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Research Article

Phyto-mycophagous nematodes of Azerbaijan: systematics, biology, and quarantine importance

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Abstract
This study explores the biological and ecological characteristics of nematodes from the genera Aphelenchus and Aphelenchoides, classified as phyto-myco-phages due to their unique dual-feeding behavior. These organisms can parasitize plant tissues and consume fungal mycelium, showcasing remarkable trophic plasticity that enhances their adaptability to diverse environments, including agricultural fields and natural ecosystems. Aphelenchus avenae, a widespread species, thrives in moist, organic-rich soils. Its morphology is distinct: post-fixation, the body curves into a "J" shape, males have a well-developed copulatory apparatus, and females exhibit a characteristic tail structure. In contrast, Aphelenchoides species display greater diversity, encompassing both free-living forms and plant pathogens like A. besseyi, A. fragariae, and A. ritzemabosi, which cause diseases such as white bloom, leaf spotting, and stunted plant growth. The life cycle of these nematodes includes an egg, four juvenile stages, and an adult phase, completing in 7-10 days under favorable conditions, facilitating rapid population growth. Development occurs in substrates like soil and plant residues or within host plant tissues and fungi, requiring specialized isolation and diagnostic techniques. Population dynamics peak in spring and summer, particularly in moderately humid climates, while activity declines in autumn and winter. Some species form resistant stages (anabiosis or cryptobiosis) to endure unfavorable conditions. Geographically, these nematodes are distributed from subtropical to temperate zones. In Azerbaijan, they are prevalent in plains with high agronomic activity, forest belts, and floodplain areas rich in organic matter and fungal microflora, underscoring their ecological significance and adaptability.
Keywords: *Aphelenchus avenae*, *Aphelenchoides* spp., phyto-mycophages, seasonal dynamics, fungivorous nematodes

Introduction

Phyto-mycophagous nematodes represent a unique trophic group of plant-parasitic nematodes capable of feeding on both higher plant tissues and fungal mycelium. Among them, particular importance is attributed to *Aphelenchus avenae* and members of the genus *Aphelenchoides*, which play a significant role in agroecosystems, soil biocenoses, and phytosanitary practices. Their study is of both theoretical relevance in the field of phytopathogenic nematology and practical importance for crop yield forecasting, quarantine regulation, and ecological balance assessment in agrocenoses.In Azerbaijan, which features a wide range of climatic zones—from coastal subtropics to continental plains and mountainous regions—representatives of this group are found in diverse biotopes. Their dual trophic nature enables them to adapt to both live plant substrates and organic-rich soils with developed mycoflora. (Diakhaté, S. 2014) .This adaptability makes them potentially hazardous in terms of crop contamination and the spread of fungal diseases. In recent years, there has been growing interest in phyto-mycophagous nematodes as objects of molecular identification, bioindication, and biological control. However, aspects such as their seasonal dynamics, geographic distribution, and ecological quarantine significance remain poorly studied. This paper presents a comprehensive characterization of representatives of this group, including their taxonomic classification, morphological features, life cycle, ecological preferences, and phytosanitary relevance. Given the urgency of the issue, special attention is devoted to their role in the structure of soil biocenoses and their potential threat to agricultural production. Due to their capacity for both saprophytic and parasitic lifestyles, these nematodes play a dual role: on one hand, they contribute to the decomposition of organic residues and participate in nutrient cycling in the soil; on the other hand, they can damage cultivated plants by infecting both aboveground and underground organs.A particularly challenging aspect is the identification of species within the genus *Aphelenchoides*, as significant morphological similarity often hinders precise classification without molecular-genetic techniques (Liu et al. 2016).

Some species, such as *A. fragariae*, *A. ritzemabosi*, and *A. besseyi*, are under international phytosanitary regulation due to their status as causal agents of economically significant diseases in strawberries, chrysanthemums, and rice, respectively. The visual symptoms caused by these nematodes can vary from leaf necrosis and stunted growth to tissue deformation and complete plant death. The life cycle of this group is characterized by rapid development, which allows for multiple generations within a single growing season. Considering Azerbaijan’s climatic conditions, especially in regions with extended vegetation periods, this trait significantly increases the risk of uncontrolled spread of phyto-mycophagous nematode populations. Their ability to survive in the soil as dormant stages also contributes to their resilience against unfavorable environmental conditions and agricultural management practices (Yildiz et al. 2017).

