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Evaluation of epidemiological factors against *Bipolaris sorokiniana* (Sacc.) Shoemaker on Wheat Spot Blotch

Mandeep Singh[1*], Subhash Chandra[2], Ramesh Chand[2], Uma Shankar[1], Abhishek Katiyar[1], Anand Milan[3]

[1]Ph.D. Research Scholar, Department of Plant Pathology, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, India (224 229).

[2]Sr. Scientist/Professor, Department of Plant Pathology, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, India (224 229).

[3] Assistant Professor (Contractual), College of Agriculture, JNKVV, Panna, M.P., India (488 001).

Corresponding author: mandeep0371@gmail.com

Mob. No. 7525009761

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ABSTRACT

Wheat (*Triticum aestivum* L.) belongs to the *Poaceae* family. It is India's second most important cereal crop, after rice in India and after maize in the world. Wheat is a self-pollinated, C3 plant that is grown primarily in temperate countries but also at higher elevations in tropical climates during the winter. It is grown in the mid-winter months of November to April. Spot blotch; *Bipolaris sorokiniana* (Sacc.) Shoemaker is a major disease of wheat in India. The experiments were conducted during the Rabi season of 2022-2023 and 2023-24. In this experiment, we did epidemiological studies on three wheat varieties; HD 2967, A 9-30-1 and Agra Local at SIF, ANDUA&T, Ayodhya. The disease favoured by moderate to warm temperatures (18-32°C) and particularly by humid, damp weather. Spot blotch is probably the most serious leaf blight disease of wheat in the mega-environment characterized by high temperature (coolest month >17°C) and high relative humidity. HD 2967 is highly resistant, with a PDI peak of 24 in both years and low RPD values. Suitable for places with similar weather conditions, reducing the impact of Spot Blotches. A 9-30-1 is highly susceptible, with PDI ranges of 88 and 89 in both years. RPD peaks show rapid disease progression under favorable conditions (warmth and wetness). Agra Local; similarly susceptible, with PDI peaks of 89 and 88 in both years, but slightly slower early progression than A 9-30-1. Agra Local and A 9-30-1 exhibit rapid PDI increases under warmer, wetter environments (e.g., weeks 9 and 13), whereas HD 2967 is less affected, most likely due to genetic resistance. Rainfall and warmer temperatures appear to be the primary causes of Spot Blotch development, especially in susceptible cultivars. HD 2967 variety is preferable for Spot Blotch prone areas in India due to its lower PDI, RPD and slower disease progression.

INTRODUCTION

The present investigation entitled **"Evaluation of epidemiological factors against *Bipolaris sorokiniana* (Sacc.) Shoemaker on Wheat Spot Blotch Disease"** was carried out at Student Instructional Farm (SIF), Department of Plant Pathology at Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya. The university is located in the Indo-Gangetic Plains (IGPs) of Eastern Uttar Pradesh at latitude 26.47° N, longitude 82.12° and at altitude of 113 meter above the sea level. The experiments were conducted during *Rabi* season 2022-2023 and 2023-24.

Wheat (*Triticum aestivum* L.) belongs to the family *Poaceae*. It is the second most important cereal crop after rice in India and after maize in the world. Generally, wheat is a self-pollinated and C_3 plant that is mainly grown in temperate regions and also at higher elevations in tropical climates during the winter season. It is grown during the mid-winter months of November to April. Three species, namely *Triticum aestivum* L. (Bread wheat), *Triticum durum* Desf. (Durum or macaroni wheat), and *Triticum dicoccum* Schrank. (Emmer wheat), are commonly cultivated at present. The archaeological records that wheat was cultivated in Mohenjo-Daro and Harappa nearly 5000 years back **(Pal, 1996).**

The most important species is common bread wheat (*T. aestivum*), which accounts for more than 90% of the country's wheat acreage and 87% of its production. India is the world's second largest wheat producer, after only China and ahead of the Russia and United States. The volume of wheat produced globally in the marketing year 2023–2024 was around 793.24 million metric tonnes **(Statista).** In the world, Wheat is grown over 220 million hectares of land with production of 763.06 million metric tonnes of grain. Maximum area under wheat is in India (14%), followed by Russia (12.43%), China (11.14%) and the USA (6.90%) which altogether accounts for about 45% of global area. China ranks first in wheat production 140.10 m.t. followed by India 113.29 m.t., and Russia 81.60 m.t. **(FAS, USDA,2024-25).**

