Research Article

FIELD RESPONSE OF WHEAT GENOTYPES TO SPOT BLOTCH UNDER DIFFERENT SOWING DATES AT RAMPUR, CHITWAN, NEPAL

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ABSTRACT

Wheat spot blotch, caused by *Bipolaris sorokiniana* (Sacc.) Shoemaker has emerged as an important fungal disease for its economic losses in Nepalese wheat production system due state of poor resistance to spot blotch exacerbated by terminal heat stress in popular released wheat varieties. Thus it has engendered a dire need for identification of new robust and improved varieties with spot blotch resistance, suited to different sowing conditions. A field experiment was conducted at premises of Agriculture and Forestry University, Rampur to elucidate the field response of twenty wheat genotypes under different sowing conditions (early- 25th November, normal- 10th December, and late- 25th December) to spot blotch by using Split plot design, each treatment with three replicates, during 2017-2018. The analysis of variance revealed highly significant interaction ($p<0.01$) between the sowing dates and genotypes for the disease progress. A higher yield penalty due to significantly higher disease severity under late-sown wheat cropping was observed due to warmer conditions later in the season. Genotypes viz., NL 1207 (168.5 and 416.77) and BL 4341 (185.97 and 428.8) outrivaled other test genotypes with substantially lower mean area under disease progress curve (AUDPC) values based on flag leaf and penultimate leaf infection, and higher yield (3.23 and 3.02 t/ha), respectively, and thus could be effectively utilized as robust progenitor in spot blotch resistance breeding programs. Our findings revealed that the simultaneous adoption of early sowing and resistant wheat genotypes could be a promising and economic avenue to reduce the disease pressure leading reduced yield penalties.

Key words: Spot blotch, AUDPC, resistance, sowing conditions, Nepal

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the one of the important cereal crops of the world along with rice and maize. It is grown on more land area than any other commercial food. Globally, it occupies approximately 218 million ha with the production of approximately 771 million t (FAO, 2019). In Nepal, wheat crop with mammoth total production of (1,736,849 Mt.) ranks third most important cereal after rice and maize accounting for 20% of the total cereal production in Nepal (MoAD, 2017). Over 60% of wheat is produced in the Terai (plain) region, though they are also produced in the mid hills and high hills of Nepal. However, the national average productivity of wheat (2.55 t) is noticeably lower as that of global average productivity (3.53 t) (MoAD, 2017; FAO, 2019). The lower productivity might be attributed to myriads of biotic and abiotic constraints rampant in Nepalese wheat production system. Among biotic constraints, wheat spot blotch incited by *Bipolaris sorokiniana* (Sacc.) Shoemaker, has emerged as a major concern posing massive threat to wheat production in Nepal and elsewhere.

Bipolaris sorokiniana 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). Spot blotch, a fearsome fungal disease, can cause substantial yield penalties in wheat and is most notably observed in the areas with warm and humid condition viz., as Latin America, South East Asia, Nepal, China, and Africa. (Raemaekers, 1991). It attacks seedlings, leaves, roots, nodes, spikes and grains during various stages of development. Symptoms mainly develop in the form of dark brown necrotic spots (boat shaped) occur on the coleoptiles, leaves, crowns, stems, and roots with or without yellow halo around these. Darkening of the sub crown inter node is a characteristic symptom confined to drylands. Lesions on the leaves start as a few mm that extend as elongated dark brown spots greater than 1-2 cm (Duveiller et al*.,* 2002). First symptoms are observed at the seedling stage, but the number of airborne conidia and leaves infected by pathogens remains low for several weeks till lower temperature prevails. As the temperature increases, unpredictable rise in infestation can be observed (Duveiller et al., 2004).