Materials and methods

In the framework of the study on phyto-mycophagous nematodes, with particular focus on *Aphelenchus avenae* and species of the genus *Aphelenchoides*, a comprehensive methodological approach was employed that combined both field-based surveys and laboratory-based analyses. The primary objective of the research was to examine the morphological diversity, developmental biology, seasonal population dynamics, geographical distribution, and phytosanitary importance of these nematodes within various agroecosystems. (Uffe N. Nielsen , 2014) Soil and plant samples were collected using the point soil augering method, with sampling depths reaching up to 20 cm—sufficient to encompass the rhizosphere, the primary zone of root activity where nematodes are most prevalent. Sampling was carried out in spring, summer, and autumn, enabling the assessment of seasonal fluctuations. The sampling sites included a diverse range of agrocenoses: cereal fields (e.g., wheat and barley), vegetable plots (e.g., tomatoes, potatoes), and natural habitats such as meadows, floodplains, forest margins, and uncultivated grasslands. To ensure statistical robustness and minimize spatial variability, replicate samples were taken from each site and pooled to form representative composites. Nematodes were extracted from soil samples using a modified Baermann funnel technique, optimized for the recovery of motile individuals, particularly juvenile and adult stages (Network, 2021).

This method provided high recovery efficiency and minimized mechanical damage to nematodes. For plant material (including leaves, stems, and tubers), nematodes were extracted by maceration in distilled water, followed by gravity sedimentation and sequential sieving through a graded sieve series (e.g., 1000 µm, 500 µm, 250 µm, 38 µm) to separate nematodes from plant debris and other organic matter. The extracted nematodes were temporarily preserved in TAF fixative (a solution of trichloroacetic acid and formalin) to maintain anatomical integrity for microscopic observation. Before permanent slide mounting, the specimens were subjected to a gentle heat-killing process to straighten the nematode bodies, facilitating accurate morphometric analysis. Morphological identification was conducted using compound light microscopes at magnifications of ×400 to ×1000. A range of diagnostic features was evaluated, including total body length, tail morphology, stylet length and shape, position and structure of the excretory pore, morphology of reproductive organs (vulva, spicules), and cuticular annulation patterns. Emphasis was placed on characters that are taxonomically relevant within the families *Aphelenchidae* and *Aphelenchoididae*. For specieslevel classification, reference was made to standard taxonomic keys, identification tables, and regional faunal checklists (J. Hallmann, 2018).

