively associated with the humus content ($r = 0.82$, $p < 0.01$), and EI is inversely associated with soil density ($r = -0.68$, $p < 0.05$) (Table 1).

Table 1
Characteristics of nematode communities and soil conditions in areas of the Mugan Plain

District	Soil type	MI maturity index	EI (enrichment)	SI (structure)	Dominant trophic group	Level of erosion/ degradation
Saatly	Meadow-gray soils	3.2	42	65	K-strategists, bacteriophages (Ba2-Ba3)	Absent (soils are stable)
Sabirabad	Alluvial-meadow	2.7	48	54	Mixed forms, moderate diversity	Light erosion, agroburden
Imishli (site 3)	Saline gley-gray soils	1.6	61	28	R-strategists, opportunists (Ba1)	Average and local erosion
Imishli (site 5)	Saline, overcompacted	1.4	68	21	Opportunists, <i>Rhabditis</i> dominance	Obvious degradation, erosion

In the wheat agrocenosis, the faunal profile showed the dominance of opportunistic forms (*Rhabditis*, *Panagrolaimus*) with a low proportion of predators and omnivores, which indicates a simplification of trophic chains and a decrease in the self-regulation of the ecosystem. On solonchaks, the greatest balance of trophic groups and taxonomic diversity was noted (Shannon $H' = 2.39$, Pielou $E = 0.88$), while in irrigated cotton agrocenoses these values are lower ($H' = 2.28$, $E = 0.84$) (Graph 1).



Graph 1. Shannon diversity indices (H') and Pielou uniformity indices (E).

Thus, it has been established that the structure of nematode communities is a sensitive indicator of soil conditions and the level of anthropogenic load. High MI and SI values can serve as markers of ecosystem stability, and the prevalence of R-strategists is an indicator of erosion and degradation. The data obtained confirm the feasibility of including nematode analysis in soil fertility monitoring and planning of nature-saving land use technologies in arid regions.

CHAPTER VII

PHYTO-MYCOPHAGES OF *APHELENCHUS AVENAE* AND *APHELENCHOIDES* SPP.

The seventh chapter of the dissertation presents the results of a comprehensive study of phyto-mycophages – a special ecological group of free-living nematodes with a double trophic potential: the ability to feed on both fungal microflora and plant tissues. The main attention in the work is paid to representatives of the genera *Aphelenchus* and *Aphelenchoides*, in particular the species *Aphelenchus avenae*, *Aphelenchoides besseyi*, *A. fragariae*, *A. ritzemabosi*, which are widespread in the agroecosystems of wheat in the Mugan Plain of Azerbaijan.

7.1. Systematics, identification, and life cycle of *Aphelenchus avenae*, *Aphelenchoides* spp.

A review of the systematics, morphological identification, and

life cycle of these nematodes provided. It is shown that phyto-mycophages develop basic plasticity in adaptation to agroecosystems: species of the genus *Aphelenchus* prevail in areas with a rich organic background and active mycoflora, while representatives of the genus *Aphelenchoides* can provide phytopathogenic properties and cause plant diseases such as ear whitening (*A. besseyi*), leaf spot (*A. fragariae*), and the formation of vegetative organs (*A. ritsemabosi*). The life cycle of this nematode is 7–10 days, with the transition to the cryptobiotic stage preserved under drought and temperature stress conditions. Based on morphological features (stylet shape, cuticle structure, vulva and tail anatomy), diagnostic illustrations were prepared and taxonomic verification of species was performed.

7.2. Seasonal dynamics of *Aphelenchus avenae*, *Aphelenchoides* spp.

The section is devoted to the analysis of the seasonal dynamics of the number of phytomycophages in agroecosystems of winter wheat in the conditions of the Mugan Plain.

