

The influence of weather changes on wheat seed mycosis in the Transylvanian Plateau

Influența schimbărilor meteorologice asupra prezenței agenților patogeni pe semințele de grâu în podisul Transilvaniei

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ABSTRACT

Wheat grains can be infected by a number of pathogens throughout their development, from the initial stages of flowering and pollination and up to the time of harvest, which can lead to quantitative and qualitative deterioration of the seeds. The present study was conducted at Agricultural Research and Development Station Turda, Cluj, Romania, from 2018/2019 to 2022/2023 growing seasons, to evaluate the health status of seeds from six wheat varieties. Using the moist chamber method, the seeds obtained after harvesting were analyzed for the presence of pathogens on the seeds. The pathogens that developed on the seeds were identified macroscopically and microscopically based on their morphological characteristics and the data obtained were quantified and statistically processed. The most present pathogens associated with wheat seeds were *Fusarium* and *Alternaria*, known for their mycotoxin production. The results of the study indicate that weather variability, particularly increased temperature and irregular rainfall patterns, has contributed to higher fungal pathogen prevalence in wheat seeds. The highest fungal infection rates were recorded in 2023 (68.8%), coinciding with excessive rainfall. In contrast, 2021 (28.8%) had the lowest infection rates, likely due to drier conditions. This suggests that prolonged wet weather promotes the development and spread of pathogens, while drier years limit it.

Keywords: winter wheat, *Fusarium* sp., *Alternaria* sp., weather conditions

REZUMAT

Boabele de grâu, pe parcursul dezvoltării lor, începând din stadiile inițiale de înflorire și polenizare și până la momentul recoltării, pot fi infectate de o serie de agenți patogeni ceea ce poate duce la deteriorarea cantitativă și calitativă a semințelor. Studiul de față a fost realizat la Stațiunea de Cercetare-Dezvoltare Agricolă Turda, județul Cluj, România, în sezoanele de vegetație 2018/2019–2022/2023, cu scopul de a evalua starea de sănătate a semințelor provenite din șase soiuri de grâu. Prin metoda camerei umede, semințele obținute după recoltare au fost analizate pentru prezența agenților patogeni. Agenții patogeni dezvoltați pe semințe au fost identificați macroscopic și microscopic pe baza caracteristicilor morfologice, iar datele obținute au fost cuantificate și prelucrate statistic. Cei mai frecvenți patogeni asociați cu semințele de grâu au fost *Fusarium* și *Alternaria*, cunoscuți pentru capacitatea lor de a produce micotoxine. Rezultatele studiului indică faptul că variabilitatea condițiilor meteorologice, în special creșterea temperaturilor și distribuția neregulată a precipitațiilor, a contribuit la o incidență mai ridicată a patogenilor fungici în semințele de grâu. Cele mai mari procente de infecție fungică au fost înregistrate în anul 2023 (68,8%), care s-au suprapus cu o perioadă de precipitații excesive. În contrast, anul 2021 (28,8%) a avut cele mai scăzute procente de infecție, probabil din cauza condițiilor mai uscate. Aceste rezultate sugerează că perioadele prelungite de umiditate favorizează dezvoltarea și răspândirea agenților patogeni, în timp ce anii mai secetoși o limitează.

Cljučne riječi: grâu de toamnă, *Fusarium* sp., *Alternaria* sp., condițiile vremii

INTRODUCTION

Wheat (*Triticum aestivum* L.), a cereal crop present in 70% of the world's cultivated regions, has been a staple food for millions of people for centuries and has played a crucial role in the evolution of human civilisation (Gohar et al., 2022; Khalid et al., 2023). In addition to proteins with unique physical and chemical attributes, wheat grains contain minerals (Cu, Mg, Zn, Fe, and P) and vitamins (riboflavin, thiamine, niacin, and alpha-tocopherol), being the main nutrient for almost 40% of the world's population, makes this crop key and contributes to global food and nutritional security (Shiferaw et al., 2013; Khalid et al., 2023). In addition to providing 20% of the daily protein and food calories, wheat is an integral part of the livelihoods of nearly 80 million farmers, underscoring its socio-economic importance in the agricultural sector (Giraldo et al., 2019). Being one of the important cereal crops globally, any disease that affects its productivity and production quality can have serious consequences on food security and economic stability (Juroszek and Tiedemann, 2012; Miedaner and Juroszek, 2021; Feurtey et al., 2023). Annually, wheat crops face various pathogenic threats, such as fungi, bacteria, and viruses, which can significantly reduce the quantity and quality of the crops (Aredo and Ambaye, 2020; Obembe et al., 2021).

