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ORIGINAL RESEARCH ARTICLE



Yield performance of wheat genotypes for resistance to spot blotch caused by *Bipolaris sorokiniana* (Sacc.) Shoemaker

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ABSTRACT

Spot blotch of wheat, caused by *Bipolaris sorokiniana* (Sacc.) Shoemaker, is an important wheat disease in Nepal. The purpose of the study was to assess wheat genotypes for resistance to the spot blotch and their yield potential in field conditions. A field trial was conducted with 100 wheat genotypes using an alpha-lattice design with two replications, under natural conditions at the National Maize Research Program, Rampur, Chitwan, Nepal. Disease assessment was performed using both double-digit (recorded four times at eight-day intervals) and single-digit (recorded three times at three-day intervals) scales. The single-digit visual scoring for the flag and flag-1 leaves began 97 days after sowing. Genotypes were categorized based on the final disease severity of the flag leaves. The genotypes differed significantly ($p < 0.001$) for resistance to spot blotch. Of the 100 genotypes, one (NRN35) was found moderately resistant, 19 were moderately susceptible, 60 were susceptible, and 20 were highly susceptible. The plot grain yield (482 g) of NRN35 was the second highest among genotypes. A significant negative correlation ($p < 0.001$) between the Area under disease progress curve and yield-attributing traits was found. In addition, a strong positive correlation ($r = 0.762$, $p < 0.001$) was found between the disease incidence in the flag-1 and flag leaves. This study identifies NRN35 as a promising genotype that combines moderate resistance with high yield, making it a valuable candidate for wheat improvement programs. Its performance under natural disease pressure underscores the potential for developing spot blotch-resilient varieties through strategic breeding.

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INTRODUCTION

The spot blotch affects all parts of plants, with the characteristic symptoms of distinct oval to oblong or sometimes even elliptical spots on leaves with dark brown margins and a dry light brownish center. Seeds act as primary sources of inoculum. The yield losses due to spot blotch in wheat vary from 15.5% to 19.6% (Dubin & van Ginkel, 1991) and 20% to 80% (Duveiller & Gilchrist, 1994). The disease is a serious concern of wheat growers in the tropical and subtropical parts of the world (Duveiller

et al., 1998). An integrated disease management system using host resistance is the best technique to manage the disease (Mehta, 1998). Thus, several studies have attempted to identify wheat genotypes resistant to spot blotch disease. Joshi *et al.* (2007) and Deepshikha *et al.* (2017) reported the spot blotch-resistant wheat genotypes. Similarly, Roy *et al.* (2023) suggested that no wheat variety is fully immune to the disease, emphasizing the need for integrated management. The study further underscored the need for strategies such as triazole fungicides, cultural practices, and host resistance to manage the disease.

Furthermore, Tabassum et al. (2022) conducted controlled field screening of doubled haploid (DH) wheat lines to assess their resistance against spot blotch disease. Kulung et al. (2023) evaluated twelve wheat genotypes for resistance to spot blotch at Khairahani, Chitwan. Their findings indicated significant variation in disease resistance, with NL1447 showing the lowest AUDPC and highest grain yield, which underscores its potential for breeding resistant wheat varieties.

Wheat is ranked second in consumption and third in production among major crops in Nepal (MoALD, 2023/2024). In addition, high temperature, high relative humidity, and long periods (>12 h) of leaf wetness provide a conducive environment for disease incidence, development, and spread (Duveiller, 2002). Moreover, the prevalence of the rice-wheat cropping system in Nepal is another cause of the disease outbreak, while sowing time plays a significant role in yield reduction (Sharma & Duveiller, 2007). Similarly, Pant & Pokhrel (2024) underscored the importance of sowing time on the yield-attributing characteristics and disease severity of wheat cultivars. Developing and identifying wheat genotypes with higher resistance to *B. sorokiniana* is essential for ensuring stable wheat production, particularly in regions vulnerable to spot blotch outbreaks. Understanding the effects of disease severity on key yield-contributing traits can aid in developing integrated disease management strategies tailored for local agro-ecological conditions. This research is particularly valuable for Nepal, where climate conditions and cropping practices predispose wheat crops to severe disease pressure. Previous studies have identified resistant genotypes (Joshi et al., 2007; Deepshikha et al., 2017) and evaluated a limited number of wheat lines under controlled or localized field conditions (Tabassum et al., 2022; Kulung et al., 2023). However, there is a lack of large-scale field evaluation involving diverse wheat genotypes under natural disease pressure in key wheat-growing areas of Nepal. Furthermore, limited research has explored the correlation between disease severity and specific yield-attributing traits across a wide genotype panel. This study addresses these gaps by assessing 100 wheat genotypes under field conditions for both disease resistance and yield performance. Thus, the objectives of this study were to evaluate 100 wheat genotypes for resistance to *B. sorokiniana*, and to assess the effects of disease severity on yield-attributing characteristics under field conditions.

