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Optimized Strategy for Monitoring and Evaluating Natural Biological Control in the Durum Wheat (*Triticum durum*) Agroecosystem in Semi-Arid Algeria

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Abstract

Accurate assessment of pest dynamics and beneficial insects is a methodological requirement for the implementation of Integrated Pest Management (IPM) in cereal farming. This study, conducted on *Triticum durum* (cv. TARGUI) in Oued Smar, Algeria (2024-2025), compared the effectiveness and complementarity of two monitoring protocols, yellow water traps (YWT) and manual plant shaking (MPS), while incorporating an analysis of climate factors and fungal pathogens. The community inventory revealed a total abundance of 456 arthropods.
The YWTs preferentially captured winged forms (*Sitobion avenae*, 94%), providing information on the risk of migration. The MPS, meanwhile, made it possible to assess resident pest pressure and identify a broader trophic community, including secondary pests (*Oulema melanopus*) and a third trophic level (hyperparasitoids). Analysis of relative abundance established a Pest/Beneficial Ratio of 1.71, confirming substantial biotic pressure. Climate data reveal that the early demographic peak of aphids in April is strongly correlated with the rapid rise in temperature, inducing a critical phenological desynchronization of two weeks in relation to the maximum activity of the main predators (Coccinellidae). The phytopathological diagnosis also revealed a significant incidence of *Fusarium spp.* It has been demonstrated that the combined MPS + YWT protocol, supplemented by climate analysis, is essential for an integrated assessment, enabling the definition of specific intervention thresholds and the development of robust IPM strategies adapted to Mediterranean agroecological constraints.

Keywords: *Triticum durum*, aphids, BYDV, *Fusarium*, biological control, IPM, Algeria

Introduction

Cereal farming is a strategic focus of agriculture in Algeria, with durum wheat (*Triticum durum Desf.*) being the predominant crop and a pillar of national food security [1]. Despite its importance, Algerian productivity remains low and unstable, the result of a convergence of abiotic (drought, rainfall variability) and biotic constraints (pests and fungal diseases) [2]. These constraints are amplified by the effects of climate change, which threatens phenology and the water cycle [3]. To ensure the resilience of this agroecosystem, a transition to Integrated Pest Management (IPM) strategies, based on ecological analysis and natural regulation, is imperative [4].

Aphids (Aphididae) are recognized as key pests of cereals, not only because of the direct damage they cause by sucking sap, but above all because of their epidemiological role as vectors of the Barley Yellow Dwarf Virus (BYDV) [5]. Among them, Sitobion avenae is identified as the dominant species and the main vector in the Maghreb [6]. However, effective aphid management cannot be limited to the dominant species; it must consider the entire associated arthropod complex, including secondary pests (*Oulema melanopus*) and, above all, beneficial insects (Coccinellidae, Syrphidae), which dictate the potential for biological control [7].

Accurate assessment of population dynamics is the cornerstone of any IPM strategy [8]. However, the monitoring protocols commonly used in the region have limitations. Yellow sticky traps (YWT) are effective for monitoring migratory flows and early viral risk [9], but they do not allow for the quantification of resident infestation in situ (wingless forms and larvae) or an accurate

assessment of actual parasitic pressure [10]. To overcome this shortcoming, direct sampling of plants by Manual Shaking (MPS) is required to obtain robust data on colony density and direct interactions between prey and predators [11].

Furthermore, in agroecosystem ecology, population control is intrinsically linked to abiotic factors. In a semi-arid context, temperature and precipitation are the main modulators of phenology. A rapid rise in temperature can induce an acceleration in the parthenogenetic reproduction of pests, creating a phenological desynchronization (time lag) between the peak of infestation and the recruitment of natural enemies [12]. Understanding this climate-biotic correlation is essential to explain the failure of biological control despite the presence of beneficial insects [13]. Finally, the identification of a complete trophic chain, including hyperparasitoids, is necessary for a realistic assessment of natural regulation, as these organisms act as negative regulators of primary parasitism efficiency [14].