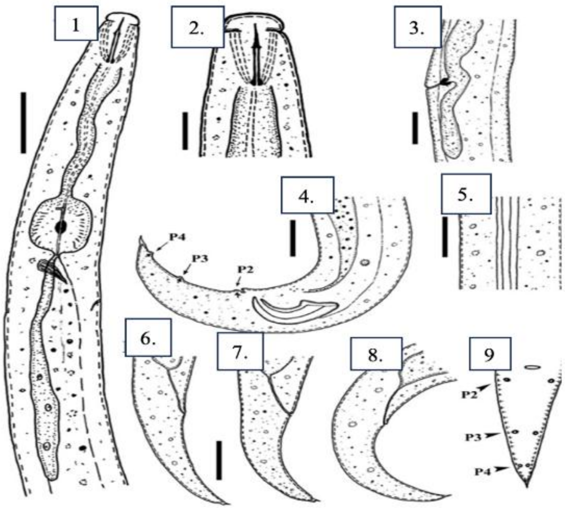

Figure 1. Screening for nematicidal activities of Apelenchus avenae

Results

Aphelenchus avenae is widespread in various soil types in Azerbaijan, particularly in areas with high humidity and organic content. Its morphology is characterized by a J-shaped body after fixation, a well-developed copulatory apparatus in males, and a distinct tail shape in females, making it relatively easy to diagnose. The genus *Aphelenchoides* exhibits greater diversity, including both free-living and potentially dangerous species such as *A. besseyi*, *A. fragariae*, and *A. ritzemabosi*, which are known to cause plant diseases like white bloom, spotting, growth retardation, leaf necrosis, tissue deformation, and, in severe cases, complete plant death. The life cycle of these nematodes comprises an egg stage, four juvenile stages (J1–J4), and an adult stage, completing in 5–7 days under favorable conditions, demonstrating high reproductive potential and adaptive flexibility. The J2 stage is particularly significant, as it is when larvae typically invade plant tissues, causing mechanical damage and physiological disturbances. Development occurs in substrates like soil and plant residues or within host plant tissues and fungal mycelium, necessitating specific isolation and diagnostic methods. Seasonal population dynamics show maximum peaks in the spring-summer period, particularly in moderately humid climates, with a decline in activity during autumn-winter months, especially in species without dormant stages. Some species, however, can enter resistant forms such as anabiosis or cryptobiosis to survive unfavorable conditions. Geographically, these nematodes are distributed across a wide zone, from subtropical to temperate regions, and in Azerbaijan, they are most frequently found in plains with high agronomic activity, forest belts, and floodplain zones rich in organic matter and fungal microflora. Morphological elements critical for systematic identification include the head region and stylet (indicating the ability to pierce plant or fungal tissues), esophagus, vulva, cuticle structure (with transverse grooves or thickenings), and the posterior body, including tail shape and features like papillae or setae (Song et al., 2015).

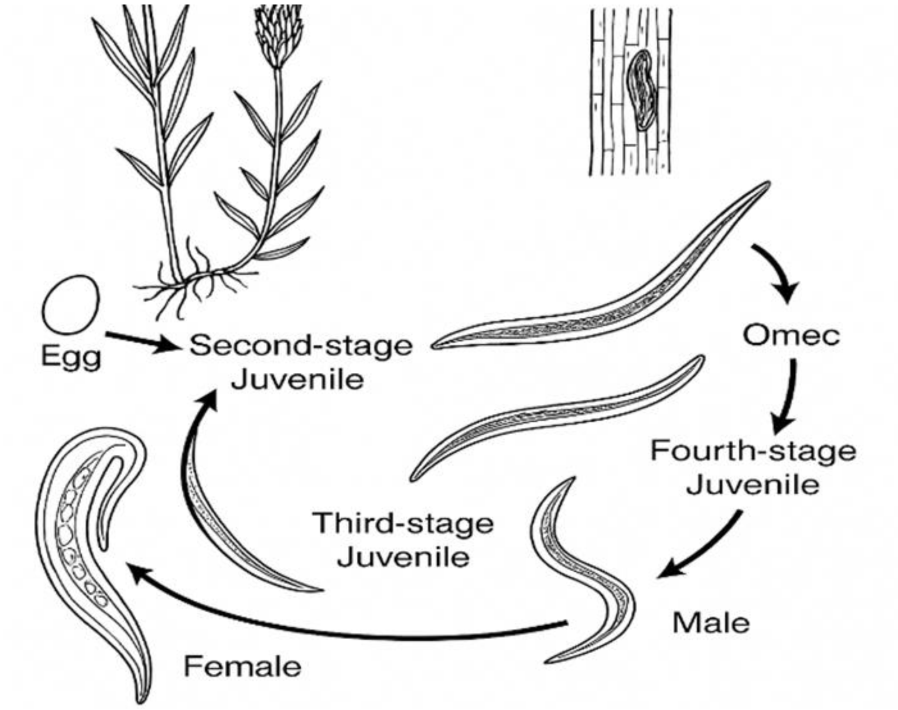

Figure 2. Life cycle of nematodes of the genus Aphelenchoides spp.: stages of development from egg to adult

Discussion

The dual trophic nature of phyto-mycophagous nematodes, exemplified by *Aphelenchus avenae* and *Aphelenchoides* species, enables their adaptability to diverse ecological niches but poses challenges for phytosanitary management. *Aphelenchus avenae* contributes to nutrient cycling by decomposing organic residues in organic-rich soils, while *Aphelenchoides* species, particularly *A. besseyi*, *A. fragariae*, and *A. ritzemabosi*, are significant plant pathogens under international phytosanitary regulation due to their economic impact on crops like strawberries, chrysanthemums, and rice. The rapid life cycle, completing in 5–7 days, allows multiple generations within a growing season, increasing the risk of uncontrolled population spread in