Table 2
Seasonal dynamics of *Aphelenchus avenae* abundance in wheat agroecosystems of the Mugan Plain (2020–2024)

Month	bundance (individuals/100 ml of soil)	Temperature (°C)	Humidity (%)	Notes
July	100 ±15	30–38	40–60	drought, minimal activity
August	50±10	30–38	40–60	cryptobiosis, low abundance
September	100 ±15	20–25	50–70	Recovery after precipitation
October	50±10	15–20	60–80	Low activity, decline

Based on monitoring in 2020–2024, it was established that the maximum abundance of *Aphelenchus avenae* and *Aphelenchoides* spp.

occurs in March–May (up to 600 individuals/100 ml of soil), with a sharp decline in summer due to drought and soil overheating. In autumn, after precipitation, a short-term reactivation of populations observed. Nematodes of the genus *Ditylenchus* (*D. dipsaci*, *D. destructor*, *D. myceliophagus*) exhibit outbreak-like activity in spring and switch to cryptobiosis by July. The tables present quantitative data for each genus and species, including temperature and humidity characteristics and agrophenological phases. These results allow us to consider phytophages and mycophages as indicators of the state of the microbial component of the soil and the ecological background of agroecosystems (Table 2).

7.3. Geographical and zonal characteristics of natural foci of phyto-mycophages *Aphelenchus avenae*, *Aphelenchoides* spp. on the Mugan Plain

The section provides geographical and zonal characteristics of natural foci of phytomycophages on the Mugan Plain. It is substantiated that the formation of stable populations is observed in areas with high mycobiota activity, especially in fields with mulch and straw residues, as well as in areas with good irrigation (Saatli, Imishli, Bilasuvar). In the northern part of the plain, saprophytic mycophages (*Aphelenchus*) dominate, in the central part, the greatest species diversity is noted, including pathogenic forms of *Ditylenchus*, and in the southeast, the number decreases due to salinization and soil degradation.

7.4. Quarantine aspects of phyto-mycophages (*Aphelenchus avenae*, *Aphelenchoides* spp., *Ditylenchus* spp.)

The section contains an analysis of the quarantine significance of the studied species. It established that *Aphelenchoides besseyi*, *A. fragariae* and *A. ritzemabosi* are included in the lists of quarantine organisms in a number of countries in Europe and Asia, which is due to their ability to cause massive phytopathological damage under stress and agronomic violations. For Azerbaijan, the need for constant phytosanitary monitoring has been determined, especially during the spring vegetation period, for the purpose of early detection of potentially dangerous foci (Table 3).

Table 3

Summary table of seasonal dynamics of *Aphelenchus avenae* and *Aphelenchoides* spp. nematode groups in the conditions of the Mugan Plain

Genus/ species	Spring (March– May)	Summer (June– August)	Autumn (September– October)	Main nutrition type
<i>Aphelenchus avenae</i>	Active population growth (150–600 individuals)	Sharp decline (<100 individuals)	Weak activation after rains	Mycophagous
<i>Aphelen- choides</i> spp.	Peak in population (200–500 individuals)	Moderate decline (~100)	Partial recovery	Mycophagous/ Phytophagous
<i>Ditylenchus</i> spp.	Sharp peak (1000–1500 individuals)	Disappearance/ anabiosis	Not recovering	Phyto- mycophagous

Thus, the phyto-mycophages considered in this chapter represent an important component of the soil biota of agroecosystems. They perform a dual function - participation in the decomposition of organic matter and maintenance of microbial balance on the one hand, and the manifestation of pathogenic properties under certain conditions - on the other. The data presented are important for the development of ecologically sound systems for monitoring and forecasting phytopathogenic risk in the agricultural sector, especially in the context of increasing climatic stress in arid regions.

ГЛАВА VIII

ECTOPARASITIC ROOT NEMATODES - GENERA HELICOTYLENCHUS, ROTYLENCHUS, MERLINIUS, TYLENCHORHYNCHUS, PARATYLENCHUS

The chapter is devoted to ectoparasitic root nematodes of the genera *Helicotylenchus*, *Rotylenchus*, *Merlinius*, *Tylenchorhynchus*

