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PHYTOSANITARY MONITORING OF STEM RUST (*PUCCINIA GRAMINIS* PERS.) AND OTHER FUNGAL DISEASES OF SPRING BARLEY IN SOUTH-EASTERN KAZAKHSTAN

ZH. TILEUBAYEVA¹, K. GALYMBEK², A. SEILKHAN², S. BAKIROV^{2*}, and A. SARDAR^{3*}

¹Al-Farabi Kazakh National University, Almaty, Kazakhstan

²Abai Kazakh National Pedagogical University, Almaty, Kazakhstan

³Kazakh Scientific Research Institute of Plant Protection and Quarantine named after Zh. Zhiembayev, Almaty, Kazakhstan

*Corresponding authors' emails: serikbakirov95@gmail.com, aizhan.888sardar@gmail.com

Email addresses of co-authors: tileubayeva_kz@mail.ru, kanat.galymbek@mail.ru, ainura_seilkhan@mail.ru

SUMMARY

Barley (*Hordeum vulgare* L.) is one of the most important crops, extensively cultivated in various countries worldwide. It plays a crucial role in the food sector, livestock farming, and the brewing industry, with its drought tolerance proving its cultivation in various climatic zones. The barley's economic values reveal distinction in the versatility of its byproducts: uses of grains serve as feed and as a raw material in the food industry, while its straw has become a promising source of biomass and cellulose for energy and industrial needs. Barley yields in Kazakhstan and globally received considerable effects from the occurrence of various fungal diseases. Rust, *Helminthosporium* leaf spot, and *Fusarium* wilt cause significant reduction in crop quality and quantity, resulting in enormous economic losses. Therefore, the consequent study transpired on a typical spring barley plot in Southeastern Kazakhstan. Using a route-based phytosanitary survey, the study identified main types of fungal infections as well as assessed their further development based on prevalence and intensity. The data on the climatic conditions, such as temperature, humidity, and precipitation, garnered recordings throughout the growing season, allowing us to determine their impact on the development and progression of fungal diseases.

Keywords: Barley (*H. vulgare* L.), fungal diseases, monitoring, yield, epiphytotic, rust, yellow spot, dark brown spot, powdery mildew

Key findings: The determination of the phytopathological state of spring barley (*H. vulgare* L.) agroecosystems succeeded in the development of a multicomponent complex of the fungal pathogens. Analysis of the disease dynamics based on the phases of ontogenesis revealed the greater intensity of the pathological process mostly occurs during the plant booting and heading stages.

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INTRODUCTION

Barley (*Hordeum vulgare* L.) is an important crop, widely cultivated worldwide. According to the Food and Agriculture Organization (FAO), barley production has consistently exceeded 140 million tons per year in previous years globally (Baik and Ullrich, 2008; FAOSTAT, 2025). Among the grain crops, barley occupies a key position by meeting food, feed, and industrial needs in various countries around the world (Çelik-Oğuz and Karakaya, 2021). However, the sustainability of its production faces considerable limitations with the impact of biotic stresses, primarily fungal diseases, which is one of the main causes of crop losses on the global scale (FAOSTAT, 2025).

According to summarized data procured from the phytopathological studies worldwide, barley yield losses from fungal pathogens ranged from 10% to 30%, and in crop seasons with epiphytotics and outbreaks, this can reach 50%–70% (Rezvitsky *et al.*, 2021). These figures emerged as comparable with the losses obtained from the most risky abiotic factors and emphasized the strategic importance of the problem for global food security. Previous studies reported that plant diseases remain one of the least controllable factors, despite the high level of development in agricultural technologies (Oerke, 2006; Savary *et al.*, 2019).

In barley, the fungal diseases show characteristics of the highest ecological plasticity and the ability to quickly adapt to changing environmental conditions. The causative agents of rusts (*Puccinia graminis* and *Puccinia striiformis*), leaf spots (*Pyrenophora teres* and *P. graminea*), root rots (*Bipolaris sorokiniana*), and powdery mildew (*Blumeria graminis*) are mostly common in the regions where the crop growing prevails. The diseases' harmfulness manifests itself through decreasing grain yield but also deteriorates the quality and technological properties, which are most crucial for the malting and fodder use of barley (Balducci *et al.*, 2025). Leaf damage leads to a decrease in photosynthetic activity, a considerable reduction in the accumulation of assimilates, and their transport to the reproductive organs, which eventually affects

grain yield in barley (Semenova *et al.*, 2021; Zhunusova and Sarbaev, 2022).