Faced with these methodological and ecological challenges, the present study was conducted on durum wheat in the Oued Semmar region (Algeria). The specific objectives were to: 1) Characterize the effectiveness and complementarity of the YWT and MPS methods for establishing intervention thresholds; 2) Conduct a complete inventory of the arthropod community (key pests, secondary pests, auxiliary fauna, and hyperparasitoids); and 3) Quantify the influence of climatic parameters on population dynamics in order to elucidate the mechanism of the observed phenological desynchronization. This work aims to provide a monitoring protocol and accurate ecological data for the development of IP strategies adapted to the Algerian agricultural context.

Materials and Methods

Objectives

This investigation was designed to comprehensively assess the impact of aphid populations and fungal diseases associated with the cultivation of durum wheat (*Triticum durum*), variety TARGUI, during the 2024-2025 growing season. The methodology is based on a combination of field sampling (manual shaking and color trapping) and diagnostic laboratory analyses. The primary objectives were: taxonomic identification of aphid species, with particular attention to potential vectors of phytoviruses (notably Barley Yellow Dwarf Virus - BYDV); characterization of the main population dynamics of harmful and beneficial arthropods; and diagnosis of prevalent fungal pathogens. This integrated approach aims to refine our understanding of biotic interactions and inform appropriate plant health management strategies.

Characterization of the Experimental Site and Acquisition of Climate Data

The study was conducted at the experimental station of the Technical Institute for Field Crops (ITGC) in Oued Smar, which is representative of the arable farming systems in the suburbs of Algiers. The site has a sub-humid climate with mild winters (Emberger Quotient).
Data on average daily temperature (Tm) and cumulative precipitation (P) were collected weekly from the ITGC weather station for the period March-June 2025. These parameters were used to analyze the thermal phenology of populations (calculation of degree days), which is essential for interpreting seasonal dynamics.

Entomological Sampling Protocol

Arthropod populations were sampled on a weekly basis from March to June 2025 in order to monitor their dynamics in relation to key phases of wheat phenological development. This protocol was based on the combined application of two complementary techniques to obtain an overall estimate of biotic pressure.

On the one hand, the manual shaking method was used to quantify the actual parasitic pressure exerted by resident populations (wingless forms and larval stages of beneficial insects). Plants were selected at random within the plot and then shaken above a defined collection surface. The specimens collected were immediately transferred and preserved in a 70% (v/v) alcohol solution for subsequent taxonomic and quantitative analysis.

In addition, chromatic trapping was used to monitor winged populations and assess migratory flows. Six Yellow Water Traps, containing distilled water with added liquid soap, were strategically placed at ground level at regular intervals to ensure representative coverage of the experimental plot. The trapping period was standardized at 24 hours for each weekly survey. This system targeted winged populations, providing indicators of aphid flight activity and the abundance of flying adult beneficial insects.

Taxonomic identification

The identification of aphids was finalized in the laboratory, using the microscopic mounting method described in [15]. This technique included abdominal incision, degreasing by heating in a 10% potassium hydroxide (KOH) solution, thinning in chloral phenol, and final mounting in Faure's liquid. Observation under an optical microscope allowed species to be distinguished based on key diagnostic criteria such as the morphology of the cornicules and cauda. The identity of the beneficial insects was confirmed by direct morphological observation.

Phytopathological Diagnosis

Organic Sampling and Stratification

The sampling protocol was designed to reflect the vertical stratification of fungal infections on the wheat plant. Symptomatic plant fragments (necrosis, discoloration) were collected on five separate dates between March and May 2025, covering the vegetative phase through to maturation. The samples were classified in situ according to three distinct anatomical zones: basal zone (roots, collar, tillering nodes), intermediate zone (leaves and sheaths), and upper zone (rachis and ears).

Isolation of Cultivable Fungi

The collected fragments were subjected to an isolation process according to the method described in [16]. Each fragment was successively disinfected on the surface by immersion in 70% ethanol (v/v) for 5 minutes, followed by a 5% sodium hypochlorite (bleach) solution for 5 minutes, then rinsed with sterile distilled water. The disinfected fragments were then seeded on Petri dishes containing Potato Dextrose Agar (PDA) selective medium and incubated in the dark at 25 ± 1°C. The fungal colonies were purified by successive subculturing until homogeneous isolates were obtained, each coded as a distinct morphotype.