MATERIALS AND METHODS

Experimental site and plant materials

The experiment was conducted at the National Maize Research Program (NMRP), Rampur, Chitwan, Nepal (27°03' N latitude, 84°25' E longitude; 256 meters above sea level) from December 2020 to April 2021. The site is characterized by a subtropical humid climate. The experimental field had been cultivated with maize and wheat during previously. A total of 100 wheat genotypes were obtained from the National Wheat Research Program (NWRP), Bhairahawa aided by National Maize Research Program (NMRP). Commercial varieties—Bhrikuti,

Tilottama, Vijay, Gautam, and WK1204—were included as resistant checks, while RR-21 was used as a susceptible check.

Experimental design and plot management

The experiment was conducted in alpha lattice design (Patterson & Williams, 1976) with two replications, each divided into 10 incomplete blocks. A total of 200 plots (100 genotypes × 2 replications) were used. Each plot consisted of a 2.0 m single row, spaced 20 cm apart with no intra-row spacing. The experiment was arranged into three strips to accommodate all genotypes (33, 33, and 34 genotypes respectively), with 1.0 m spacing between strips and 1.0 m border distance on all sides. Two border rows were planted around the experimental field to minimize the border effects.

Agronomical practices: The land was prepared by plowing two weeks before sowing, followed by application of farmyard manure (6 t ha⁻¹). Fertilizer application followed a recommended dose of N: P₂O₅: K₂O = 120:60:40 kg ha⁻¹, applied as urea, DAP, and MOP. Nitrogen was applied in two split doses, with the second application at the maximum tillering stage. Seeds were sown on December 10, 2020 (Nepal et al., 2020). A pre-emergence herbicide, atrazine (2 g L⁻¹), was applied one day after sowing. Manual weeding was done at 30 days after sowing (DAS) and again at tillering. Two surface irrigations were provided during critical growth periods. Harvesting was done on April 16, 2021 (126 DAS), using sickles at full physiological maturity. The following yield-related traits were recorded: Number of grains per spike, Spike length (cm), 1000-grain weight (g), Plot weight (g), Spike weight (g), Plant height (cm).

Inoculum preparation and disease scoring: The pathogen *Bipolaris sorokiniana*, was cultured on PDA medium. Spores were scraped from fully grown plates using sterile glass slides. Finally, it was, filtered through double-layered muslin cloth. A spore concentration of 4 × 10⁴ spores/mL was maintained (Duveiller et al., 1998) and sprayed on seedlings at 21 DAS by using a handheld sprayer.

Double-Digit Disease Scoring (Canopy-Wide Assessment):

Disease assessment began at 58 DAS. It was then repeated twice at eight-day intervals. The double-digit scale (00–99), developed by Saari & Prescott (1975) and modified by Mujeeb-Kazi et al. (1996), was used to evaluate disease incidence based on D₁ (vertical disease progression) and D₂ (severity of infected leaf area) as shown in Table 1.