Spot blotch is the overriding disease of wheat in the Eastern gangetic plains seriously damaging the crops of farmers who are mostly smallholders, covering 9 million hectares in total (CIMMYT, 2013). Similarly, yield penalties of an average of 30% due to foliar blight complex caused by combination of spot blotch and tan spot pathogens was reported by Duveiller et al. (2005). It is often reported that the disease is more severe in the plains (Terai) of Nepal as compared that in hills. Up to 100% foliar blight incidence was reported in the field with yield losses up to 52% in eastern plains of Nepal (Sharma and Duveiller, 2006). Yield losses, however, vary with sowing time, years, locations, host cultivar, climatic factors and stress conditions (Duveiller et al.,2005; Sharma & Duveiller, 2006). Duveiller et al. (2005) reported average yield loss of 20, 30 and 32% on 26 November, 10 December and 25 December sowing dates under Chitwan conditions, respectively. Higher yield losses at late sown condition are due to combined effect of higher temperature which favor spot blotch severity and terminal heat stress and hence, the fact signifies the relevance of effect of sowing dates on the yield losses in wheat production.

The shift of rice-wheat cropping pattern from the normal date to delayed condition due to dramatic effect of climate change has compelled the Nepalese wheat growing farmers to practice late sowing of wheat, rendering serious vulnerabilities to coupled effect of spot blotch and terminal heat stress. Additionally, many released and registered popular wheat varieties in the national agricultural system viz., Vijay, NL-297, Bhrikuti are reported to lack complete level of resistance to spot blotch. Spot blotch has evolved as an intractable and devastating fungal disease of wheat in plains of Nepal, which might be attributed to poor spot blotch resistance and tolerance to terminal heat stress in existing popular varieties and thus, has instigated expeditious need for identification of new robust and improved varieties with spot blotch resistance, suited to different sowing conditions, particularly, late sown conditions.

Hence, the present investigation was propelled in an attempt to scout high-yielding, robust and promising resistant wheat genotypes adaptive to different sowing conditions for fostering crop improvement programs.

MATERIAL AND METHODS

Planting materials, site description and field experiment

A set of twenty wheat genotypes comprising of four released and sixteen pipeline wheat genotypes procured from National Wheat Research (NWRP), Bhairahawa was included in the field experiment laid out at Agronomy Research Farm of Agriculture and Forestry University (AFU), Rampur, Chitwan, Nepal (N27^{o}31’ E84^{o}25’ and 256 m above from sea level) during November 2017 to May 2018. The list of genotypes used in the study is depicted in Table (1). The genotype viz., RR21 was used as susceptible check for wheat spot blotch caused by *B. sorokiniana*. The experiment was set up in split plot design and the treatments were replicated thrice with three dates of sowing viz., 25th November (early), 10th December (normal) and 25th December (late) as main plot treatments and twenty genotypes as sub-factor treatments. Length of each strip was 20m with 6 rows in every 1.5 m^2 plot while breadth of each strip was 1m. Distance between each replication and main factors was 1m and 0.5, respectively. The climate of the study location is subtropical and humid where wheat was cultivated previous year. The maximum and minimum temperature recorded for the early sowing (November 25th) was 26.35°C and 12.7°C respectively with 97% relative humidity and no rainfall. For normal sowing (10th December), the maximum and minimum temperature recorded for the day was 28.25°C and 12.2°C, respectively with 91.5% relative humidity and no rainfall. Similarly, for late sowing (25th December), the maximum and minimum temperature recorded for the day were 24°C and 10.75°C, respectively with 96.91% relative humidity and no rainfall was recorded. The agro-meteorological data was retrieved from weather station installed at National Maize Research Program, Rampur, Chitwan. The treatments were sown manually in continuous rows with row to row distance of 25 cm. Further, the susceptible check (RR21) was sown uniformly around the experimental plot of 1 m width to trap the disease spores and supply inoculums homogenously to all test genotypes.

The seed rate was 120 kg/ha and NPK was applied @ 120:60:40 kg/ha through urea, diammonium phosphate (DAP) and muriate of potash (MOP) as per national recommendations. One hand weeding was done a month after sowing and final weeding was done manually at tillering stage to suppress weed growth in all the 3 dates of sowing. Irrigation was supplied twice first at crown root initiation stage and second at heading stage for all three dates of sowing.