Taxonomic and Diagnostic Identification

The identification of the purified isolates was based on a two-step characterization:

Macroscopic Characterization: Evaluation of cultural criteria after 7 days of incubation, including growth rate, pigmentation of the mycelium and medium, and colony texture.

Microscopic Characterization: Fresh mounts were prepared from colony fragments stained with Lactophenol Cotton Blue for observation under an optical microscope (up to 400x magnification). Generic identification was based on the morphology of sporulation structures, particularly the shape and septation of conidia (fusiform macroconidia for *Fusarium*, muriform for *Epicoccum*, etc.), using recognized taxonomic keys.

Statistical analysis

The count data were analyzed using XLSTAT software. The comparison of total arthropod numbers between the Yellow Water Trap (YWT) and Manual Shaking (MPS) was performed using the non-parametric Mann-Whitney test. To visualize and interpret the temporal dynamics of aphid and beneficial insect communities, a Principal Component Analysis (PCA) was applied.

Results and discussions

The integrated assessment of the durum wheat agroecosystem revealed complex biotic and abiotic dynamics, characterized by severe trophic imbalance and stratification of disease risks.

Effectiveness and Complementarity of Monitoring Methods

A comparative assessment of Manual Plant Shaking (MPS) and Yellow Water Traps (YWT) reveals significant complementarity (Table 1). MPS provided the highest abundance estimate (N=137 vs. 36) and enabled the counting of predator larval stages. Principal Component Analysis (PCA, Figure 1) and the Dendrogram (Figure 2) of YWT captures reveal a clear temporal separation of migratory flows: vector aphids (Rh. padi, Me. di) are associated with early clusters (MAR/APR), justifying the role of YWT in diagnosing viral risk.

Table 1. Comparative assessment of the effectiveness of aphid sampling methods on durum wheat**.**

Sampling method	Total abundance Aphids (N)	Species richness Aphids (No. of species)	Key information provided
Manual shaking (MPS)	137	6	Infestation rate of resident forms/Trophic interactions
Bassins Yellow (YWT)	36	3	Monitoring of migratory flows and viral risk (alates)

Key: The significant difference in abundance and species richness between the two protocols highlights that MPS is the only method that provides a reliable estimate of parasite pressure and wingless forms, which is essential for IP decision-making.

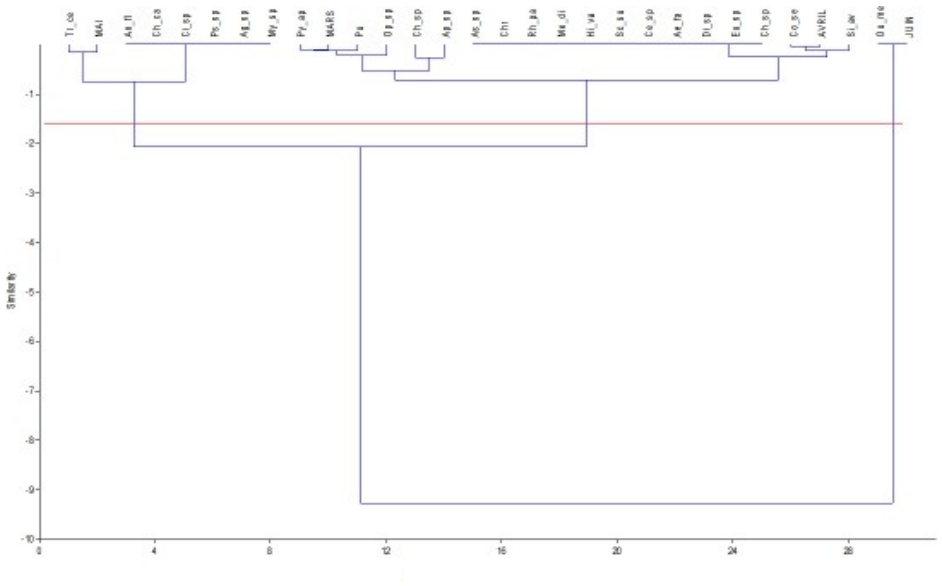


Figure 1: Principal Component Analysis (PCA) of the arthropod community captured by Yellow Water Traps (YWT), illustrating the temporal segregation of migratory flows and the onset of epidemiological risk.