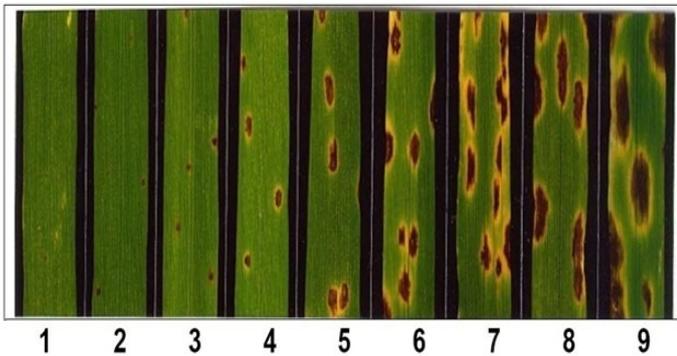
$$\text{Disease severity (\%)} = (D_1/9) \times (D_2/9) \times 100$$

Flag Leaf Scoring (Visual Assessment):

Disease severity on flag and flag-1 leaves was recorded at 97, 100, and 103 DAS using a single-digit visual rating scale (1–9) based on percent leaf coverage (CIMMYT) as shown in Figure 1. For each genotype in each replication, 10 randomly selected tillers were scored.

Table 1. Scale and severity of infection according to host reaction.

Scale for height of infection (D ₁)	Scale for severity of infection based on coverage (D ₂)
1= lowest leaf	1= 10%
2 = second leaf from base	2= 20%
3-4= second leaf up to below middle of the plant	3= 30%, 4= 40%
5= up to middle of the plant	5= 50%
6-8= from center of plant to below of the flag leaf	6= 60%, 7= 70%, 8= 80%
9 = up to flag leaf	9= more than 90%

**Figure 1.** Standard diagram developed by CIMMYT for single-digit disease scoring of wheat spot blotch.

Severity (%) = (Sum of Ratings) / (No. of Observations × Max Rating) × 100

Area Under Disease Progress Curve (AUDPC): AUDPC was calculated using the trapezoidal method (Shaner & Finney, 1977; Das et al., 1992):

$$\text{AUDPC} = \sum_{i=1}^{n-1} \left[\frac{(Y_{i+1} + Y_i)}{2} \times (T_{i+1} - T_i) \right]$$

Where,

Y_i and Y_{i+1} indicate disease severity values taken at T_i and T_{i+1} time points, respectively, and n = number of dates on which the disease was scored.

Genotypic categorization based on disease reaction: Wheat genotypes were grouped into six categories based on flag leaf severity at 103 DAS: Immune (I), Resistant (R), Moderately Resistant (MR), Moderately Susceptible (MS), Susceptible (S), and Highly Susceptible (HS) (Duveiller et al., 1998). Final severity values were then averaged from three different scoring dates.

Statistical analyses

All analyses were performed using Minitab v21.2.0 (Minitab Inc., 2022). A Generalized Linear Model (GLM) was used to analyze AUDPC:

$$\text{AUDPC}_{ijk} = \mu + G_i + R_j + B_{k(j)} + \epsilon_{ijk}$$

Where, μ is the overall mean, G_i is the effect of i^{th} genotype, R_j is the effect of j^{th} replication, $B_{k(j)}$ is the effect of k^{th} block nested within the J^{th} replication, and ϵ_{ijk} is the residual error. Post hoc analysis was performed using LSD at $\alpha = 0.05$.

Correlation and Regression Analysis

Pearson's correlation coefficients and simple linear regression analyses were conducted using Minitab to assess the relationship between AUDPC and agronomic traits such as spike length, grain number per spike, 1000-grain weight, plot weight, spike weight, and plant height.

RESULTS AND DISCUSSION

Area Under Disease Progress Curve (AUDPC)

The AUDPC values of wheat genotypes increased significantly at 81 DAS compared to 73 DAS, based on disease severity recorded at 58, 65, 73, and 81 DAS. At 73 DAS, AUDPC values ranged from 128.0 (NRN56) to 237.7 (NRN91), while at 81 DAS, they ranged from 144.7 (NRN69) to 280.8 (NRN93). This progressive increase indicated continuous disease development throughout the crop's growth stages, which is expected as spot blotch is known to intensify with plant maturity and favorable environmental conditions. The genotypes with consistently low AUDPC values, such as NRN56, NRN69, and NRN44, may possess partial resistance to *B. sorokiniana*, especially during later crop stages. A similar pattern of disease buildup under field conditions was observed by Kumar et al. (2021), who found AUDPC increasing steadily toward crop maturity, especially under warm and humid conditions typical of the Terai region. Moreover, the higher AUDPC values observed in genotypes like NRN93 and NRN91 can be attributed to their genetic susceptibility and possibly higher leaf area index, which may create a microclimate conducive for pathogen development. Yadav et al. (2022) also reported higher AUDPC in genotypes with prolonged canopy retention under similar agro ecological settings in South Asia.