Spring barley (*H. vulgare* L.) cultivated in Southeastern Kazakhstan is highly susceptible to a wide range of economically significant fungal diseases, and the most widespread and damaging are the rust diseases and helminthosporiosis. The early onset and the combined development of these fungal diseases lead to a significant increase in the infectious background of pathogens in field agrobiocenoses (Zhumagulova *et al.*, 2019; Sardar *et al.*, 2022; Amangeldikyzy *et al.*, 2023; Madenova *et al.*, 2021).

The development of mixed infections, in which the combined harmful effects of various pathogens significantly exceed the effect of their isolated manifestation, poses a particular danger (FAO, 2012; Walters *et al.*, 2012; Assefa *et al.*, 2021). Currently, there are no spring barley cultivars in the production system that own stable economic resistance to these fungal diseases. As a result, the meteorological conditions develop the favorable conditions for the intensive development of obligate and facultative pathogens, which can lead to epiphytotics and significant yield losses.

Therefore, preventing widespread disease outbreaks, replacing susceptible cultivars with more resistant ones, and implementing scientifically sound chemical plant protection measures are particularly crucial. The presented study sought to carry out a route-based phytosanitary survey of the main fungal infections and their further development based on prevalence and intensity in the spring barley in Kazakhstan.

MATERIALS AND METHODS

Spring barley (*H. vulgare* L.) crops and the fungal diseases affecting this crop were the study materials used. The research proceeded using a local phytosanitary monitoring method, which allowed for an objective assessment of the spread and development of fungal diseases in the barley fields (Geshele, 1961; Shutko and Tuturzhans, 2018). For investigating the fungal pathogens in spring barley crops, the study

identified several sampling plots within the experimental fields. The recording of data on the fungal diseases used the route method.

Barley plants sampled sustained analysis every 25–50 steps, with 10–15 stems (with leaves) analyzed at each sampling point. The total number of samples was 10–15 samples per plot. In case of a uniform distribution of the disease, sampling continued at an interval of 25–50 m from the edge of the field, with samples taken from the central part of the crop (200–300 m from the field boundary) based on the triangular or rectangular pattern. In case of uneven distribution of the infection of various diseases, taking samples was according to a checkerboard pattern, which allowed for a more accurate reflection of the phytopathological conditions of the crops.

During the monitoring period, the research determined two indicators: distribution (or the number of affected plants in the specific area of the crop) and the intensity (or degree) of infection development in that study area. Disease distribution (P) determination used the formula of Koishibaev (2002). The intensity of the fungal diseases' development in the spring barley crop reached assessment on a six-point scale based on the percentage of the affected leaf surface area following the methodology of Geshele (1961). The data on climatic factors required for the study came from the meteorological station of the RSE "Kazhydromet" (<https://www.kazhydromet.kz/ru/branches/14>).

RESULTS AND DISCUSSION

Given the relevance of the said problem, a study took place in the Kumaraly rural district on the production crops of peasant farms (PF) and the Nazerenko PF, located in the foothills of Southeastern Kazakhstan. It assessed the distribution and dynamics of fungal diseases in spring barley (*H. vulgare* L.). The spring barley cultivar Baisheshek, widely cultivated in the region, served as the research object.

The primary observations occurred in two experimental plots. The first experimental plot has its location in the Kumaraly Village,

peasant farm 'Kumaraly,' with a sowing area of 10 hectares and an absolute altitude of 827 m above sea level (coordinates N 43°13'14", E 76°30'41"). The second experimental plot sat within the village of Enbekshi, peasant farm 'Enbekshi,' with a sowing area of 16 hectares and an altitude of 810 masl (coordinates N 43°13'90", E 76°30'37"). Field monitoring primarily proceeded during the main phenological growth stages of the crop—tillering, heading, and grain-filling—considering the prevalence (P, %) and disease severity (R, %) of the major fungal pathogens. The obtained results showed the highest levels of disease prevalence and severity were evident during the heading and grain-filling stages. These findings are consistent with previous studies indicating an increase in the intensity of fungal infections during the formation of generative organs and the accumulation of assimilates in developing grains (Chen, 2005; Zhang et al., 2014).