One of the greatest challenges of the 21st century is climate change, which has a significant impact on agriculture globally. Increasing average temperatures, changing precipitation patterns (which were regular and timely, gentle and sustained, sufficient during growth stages, low during harvest, stable from year to year) and extreme weather events are directly and indirectly affecting the quantity and quality of wheat production. Wheat is vulnerable to the effects of weather change, in terms of plant health, especially diseases that can affect the ear, a crucial element in the formation of the crop (Le Gouis et al., 2020; Prasad et al., 2021). Due to climate change, pathogens can evolve to survive in warmer environments, which can make diseases more common and harder to control. As a result, it becomes more challenging for

scientists to breed wheat varieties that can resist these diseases, ultimately threatening wheat production (Esse et al., 2019). Understanding how diseases emerge and how pathogens adapt is very important for developing effective management strategies that ensure long-term food security (Montes et al., 2022). As climate change persists, temperature increases and variable distribution of precipitation may exacerbate wheat seed diseases, leading to greater vulnerability and production losses due to more severe and widespread pathogen outbreaks (Tang et al., 2017; Aredo and Ambaye, 2020; Miedaner and Juroszek, 2021; Bajwa et al., 2020; Pequeno et al., 2024). Climate change can influence the distribution and severity of the most common and damaging pathogens of wheat seeds, such as *Fusarium* sp., *Blumeria graminis*, *Puccinia* sp., *Pyrenophora tritici-repentis* and *Alternaria* sp., by creating more favourable conditions for their proliferation and survival, leading to increased disease frequency and intensity and decreased quality and quantity of crops (Duveiller et al., 2007; Juroszek and Tiedemann, 2012). As temperature and precipitation patterns change, pathogen life cycles may also be altered, resulting in earlier infections or prolonged disease durations that could further affect wheat crop health and production levels (Juroszek and Tiedemann, 2012).

Fusarium head blight (FHB) is an important disease of wheat, and the main causative agent of this disease is *Fusarium graminearum* Schwabe (Bockus et al., 2010). However, there are other *Fusarium* species, grouped in the *Fusarium graminearum* species complex, that cause disease in wheat grains (Aoki et al., 2012). FHB causes not only economic losses due to lower production but also due to the accumulation of mycotoxins such as deoxynivalenol (DON, vomitoxin), nivalenol and its acetylated derivatives and the mycotoxin zearalenone (ZEN), these can increase the likelihood of price penalties or even the rejection of entire loads of grain at sale (Huang et al., 2023; Sherif et al., 2023, Kecskés et al., 2024). Infection with mycotoxigenic fungi can occur before harvest and spread while the grains are in storage,

in warm and humid conditions (Petrović et al., 2022). In addition to the genus *Fusarium*, the genera *Penicillium*, *Aspergillus*, *Claviceps*, *Stachybotris*, and *Alternaria* also produce mycotoxins in wheat grains (Marin et al., 2013; Havranek et al., 2014; Hassan, 2019). Kumar et al. (2002) showed that *Bipolaris sorokiniana*, *Alternaria alternata*, *Cochliobolus sativus* and *Pyrenophora tritici-repentis* are also associated with the diseases present on wheat grains known as “black point”.

This study aimed to assess the health quality of six winter wheat varieties, determine the incidence of the most common fungal pathogens affecting wheat grains, and examine whether climate changes influence the fungal load in seeds.

MATERIALS AND METHODS

The biological material used in this research consisted of winter wheat seeds belonging to six different cultivars (Glosa, Andrada, Codru, Cezara, Luminita, and Bezostaia). These seeds were obtained from the experimental field of the Agricultural Research and Development Station in Turda, Romania, located in the Transylvanian Plateau. The seeds were harvested over five years, from 2019 to 2023. The cultivation technology applied is specific to wheat cultivation; the precursor plant was the spring pea, and no fungicide treatment was used. Every year, an assessment of the mycotic (fungal) load of wheat seeds was conducted. Unsterilized wheat seeds were placed for germination on moist filter paper in disinfected and sterilised Petri dishes. The blotter paper was soaked in distilled water, and 100 seeds in two replicates were used for each experimental variant. Germination trays were disinfected and sterilised before seeds were placed for germination. For each experimental variant, 100 seeds in two replicates were used. After 4 days, the germination rate and occurrence of infection were assessed. Based on observations, the germination rate, overall infection rate, and frequency of *Alternaria* sp. and *Fusarium* sp. were determined for each wheat cultivar. Fungal identification was conducted according to laboratory guide keys and taxonomic manuals for identifying