AUDPC on flag and flag-1 leaf

At 100 DAS, AUDPC for the flag leaf ranged from 33.0 (NRN37 and Gautam) to 131.0 (BL5130), and at 103 DAS, it increased from 66.0 (NRN41) to 222.5 (BL5141). A similar pattern was observed in the flag-1 leaf, where AUDPC ranged from 97.7 (NRN69) to 214.0 (BL5138) at 100 DAS, and 192.1 (NRN50) to 270.0 (NRN39, NRN61, NRN97) at 103 DAS. These results demonstrate that disease severity intensifies on upper leaves during reproductive stages, which is critical since these leaves contribute significantly to photosynthetic accumulation in grains. The high correlation ($r = 0.762$) between AUDPC of flag-1 and flag leaves found in this study corroborates findings by Lozano-Ramirez et al. (2022), suggesting upward disease movement facilitated by air-borne conidia and high inoculum pressure during flowering and grain-filling periods.

Table 2. Ranking of genotypes based on disease severity on flag leaf on different scoring dates.

Rank	Genotypes with disease severity		
	97 DAS	100 DAS	103 DAS
1	NRN61 29.36 ^e	BL5130 59.27 ^m	WK1204 106.4 ^u
2	NRN71 25.56 ^{de}	NRN79 57.69 ^{lm}	BL5147 94.97 ^{tu}
3	NRN86 23.56 ^{cde}	BL5135 55.47 ^{klm}	VIJAY 91.97 ^{stu}
98	NRN35 6.76 ^{ab}	NRN35 18.09 ^{abc}	BL5131 43.97 ^{abc}
99	NRN85 6.76 ^{ab}	BL5131 14.97 ^{ab}	BL5139 40.03 ^{ab}
100	NRN99 3.96 ^a	BL5139 12.17 ^a	NRN35 34.57 ^a

Each row contains genotype followed by their disease severity values.

Disease severity on flag leaf

Disease severity increased progressively across dates, ranging from 3.96 (NRN99) to 29.36 (NRN61) at 97 DAS, 12.17 (BL5139) to 59.27 (BL5130) at 100 DAS, and 34.57 (NRN35) to 106.40 (WK1204) at 103 DAS (Table 2). This temporal escalation is likely driven by increasing temperature and humidity, especially after anthesis, which are known to favor *B. sorokiniana* sporulation and infection. The high variability among genotypes confirms the quantitative nature of spot blotch resistance and underlines the need for regular screening.

Yield and yield-attributing characters

Significant variation was observed among genotypes for yield and associated traits. Plot weights ranged from 202 g (BL5144) to 522 g (NRN69), with resistant checks averaging 345 g. Genotypes with higher yields such as NRN69 and NRN35 also exhibited lower AUDPC and severity scores, confirming the detrimental impact of spot blotch on yield. The 1000-grain weight varied from 27 g (BL514) to 55 g (NRN59). Genotypes with severe spot blotch (e.g., NRN94 and BL514) showed notably lower grain weights, which agrees with Pandey et al. (2018), who found significant reduction in grain weight under high disease pressure. Grain per spike ranged from 25.77 (NRN89) to 63.62 (NRN44), while spike length and weight also showed similar negative trends with disease. Interestingly, genotype NRN35, which was moderately resistant, ranked second in plot yield and had low flag leaf severity. These results are supported by Dhakal et al. (2020), who observed that moderately resistant genotypes under natural epiphytotic conditions sustained both physiological performance and grain productivity.

Correlation and regression analyses

Correlation analysis revealed a significant negative relationship between AUDPC and yield components, particularly plot weight ($p < 0.03$), grain per spike, and spike weight (Table 3). This suggests that increased disease progression leads to reduced photosynthetic efficiency and ultimately yield loss. Scatter plots and regression lines (Figure 2) further illustrated this inverse relationship. However, plant height showed a non-significant correlation ($r = 0.084$, $p = 0.404$), implying that resistance is not linked to plant stature. Additionally, the weak negative correla-