An enormous infection of the flag leaf with yellow rust (*Puccinia striiformis*; P = 37.86%, R = 17.65%) entailed recording, as well as the prevalence of stem rust 'uredinia' (*P. graminis*; P = 24.6%, R = 9.21%), revealing the commencement of intensive secondary infection cycles (Table 1). In parallel, an increase in the development of dark brown spot (*B. sorokiniana*; P = 38.36%, R = 21.6%) and net spot (*P. teres*; P = 35.14%, R = 15.85%) was also prevalent. However, the powdery mildew (*E. graminis*) had a limited prevalence (P = 11.7%, R = 8.56%). Dark brown spots caused by the fungal species *B. sorokiniana* during the plant's heading stage showed features of a considerable enhancement in the area of necroses and their merging, leading to premature death of the leaf blade sections. The highest phytosanitary stress levels were notable during the grain-filling phase (in June) with high temperatures (25 °C–27 °C), precipitation deficit conditions (5–10 mm), and decreased air humidity (40%–45%). During this period, the fungal species *B. sorokiniana* reached P = 55.45% and R = 31.2%, and *P. teres* scored P = 50.21% and R = 36.12%, forming an epiphytotic nature of the lesions. Rust diseases were characteristic of moderate

Table 1. Monitoring the spread and intensity of development of fungal diseases of spring barley crops in 2024–2025.

Rural district, peasant farm	Coordinates	Plant development phase	<i>Puccinia graminis Pers.</i>		<i>Puccinia striiformis f. sp. tritici Erikss.</i>		<i>Bipolaris sorokiniana (Sacc.) Shoemaker</i>		<i>Pyrenophora teres</i> Drechsler		<i>Drechslera graminea Shoemaker</i>		<i>Blumeria graminis f. sp. hordei</i> Em. <i>Marchal</i>	
			P	R	P	R	P	R	P	R	P	R	P	R
			Disease prevalence rate, %. 2024											
Uzynagash, "Nazerenko" Farm	N43°12'20", E 76°21'67"	Tillering	0	0	0	0	21.12	14.5	13.81	3.69	13, 54	3.02	0	0
		Earring	20.5	10.56	40, 4	20, 81	45.14	25.3	30.52	13, 36	30, 44	16, 33	16.7	6.32
		Grain-filling phase	15.1	7.57	30, 22	15, 11	60.32	37.6	55, 63	30, 44	31, 08	15, 87	30.6	12, 52
Kumaraly Village, "Kumaraly" Farm	N 43°13'14", E 76°30'41"	Tillering	0	0	0	0	19.07	11.2	16.08	4.12	16.22	5.21	0	0
		Earring	24.6	9.21	37.86	17.65	38.36	21.6	35.14	15, 85	33.85	19.75	11.7	8.56
		Grain-filling phase	13.1	5.04	28.54	12.09	55.45	31.2	50.21	36.12	35.87	17.15	33.7	16.04
Disease prevalence rate, %. 2025														
Uzynaghash Village, "Nazerenko" Farm	N43°12'20", E 76°21'67"	Tillering	0	0	15.61	5.58	26.65	14.2	11.79	5.12	9.45	5.66	0	0
		Earring	3.11	0.24	61.88	38.64	47.11	28.7	16.32	13.63	24.36	12.44	12.9	6.31
		Grain-filling phase	2.04	0.06	15.33	9.64	65.63	41.6	36.45	31.21	36.78	18.56	24.2	11.25
Kumaraly Village, "Kumaraly" Farm	N 43°13'14", E 76°30'41"	Tillering	0	0	10.75	4.45	20.63	10.8	10.25	5.85	9.32	4.77	0	0
		Earring	6.11	1.12	41.21	33.68	38.75	24.7	19.68	14.08	22.61	15.63	14.9	6.68
		Grain-filling phase	3.98	0.69	8.25	8.57	49.63	33.4	43.64	26.46	35.76	20.64	27.7	12.55
Note: P – disease prevalence, R – disease damage.														