Table 1. List of test wheat genotypes included in the study

SN	Genotypes	SN	Genotypes
1.	Baanganga	11.	NL1193
2.	BL4335	12.	NL1202
3.	BL4341	13.	NL1207
4.	BL4406	14.	NL1211
5.	BL4407	15.	NL1217
6.	BL4463	16.	NL1231
7.	BL4621	17.	NL1244
8.	BL4708	18.	NL1254
9.	NL1164	19.	RR21
10.	NL1179	20.	Tilotamma

Data collection and data analysis

Initially, data on disease incidence was taken at seedling in all the treatment combinations. Further, data on the disease severity was taken soon after the genotypes completed heading in all the three different sowing conditions using single digit scoring. Visual scoring of flag leaf (F) and penultimate leaf (F-l) from 10 randomly selected single tillers per genotype in each replication by using standard diagram developed by CIMMYT was employed to estimate the percentage of diseased leaf area (Mujeeb-Kaazi et al., 1996). Mean plant infection of the flag leaf and penultimate leaf in a plot was compared with standard diagram developed by CIMMYT. Four visual scorings were done at 7 days intervals on 87 , 94 , 101 and 108 days after sowing (DAS) in early sown plots; on 82 , 89 , 96and 103 DAS in normally sown plots; and on 74 , 81 , 88 and 95 days after sowing on late sown plots to estimate the area under disease progress curve (AUDPC) value. AUDPC values based on infection of flag leaf and penultimate were calculated using the following formula given by Das et al. (1992).

$$AUDPC = \sum_{i=1}^{n} (Y_{i+1}) 0.5 (T_{i+1} - T_i)$$

Where,

Yi= disease scored on i^{th} first date

Ti= date on which the disease was scored

n = Number of dates on which disease was scored

Further, genotypes were categorized into different resistance/susceptibility spectrum viz. highly resistant (AUDPC≤250) , resistant (AUDPC= 251-300) , moderately resistant (AUDPC=301-350), susceptible (351-400) and highly susceptible (AUDPC≥ 401) based on the critical comparison between average of AUDPC values based on flag leaf and penultimate leaf infection recorded in the genotypes with that of RR21(susceptible check). Besides, data on grain yield at 12% moisture was recorded after crop harvest for all the treatments in gram per plot and later extrapolated in t/ha.

Data analysis

The data on disease variables and grain yield was subjected to analysis of variance under split-plot design using R Studio to decipher the main effects and interaction effects and the significance of differences between the means were compared using Fisher's LSD testat 5% level of significance.

RESULTS AND DISCUSSION

The analysis of variance revealed highly significant differences among the three distinct dates of sowing and twenty test genotypes for mean spot blotch incidence at seedling stage (Table 2 and Table 3). Nonetheless, no significant interaction effect between the two factors for mean seedling disease incidence was found. The mean seedling disease incidence (8.69%) on first date of sowing substantially surpassed the mean seedling disease incidence on second sowing date (6.37%) and third sowing date (5.03%). Higher seedling disease incidence (10.04%) was recorded in NL1211 followed by NL 1254 (9.61%) and NL 1193 (9.05%) being statistically at par with each other while BL4341 (2.82%) recorded minimum seedling disease incidence followed by Baanganga (3.09%) and BL4407 (3.30%).

Table 2. Effect of date of sowing on seedling incidence, AUDPC F, AUDPC F-1 and grain yield

Date of sowing	SI (%)	AUDPC F	AUDPC F-1	GY(t/ha)
25-Nov	8.69^{a}	199.00^{c}	409.14^{c}	3.62^{a}
10-Dec	6.37^{b}	237.60^{b}	460.88^{b}	3.14^{a}
25-Dec	5.03^{c}	282.10^{a}	506.62^{a}	2.38^{b}
LSD	0.65	19.48	73.75	0.6
SEm(±)	0.47	11.3	7.85	0.11
CV(%)	19.2	16	12	19.1
p-value	0.000252	0.000768	0.001664	0.01
Grand Mean	6.7	239.57	458.88	3.06