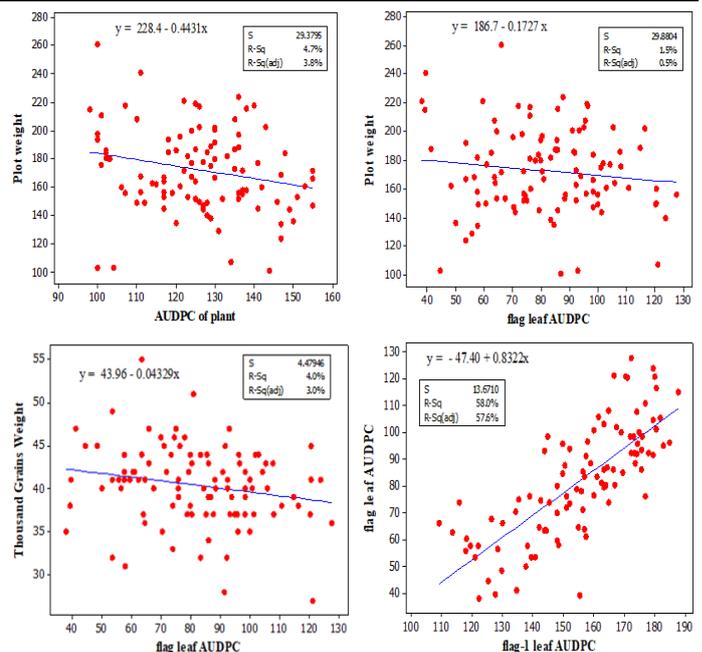


Figure 2. Scatterplot depicting relationship between Area Under Disease Progressive Curve (AUDPC) vs various traits: plot weight vs AUDPC of whole plant, plot weight vs AUDPC of flag leaf, Thousand grain weight vs AUDPC of flag leaf, and AUDPC of flag leaf vs flag-1 leaf.

tion between 1000-grain weight and AUDPC may be due to the quantitative, polygenic nature of resistance (Lozano-Ramirez et al., 2022) and the effect of timely sowing, as suggested by Nepal et al. (2020). These results reinforce the importance of genotype \times environment interaction and early planting in managing spot blotch.

Relationship of disease severity with temperature

Temperature was positively associated with AUDPC progression (Figure 3). As temperatures rose during the post-heading stage, AUDPC values of both flag and flag-1 leaves also increased. This confirms that spot blotch severity intensifies under warm conditions, which in turn promote faster pathogen growth and conidial spread. Kumar & Dubey (2021) reported a similar trend, indicating that optimal disease development occurs around 28–30°C. Furthermore, the sharp increase in disease at 100–103 DAS coincided with rising mean temperatures in Rampur, suggesting an ecological trigger for epidemic development. These findings further validate the concern that climate change may exacerbate foliar diseases in wheat.

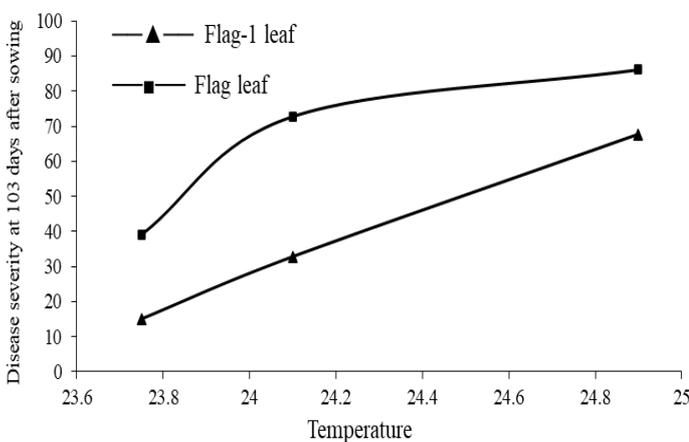
Table 3. Pearson correlation coefficients and the associated p-values for disease and yield-attributing parameters.

Parameters	AUDPC of flag leaf	AUDPC of flag-1 leaf	Plant height (cm)	1000-grain weight (g)	Plot weight (g)	Grain per spike	Spike length (cm)	Spike weight (g)
AUDPC of plant	0.060	0.142	0.084	0.027	-0.217*	-0.306**	0.099	-0.080
AUDPC of flag leaf		0.762	-0.015	-0.215*	-0.121	-0.151	-0.078	-0.238*
AUDPC of flag-1 leaf			-0.004	-0.209*	0.027	-0.197*	-0.010	-0.119

*and ** indicate statistically significant correlations at 0.05 and 0.01 significance levels.