Note: P – disease prevalence, R – disease damage.

and reduced levels of spread and development. The obtained results are consistent with studies showing that *B. sorokiniana* and *P. teres* actively develop under high temperatures and moisture deficiency, whereas the intensity of rust diseases may decrease under dry conditions (Mathre, 1997; Chen, 2005).

Thus, the prevalence of the fungal species *P. graminis* was 13.1% with a development of 5.04%, while *P. striiformis* manifested itself with a moderate prevalence (28.54%) and a low level of prevalence (12.09%) (Table 1). During the heading phase, the complex damage of the flag leaf by rust and spot diseases led to a noteworthy decrease in photosynthetic activity, disruption of

carbohydrate metabolism, and weakening of transpiration processes. Hence, the heading phase in the crop season of 2024 became a critical point in the epiphytotic development of the pathogenic complex, determining the transition from the background level of damage to the intensive spread of diseases. This had a direct impact on the yield and quality traits of barley grains. Similar findings have emerged in reports by other authors, indicating that combined infection of the flag leaf by rusts and leaf spot diseases significantly reduces photosynthetic activity and barley yield productivity (Savary *et al.*, 2006).

With an optimum temperature of +10 °C–18 °C and high relative humidity (60%–70%), the response of *Puccinia striiformis* Westend., characterized as a mesophilic biotroph (Chen, 2005), also deserves special attention. However, at temperatures above +22 °C–25 °C and low humidity, the rate of the urediniospore germination and the formation of secondary infection cycle gained general suppression. Nevertheless, in 2024 conditions in Southeastern Kazakhstan (temperatures 25 °C–27 °C; relative humidity 40%–45%), a moderate prevalence of yellow rust manifested even under xerothermic conditions during the grain-filling phase. The prevalence of fungal pathogen *P. striiformis* was 28.54%, with a relatively low disease development rate ($R = 12.09\%$), revealing the limited epiphytotic activity with no intense secondary infection cycle (Table 1). However, this reaction can be due to several factors. Firstly, the modern research enunciated that the fungus *P. striiformis* population exhibited an expanded temperature range for the development and partial adaptation to higher temperatures, especially in regions with a continental climate (Mboup et al., 2012). However, this showed an association with the genetic variability of pathogen races and their selection under climate change conditions. Secondly, the crop microclimate plays a significant role. Even with high average daily temperatures, short-term temperature drops at night and the formation of dew can develop locally favorable conditions for fungus infection (Zadoks et al., 1974). Thirdly, the moderate development of the disease may have an association with the plant's phenological stage. During the grain-filling phase, the physiological activity of the leaf apparatus decreases, limiting the resource base for the biotrophic pathogen and reducing the intensity of further infection (Chen, 2005).

The presented results necessitate a comprehensive analysis of the epiphytotic process, based on the daily dynamics of temperature and humidity as well as the genetic structure of pathogen populations (Figure 1). Powdery mildew (*Blumeria graminis* f. sp. *hordei*) manifested itself during the heading stage as a gray-white powdery coating

on the leaves and leaf sheaths, comprising dense mycelium and conidial sporulation of the pathogen. Striped spot (*Pyrenophora graminea*) expressed itself as the formation of longitudinal brown necrotic streaks on plant leaves, oriented along the veins of the leaf blade. Similar symptoms and developmental characteristics of these pathogens in barley had previous descriptions from Mathre (1997) and Walters et al. (2012), who emphasized the strong dependence of disease intensity on weather conditions during the heading stage.