In India, wheat is grown over 31.61 lakh. ha. area with production of 1175.07 lakh tonnes and yield of 3587 kg per hectare **(DOA&FW, MOA&FW, GOI, 2024-25).** About 91% of the total wheat production is contributed by northern states of India. Among them, Uttar Pradesh ranks first with respect to production of 35.34 m.t. (31.19%), Madhya Pradesh stands second rank in production 22.58 m.t. (19.93%) and Punjab holds third rank in wheat production 17.74 m.t. (15.66%). **(Economic Survey, Statistical appendix report, 2024-25).**

Bipolaris sorokiniana (Sacc.) Shoemaker, which causes spot blotch disease in wheat, is a globally economically significant foliar disease of wheat. This disease primarily affects warm, humid wheat growing environments and produces grain losses ranging from 24-27% in highly sensitive cultivars **(Bhandari *et al*., 2003).** Spot blotch is the most serious disease of wheat in the warm plains of South Asia, according to **Sharma and Duveiller (2004),** who observed reductions of 20.5 and 15.5% in grain yield and thousands kernel weight (TKW), respectively.

Foliar blight is a devastating disease of wheat in warmer areas of South Asia caused by *Bipolaris sorokiniana* and *Pyrenophora tritici-repentis* **(Dubin and Duveiller, 2000).** According to a survey conducted by wheat researchers from tropical and subtropical countries such as Indonesia, Bangladesh, Vietnam, Thailand, the Philippines, China, Nepal, India, Zambia, Zimbabwe, and Tanzania, *C. sativus* was the most economically important foliar pathogen, with yield loss estimates ranging from 5-20% on an annual basis **(Dubin and Ginkel, 1991).**

Foliar blight or Helminthosporium leaf blight a complex of spot blotch caused by *Cochliobolus sativus* (Ito & Kuribayashi) Drechs. Ex-Dastur (Anamorph: *Bipolaris sorokiniana* (Sacc.) Shoemaker) and tan spot, caused by *Pyrenophora tritici-repentis* (Died.) Drechs. (Anamorph: *Drechslera tritici-repentis* (Died.) Shoemaker) and *Alternaria triticina* Prasada & Prabhu are of major consequences.

The pathogen's principal symptom is spot blotch, which is nothing more than leaf disease. Early leaf lesions are 1-2 mm long, tiny, and dark brown in colour. At the beginning of the infection, there is no evidence of a chlorotic border. In the case of a vulnerable genotype, the tiny lesions spread quickly and eventually reach several centimetre. When the infection spreads to the spikelet, it causes shrivelled grain and darkens the embryo end of the seed. Dark brown lesions appear on the coleoptiles, crowns, stems, and roots of diseased seedlings. Seedlings can die before or shortly after emergence. Dark brown to black roots is indicative of common root rot. Dark brown to black necrotic lesions on the roots, sub crown, internodes, and basal portion of the stem distinguish common root rot. Multiple lesions frequently merge to generate extensive regions of necrosis when severe **(Jones and Clifford 1983; Mathre, 1987).** Common root rot causes fewer tillers and fewer kernels per ear.

Recently change in cropping system, cropping intensity, crop management and varietal spread the disease scenario has changed and foliar blight complex is causing serious losses to wheat crop in eastern U.P., followed by brown rust, loose smut being observed regularly in endemic form. Foliar blight was noticed in India since as early as 1924 **(Kulkarni,1924),** but it was not of much concern till very recently. A number of pathogens causing leaf blight, blotches and spots on wheat crops have been reported in India. Amongst them spot blotch (*Helminthosporium sativum* Pammel, King and Bakke) and *Alternaria triticina* (Prasada and Prabhu) are considered important ones.

Grain yield losses in South Asia due to spot blotch ranged from 4% to 38% and 25% to 43% in 2004 and 2005, respectively, and the number of kernels per spike and thousand-kernel weight were lowered by 10% and 15% in 2004 and 11% and 18% in 2005. (Sharma *et al.*, 2006). Yield loss in India has been estimated to be 18-22% **(Singh *et al*., 1997),** which can be catastrophic for farmers in the Eastern Gangetic Plains, who often have small holdings with little land or profitability **(Joshi *et al*., 2007).**

Bipolaris sorokiniana (Sacc.) Shoemaker is a seed and soil borne pathogen, causes head blight, seedling blight, foliar blight/ spot blotch, common root rot and black point of wheat, barley and other small cereal grains and grasses **(Wiese, 1998).**

Most Helminthosporium species are favoured by moderate to warm temperatures (18-32°C) and particularly by humid, damp weather. Spot blotch is probably the most serious leaf blight disease of wheat in the mega-environment characterized by high temperature (coolest month >17°C) and high relative humidity **(Van Ginkel and Rajaram, 1993).**

MATERIAL AND METHODS

Disease Assessment:

Disease severity following **Kumar *et. al.* (1998)** double digit scale based on per cent blighted area on the flag and flag-1 leaf at flowering, soft dough and hard dough stages. The disease score of each genotype were recorded thrice.