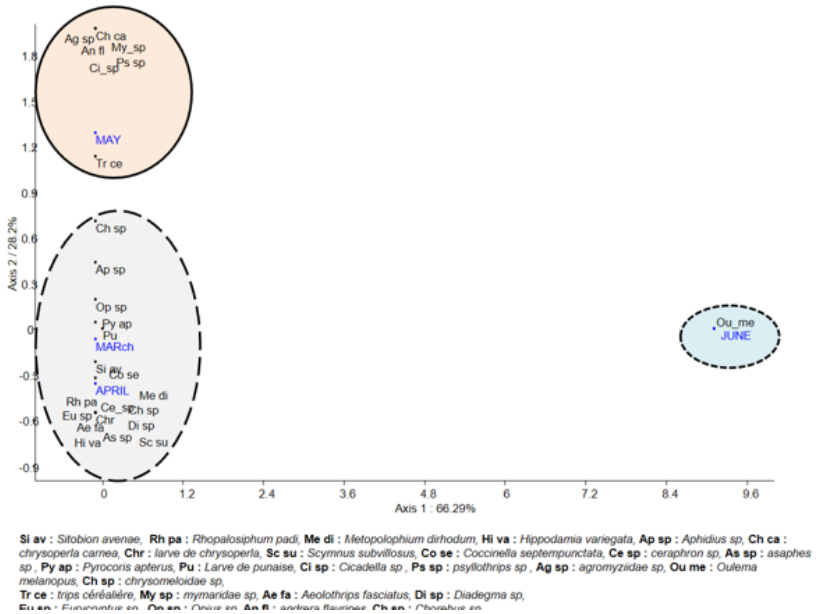


Figure 2. Hierarchical classification analysis (dendrogram) of Yellow Water Traps (YWT) data, confirming the grouping of migratory species and their seasonal distribution (March-June).

The integration of YWT and MPS statistical data is a methodological requirement for Integrated Protection (IP) [17]. YWT measures the epidemiological risk input from vector migration flows (proven by temporal segregation, Figures 1 and 2), a critical indicator for BYDV prevention [18].
The MPS establishes the actual pest pressure and the potential for biological control in situ. This combined approach is essential to avoid underestimating the actual risk when establishing intervention thresholds [19].

Specific Identification and Demographic Pressure of Aphids

The inventory established that the aphid complex was characterized by an overwhelming dominance of *Sitobion avenae*... Principal Component Analysis (PCA, Figure 4) confirms that late temporal clusters are strongly correlated with *S. avenae*, validating its status as a key pest [20]. At the same time, the confirmed presence of major phytoviral vectors, such as *Rhopalosiphum padi* and *Metopolophium dirhodum*, corroborates a proven viral risk (BYDV) [21]. The pressure from S. avenae is often exacerbated in simplified cereal systems in the Maghreb [22].

Climatic Characteristics and Relationship with Population Dynamics

Climate analysis revealed a rapid rise in temperature from early April. The peak abundance of the key aphid, Sitobion avenae, was recorded on April 20 (N=76), while the maximum activity of beneficial insects was not reached until early May, a delay of two weeks (Figure 3). Principal component analysis (PCA) of MPS data (Figure 4) and the dendrogram (Figure 5) statistically confirm this dynamic. The MAY/JUNE grouping is strongly correlated with the key pest Sitobion avenae, in contrast to the APRIL grouping, which combines vectors and the first beneficial insects (Hi va).