In the agrocenoses of Southeastern Kazakhstan in 2024, the formation of a highly active multicomponent pathocomplex of fungal diseases developed a significant and persistent phytosanitary pressure on spring barley crops (Figure 2). In Southeastern Kazakhstan, unlike 2024, the 2025 growing season revealed attributes of an early transition of average daily temperatures through biological zero (+5 °C) in early March and a steady increase in relative air humidity (60%–75% during April–May). This transformed the structure and dynamics of the phytopathogenic complex development in agrocenoses of spring barley. According to phytopathological monitoring survey data, dark brown spots of *B. sorokiniana* were the dominant pathogen during the tillering stage, with a prevalence of $P = 26.65\%$ and $R = 14.2\%$, revealing the highest level of background infestation. Lesions also indicated predominant localization in the lower leaf layer, where limited air exchange developed the microzones with increased humidity, facilitating the intensive development of the pathogen. Simultaneously, recording the first signs of net spot (*Pyrenophora teres*) occurred, with a prevalence of $P = 11.79\%$ and $R = 5.12\%$. The absence of biotrophic fungal pathogens (*P. graminis*, *B. graminis*; $P = 0$; $R = 0$) also confirmed that during the initial period of vegetation, the infectious background's development was primarily due to necrotrophic pathogens (Figure 3). Comparable findings came from reports of Tomić et al. (2024), who noted that increased air humidity and moderately warm conditions promote the active development of *Pyrenophora teres* and intensify the infectious background in barley crops.

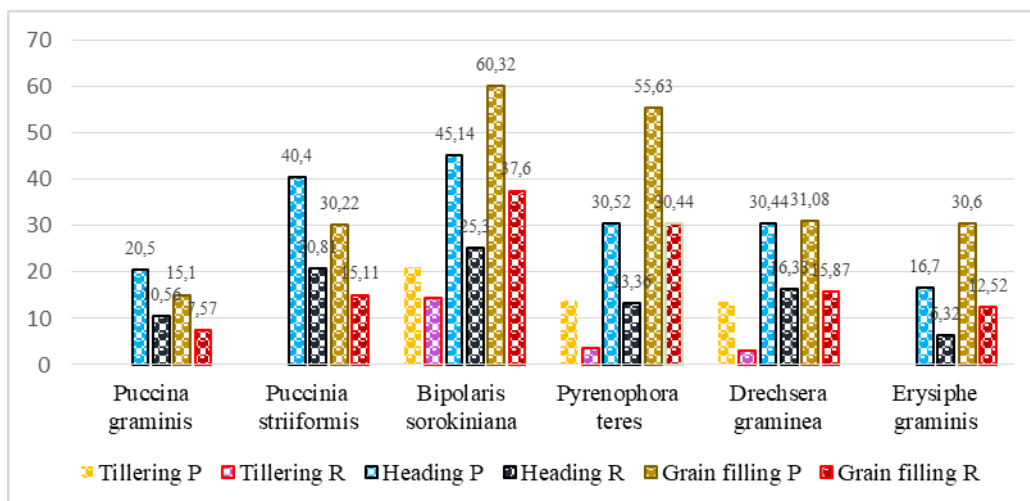


Figure 1. Phytopathological monitoring of the spread and development of fungal diseases in spring barley crops in 2024 (Nazerenko farm).



Figure 2. Spread and development of pathogens causing fungal diseases in spring barley crops in 2024 (Nazarenko farm, Kumaraly farm).