Table 1: The double-digit scale, based on per cent blighted area on the flag leaf and one leaf just below given by Kumar *et. al.* (1998)

A double digit* scale for appraising for blight severity				
S. N.	Severity**		Rating	
	Flag leaf	Flag-1 leaf	Disease response	Range of value
1	0	0-1	Immune (I)	00-01
2	1-2	2-4	Resistant (R)	12-24
3	3-4	4-6	Moderately Resistant (MR)	34-46
4	5-6	6-8	Moderately Susceptible (MS)	56-68
5	7-8	8-9	Susceptible(S)	78-89
6	9	9	Highly susceptible (HS)	99

*First and second value respectively, represents per cent blighted area on the flag leaf and flag-1 leaves.
**Value 1,2,3,4,5,6,7,8 and 9 respectively correspond to 10,20,30,40,50,60,70,80 and 90 per cent blighted area.

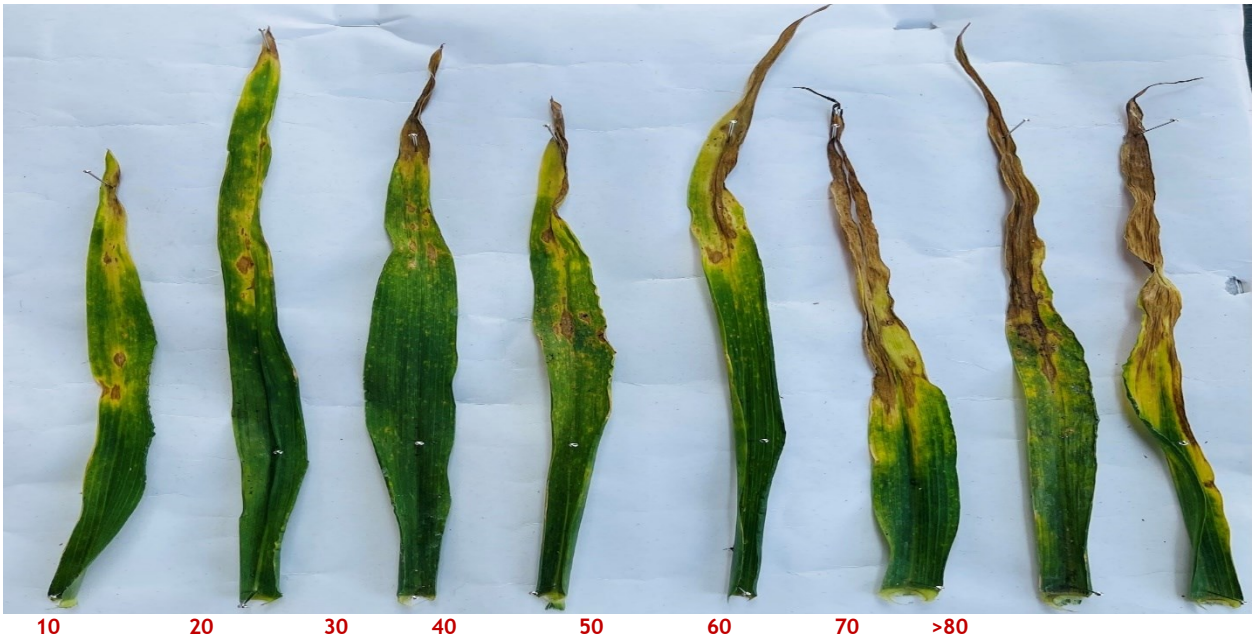

Figure 1: Leaf assessment key for Germplasm Screening by Kumar *et al*. (1998) double digit scale based on per cent blighted area on the flag and flag -1 leaf 0-9 double digit (dd) scale

The recording of spot blotch was done in 0-9 double digit scale at dough stage. The scoring of the disease incidence was done on the top two leaves, *i.e.* flag leaf and one below it. Of two digits, while the first indicates the score of flag leaf, the second digit gives the score of next (flag-1) leaf. Assessment of disease severity as percentage of leaf area damaged at dough stage was done following the double-digit score revised by Directorate of Wheat Research (DWR), Karnal. An average reaction was calculated after taking the mean of both digits separately.

RESULT & DISCUSSION

Spot Blotch PDI Progression (2022-23):

HD 2967: PDI is 0 from Weeks 45–2, starts at 1 in Week 3, increases to 12 in Week 5, and peaks at 24 in Weeks 12–13. Shows the lowest PDI, indicating high resistance to Spot Blotch.