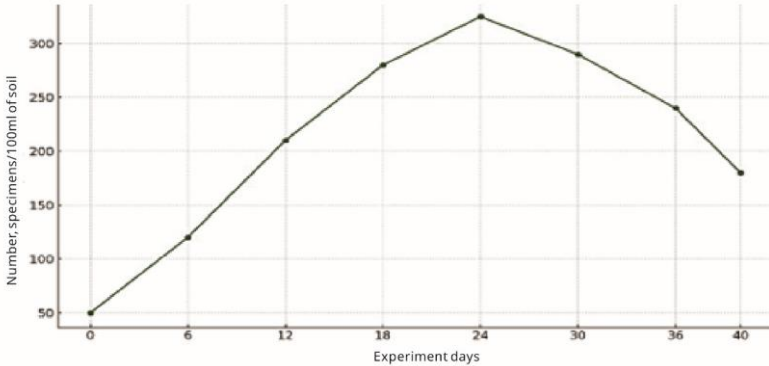
and *Paratylenchus*, which are widespread in agrocenoses of the Mugan Plain and have phytopathogenic potential. The species causing growth inhibition, chlorosis, root damage and yield reduction, especially at high population densities, are considered. Thus, *Helicotylenchus dihystera* and *H. pseudorobustus* are often found in zones with organic-rich soils, demonstrating polyphagy and drought resistance. *Rotylenchus robustus*, *R. uniformis* and *Merlinius brevidens* affect cereals and grasses, promoting secondary infections. *Tylenchorhynchus brassicae* and *Paratylenchus projectus* have a narrower specialization and high sensitivity to moisture supply fluctuations.

8.1. Life cycles and seasonal dynamics of nematodes of the genera *Helicotylenchus*, *Rotylenchus*, *Merlinius*, *Tylenchorhynchus* and *Paratylenchus*.

The life cycle of these nematodes includes an egg, four larval stages and an adult, with the invasive stage J2. Under favorable conditions ($t=20-27^{\circ}\text{C}$, humidity, presence of roots), the cycle is completed in 21–25 days, which allows for the formation of up to 3–5 generations per season. Seasonal dynamics are characterized by a spring-summer peak in numbers and a decline in autumn, and drought-resistant forms persist as eggs and J2.

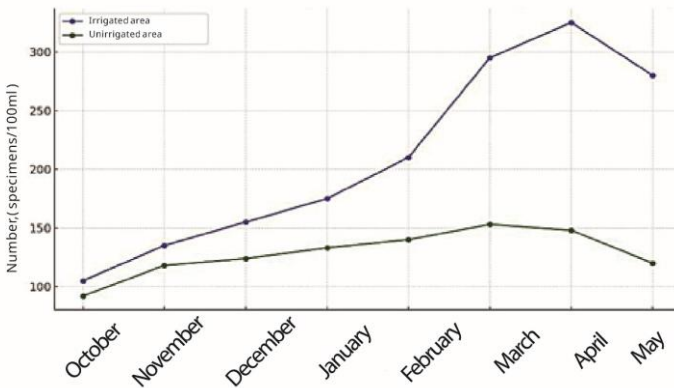
Laboratory and field studies on wheat in the Saatli district showed a high abundance of *Helicotylenchus* spp. in irrigated areas and its correlation with plant growth phases and soil moisture. Under water deficit conditions, the abundance and activity of nematodes decreased significantly, confirming their dependence on the rhizosphere microclimate. The life cycle of *H. dihystera* and *H. pseudorobustus* was successfully reproduced under controlled conditions, with confirmation of their morphological and morphometric characteristics (Graph 2)

Seasonal dynamics depend on temperature and humidity conditions and host development phases. All species are characterized by a spring-summer population peak, egg resistance to adverse conditions, and the possibility of several generations per season. Understanding these dynamics is important for developing monitoring systems and agrotechnical measures.



Graph 2. Dynamics of the number of *Helicotylenchus* spp.

In Saatli district in 2023-2024, field installation experiments were conducted on two sites - with and without drip irrigation (natural precipitation regime). Soils and agricultural technology were similar. Soil and root samples were collected monthly from October to May, the number of nematodes was determined by standard methods. The results showed a clear dependence of the number of *Helicotylenchus* spp. on moisture: in the irrigated site, the maximums reached 325 specimens / 100 ml of soil (2.1 times higher than in the control site). The number increased 7-10 days after each watering. In the non-irrigated site, the number decreased by the heading phase due to a decrease in moisture below 20% of the full moisture capacity (Graph 3).



Graph 3. Dynamics of *Helicotylenchus* spp. population by months.

Agrobiological indicators were also higher in the irrigated area: the biomass of the above-ground part of wheat at the milk ripeness stage was 18.7% higher, the grain yield was 0.61 t/ha higher, all other things being equal.