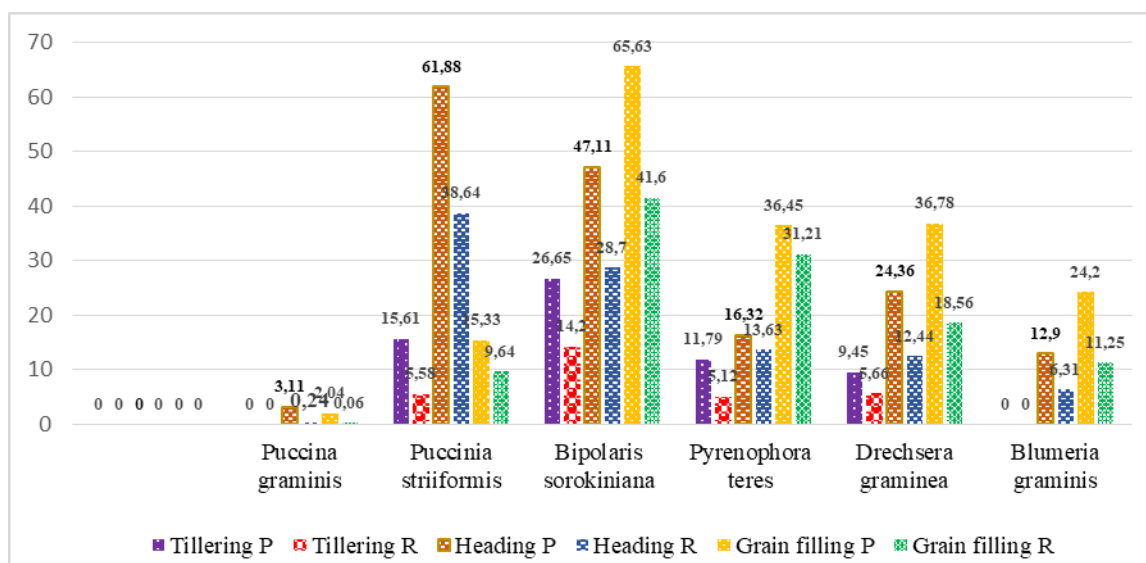


Figure 3. Monitoring the development and spread of fungal diseases of spring barley (2025).

During the plants' heading phase, average daily air temperature remained stable within the range of +20 °C–+23 °C, and relative air humidity was 65%–70%, corresponding to the physiological optimum for sporulation and secondary infection of both biotrophic and necrotrophic phytopathogens. During the growing season, the climatic conditions were generally favorable for the germination of urediniospores and conidia of phytopathogens. However, regarding stem rust, the conditions were not favorable for the secondary infection cycles and the formation of an epiphytotic focus. The prevalence of the disease was slow: the prevalence of *P. graminis* was only 0.24% and did not exceed 3.11% (Table 1). The development of *P. striiformis* displayed features of the highest level (P = 61.88% with R = 38.64%). The level of development of *B. sorokiniana* had characteristics of values of P = 47.11% and R = 28.7%, which confirmed it as the dominant necrotrophic component of the epiphytotic complex. The necrotic lesions covered a significant portion of the assimilatory surface of leaves in the middle and upper tiers, forming extensive zones of premature tissue death. The powdery mildew caused by *B. graminis* demonstrated a reduced level (P = 12.9% with R = 6.31%). The obtained results were

consistent with the findings of Tini *et al.* (2022), who reported that moderately warm temperatures and increased air humidity promote the active development of *P. teres* and intensify secondary infection cycles in barley crops.

During the crop season of 2025, the grain-filling phase was the physiologically most vulnerable stage of spring barley development, during which the crop's potential yield achieved optimum. In June, average daily air temperature consistently ranged between 24 °C and 27 °C, and relative humidity was 55%–60%. The fungus *B. sorokiniana* reached the highest prevalence (P = 65.63% and R = 41.6%), suggesting that the said pathogen was the absolute dominant agent of the epiphytotic complex during the grain-filling phase (Table 1). The *Pyrenophora teres* prevalence during the grain-filling phase was high (P = 36.4% at R = 31.21%), enunciating a pronounced epiphytotic potential of the pathogen. The lesions were prominent in the reticular necrotic patterns covering a significant portion of the leaf surface. The fungus *Drechslera graminea* development and prevalence during the grain-filling phase were moderate (P = 24.2% at R = 11.25%). The fungus *Blumeria graminis* development during the grain-filling phase was characteristically moderate but with

phytopathologically significant values ($P = 24.2\%$ and $R = 11.25\%$), revealing its persistent activity even at low air humidity. The infection concentrated primarily in the upper layer of the flag leaf, where temperatures ($+23\text{ }^{\circ}\text{C}$ – $+25\text{ }^{\circ}\text{C}$) and relative humidity (45%–50%) developed microclimatic conditions, which proved favorable for sporulation and secondary infection of the pathogen. Symptoms of net and striped leaf spots (*P. teres*, *P. graminea*) reached a wide recording on mid- and upper-tier leaves, manifesting as elongated chlorotic-necrotic stripes oriented along the veins. The dark brown leaf spots caused by *B. sorokiniana* were distinctly a widespread development and manifested as numerous necrotic spots with a pronounced chlorotic border, prone to merging (Figure 3). Taliadoros *et al.* (2024) highlighted the increasing importance and widespread distribution of *Pyrenophora teres* as one of the major pathogens affecting barley worldwide. Moya-Elizondo *et al.* (2013) also reported that favorable microclimatic conditions within the crop canopy can support pathogen sporulation and secondary infection even under relatively dry environmental conditions.