A 9-30-1: PDI starts at 1 in Week 1, rises steadily (e.g., 12 in Week 4, 34 in Week 7, 56 in Week 9), and peaks at 88 in Week 13. Rapid progression suggests high susceptibility.

Agra Local: PDI starts at 1 in Week 2, increases gradually (e.g., 2 in Week 4, 23 in Week 7, 45 in Week 9), and peaks at 89 in Week 13. Similar to A 9-30-1, it shows high susceptibility but with a slightly slower early progression.

Comparison: HD 2967 is significantly more resistant, with a maximum PDI of 24, compared to 88 (A 9-30-1) and 89 (Agra Local). A 9-30-1 shows earlier disease onset (Week 1) than Agra Local (Week 2) and HD 2967 (Week 3). Compared to the second dataset, PDI values are similar for HD 2967 (24 vs. 24), slightly lower for A 9-30-1 (88 vs. 89), and higher for Agra Local (89 vs. 88).

Figure 2: Symptoms of Spot Blotch on Wheat leaves

Table 2: Meteorological data received during the crop period (2022-23)

Met. Week	Average Temp. (°C)		Relative Humidity (%)		Total Rainfall (mm)	Bright Sunshine (hrs.)	Spot Blotch					
							HD 2967		A 9-30-1		Agra Local	
	Max.	Min.	Max.	Min.			PDI	RPD	PDI	RPD	PDI	RPD
45	29.5	16.3	84.0	64.7	0	4.7	00	00	00	00	00	00
46	28.1	11.3	83.4	59.8	0	7.1	00	00	00	00	00	00
47	26.7	9.7	80.0	53.5	0	8.0	00	00	00	00	00	00
48	26.8	10.2	78.5	52.8	0	6.1	00	00	00	00	00	00
49	24.5	8.2	81.4	61.1	0	6.4	00	00	00	00	00	00
50	25.8	8.3	79.8	52.2	0	8.0	00	00	00	00	00	00
51	23.5	7.0	84.7	54.8	0	5.2	00	00	00	00	00	00
52	19.2	7.1	90.2	58.5	0	3.8	00	00	00	00	00	00
1	13.7	6.2	91.4	77.0	2.2	0.7	00	00	01	01	00	00
2	14.0	6.2	89.5	67.8	0	1.5	00	00	00	00	01	01
3	19.9	5.0	89.7	63.4	0	5.3	01	01	01	01	01	00
4	23.1	11.3	90.7	63.4	4.4	4.0	02	01	12	11	02	01
5	22.5	7.4	90.7	60.4	0	6.3	12	10	13	01	02	00
6	26.9	9.2	85.5	61.5	5.5	8.5	12	00	23	10	13	11
7	26.1	8.4	87.4	59.5	6.4	7.5	13	01	34	11	23	11
8	29.6	11.3	85.0	58.0	8.2	7.7	13	00	46	12	34	11
9	31.5	12.6	87.8	56.2	3.5	8.5	23	10	56	12	45	11
10	30.8	14.7	88.5	56.1	0	7.6	23	00	67	11	56	11
11	30.5	15.7	90.0	59.5	0	5.4	23	00	77	10	67	11
12	27.5	15.0	94.4	63.0	1	5.3	24	01	78	01	77	10
13	32.6	15.7	90.8	61.7	2	8.2	24	00	88	10	89	12

Spot Blotch RPD Progression:

HD 2967: RPD is 0 in most weeks, with peaks at 10 (Week 5) and 10 (Week 9), and minor increases (1) in Weeks 3, 4, 7, and 12. Low RPD aligns with slower PDI progression, indicating limited disease spread.

A 9-30-1: RPD starts at 1 in Week 1, with peaks at 11 (Weeks 4, 7, 10), 12 (Weeks 8, 9), and 10 (Weeks 6, 11, 13). Frequent high RPD values reflect rapid disease spread.

Agra Local: RPD starts at 1 in Week 2, with peaks at 11 (Weeks 6-9, 11) and 12 (Week 13). Similar to A 9-30-1, high RPD indicates fast disease progression.

Comparison: A 9-30-1 and Agra Local have higher and more frequent RPD peaks (up to 12) than HD 2967 (up to 10), reflecting faster disease spread. Compared to the second dataset, RPD patterns are similar, but A 9-30-1 has a higher peak RPD (12 vs. 11), and Agra Local's Week 13 RPD (12) is higher than in the second dataset (11).