Note: Mean values in columns with different letters are significantly different ($p \leq 0.05$) according to Fisher's LSD test ; SI (%): Seedling incidence; AUDPC F: Area Under Disease Progress Curve value based on flag leaf infection; AUDPC F-1 : Area Under Disease Progress Curve value based on penultimate leaf infection; , GY: Grain Yield

Table 3. Effect of date of sowing on seedling incidence, AUDPC F, AUDPC F-1 and grain yield

Genotypes	SI(%)	Mean AUDPC F	Mean AUDPC F-1	GY(t/ha)
Baanganga	3.09^{l}	227.34^{ghi}	456.12^{cde}	3.10^{a}
BL4335	7.14^{efgh}	204.99^{ijk}	446.18^{cde}	3.02^{ab}
BL4341	2.82^{l}	185.95^{kl}	428.77^{de}	3.33^{a}
BL4406	4.54^{jk}	280.95^{c}	454.49^{cde}	3.27^{a}
BL4407	3.30^{kl}	253.88^{def}	444.35^{cde}	3.21^{a}
BL4463	5.89^{hij}	221.64^{ghi}	457.04^{cde}	2.91^{ab}
BL4621	7.78^{cdef}	272.29^{cd}	488.42^{bc}	2.82^{ab}
BL4708	6.84^{fgh}	193.59^{jkl}	438.06^{cde}	3.24^{a}
NL1164	8.46^{bcde}	242.24^{efg}	460.12^{bcde}	2.96^{ab}
NL1179	7.44^{defg}	313.64^{b}	475.95^{bcd}	2.86^{ab}
NL1193	9.05^{abc}	266.56^{cde}	506.54^{b}	2.93^{ab}
NL1202	8.76^{abcd}	202.43^{ijk}	446.42^{cde}	3.17^{a}
NL1207	8.03^{cdef}	168.52^{l}	416.79^{e}	3.23^{a}
NL1211	10.04^{a}	223.27^{ghi}	454.20^{cde}	3.23^{a}
NL1217	6.81^{fgh}	215.17^{hij}	419.73^{e}	2.94^{ab}
NL1231	7.34^{defg}	306.48^{b}	476.91^{bcd}	2.51^{b}
NL1244	4.69^{ijk}	181.79^{kl}	429.21^{de}	3.27^{a}
NL1254	9.61^{ab}	239.59^{fgh}	453.36^{cde}	3.12^{a}
RR21	6.31^{gh}	370.71^{a}	574.94^{a}	2.51^{b}
Tilotamma	6.06^{ghi}	220.56^{ghi}	450.12^{cde}	3.34^{a}
SEm(±)	0.47	11.3	7.85	0.83
CV(%)	23.1	10.5	12	15.8
***p*-value**	2.20E-16	2.20E-16	2.82E-09	0.00357
Grand Mean	6.7	239.57	458.88	37.6

Note: Mean values in columns with different letters are significantly different ($p \leq 0.05$) according to Fisher's LSD test ; **SI (%):** Seedling incidence; **AUDPC F**: Area Under Disease Progress Curve value based on flag leaf infection; **AUDPC F-1** : Area Under Disease Progress Curve value based on penultimate leaf infection; , **GY**: Grain Yield