The findings highlight the importance of the hydrothermal regime for the reproductive activity of *Helicotylenchus* spp. Regular irrigation stabilizes the population and activates the life cycle by improving the rhizosphere microclimate and enhancing root signaling. Water deficit has a suppressive effect on populations. These patterns are important for predicting the phytohelminthological situation under climate change and water resource limitations.

8.2. Natural foci, quarantine aspects of species of the genus *Helicotylenchus*, *Rotylenchus*, *Merlinius*, *Tylenchorhynchus*, *Pratylenchus* and their geographical, zonal characteristics

The geographic distribution of the genera *Helicotylenchus* and *Pratylenchus* is cosmopolitan, *Rotylenchus* and *Merlinius* are more common in arid regions, and *Tylenchorhynchus* is confined to agrocenoses. Although they are not included in international quarantine lists, their high numbers require monitoring and accounting during phytoexpertise and agrotechnical measures.

CHAPTER IX

ENDOPARASITIC MIGRATING NEMATODES OF THE GENERA *PRATYLENCHUS*, *PRATYLENCHOIDES*

This chapter presents the results of a comprehensive study of endoparasitic migratory nematodes of the genera *Pratylenchus* and *Pratylenchoides*, which have high phytopathogenic activity and are important for the agrocenoses of Azerbaijan, in particular the Mugan Plain.

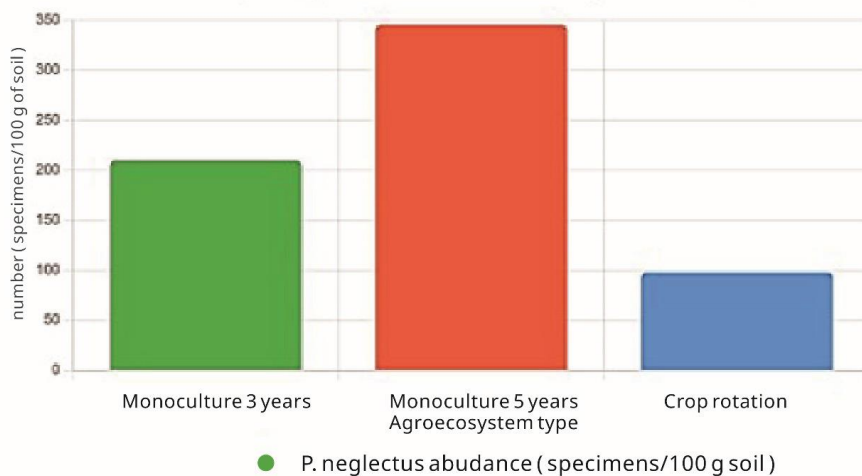
9.1. Systematics, identification and life cycles of nematodes of the genera *Pratylenchus* and *Pratylenchoides*

The systematics and life cycle features of these nematodes, their high ecological plasticity, ability to migrate inside the root tissues of plants, causing necrosis and physiological disorders, which significantly reduces crop yields are considered. It has been established that these nematodes are able to persist in the soil as resistant forms - eggs

and second-stage larvae (J2), which ensures their survival in unfavorable non-vegetation periods and contributes to the accumulation of phytopathogenic inoculum in monoculture farming.

9.2. Survival of the inter-vegetation period and resistant stages

During field studies in 2020–2024, a significant impact of wheat monoculture on the number of *Pratylenchus neglectus* and the associated negative consequences for plant development and productivity were revealed. Harmfulness thresholds were determined, at which the number of nematodes leads to significant yield losses (up to 35%). An analysis of biotic indices showed a shift in the structure of soil communities towards parasitic forms during long-term cultivation of monotonous crops (Graph 4).



Graph 4. Effect of wheat monoculture on the abundance of *Pratylenchus neglectus*.

Geographical and ecological analysis confirmed the wide distribution and formation of stable foci of nematodes in the territory of Azerbaijan, especially in conditions of intensive agriculture with irrigation and light soils. Particular attention is paid to the quarantine status of a number of species, including international requirements and prospects for the use of modern molecular diagnostic methods.

9.3. Natural foci of species of the genus *Pratylenchus*, *Pratylenchoides* and their geographical, zonal characteristics

The practical significance of the study lies in the development of recommendations for phytosanitary monitoring, the introduction of crop rotations, the use of resistant varieties and biological control agents aimed at preventing the accumulation and spread of migratory endoparasites in the region's agroecosystems.