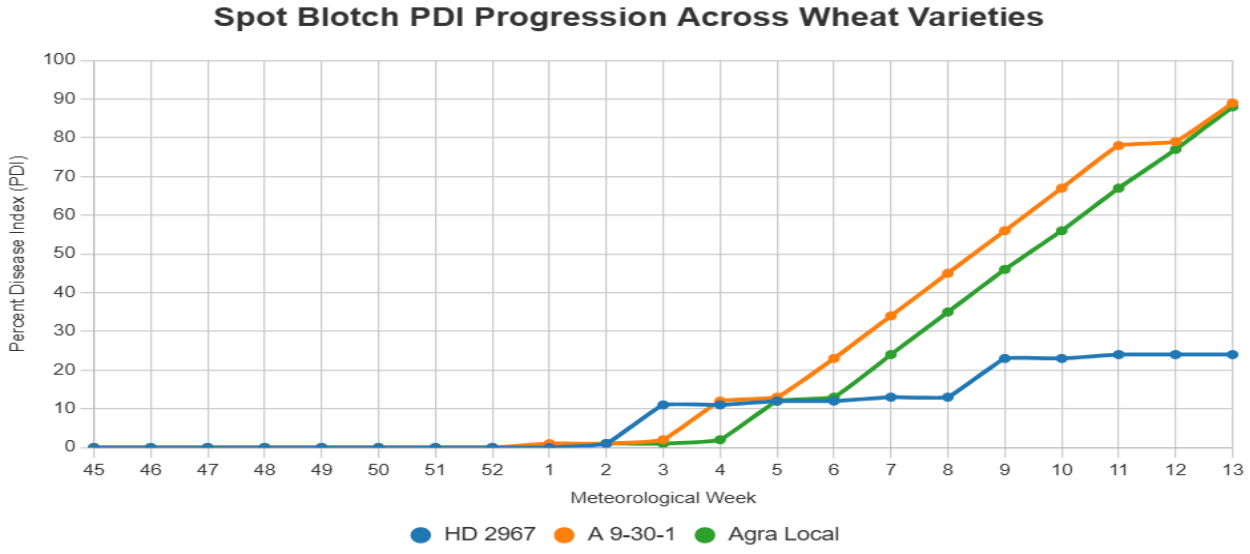

Figure: 3 Spot Blotch PDI progression across Wheat varities and meterological weeks (2022-23)

Meteorological Trends:

Temperature: Maximum temperature drops from 29.5°C (Week 45) to 13.7°C (Week 1), then rises to 32.6°C (Week 13). Minimum temperature follows a similar pattern, dropping to 5.0°C (Week 3) and rising to 15.7°C (Week 13).

Humidity: Maximum humidity peaks at 94.4% (Week 12) and is generally high (78.5–94.4%), with a low of 78.5% in Week 48. Minimum humidity ranges from 52.2% (Week 50) to 77.0% (Week 1).

Rainfall: Rainfall occurs in Weeks 1 (2.2 mm), 4 (4.4 mm), 6 (5.5 mm), 7 (6.4 mm), 8 (8.2 mm), 9 (3.5 mm), 12 (1 mm), and 13 (2 mm).

Sunshine Hours: Range from 0.7 (Week 1) to 8.5 (Weeks 6, 9), with higher hours in warmer weeks.

Table: 3 Coorelation coficient between the weather data and Wheat germplasm (2022-23)

Germplasm	Avg. Temperature (ºC)		Relative Humidity (%)		Total Rainfall (mm)	Bright Sunshine (hrs.)
	Max.	Min.	Max.	Min.		
HD 2967	0.637**	0.643**	0.586**	0.554**	0.413*	0.657**
A 9-30-1	0.587**	0.623**	0.500*	0.470*	0.469*	0.574*
Agra Local	0.562**	0.614**	0.476*	0.450*	0.420*	0.524**

Correlation between weather and Spot Blotch: To assess meteorological influences on Spot Blotch, I examined the PDI trends in relation to weather factors, focusing on Weeks 1–13 where disease is present.

Temperature: PDI increases significantly from Week 6 (26.9°C max.) to Week 13 (32.6°C max.) for A 9-30-1 (23 to 88) and Agra Local (13 to 89), suggesting warmer temperatures promote disease spread. HD 2967 shows slower PDI increase (12 to 24) despite rising temperatures, indicating resistance mitigates temperature effects. Example: Week 9 (31.5°C max.) sees PDI jumps to 23 (HD 2967), 56 (A 9-30-1), and 45 (Agra Local).

Humidity: High humidity (e.g., 91.4% max. in Week 1) coincides with early PDI onset for A 9-30-1 (1). Peak humidity (94.4% in Week 12) aligns with high PDI (78 for A 9-30-1, 77 for Agra Local). However, humidity remains high throughout (78.5–94.4%), so its role may be secondary to temperature or rainfall.