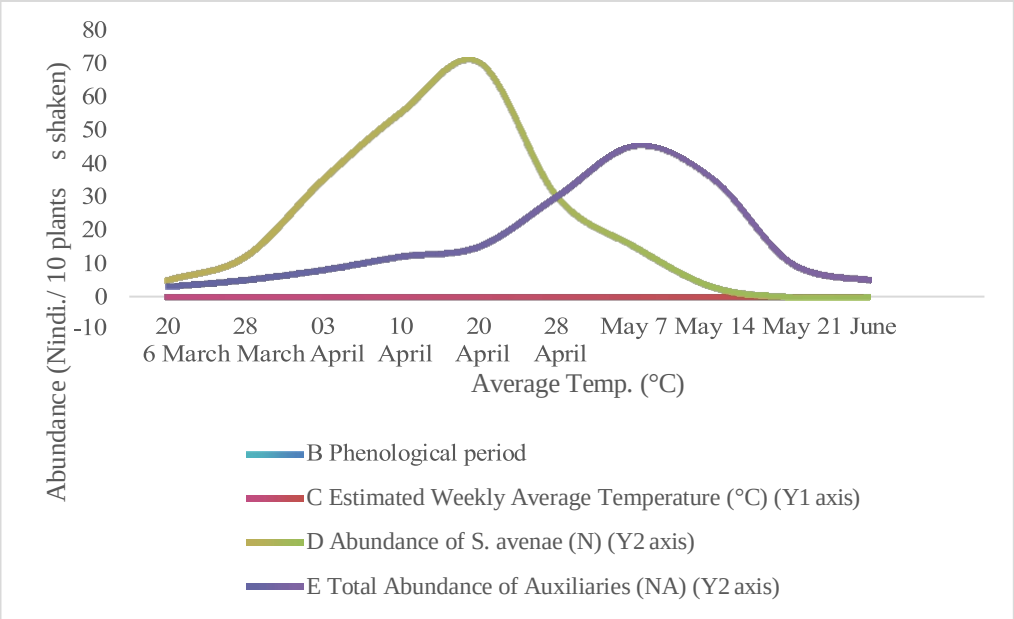


Figure 3. Weekly dynamics of the abundance of the key aphid (Sitobion avenae) and total beneficial fauna (NA) as a function of average air temperature (∘ C) over the critical period (March to June 2025) at the Oued Semmar station.

Caption: The graph illustrates the phenological desynchronization between the key pest and its natural enemies. The demographic peak of the dominant species, Sitobion avenae, was recorded on April 20 (N=70 individuals), correlating with the observed acceleration in temperature rise. The maximum abundance of beneficial insects (NA) was not reached until May 7 (N=45), a time lag of approximately two weeks. This delay, highlighted by the negative correlation between the peaks, explains why natural biological control failed to regulate pest pressure during the critical phenological phase of wheat (stem elongation/heading).

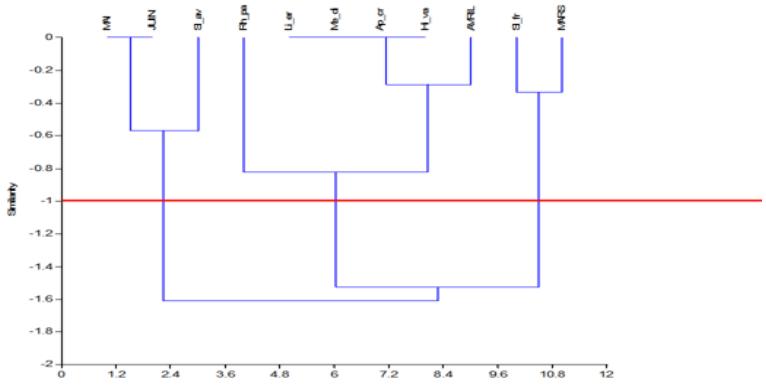
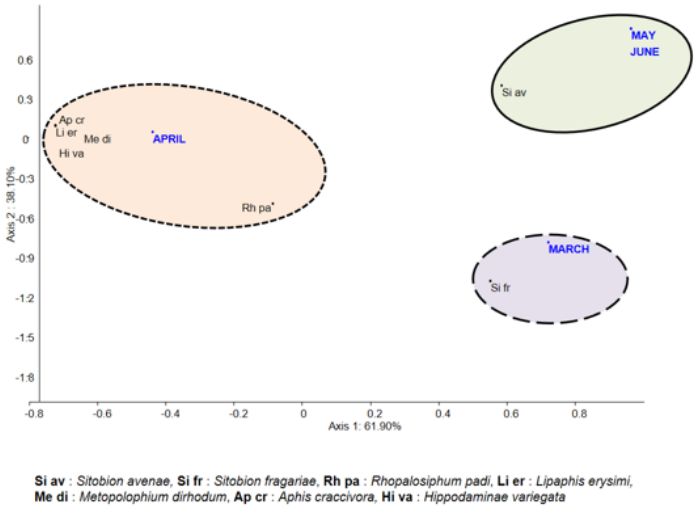