9.4. Quarantine aspects of species of the genus *Pratylenchus* and *Pratylenchoides*

The migratory endoparasitic nematodes *Pratylenchus* and *Pratylenchoides* are widespread and economically significant in temperate and subtropical agroecosystems. Some *Pratylenchus* species are included in the EPPO quarantine lists, while *Pratylenchoides* are not yet officially regulated.

CHAPTER X

CYST-FORMING NEMATODES *HETERODERA* SPP.

This chapter presents the results of a study of cyst-forming nematodes of the genus *Heterodera*, one of the most economically significant groups of phytoparasitic helminths capable of causing serious disruptions in agroecosystems. Their biology, taxonomy, life cycle, features of natural foci and quarantine aspects are considered.

10.1. Taxonomy, identification and life cycle of nematodes *Heterodera* spp.

The genus *Heterodera* includes many species specialized on different host plants. The most common ones include *H. avenae* (oat nematode), *H. schachtii* (sugar beet nematode), *H. glycines* (soybean nematode) and others. Accurate identification requires a combination of morphometric and molecular analysis, given the similarity of morphological features. An important discovery was the registration of *H. mothi* in Azerbaijan, first identified in the Araz River valley, which was confirmed by genetic analysis of ITS rRNA and COI indicating the emergence of a new phytopathogenic species in the region.¹²

¹² Ryss, A.Y., Subbotin, S.A., Huseynova, G.T. Report of *Heterodera mothi* Khan & Husain, 1965 (Tylenchida, Heteroderidae) in Azerbaijan // - Moscow: Russian Journal of Nematology, - 2018. Vol. 26, №1, - p. 43–49.

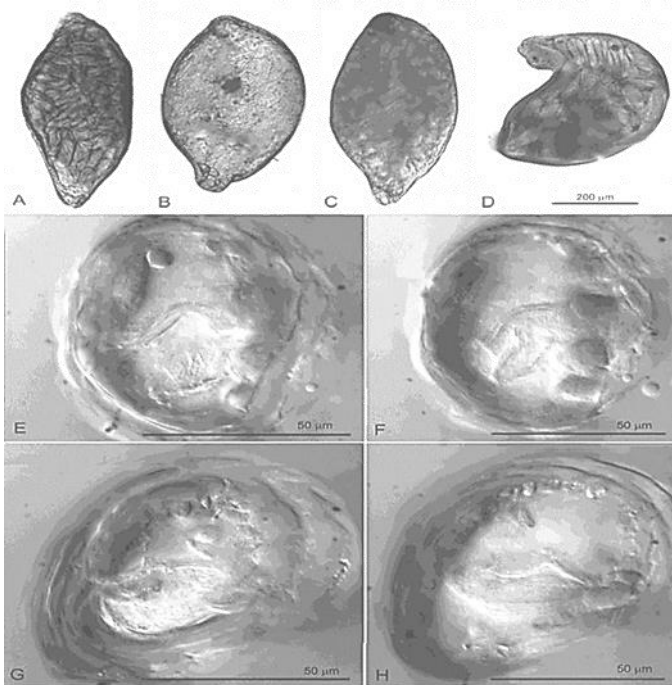


Fig. 1. *Heterodera moths*. A–D: cyst shapes; E, F and G, H: vulval cone at different optical levels.

The chapter describes the specifics of the life cycle of *H. avenae* in the agroclimatic conditions of the Mugan Plain, including the relationship with the phenological phases of cereals according to the international BBCH scale. Morphological and molecular data presented confirming the identification and phylogenetic position of *H. moths* in the South Caucasus, which expands the known range of this species and emphasizes the need for monitoring (Figure 1).

10.2. Natural foci and quarantine aspects of genus *Heterodera* species

Special attention is paid to natural foci of cyst nematodes and their resistance to adverse conditions, which ensures the preservation of populations even in the absence of hosts.

Quarantine aspects are considered, including the international status of the main species of the genus, phytosanitary risks and the

need to implement control measures, especially in the context of identifying *H. mothi* in Azerbaijan.

The chapter provides a summary table of the characteristics, distribution and quarantine significance of key species of the genus *Heterodera*, reflecting their biological features and economic importance. A conclusion is made about the need for an integrated approach to the identification, monitoring and management of these pests in the agrocenoses of the region.