Highly significant variation for mean AUDPC value based on both the flag and penultimate leaf infection was affirmed among the dates of sowing as well as test wheat genotypes (Table 2 and Table 3). Mean AUDPC value hinged on both the flag and penultimate leaf infection on third date of sowing (282 and 409.14) significantly outdistanced the mean AUDPC value on second (237.6 and 460.88) and third date of sowing (199 and 409.14), respectively manifesting the pronounced effect of sowing dates on the disease progression. Pertaining to the eminence of the genotypes to the disease based on both the flag and penultimate infection, NL1207 outperformed all other test genotypes with lowest mean AUDPC values (168.52 and 416.79) followed by NL1244 (181.79 and 429.21), BL4341 (185.95 and 428.77) and BL4708(193.59 and 438.06), respectively while RR21 was found to record maximum AUDPC values (370.71 and 574.94). Similarly, highly significant interaction was also revealed between the dates of sowing and genotypes for both the mean AUDPC values based on flag and penultimate leaf (Table 4). Many of the test genotypes displayed variation in extent of responses to spot blotch from highly resistant to highly susceptible under different sowing dates (Table 5) which elucidates the varying degree of resistance or susceptibility to the disease in a particular variety massively effected by the environmental conditions as a result of different planting times. NL1244 found highly resistant with mean AUDPC values lower than 250 descended to moderately resistant on second sowing date and remained stable on subsequent sowing date while BL4341 categorized as highly resistant on first date of sowing ebbed progressively to moderately resistant and susceptible on second and third date of sowing consecutively. The resistance spectrum of genotypes viz., NL1207, BL4335 and NL1244 shifted from resistant to moderately resistant to spot blotch until the third date of sowing and was apparently stable as compared to other genotypes. Though many test genotypes as depicted in Table 5 revealed highly resistant to resistant response to spot blotch and seemed promising under early sown condition, very few genotypes viz., NL1207, Bl4335 and NL1244 were found modest with moderate degree of resistance (mean AUDPC value ranging from 301-350) under late-sown condition. On the stark contrast to drastic variation observed in resistance spectrum of the test varieties, RR 21 stood steady being highly susceptible under all the three dates of sowing.

Table 4. Interaction between dates of sowing and genotypes for mean AUDPC value based on flag leaf and penultimate leaf infection

Genotypes	AUDPC F 25th Nov	AUDPC F 10th Dec	AUDPC F 25th Dec	AUDPC F-1 25th Nov	AUDPC F-1 10th Dec	AUDPC F-1 25th Dec
Baanganga	175.60	233.70	272.80	374.70	483.10	510.50
BL4335	168.20	204.30	242.50	401.50	479.30	443.00
BL4341	146.10	185.50	226.30	331.90	441.50	513.00
BL4406	224.7	282.40	335.80	358.70	422.60	557.80
BL4407	232.60	246.90	282.10	419.00	447.00	491.50
BL4463	219.70	198.50	246.70	480.70	430.70	459.60
BL4621	241.40	269.70	305.80	501.50	489.30	476.30
BL4708	156.20	199.90	224.70	371.60	440.10	488.80
NL1164	195.60	255.70	275.30	393.00	477.80	509.60
NL1179	266.40	297.00	377.50	429.50	448.07	549.60
NL1193	259.50	242.4.00	297.80	504.80	478.90	535.90
NL1202	176.60	183.4.00	247.30	397.80	421.10	520.40
NL1207	142.90	163.10	199.50	380.00	418.10	452.20
NL1211	1920	216.30	261.60	390.40	421.60	502.20
NL1217	169.00	195.70	280.80	358.40	470.00	479.30
NL1231	220.90	337.70	360.90	387.00	493.00	550.70
NL1244	132.30	203.70	209.40	338.90	467.80	481.50
NL1254	192.00	245.10	281.70	387.20	474.70	489.00
RR21	306.60	360.20	445.30	561.10	575.20	588.50
Tilotamma	162.70	230.40	268.60	409.30l	435.90	505.20
LSD *(*p≤*0.05*)	42.42			73.75		
SEm(±)	11.3			7.85		
CV(%)	10.5			9.8		
***p*-value**	0.005			0.005		
Grand mean	239.7			458.88		

Note: SI (%): Seedling incidence; **AUDPC F**: Area Under Disease Progress Curve value based on flag leaf infection; **AUDPC F-1**: Area Under Disease Progress Curve value based on penultimate leaf infection; , **GY**: Grain Yield

Table 5. Field reaction of wheat genotypes against spot blotch under three different sowing dates at Rampur, Chitwan