Table 4. Categorization of wheat genotypes (Source: Singh & Kumar, 2005) based on disease reaction against spot blotch.

Scale	Reaction	Host response	Genotypes
1	00	Immune (I)	-
2	01-14 score; lesions absent or small without chlorosis	Resistant (R)	-
3	15-35 score; lesions small but with some chlorosis	Moderately resistant (MR)	NRN35
4	36-55 score; lesions large with extensive chlorosis but little or no coalescence	Moderately susceptible (MS)	BL5131, BL5139, BL5145, NRN37, NRN38, GAUTAM, NRN48, NRN52, NRN53, NRN58, NRN61, NRN62, NRN67, NRN66, NRN68, NRN84, NRN89, NRN98
5	56-79 score; lesions large and coalescence with chlorosis	Susceptible (S)	BL5136, BL5132, BL5133, BL5134, BL5135, BL5137, BL5140, BL5142, BL5144, BL5146, BL5148, BL5149, BL5150, BL5151, BL5152, BL5153, BL5154, BL 5155, NRN28, NRN30, NRN31, NRN29, NRN32, NRN34, NRN36, NRN39, NRN42, NRN44, NRN45, NRN49, NRN50, NRN54, NRN55, NRN59, NRN56, NRN57, NRN63, NRN64, NRN65, NRN70, NRN72, NRN76, NRN77, NRN71, NRN73, NRN85, NRN90, NRN74, NRN75, NRN82, NRN83, NRN86, NRN88, NRN91, NRN92, NRN93, NRN94, NRN95, NRN96, NRN97
6	More than 79 score; lesions large and extensive coalescence with severe chlorosis	Highly susceptible (HS)	BL5130, BL5138, BL5141, BL5143, BL5147, NRN33, NRN41, NRN43, NRN46, NRN47, NRN51, VIJAY, NRN69, NRN78, NRN79, TILOTTAMA, NRN81, NRN87, NRN99, WK1204

**Figure 3.** Relationship of disease severity of flag-1 and flag leaves with temperature.

Categorization of genotypes based on resistance

Among the 100 genotypes tested, only NRN35 exhibited moderate resistance (Table 4). The limited resistance pool aligns with Dhakal et al. (2020), who noted diminishing resistance in widely adopted commercial cultivars due to prolonged use and pathogen adaptation. Sharma et al. (2007) and Sharma et al. (2021) emphasized that older cultivars in the Gangetic plains showed higher susceptibility over time, suggesting that resistance erodes unless continuously improved. The current study reinforces the necessity of incorporating resistance into high-yielding lines. Genotypes like NRN35, NRN69, and NRN44, with lower disease severity and better yield traits, hold potential for use in resistance breeding programs in South Asia.

Conclusion

This study identified significant variation in spot blotch response among 100 wheat genotypes evaluated under natural disease pressure in Nepal. None of the genotypes exhibited complete resistance or immunity to *Bipolaris sorokiniana*. Only one genotype, NRN35, demonstrated moderate resistance, highlighting the limited availability of resistant germplasm. Disease progression, measured through AUDPC, increased consistently over time and was especially severe after the flowering stage. A strong positive correlation between disease severity in flag-1 and flag leaves confirmed the upward movement of infection within the plant. In contrast, disease severity was negatively correlated with key yield traits such as plot weight, 1000-grain weight, grain per spike, and spike weight—demonstrating the direct impact of spot blotch on productivity. The absence of resistant varieties in Nepal underscores the urgent need for incorporating resistant traits into high-yielding cultivars. While this study identified promising genotypes with relatively lower disease impact and higher yields, the findings should be validated through multiplication and multi-season trials before varietal recommendations can be made.

DECLARATIONS

Author contribution statement: Conceptualization: P. A. and R. D.; Methodology: R. D.; Software and validation: R. D., M. T., and R. K.; Formal analysis and investigation: R. D.; Resources: S. B. G.;

Data curation: M. T. and R. D.; Writing—original draft preparation: R. D.; Writing—review and editing: R. K.; Visualization: R. D.; Supervision: P. A., S. B. G., and N. D.; Project administration: P. A.; Funding acquisition: P. A. All authors have read and agreed to the published version of the manuscript.