CHAPTER XI DISCUSSION

11.1. New findings of plant parasitic nematodes and their significance

This chapter presents the key results of the research on plant-parasitic nematodes in Azerbaijan, especially in the Mugan Plain, their impact on wheat and agroecosystems. New species records, their biogeographic distribution, seasonal population dynamics, quarantine aspects and recommendations for reducing damage discussed. Special attention paid to the discovery of a new species *Heterodera mothi* in the Aran region, which highlights the need for further monitoring and research.

11.2. Biogeography and zonal conditions of foci of phyto-parasitic nematodes in a comparative aspect

The chapter also raises the issue of biogeographical distribution of phytoparasitic nematodes in different regions of Azerbaijan and neighboring countries. The analysis of the comparison of environmental conditions allows us to better understand the distribution patterns of species such as *Pratylenchus neglectus* and *Heterodera avenae* in the context of climatic factors and agricultural practices, including crop rotation and irrigation.

11.3. Comparison of life cycles of different groups of plant nematodes and their resistant stages for survival among seasons

A comparative analysis of different groups of plant nematodes affecting wheat allows us to identify a number of key differences in their biology, resistance and ecological adaptation. The most important parameter determining the degree of harmfulness is the duration of the life cycle.

11.4. Seasonal dynamics and quarantine aspects in comparative aspect for different groups of helminths

In addition, the discussion section touches upon the issues of seasonal dynamics of nematode populations, their activity in different phases of wheat vegetation, which allows more accurate prediction of invasion peaks and threat to yield depending on climatic conditions. The studies also revealed important differences in the life cycles of different groups of plant nematodes, which is of critical importance for the development of effective control methods.

11.5. Indication of soil fertility and erosion using nematode community parameters

Practical recommendations for plant growers are also discussed, including phytosanitary monitoring, agrotechnical measures, and the use of biological methods of protection against phytonematodes, which improves the stability of agrocenoses and reduces dependence on chemical pesticides. Attention is also paid to the selection of resistant wheat varieties, which is becoming an important direction in the fight against phytoparasites.

Thus, this chapter summarizes the results of the conducted research and proposes key scientific and practical recommendations for effective control of plant nematodes, which is the basis for sustainable development of agriculture in Azerbaijan and other regions with similar climatic and agronomic conditions.

CONCLUSION

For the first time in Azerbaijan, the cyst-forming nematode *Heterodera moths* was identified in the Mughan Plain, significantly expanding its known range and confirming the high adaptability of phytoparasitic nematodes in the region. A total of 36 species were identified, among which *Pratylenchus* and *Heterodera* cause up to 30% yield losses in wheat. Biogeographic and phenological analysis revealed that nematode dynamics depend on climatic conditions, agricultural practices, and plant developmental phases, necessitating integrated management strategies. These findings highlight the importance of phytosanitary monitoring, molecular diagnostics, breeding resistant wheat varieties, and employing nematodes as indicators of soil health for sustainable agriculture in the region.

RESULTS

1. In Azerbaijan, high biodiversity of nematodes (36 species from 20 genera and 13 families) found in the wheat fields of the Mugan Plain, reflecting the complexity of soil ecosystems. Nematodes are distributed among five trophic groups, among which phytoparasites cause significant damage to crops, and predatory and omnivorous forms play a stabilizing role [9, 10].
2. The Mugan Plain it was established that the number and composition of nematode communities depend on the type of soil: on meadowserozems up to 16 genera with high values of MI (2.8–3.5) and SI (60–65) were identified, which reflects fertility. On alluvial-meadow soils (8–10 genera) the indicators correspond to moderate degradation, and on saline gley-serozems (5–6 genera) low indices (MI = 1.4–1.6, SI = 21–28) indicate erosion and loss of organic matter [3, 10].
3. For the first time, for the agroecosystems of the Mugan Plain the trophic structure of nematodes and its relationship with soil factors characterized. It has been established that bacteriophages dominate in irrigated fields (up to 60–65%), while the proportion of mycophages and phytophages increases in saline and degraded soils (25–30%), and predatory and omnivorous forms do not exceed 5% everywhere, which reduces the stability of agrocenoses. Significant correlations revealed between the indices of nematode structure and soil parameters: MI is positively associated with the content of organic carbon ($r = 0.82$), SI – with humidity ($r = 0.75$), EI inversely correlated with soil density ($r = -0.68$). Taxonomic diversity reaches $H' = 2.27$ – 2.39 with high evenness ($E = 0.84$ – 0.88), reflecting the simplification of the food web and the vulnerability of ecosystems to pathogens [3, 5, 10].
4. For the first time in Azerbaijan, it was shown that the phyto-mycophages *Aphelenchus avenae*, *Aphelenchoides* spp. and *Ditylenchus* spp. have a pronounced zonal distribution and seasonal dynamics. *Aphelenchus avenae* reached a peak abundance of 150–600 individuals/100 ml of soil in March–May, *Aphelenchoides* spp. – 200–500 individuals/100 ml of soil in April–May, and *Ditylenchus* spp. – 1000–1500 individuals/100 g of soil in March–April. The