Rainfall: Rainfall events align with PDI increases: Week 1 (2.2 mm); PDI starts at 1 for A 9-30-1. Week 4 (4.4 mm); PDI rises to 12 (A 9-30-1) and 2 (Agra Local, HD 2967). Week 8 (8.2 mm); PDI jumps to 46 (A 9-30-1) and 34 (Agra Local). HD 2967 shows smaller PDI increases post-rainfall, reinforcing its resistance.

Sunshine Hours: High sunshine hours (e.g., 8.5 in Week 9) coincide with PDI spikes (56 for A 9-30-1, 45 for Agra Local), but low hours (0.7 in Week 1) align with early PDI onset, suggesting sunlight has a variable role.

Key Insight: Warmer temperatures (>26°C) and rainfall events (e.g., 8.2 mm in Week 8) strongly correlate with PDI increases in A 9-30-1 and Agra Local, while HD 2967 is less affected. High humidity supports disease onset but is less variable, making temperature and rainfall primary drivers.

Varietal Comparison: HD 2967; Most resistant, with PDI peaking at 24 and low RPD (max. 10). Ideal for regions with Spot Blotch risk. A 9-30-1: Highly susceptible, with PDI peaking at 88 and frequent high RPD (up to 12). Early disease onset and rapid spread. Agra Local: Similarly susceptible, with PDI peaking at 89 and RPD up to 12, but slightly slower early progression than A 9-30-1.

Spot Blotch PDI Progression (2023-24):

HD 2967: PDI remains 0 from Weeks 45–1, starts at 1 in Week 2, and increases gradually to 24 by Week 11, where it plateaus through Week 13. This variety shows the lowest PDI, suggesting higher resistance to Spot Blotch.

A 9-30-1: PDI starts at 1 in Week 1, increases steadily (e.g., 2 in Week 3, 12 in Week 4, 23 in Week 6), and peaks at 89 in Week 13. This variety shows rapid disease progression, indicating high susceptibility.

Agra Local: PDI starts at 1 in Week 2, rises steadily (e.g., 2 in Week 4, 12 in Week 5, 24 in Week 7), and peaks at 88 in Week 13. Similar to A 9-30-1, this variety is highly susceptible, with a slightly slower increase in early weeks compared to A 9-30-1.

Comparison:

A 9-30-1 and Agra Local show similar PDI trends, both reaching high values (89 and 88) by Week 13, while HD 2967 peaks at only 24, indicating significantly better resistance. Disease onset occurs earlier in A 9-30-1 (Week 1) than in Agra Local (Week 2) and HD 2967 (Week 2).

Spot Blotch RPD Progression:

HD 2967: RPD is 0 in most weeks, with spikes at 10 (Week 3) and 10 (Week 9), and smaller values (1) in Weeks 2, 5, 7, 8, and 11. Low RPD values align with lower PDI, suggesting slower disease spread.

A 9-30-1: RPD starts at 1 in Week 1, with notable peaks at 10 (Weeks 4, 6, 10, 12, 13) and 11 (Weeks 7–11).

Agra Local: RPD starts at 1 in Week 2, with peaks at 10 (Weeks 5, 10, 12) and 11 (Weeks 7–9, 11, 13). Similar to A 9-30-1, high RPD values reflect rapid disease progression.

Comparison: A 9-30-1 and Agra Local have more frequent and higher RPD values (up to 11), indicating faster disease spread compared to HD 2967, which has sporadic and lower RPD peaks.

Table 4: Meteorological data received during the crop period (2023-24

Met. Week	Average Temp. (°C)		Relative Humidity (%)		Total Rainfall (mm)	Bright Sunshine (hrs.)	Spot Blotch					
							HD 2967		A 9-30-1		Agra Local	
	Max.	Min.	Max.	Min.			PDI	RPD	PDI	RPD	PDI	RPD
45	29.6	15.5	71.8	56.6	0.0	5.6	00	00	00	00	00	00
46	28.7	14.1	70.4	55.2	0.0	6.5	00	00	00	00	00	00
47	27.1	12.6	70.5	55.3	0.0	6.5	00	00	00	00	00	00
48	26.3	12.6	71.8	55.9	2.4	3.8	00	00	00	00	00	00
49	25.9	14.2	71.8	56.0	2.0	3.6	00	00	00	00	00	00
50	23.9	7.0	69.7	54.5	0.0	7.9	00	00	00	00	00	00
51	23.2	6.0	71.3	54.8	0.0	7.0	00	00	00	00	00	00
52	20.7	9.6	75.8	61.7	0.0	3.9	00	00	00	00	00	00
1	18.2	9.6	79.5	66.9	5.0	1.9	00	00	01	01	00	00
2	16.7	7.5	77.4	64.4	0.0	3.7	01	01	01	00	01	01
3	13.2	6.5	79.3	65.9	0.0	0.8	11	10	02	01	01	00
4	15.2	5.3	74.5	63.5	0.0	3.7	11	00	12	10	02	01
5	22.0	8.0	73.9	63.2	0.0	5.8	12	01	13	01	12	10
6	20.5	7.4	74.0	64.2	0.0	5.4	12	00	23	10	13	01
7	24.7	10.8	72.9	62.8	2.4	7.1	13	01	34	11	24	11
8	26.2	10.7	70.0	61.5	3.8	7.8	13	01	45	11	35	11
9	25.7	11.7	70.6	62.1	7.8	7.8	23	10	56	11	46	11
10	30.3	9.6	69.5	58.3	0.0	8.1	23	00	67	11	56	10
11	31.0	12.1	69.0	57.8	0.0	9.3	24	01	78	11	67	11
12	30.2	13.2	69.7	56.3	0.0	8.2	24	00	79	01	77	10
13	35.0	18.0	69.5	56.1	0.0	9.4	24	00	89	10	88	11