Figure 4. Principal Component Analysis (PCA) of the arthropod community sampled by Manual Shaking (MPS), revealing the temporal segregation of resident populations and the peak infestation.

Climate analysis (Figure 3) and PCA of MPS data (Figure 4) jointly establish the existence of a critical phenological mismatch [12], a phenomenon exacerbated in regions subject to significant spring temperature variations [23]. This mismatch is typical of systems subject to Mediterranean climate variability [24]. The failure of natural biological control is therefore not due to a lack of beneficial organisms, but to a lack of temporal synchronization. This phenomenon, aggravated by climate change [3], warrants particular attention to the phenological stages of wheat in order to target intervention.

Trophic Structure and Natural Biological Control Potential



Si av : *Sitobion avenae*, **Si fr** : *Sitobion fragariae*, **Rh pa** : *Rhopalosiphum padi*, **Li er** : *Lipaphis erysimi*, **Me di** : *Metopolophium dirhodum*, **Ap cr** : *Aphis craccivora*, **Hi va** : *Hippodaminae variegata*

Figure 5. Hierarchical classification analysis (dendrogram) of Manual Shaking (MPS) data, confirming the seasonal groupings of resident taxa and the phenological shift.

The complete inventory of arthropods (N=456) made it possible to calculate a Pest/Beneficial Ratio (P/B) of 1.71, confirming the quantitative dominance of pests (63.16%). The trophic complex included secondary pests (*Oulema melanopus*) and, significantly, hyperparasitoids (*Ceraphron sp, Asaphes sp*) representing 0.66% of the total abundance (Table 2).

Table 2. Trophic Structure of the Arthropod Community Associated with Durum Wheat Vegetation Cover

Trophic Category	Key Taxa	Total Abundance (N)	Relative Frequency (%)
Pests (P)	*S. avenae, R. padi, M. dirhodum*	288	63.16
Beneficial Insects (B)	*H. variegata, C. septempunctata,* Parasitized mummies	168	36.84
Key Trophic Metrics	Pest/Beneficial Ratio (P/B)	1.71	-

Caption: Abundance and structure of the arthropod community associated with durum wheat vegetation cover. Analysis reveals a severe trophic imbalance, quantified by a Pest/Beneficial Ratio (P/B=1.71), where the biomass of Pests is significantly higher than that of Beneficials. The pest complex is dominated by the key aphid Sitobion avenae (49.34% of the total community) and vectors (R. padi, M. dirhodum). Biological control relies mainly on Coccinellidae (H. variegata and C. septempunctata, >23% combined). The presence of hyperparasitoids (Ceraphron sp, Asaphes sp), representing 0.66% of the total abundance, indicates the existence of a third trophic level and a potential factor in the negative regulation of primary parasitism.

The severe trophic imbalance (R/A=1.71) is amplified by two structural factors: phenological shift (Section 5.3) and the existence of the third trophic level (hyperparasitoids), which act as negative regulators of primary parasitism [25]. The failure of biological regulation is thus multiple, highlighting the impact of agricultural practices on the resilience of the system [26]. Quantifying this imbalance using the R/A ratio is a recognized metric for assessing the performance of ecosystem services in wheat [27].
Trophic imbalance is symptomatic of a simplification of agroecosystems [14], requiring a reorientation of IPM towards the conservation of beneficial organisms.