fungi species commonly found in wheat (Warham et al., 1996). A detailed microscopic examination of fungal structures, such as mycelium, spores, and fruiting bodies, was performed to accurately determine the species of *Alternaria*, *Fusarium*, *Aspergillus*, *Penicillium*, *Cladosporium*, and *Rhizopus*, and other fungal pathogens present on the wheat seeds. The experiment involves two factors: the year, with 5 levels of gradation, and wheat varieties, with 6 different cultivars. The obtained results were processed statistically by the variance analysis method and establishing the least significant difference - LSD - (5%, 1%, and 0.1%) (ANOVA, 2015).

RESULTS AND DISCUSSION

Monthly air temperature and precipitation data were recorded at the meteorological station at Turda Weather Station, located at longitude 23°47', latitude 46°35', and altitude 427 m (Figures 1 and 2). Average air temperature (°C) and total precipitation (mm) in the years of the study (2018-2023) were compared with the averages for the period 1957-2022. Over the five-year study period, average monthly temperatures showed a cooling trend in the spring and a marked warming in the summer, a phenomenon that aligns with the broader trends of global warming. While most of the months during the wheat growing season were warm, the spring months were notably cooler. 2023 was a warm year, with an average temperature of 11.4 °C, the second warmest year after 2019, which also had an average temperature of 11.4 °C.

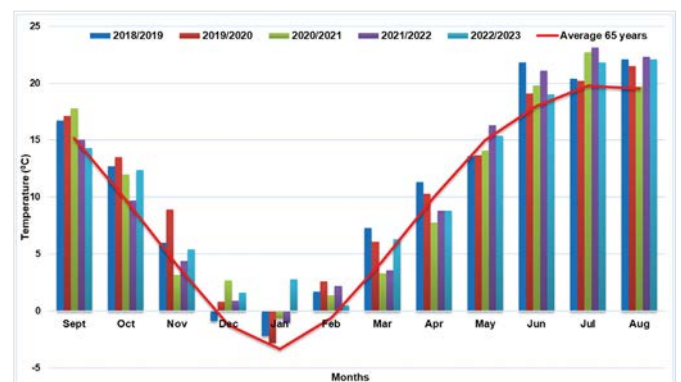


Figure 1. The monthly average air temperature in the growing seasons of 2018– 2023

Precipitation during the wheat vegetation period exhibited high variability, fluctuating between dry and rainy months, with the drier conditions more often encountered in the spring and summer. The most important lack of precipitation was observed in 2021 and 2022, especially in June. Although the year 2023 was characterised as excessively rainy, rainfall was not evenly distributed throughout the year, with the variability being quite high from one month to another. June was a rainy month, with a surplus of 59.9 mm compared to the average, precipitation that also brought the soil water reserve to a higher level; this month recorded 10 consecutive days in which it rained. These microclimatic conditions can prolong the persistence of fungal pathogens and exacerbate disease pressure on winter wheat during critical growth stages (Suciu et al., 2021a).

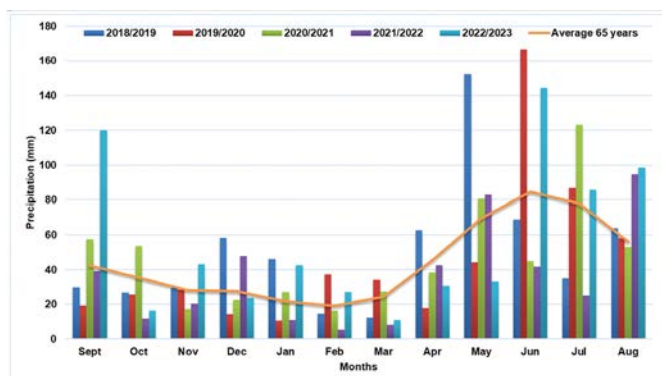


Figure 2. The monthly sum of precipitation in the growing seasons of 2018 - 2023

Analysing the influence of climatic conditions on wheat seed germination, it is observed that, although there are differences between years, they are not statistically significant (Table 1). The analysis revealed that the average seed germination rate was 97.20%, the lowest value observed in 2019 (96.17%) and the highest in 2022 (98.83%).