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REFERENCES

- Das, M. K., Rajaram, S., Mundt, C. C., & Kronstad, W. E. (1992). Inheritance of slow-rusting resistance to leaf rust in wheat. *Crop Science*, 32 (6), 1452-1456. <https://doi.org/10.2135/cropsci1992.0011183X003200060028x>
- Deepshikha, Kumari, B., & Devi, E. P. (2017). Evaluation and standardization of growth stage of wheat against spot blotch caused by *Bipolaris sorokiniana*. *Journal of Environmental Biology*, 38 (2), 277–281. <https://doi.org/10.22438/jeb/38/2/ms-179>
- Dhakal, N., Shrestha, S. M., Manandhar, H. K., Aryal, L., Sagar, G. C., & Pant, K. R. (2020). Screening of advance wheat genotypes against spot blotch disease (*Bipolaris sorokiniana*) under varying sowing dates at Chitwan, Nepal. *Fundamental and Applied Agriculture*, 5(3), 383–392. <https://doi.org/10.5455/faa.76857>
- Dubin, H. J., & van Ginkel, M. (1991). The status of wheat diseases and disease research in warmer areas. In D. A. Saunders (Ed.), *Wheat for the nontraditional warmer areas* (pp. 125–145). CIMMYT. Accessed from: <https://hdl.handle.net/10883/1122>
- Duveiller, E. (2002). *Helminthosporium* blights of wheat: challenges and strategies for a better disease control. In advance of wheat breeding in China. Proceedings of first national wheat breeding conference, China Science and technology press, Jinan, Shandong, People's Republic of China. pp. 57–66.
- Duveiller, E., & Gilchrist, L. I. (1994). Production constraints due to *Bipolaris sorokiniana* in wheat: Current situation and future prospects. In D. A. Saunders (Ed.), *Wheat in heat stressed environments* (pp....). APS Press. <https://doi.org/10.1094/PDIS-91-6-0692>
- Duveiller, E., Dubin, H. J., Reeves, J., & McNab, A. (1998). *Helminthosporium* blights of wheat: spot blotch and tan spot. In: Proceedings of the International Workshop, El Batán, Mexico, 9–4 February 1997. CIMMYT, Mexico. pp. 1–375.
- Joshi, A. K., Ortiz Ferrara, G., & Crossa, J. (2007). Associations of environments in South Asia based on spot blotch disease of wheat caused by *Bipolaris sorokiniana*. *Crop Science*, 47(3), 1071–1081. <https://doi.org/10.2135/cropsci2006.07.0477>
- Kulung, O., Gurung, S. K., Rai, K., Rana, M., & Tamang, A. (2023). Evaluation of wheat genotypes for spot blotch resistance at Khairahani, Chitwan. *Agriculture Extension in Developing Countries*. 1(1), 12–18. <http://doi.org/10.26480/aedc.01.2023.12.18>
- Kumar, A., & Dubey, R. (2021). Temperature influence on *B. sorokiniana* spread. *Climate and Disease Dynamics*.
- Kumar, J., Singh, G., Singh, P. K., Sharma, R., Tiwari, R., Rawat, N., Joshi, A. K. (2022). Progress toward genomic-based resistance to spot blotch in wheat. *Frontiers in Plant Science*, 13, 835095. <https://doi.org/10.3389/fpls.2022.835095>
- Lozano-Ramirez N., Dreisigacker S., Sansaloni C.P., He X., Sandoval-Islas J.S., Pérez-Rodríguez P., Carballo A.C., Díaz C.N., Kishii M., & Singh P.K. (2022). Genome-Wide Association Study for Spot Blotch Resistance in Synthetic Hexaploid Wheat. *Genes*, 13 (8),1387. <https://doi.org/10.3390/genes13081387>
- Mehta, Y. R. (1998). Constraints on the Integrated Management of Spot Blotch of Wheat. In E. Duveiller, H.J. Dubin, J. Reeves, & A. McNab (Eds), *Helminthosporium* Blight of Wheat: Spot Blotch and Tan Spot. Mexico, DF: CIMMYT (pp 18–27)