On the barley stems and leaf sheaths, massive outbreaks of stem rust (*P. graminis*) were visible, accompanied by the formation of dense uredinial pustules and the destruction of vascular tissue. Yellow rust (*P. striiformis*)

primarily affects the flag and sub-flag leaves, forming linear rows of bright yellow uredinial pustules (Figure 4). By comparing the phytopathological studies conducted in 2024 and 2025, significant differences were notable in the development and prevalence of the fungal diseases in spring barley. However, the variations in fungal diseases showed a direct association with the contrasting agrometeorological conditions of the growing seasons (Figures 5 to 7) as well as the dynamics of the initial infection in agroecosystems. In 2024, the crop's growth period occurred under relatively moderate temperature and limited moisture, most pronounced in the late spring and early summer. During the tillering phase, biotrophic pathogens, including yellow and stem rust, as well as powdery mildew, were undetected, while determining the phytosanitary condition of the crop occurred primarily by the activity of necrotrophic *Helminthosporium* fungi. According to Chen (2005), the development of rust diseases in barley largely depends on the hydrothermal conditions of the growing season and may vary considerably between years. Taliadoros *et al.* (2024) also highlighted the high ecological adaptability of *Pyrenophora teres*, which enables the pathogen to maintain its infectious potential under diverse agroclimatic conditions and persist in barley-growing regions.



Figure 4. Monitoring the spread and development of fungal pathogens in 2025.

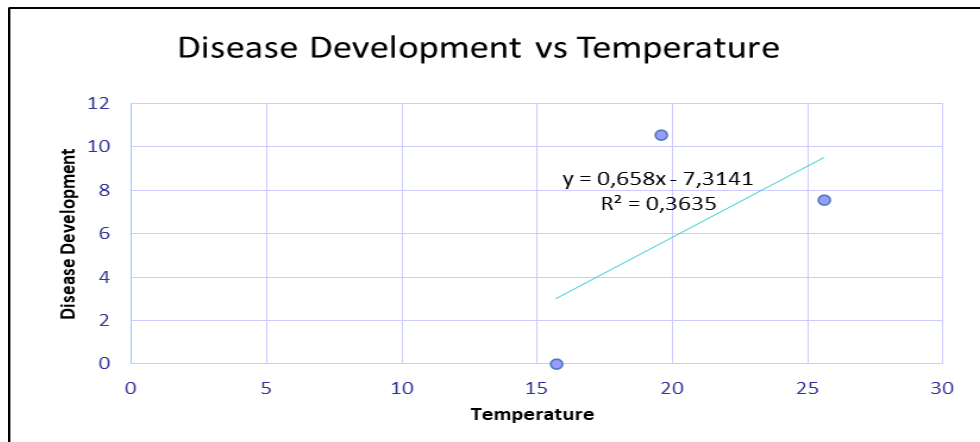


Figure 5. Correlation between the development rates of the disease caused by *Puccinia graminis* and temperature indicators during 2024.