In comparison with the average (control), no significant differences are recorded in any variety from the 5 years of experimentation (Figure 3). The lowest germination rates were recorded in 2019, ranging from 94 to 97% depending on the variety. In contrast, the highest germination rates were observed in 2022, with all varieties exceeding

98%. The Codru variety in 2020 exhibited the maximum germination rate, while the Luminita variety reached 100% germination in 2022.

Table 1. The influence of climatic conditions on germination rate

No.	Year	Germination (%)	Difference (%)	Difference	Significance
1	Average	97.20	100.0	0.00	Control
2	2019	96.17	98.9	-1.03	-
3	2020	97.33	100.1	0.13	-
4	2021	97.17	100.0	-0.03	-
5	2022	98.83	101.7	1.63	-
6	2023	96.50	99.3	-0.70	-
LSD _{0.05}				2.65	

Data are presented as statistical significance $P < 0.001$ (***), $P < 0.01$ (**), $P < 0.05$ (*), $P > 0.05$ (-) positive, respectively negative values; + = increase, - = decrease;

The seeds observed after incubation showed an overall pathogen infection frequency of 45.1%, ranging from 28.8% to 68.8% (Table 2). The most favourable conditions for pathogen establishment on wheat seeds were observed in 2023, when 68.8% of the seeds were infected, while not optimal for pathogen growth were observed in 2021, when only 28.8% of the seeds developed pathogens.

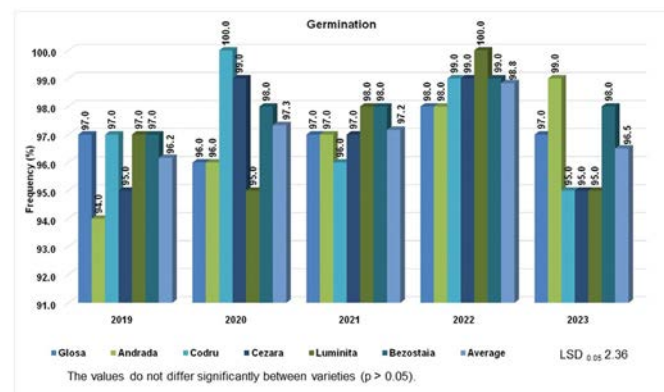


Figure 3. The influence of the interaction of year and variety on seed germination (%)

Table 2. The influence of climatic conditions on infected grains

No.	Year	Infected grains		Difference %	Difference	Significance
		arcsin√%	(%)			
1	Average	41.80	45.1	100.0	0.00	Control
2	2019	43.28	47.3	103.6	1.48	-
3	2020	39.72	41.3	95.0	-2.08	-
4	2021	30.85	28.8	73.8	-10.95	**
5	2022	38.42	39.3	91.9	-3.38	-
6	2023	56.72	68.8	135.7	14.92	***
LSD _{0.05}					5.30	

Data are presented as statistical significance $P < 0.001$ (***), $P < 0.01$ (**), $P < 0.05$ (*), $P > 0.05$ (-) positive, respectively negative values; + = increase, - = decrease;

The climatic conditions of 2021 were the most unfavourable for the colonisation of pathogens on wheat seeds. This year, there were low values of grains infected with various pathogens, with the exception of the Andrada variety. In 2023, high values of the percentage of diseased grains were recorded for all varieties (Figure 4).

Fusarium and *Alternaria* species were among the most prevalent pathogens detected on the wheat grains analysed. Fungi belonging to the genera *Aspergillus*, *Penicillium*, *Cladosporium*, and *Rhizopus* were also identified on the wheat seeds. These pathogens were found either alone or together with other fungi present on wheat seeds.

Wheat is a crucial component of global food security, and its production is often threatened by various fungal diseases. One such disease is *Fusarium* head blight, which is caused by a group of *Fusarium* species and can have a significant impact on both the quantity and quality of wheat grain production. The prevalence and severity of FHB are heavily influenced by climatic conditions, which can vary significantly across different regions and time periods (Champeil et al., 2004; Osborne and Stein, 2007; Torres et al., 2019).

In 2023, the climatic conditions were highly favourable for wheat grains to become heavily infected with *Fusarium* (11.17%), resulting in the highest recorded percentage of *Fusarium*-infected grains. Conversely, in 2020, the conditions were less conducive, leading to the lowest recorded percentage of *Fusarium*-infected wheat grains (2.33%) during that period (Table 3).