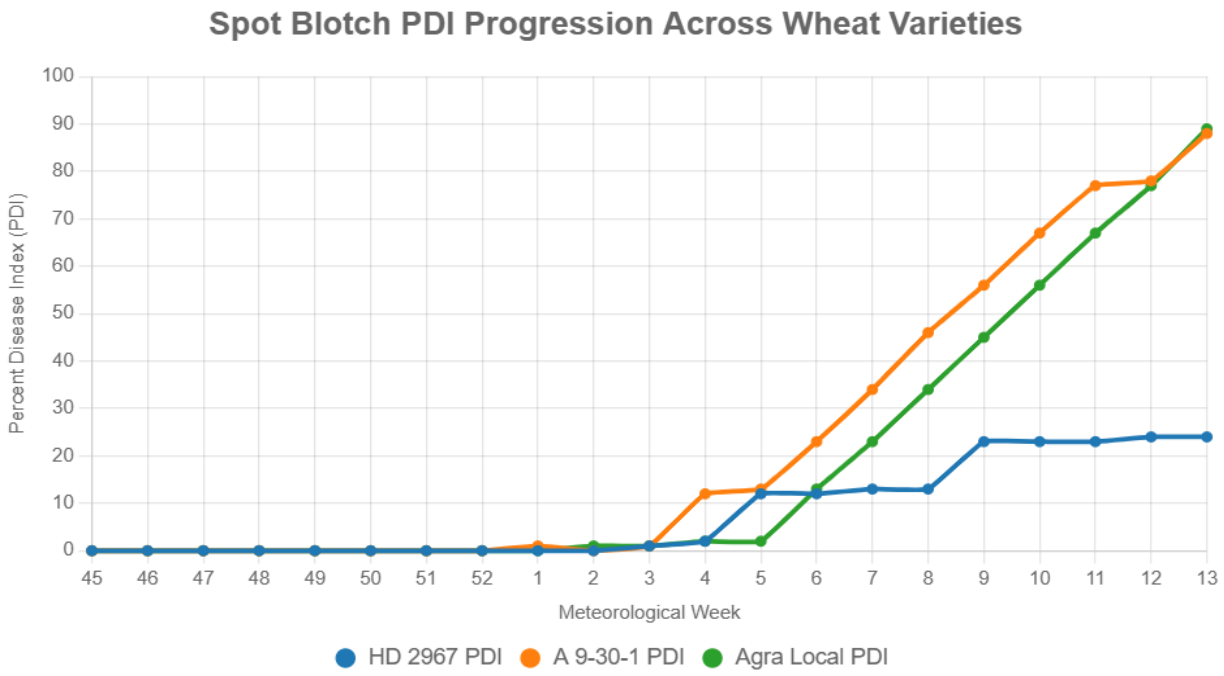

Figure: 4 Spot Blotch PDI progression across Wheat varities and meterological weeks (2023-23)

Meteorological Trends:

Temperature: Average maximum temperature decreases from 29.6°C (Week 45) to 13.2°C (Week 3), then rises sharply to 35.0°C (Week 13). Minimum temperature follows a similar pattern, dropping to 5.3°C (Week 4) and rising to 18.0°C (Week 13).

Humidity: Maximum humidity peaks at 79.5% (Week 1) and stays relatively high (69–79.5%), with a slight dip in later weeks (e.g., 69.0% in Week 11). Minimum humidity ranges from 54.5% (Week 50) to 66.9% (Week 1), with a slight downward trend toward Week 13.

Rainfall: Most weeks have 0 mm rainfall, with exceptions in Week 1 (5.0 mm), Week 4 (2.4 mm), Week 8 (3.8 mm), and Week 9 (7.8 mm).