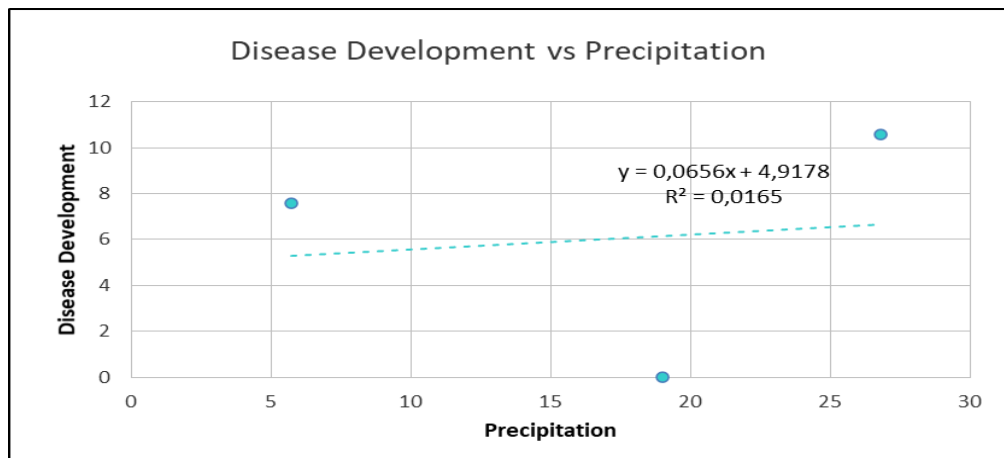


Figure 6. Correlation between the development rate of the disease caused by *Puccinia graminis* and the precipitation rate during 2024.

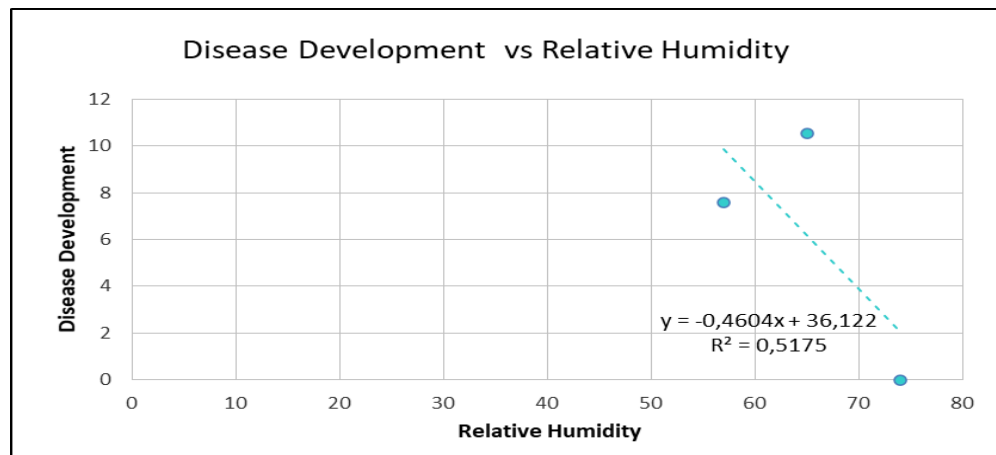


Figure 7. Correlation between the development rate of the disease caused by *Puccinia graminis* and the humidity indicator during 2024.

In 2025, the phytosanitary situation developed differently. Increased air humidity in March and April, along with the earlier onset of stable positive temperatures, contributed to the accelerated accumulation of primary infectious potential in the early stages of crop development. Past studies also confirmed the intensification of phytopathological processes in spring barley agroecosystems and the complex development of several types of fungal pathogens. Backes *et al.* (2021) reported the high humidity and moderate temperature intensify the secondary infection cycle in the fungus *Pyrenophora teres*. This was entirely consistent with these present results on the intensive development of net blotch during the plants' booting and heading phases.

CONCLUSIONS

During the barley crop seasons of 2024 and 2025, relatively mild temperatures in early spring facilitated uniform emergence and development of spring barley (*H. vulgare* L.) vegetative mass. However, in the crop season of 2025, the increased precipitation and humidity in April and May led to prolonged moisture retention on the leaf surface, developing favorable conditions for the formation of primary foci of fungal infection. During this period, young plant tissues proved more susceptible to infection, which crucially contributed to the rapid early development of necrotrophic fungal pathogens, such as *B. sorokiniana*, *P. teres*, and *D. graminea*. In the crop season of 2024, the development of fungal diseases was relatively low due to a more stable hydrothermal regime. In contrast, in 2025, the enhanced spring humidity combined with temperature stress in early summer accelerated the spread of fungal diseases and increased phytopathological pressure. This led to the deterioration in the phytosanitary condition of barley crops, weakened plant physiological conditions, and eventually reduced the yield potential.

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