Analysing the fungal load of *Fusarium* species in the 6 wheat varieties studied between 2019 and 2023, we observe distinct annual fluctuations. High *Fusarium* levels were recorded in 2019, 2021, and 2023 (Figure 5). The Codru variety exhibited particularly elevated *Fusarium* levels due to the climatic conditions in 2019 and 2023, while the Glosa variety showed the highest *Fusarium* values in 2021.

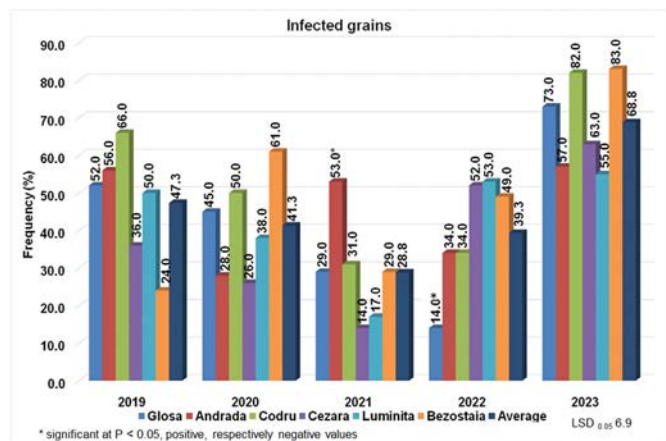


Figure 4. The influence of the interaction of year and variety on infected grains with fungi

Table 3. The influence of climatic conditions on *Fusarium* sp. frequency

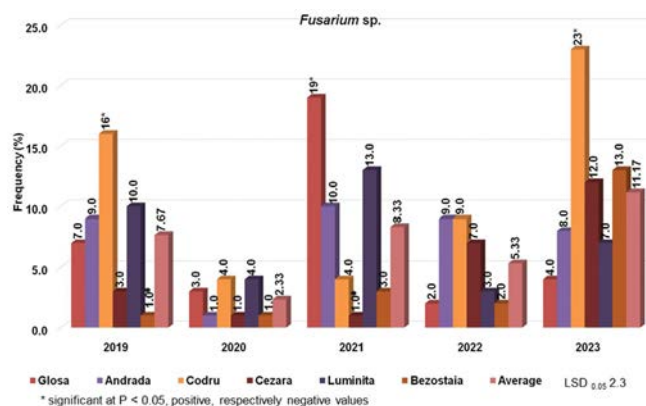
No.	Year	<i>Fusarium</i> sp.		Difference %	Difference	Significance
		arcsin√%	(%)			
1	Average	13.43	6.97	100.0	0.00	Control
2	2019	14.68	7.67	109.3	1.25	-
3	2020	7.09	2.33	52.8	-6.34	**
4	2021	14.67	8.33	109.2	1.24	-
5	2022	12.18	5.33	90.7	-1.25	-
6	2023	18.55	11.17	138.1	5.12	**
LSD _{0.05}					3.31	

Data are presented as statistical significance $P < 0.001$ (***), $P < 0.01$ (**), $P < 0.05$ (*), $P > 0.05$ (-) positive, respectively negative values; + = increase, - = decrease;

The severity of *Fusarium* infections is expected to increase further with increasing temperatures during the period from anthesis to harvest. In addition to production losses, another major concern is the change in seed quality. Contamination of cereal grains with mycotoxins leads to degradation of quality for human consumption and poses problems in processing and feeding contaminated grains to animal species (Timmusk et al., 2020).

Alternaria species, particularly *Alternaria alternata*, *Alternaria triticina*, and *Alternaria tenuissima*, are known pathogens that can infect wheat seeds. This seed infection can lead to various issues, such as reduced germination, seedling blight, and the production of mycotoxins harmful to humans and animals. While the specific impact on wheat seed germination rates is unclear, it's crucial to note that *Alternaria* seed infection can significantly compromise seed quality and overall production (Warham et al., 1996; Suci et al., 2021a).

Table 4 shows the load of wheat seeds infected with the pathogen *Alternaria* over the 5 years of study compared to the average. The climatic conditions in 2023 were very favourable for the establishment of the pathogen on the grains, with over 50% of the analysed grains showing *Alternaria* infections. In contrast, less favourable conditions occurred in 2019, followed by 2021, when the percentage of grains infected with *Alternaria* was 1.7% and 8.8%, respectively.