- MoALD. (2023/2024). *Statistical information on Nepalese agriculture, 2079/80 (2022/23)*. Government of Nepal Ministry of Agriculture and Livestock Development. Accessed from: https://giwmscdnone.gov.np/media/pdf_upload/MOALD-Statistical-Book-Magre-2081-Final_wgfs8ph.pdf
- Mujeeb-Kazi, A., Villareal, R. L., Gilchrist, L., & Rajaram, S. (1996). Registration of five wheat germplasm lines resistant to *Helminthosporium* leaf blight. *Crop Science*, 36 (1), 216–217. <https://doi.org/10.2135/cropsci1996.0011183X003600010054x>
- Nepal, S., Shrestha, S. M., Manandhar, H. K., & Yadav, R. K. (2020). Field response of wheat genotypes to spot blotch under different sowing dates at Rampur, Chitwan, Nepal. *Journal of Agriculture and Forestry University*, 4(1), 83–90. <https://doi.org/10.3126/jafu.v4i1.47050>
- Pandey, A., Paudel, R., Kafle, K., Sharma, M., Maharjan, N., Das, N., & Basnet, R. (2018). Varietal screening of wheat genotypes against spot blotch disease (*Bipolaris sorokiniana*) under field conditions at Bhairahawa, Nepal. *Journal of the Institute of Agriculture and Animal Science*, 35(1), 267–276. <https://doi.org/10.3126/jiaas.v35i1.22555>
- Pant, Y., & Pokhrel, D. K. (2024). Disease incidence and severity of spot blotch in different sowing dates of wheat—Nepal. *Journal of Plant Resources*, 22(1), <https://doi.org/10.3126/bdpr.v22i1.68289>
- Patterson, H. D., & Williams, E. R. (1976). A new field design for experiments with progressives. *Biometrics*, 32(1), 13–21.
- Roy, C., He, X., Gahtyari, N. C., Mahapatra, S., & Singh, P. K. (2023). Managing spot blotch disease in wheat: conventional to molecular aspects. *Frontiers in Plant Science*, <https://doi.org/10.3389/fpls.2023.1098648>
- Saari, E. E., & Prescott, J. M. (1975). A scale for appraising the foliar intensity of wheat diseases. *Plant Disease Reporter*, 59(5), 377–380.
- Shaner, G., & Finney, R. E. (1977). The effect of nitrogen fertilization on susceptibility of wheat to *Helminthosporium sativum*. *Phytopathology*, 67, 1051–1056.
- Sharma, R. C., Ortiz-Ferrara, G., Crossa, J., Bhatta, M. R., Sufian, M. A., Shoran, J., & Orgiz, R. (2007). Genetic improvement and stability of wheat grain yield assessed through regional trials in the Eastern Gangetic Plains of South Asia. *Euphytica*, 157, 457–464. <https://doi.org/10.1007/s10681-007-9470-y>
- Sharma, R. C., & Duveiller, E. (2007). Spot blotch disease of wheat: A serious constraint in the warmer plains of South Asia. *Crop Science*, 47, 1071–1081. <https://doi.org/10.2135/cropsci2006.07.0477>
- Singh, D. P. & Kumar P. (2005). Method for scoring of leaf blight of wheat caused by *Bipolaris sorokiniana* (Sacc.) Shoem. on top two leaves at adult plant stage. In: *Integrated Plant Disease Management* (eds. R. C Sharma and J. N. Sharma), Scientific Publishers (India), Jodhpur, pp. 289–294. <https://www.cabidigitallibrary.org/doi/full/10.5555/20053203334>
- Tabassum, S., Kumari, N., Singh, A., Kumar, U., & Pal, A. K. (2022). Development of spot blotch resistance in bread wheat (*Triticum aestivum* L.) using DH technology. *Scientific Research Journal of India*, 6(1), 28–34.
- Yadav, P. S., Singh, A. K., Kumari, N., Kumar, U., Kumar, S., & Joshi, A. K. (2022). Trends in AUDPC and yield loss due to spot blotch in South Asia. *BMC Plant Biology*, 22, 4013. <https://doi.org/10.1186/s12870-022-04013-w>