- northern part of the plain was characterized by the predominance of mycophages, the central part by mixed populations, and the southeastern (saline) part by low abundance of all species [2, 5, 10].
5. In Azerbaijan, comprehensive studies of ectoparasitic root nematodes of the genera *Helicotylenchus*, *Rotylenchus*, *Merlinius*, *Tylenchorhynchus* and *Paratylenchus* conducted, including laboratory and field experiments. It was established that *Helicotylenchus* spp. reach a maximum population of 325 specimens/100 ml of soil in irrigated areas (Saatli) in March–April, with a life cycle of 23–26 days at 22–28°C. For the first time, the effect of irrigation on the growth of ectoparasite population and wheat yield (+0.61 t/ha) was shown [5, 8].
 6. Research has shown that endoparasitic migratory nematodes of the genera *Pratylenchus* and *Pratylenchoides* cause root necrosis and reduce wheat yields by 25–40% in monoculture, while with crop rotation, losses reduced to 10–15%. The abundance indicators of *Pratylenchus neglectus* (345±31 specimens/100 g of soil in monoculture) and *Pratylenchoides* spp. (180–200 specimens/100 g during drought) were established, which for the first time reflects their pathogenic potential in the agrocenoses of Azerbaijan [7, 10].
 7. *Heterodera moths* was first detected in Sabirabad district on wheat. Morphological characteristics of cysts (L=626±81 µm) and J2 larvae (L=433±24 µm), as well as molecular markers (ITS rRNA, COI) confirmed the belonging to the Cyperi group. This discovery highlights the potential threat to grain crops in the Caucasus and the need for monitoring [1, 6].

PRACTICAL RECOMMENDATIONS

1. It is necessary to apply agronomic measures, including strict crop rotation with legumes and corn, deep plowing, the introduction of organic matter and the use of certified seed material, which helps to reduce crop losses from nematodes and restore soil structure.
2. It is necessary to implement biological protection using antagonistic fungi and bacteria (*Trichoderma*, *Bacillus subtilis*, *Pseudomonas fluorescens*) and local biopreparations, which allows to reduce the number of phytoparasites by 30–40% and maintain the balance of soil biota.

3. The use of genetically resistant wheat varieties and molecular markers is recommended; this limits the spread of *Pratylenchus* and *Heterodera* and prevents the emergence of new species such as *H.mothi*.
4. Chemicals should be used only when nematode numbers are high, with preference given to biopreparations based on plant extracts that are safe for soil biota.
5. Soil health should be monitored using MI, SI and PPI indices, and the trophic structure of nematodes should be analyzed for early detection of degradation, erosion and salinization.
6. It is recommended to use digital tools, including GIS mapping of nematode outbreaks, remote sensing, sensor networks, mobile applications and cloud databases, to predict nematode numbers and ensure effective phytosanitary control.

List of scientific works published on the topic of the dissertation

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The defense will be held on 24 october 2025 at 14⁰⁰ at the meeting of the Dissertation Council FD 1.09 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at the Institute of Zoology of the Ministry of Science and Education of the Republic of Azerbaijan.

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Dissertation is accessible at the library of the Institute of Zoology of the Ministry of Science and Education of the Republic of Azerbaijan.

Electronic version of dissertation and its abstract are available on the official website of the Institute of Zoology of the Ministry of Science and Education of the Republic of Azerbaijan ([https:// zoologiya.az](https://zoologiya.az)).

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