Azerbaijan's extended vegetation periods. Morphological similarities among *Aphelenchoides* species complicate identification, often requiring molecular-genetic techniques for precision, as traditional microscopy may not distinguish closely related taxa (Liu et al., 2016). The ability of some species to enter dormant stages (anabiosis, cryptobiosis) enhances their resilience against environmental stresses and agricultural practices, further complicating control efforts (Yildiz et al., 2017). In Azerbaijan, the prevalence of these nematodes in plains, forest belts, and floodplains correlates with high organic matter and fungal microflora, highlighting their ecological significance. The latent presence of quarantine species like *A. besseyi* and *A. fragariae* in seed material, substrates, and plant residues underscores the need for stricter border controls and biosafety standards in agricultural production cycles. Local species, such as *Aphelenchoides saprophilus* identified in the Mugan Plain, hold potential as bioindicators of soil health or biological control agents against fungal pathogens, warranting further research.

Table 1. Comparative characteristics of the main types of phyto-mycophages by trophic type, geographic distribution, and quarantine significance

№	Nematode species	Trophic type	Geographical distribution	Zonal characteristics	Agronomic importance	Quarantine status
1	*Aphelenchus avenae*	Phyto-myco-phage (saprotroph)	Europe, Asia, Caucasus	Temperate zone	Participates in the regulation of microbial background, low pathogenicity	No
2	*Aphelenchoides besseyi*	Phyto-myco-phage, facultative phytoparasite	Tropics, subtropics	Subtropical zone	Parasite of rice and cotton, causes chlorosis	Yes (quarantine)
3	*Aphelenchoides fragariae*	Phyto-myco-phage	North America, Europe	Humid regions, greenhouse zones	Parasitic on strawberries, ornamental plants	Yes
4	*Aphelenchoides ritzemabosi*	Phyto-myco-phage	Widely distributed	From wet to dry zones	Causes leaf curling in vegetable crops	Yes
5	*Aphelenchoides saprophilus*	Mycotroph, saprotroph	Local populations (including Mugan)	Peat and sierozem soils	Participates in the decomposition of fungal biomass	Yes

Conclusion

Given global climate change, expanding international trade, and intensifying agriculture, forecasting the migration of quarantine nematode species and strengthening preventive measures are critical. Species like *Aphelenchoides besseyi* and *A. fragariae* are particularly concerning due to their ability to persist latently in seed material, substrates, and plant residues, facilitating long-distance transport. This necessitates stricter border controls and biosafety standards across agricultural production cycles. The study of local populations, such as *Aphelenchoides saprophilus* in the Mugan Plain, is significant for both basic scientific research and the development of adaptive agricultural strategies that account for biodiversity and ecological interactions in soil biota. These species may serve as bioindicators of soil health or potential biological control agents against fungal pathogens. Developing national atlases mapping the distribution of phyto-mycophagous nematodes, incorporating geographic, phenological, and quarantine data, will enhance phytosanitary assessments, improve crop rotation planning, and aid in selecting resistant plant varieties. Integrating nematology modules into agricultural university curricula and conducting training programs for plant quarantine and agroecology specialists are recommended to address these challenges effectively.

The life cycle of nematodes of the genus *Aphelenchoides* spp. is visually illustrated as it is essential for understanding their biology, trophic behavior, and potential phytosanitary risks. This life cycle begins with the deposition of eggs by females either within plant tissues or in the surrounding environment. From the eggs, first-stage juveniles (J1) hatch, which subsequently molt through the J2, J3, and J4 stages, gradually approaching sexual maturity. Particular attention is given to the J2 stage, as it is at this point that the larvae typically invade plant tissues, causing mechanical damage and physiological disturbances. After completing the molting process, adult males and females are formed. Females then lay a new batch of eggs, ensuring the continuity of the cycle. Under favorable environmental conditions, the entire cycle can be completed within 5–7 days, which demonstrates the high reproductive potential and adaptive flexibility of *Aphelenchoides* spp 3.(Matplotlib-Lollipop, 2021).

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