Analysis of the Fungal Complex and Stratification of Infections Isolation

Frequency and Organic Distribution

A total of 49 fungal colonies were isolated and classified into seven distinct morphological genera. The distribution of isolates confirmed a marked ecological stratification , with a concentration in the upper zone (ears and rachis), representing 63% of isolates (N=31). The detailed isolation frequencies for each genus and zone are presented in Table 3.

Table 3. Distribution and frequency (number of isolates) of fungal genera according to the

anatomical zone of the wheat plant, and their main ecological role.

Incidence and

Fungal genus	Key Pathogenic Role	Basal Zone (N=10)	Intermediate Zone (N=13)	Upper Zone (N=26)
Fusarium spp.	Soil-borne / Fusariotoxins	5	0	0
Alternaria spp.	Aerial / Alternariol	1	3	4
Trichoderma spp.	Biocontrol / Antagonist	1	0	0
Other isolates	Saprophytes or miners	3	10	22

Differentiation of Ecological Niches

The stratification analysis reveals a dual health threat impacting grain quality. The strict confinement of Fusarium spp. to the basal zone (N=5) warns of the danger of Fusariotoxins (DON, ZEA) via systemic pathways [28]. The emergence of highly virulent strains of F. culmorum in Algerian cereal soils warrants increased surveillance [29]. Conversely, the concentration of Alternaria spp. warns of the risk of emerging mycotoxins (Alternariol, AOH), the monitoring of which is crucial given regulatory developments [30] and prevalence in regional studies [31]. The antagonist Trichoderma spp. highlights promising potential for natural biocontrol [32]; [33] against soil-borne pathogens.

Morphological Characterization and Diagnostic Evidence

The identification of the main fungal genera isolated was confirmed by careful analysis of cultural criteria and sporulation structures, a summary of which is presented in Table 4.

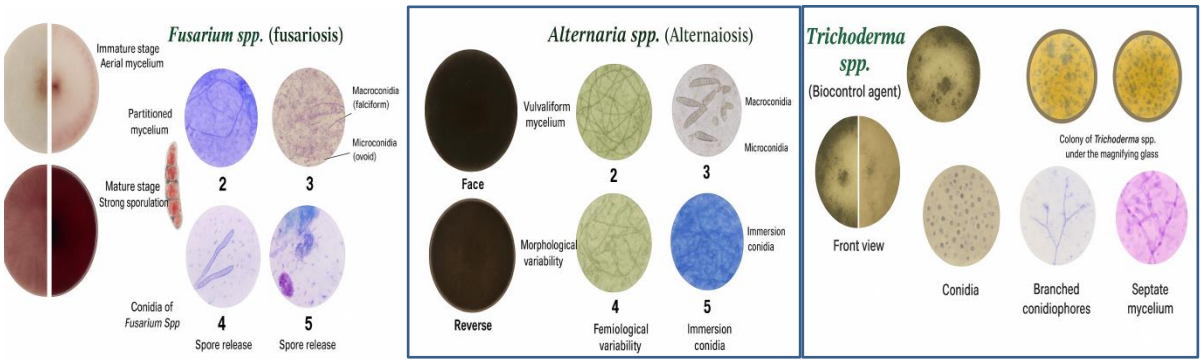
Table 4. Summary of morphological identification characteristics of the main fungal genera isolated.

Fungal Genus	Key Ecological Role	Predominant Location	Main Impact on Cereals
Fusarium spp.	Major soil-borne pathogen	Basal zone (roots/collar)	Fusarium wilt, production of DON/ZEA (mycotoxins)
Alternaria spp.	Opportunistic pathogen	Ears and Grains	Black Point, Alternariol production (emerging mycotoxins)
Trichoderma spp.	Antagonist (Biocontrol)	Isolated in all areas	Potential for biological control against pathogens
Epicoccum spp.	Saprophyte	All areas	Indicator of necromass and general biodiversity

The limitations of morphological identification are evident here. Although it provides diagnostic evidence of the genera, it is insufficient for assessing toxicogenic risk. Taxonomy at the genus level does not allow us to infer the ability of strains to produce specific mycotoxins. The analysis must therefore be supplemented by molecular biology (sequencing of ITS and TEF1-α genes) to quantify the toxicogenic potential of strains, which is an academic imperative for robust health conclusions [34]. Recent work in North Africa highlights the need to use TEF1-α to discriminate between the biodiversity of Fusarium species associated with wheat, which is often masked by conventional methods [35]. The integration of morphology and genetics is the standard for effective risk management.