Sunshine Hours: Vary from 0.8 (Week 3) to 9.4 (Week 13), with higher hours in later weeks (e.g., 9.3 in Week 11, 8.2 in Week 12).

Table: 5 Coorelation coficient between the weather data and Wheat germplasm (2023-24)

Germplasm	Avg. Temperature (℃)		Relative Humidity (%)		Total Rainfall (mm)	Bright Sunshine (hrs.)
	Max.	Min.	Max.	Min.		
HD 2967	0.610**	0.535*	0.526*	0.559*	0.282^{NS}	0.746**
A 9-30-1	0.583**	0.524*	0.472*	0.500*	0.358^{NS}	0.719**
Agra Local	0.590**	0.532**	0.483*	0.508**	0.331^{NS}	0.720**

Correlation between weather and Spot Blotch: To explore how meteorological factors might influence Spot Blotch progression, I analyzed potential correlations with PDI, focusing on key weeks where disease appears (Weeks 1–13).

Temperature: PDI increases significantly from Week 5 (22.0°C max.) to Week 13 (35.0°C max.) for A 9-30-1 and Agra Local, suggesting higher temperatures may favor disease spread. HD 2967 shows slower PDI increase despite rising temperatures, indicating varietal resistance may mitigate temperature effects. Example: In Week 9 (25.7°C max., 7.8 mm rain), PDI jumps to 23 (HD 2967), 56 (A 9-30-1), and 46 (Agra Local), possibly due to combined warmth and moisture.

Humidity: High humidity (e.g., 79.5% max. in Week 1) coincides with early disease onset (PDI 1 for A 9-30-1). However, humidity remains relatively stable (69–79.5%), so its role may be secondary to temperature. Weeks with high PDI (e.g., Week 13: 69.5% max. humidity) don't show significantly higher humidity, suggesting humidity alone isn't the primary driver.

Rainfall: Rainfall events (Weeks 1, 4, 8, 9) align with PDI increases: Week 1 (5.0 mm); PDI starts at 1 for A 9-30-1. Week 9 (7.8 mm); PDI spikes to 56 (A 9-30-1) and 46 (Agra Local). HD 2967 shows smaller PDI increases despite rainfall, reinforcing its resistance. Limited rainfall events make it hard to confirm a strong correlation, but moisture appears to facilitate disease spread, especially for susceptible varieties.

Sunshine Hours: Higher sunshine hours (e.g., 9.4 in Week 13) coincide with peak PDI for A 9-30-1 (89) and Agra Local (88), but HD 2967 remains stable at 24. Lower sunshine in Week 3 (0.8 hrs.) aligns with early PDI increases for HD 2967 (11), suggesting less dependence on sunlight for disease progression.

Key Insight: A 9-30-1 and Agra Local show rapid PDI increases in warmer, wetter conditions (e.g., Weeks 9 and 13), while HD 2967 is less affected, likely due to genetic resistance. Rainfall and higher temperatures appear to be the strongest drivers of Spot Blotch progression, particularly for susceptible varieties.

Varietal Comparison: HD 2967; Most resistant, with PDI peaking at 24 and low RPD values. Suitable for regions with similar weather conditions to minimize Spot Blotch impact. A 9-30-1: Highly susceptible, with PDI reaching 89 and consistent RPD peaks, indicating rapid disease spread under favorable conditions (warmth, moisture). Agra Local: Similarly susceptible, with PDI peaking at 88, but slightly slower early progression compared to A 9-30-1.

CONCLUSION

A 9-30-1 and Agra Local exhibit rapid PDI increases under warmer, wetter environments (e.g., weeks 9 and 13), whereas HD 2967 is less affected, most likely due to genetic resistance. Rainfall and warmer temperatures appear to be the primary causes of Spot Blotch development, especially in susceptible cultivars. HD 2967 is highly resistant, with a PDI peak of 24 in both years and low RPD values. Suitable for places with similar weather conditions, reducing the impact of Spot Blotches. A 9-30-1 is highly susceptible, with PDI ranges of 88 and 89 in both years. RPD peaks show rapid disease progression under favourable conditions (warmth and wetness). Agra Local: Similarly susceptible, with PDI peaks of 89 and 88 in both years, but slightly slower early progression than A 9-30-1.

Recommendations: Variety Selection; HD 2967 is preferable for Spot Blotch prone areas due to its lower PDI, RPD and slower disease progression.

Ethics declarations: The authors declare that ethical standards have been followed and that no human participants or animals were involved in this research.

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Conflict of Interest: The authors declare that they have no competing interests and no potential conflicts of interest was reported by the authors.

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