**Figure 5.** The influence of the interaction of year and variety on *Fusarium* sp. frequency

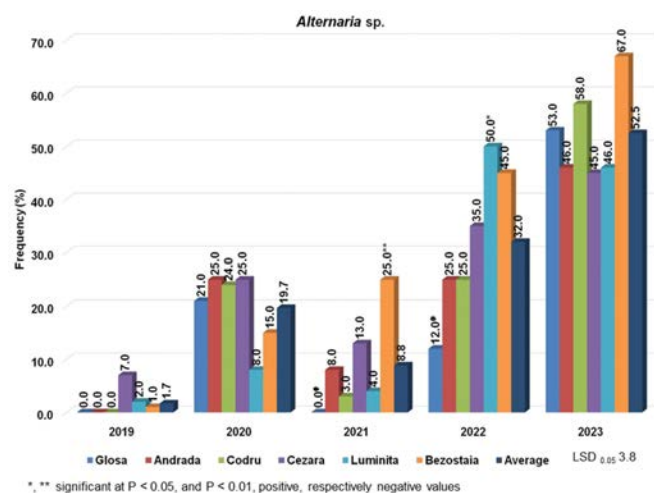
The diverse climatic conditions across Europe influence the prevalence and severity of *Alternaria* in wheat. (Miedaner and Juroszek, 2021) highlights how climate change, particularly increased dryness and warmth in Southern and Central Europe, will impact disease resistance breeding in wheat in Northwestern Europe. While this study doesn't focus solely on *Alternaria*, it highlights the regional variations in disease pressure due to changes in weather conditions.

The analysis of the grain load across the 5 years shows a concerning trend of increasing *Alternaria* infection over time (Figure 6). While *Alternaria* was nearly non-existent on wheat grains in 2019, by 2023 it reached an alarming 67% infection rate on the Bezostaia variety.

Table 4. The influence of climatic conditions on *Alternaria* sp. frequency

No.	Year	<i>Alternaria</i> sp.		Difference %	Difference	Significance
		arcsin√%	(%)			
1	Average	24.72	22.9	100.0	0.00	Control
2	2019	4.56	1.7	18.4	-20.17	***
3	2020	25.00	19.7	101.1	0.28	-
4	2021	14.08	8.8	56.9	-10.65	**
5	2022	33.53	32.0	135.6	8.81	*
6	2023	46.46	52.5	187.9	21.73	***
LSD _{0.05}					7.31	

Data are presented as statistical significance $P < 0.001$ (***), $P < 0.01$ (**), $P < 0.05$ (*), $P > 0.05$ (-) positive, respectively negative values; + = increase, - = decrease;

**Figure 6.** The influence of the interaction of year and variety on *Alternaria* sp. frequency

Moreover, the other wheat varieties also exhibited very high percentages of *Alternaria*-infected grains. These results underscore the growing threat this pathogen poses to wheat crops.

These diseases can severely impact wheat production and plant mortality (Singh et al., 2023). Effective fungicide treatments during the growing season can help mitigate the impact of these seed-borne pathogens (Suciu et al., 2021b).

The shift toward warmer temperatures due to climate change may also lead to the re-emergence of previously

controlled wheat diseases. Furthermore, different weather conditions can influence the species composition and mycotoxin production within disease complexes, posing additional challenges for wheat disease management (Miedaner and Juroszek, 2021).

CONCLUSIONS

The study indicates that different weather conditions, particularly temperature rise and irregular precipitation patterns, have contributed to higher fungal pathogen prevalence in wheat seeds. The most frequently detected fungi were *Fusarium* and *Alternaria*, both known to produce harmful mycotoxins that reduce grain quality and pose health risks. *Fusarium* infections peaked in 2023 (11.17%), while the lowest was observed in 2020 (2.33%), indicating that yearly climatic differences significantly impact disease outbreaks. *Alternaria* displayed an increasing trend, rising from 1.7% in 2019 to 52.5% in 2023, emphasising its growing threat under changing weather conditions.

Weather conditions change, particularly increased temperature and rainfall variability, exacerbating wheat seed vulnerability to fungal pathogens. Effective management strategies, including fungicide application, are critical to mitigating the impact of climate-induced diseases on wheat productivity.

The data underscores the need for weather conditions - resilient wheat cultivation strategies. Climate-induced changes in fungal disease dynamics pose a growing threat to wheat production, requiring integrated management approaches to ensure long-term food security.

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