The differential diagnosis was then established by microscopic examination (400x magnification), confirming the key structures (Figure 6):
-*Fusarium spp.*: The soil-borne pathogen was confirmed by the abundance of fusiform and multiseptate (crescent-shaped) macroconidia (A).
-*Alternaria spp.*: This opportunistic genus was identified by large pigmented conidia, characterized by transverse and longitudinal septa (muriform) that give them a club-like appearance (B).
-*Trichoderma spp.*: The antagonist was recognized by the formation of bulbous phialides bearing clusters of green or hyaline spores (C).

Finally, the identification of the non-cultivable biotroph, *Puccinia spp.* (rust), was definitively established by direct observation of pustules and the morphology of uredospores , highlighting the need to integrate in situ diagnostics beyond culture methods alone to map the full pathological spectrum of the agroecosystem.



(A) (B) (C)

Figure 6. Morphological characterization of the main fungal genera isolated from durum wheat. (A) *Fusarium spp*. (colony and falciform macroconidia), (B) *Alternaria spp.* (colony and multiseptate conidia), and (C) *Trichoderma spp.* (colony and sporulating phialides).

Conclusion

The integrated assessment of biotic pressure on 'TARGUI' durum wheat in Oued Semmar shows that phytosanitary threats are not random, but result from temporal desynchronization and spatial segregation of aggressors, exacerbated by climatic conditions. Entomological analysis revealed the criticality of the early peak abundance of *Sitobion avenae*, whose sucking during the stem elongation phase directly compromises grain formation. A major contribution of this work lies in the quantification of a severe trophic imbalance, reflected in a Pest/Beneficial Ratio (P/B) of 1.71 and a significant phenological shift between the pest and its natural enemies. This

imbalance is the main obstacle to effective biological control through conservation. Mycological work confirmed a clear ecological stratification of threats. The telluric threat is limited to the genus *Fusarium*, isolated only in the zone basal, highlighting the predominant influence of soil conditions on primary inoculum. Conversely, the aerial threat is dominated by *Alternaria spp.*, concentrated on the ears. This location is of paramount importance for food safety, as it identifies a high risk of contamination by Alternariol and other emerging mycotoxins on maturing grain. However, the joint identification of the antagonist *Trichoderma spp.* opens up concrete avenues for the endogenous biocontrol of these pathogens.

The demonstration of a biotic-abiotic nexus (Aphid-Virus-Fungal-Climate), where the incidence of secondary infections is exacerbated by vector pressure and climate desynchronization, confirms the inadequacy of single-criterion management. These results call for the urgent adoption of agroecological resilience strategies based on a holistic understanding of the system.

Perspectives

In order to transform this fundamental knowledge into operational strategies for sustainable Integrated Pest Management (IPM), future research must focus on several key areas. The top priority is to go beyond morphological identification for risk validation. It is imperative to consolidate the taxonomy of fungal isolates through molecular analysis (sequencing of ITS and TEF1-α genes), the only method that can reliably assess the actual toxinogenic potential of Fusarium and *Alternaria* species. At the same time, the circulation of BYDV must be validated by quantitative RT-PCR in order to establish the viral load and the epidemiological correlation with the prevalence of the virus. In terms of IPM, research efforts must focus on correcting the phenological shift of beneficial insects. This involves eco-phenological modeling of pest-beneficial insect pairs, enabling the development of decision support tools (DSTs) to optimize release schedules or habitat management (such as the establishment of flower strips). Finally, an in-depth study of the antagonist *Trichoderma spp.* isolated from the soil environment is necessary. The molecular characterization of its local strain and the evaluation of its in vivo efficacy against local *Fusarium* species could constitute a promising biocontrol solution for the biological management of crown rot. This work lays the foundations for multi-risk ecological monitoring, providing the empirical data essential for the agroecological transition of the durum wheat sector in the region.

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