Category	Early sown condition (25th November sowing)	Normally sown condition 10th December sowing	Late sown condition 25th December sowing
Highly Resistant	NL1244, BL4341	-	-
Resistant	NL1207, NL1217, BL4708, Baanganga Tilotamma, NL1202, BL4335, NL1254 NL1164	NL1207	
Moderately resistant	NL1231, BL4407, NL1179, BL4462, BL 4463, NL1211	NL1202, NL1217, BL4341 BL4463, BL4708 NL1244, Tilotamma, BL4407, BL4335, NL1211	NL1207, BL4335 NL1244, NL1211
Susceptible	BL4621. NL1193, BL4406	Baanganga, NL1254, NL1193 BL4406, NL1164, NL1179 BL4621	BL4463, BL4708, BL4341 NL1217, NL1211, BL4407 Tilotamma, NL1254 BL4621, Baanganga, NL1164
Highly susceptible	RR21	NL1231, RR21	NL1193, BL4406, NL1231 NL1179, RR21

Owing to mean grain yield, highly significant differences among date of sowing as well as genotypes were observed (Table 2; Table 3). Wheat sown early (3.63 t/ha) significantly transcended the wheat crop under normal (3.14 t/ha) and late (2.38 t/ha) sowing conditions in terms of mean grain yield. Further, no significant interaction between genotypes and sowing dates was detected for grain yield. Tilotamma exhibiting resistant and moderately resistant response under early and normal sown condition and susceptible reaction under late sown condition recorded the highest mean grain yield (3.34 t/ha) followed by BL4341 (3.33 t/ha) and NL1244 (3.27 t/ha), respectively, which also followed similar pattern in fluctuation of degree of resistance as that of Tilotamma. Genotypes viz., Tilotamma, BL4341, BL 4406 and NL1244 recorded significantly higher mean yields as compared to other test genotypes with notable tolerance to the disease which accentuates their eminence for utilization in crop improvement programs.

DISCUSSION

Soil moisture might have played a major role in seedling disease incidence. Delay in sowing reduced soil moisture which might have adverse effect on seed germination, growth of seed and consequently on seed and soil borne inoculum. However, lower seedling infection had no effect on disease development later in the season as the AUDPC values were maximum in late sown crop. This might be because inoculums developed on early-sown plots were spreading over late planted plots. Furthermore, under late-sown conditions, possibly due to increasing temperature, *B. sorokiniana* multiplied quickly as the plants grew and caused infection on more than 90% of plants of the susceptible genotypes before heading, whereas, in early sown plots, it occurred at a later growth stage. No effect of seedling infection on disease development as found in the present study was well corroborated by the findings of Aryal et al. (2013) who also reported that seed infection did not influence disease development later in the season.

Pronounced increase in disease severity as illustrated in the results of the present study is well-substantiated by the similar findings of Gurung et al. (2012) and Aryal et al. (2013) who also reported increased AUDPC value under late sown conditions. Similarly, the drift of resistance spectrum of the genotypes from higher to lower degree under delayed sowing conditions as unveiled in our study are in close agreement with findings of Duveiller et al. (2005). This might be attributed to compounded effect of terminal heat stress and easily available inoculums from the wheat fields sown early and relatively warmer and humid conditions prevailing during second and third date of sowing. Duveiller et al. (2005) also suggested that higher temperatures and greater inoculum pressure at a later crop growth stage could render the plants more vulnerable to pathogen attack and lead to disease development even in resistant genotypes. Since there is no immunity, even resistant wheat cultivars seeded very late, could not often escape disease damage, especially under high temperatures, which is in alignment with the observations of Nema and Joshi (1973). The higher values of AUDPC under late-sown conditions are likely caused by heat stress, which enhances spot blotch development (Nema & Joshi, 1973; Regmi et al., 2002). Higher grain yields obtained under early and normal sowing conditions in the present study was also reported by Duveiller et al. (2005). Lower yields noticed in some genotypes such as RR21, NL1231, NL1179 might be accounted for their low yield genetic potential and higher disease severity. Genotypes like NL1231 which had lower yield in all sowing dates might also be due to their agronomic traits like late maturity, few effective tillers, and lower grain per spikes combined with high disease. Despite higher mean AUDPC values recorded in genotypes like Baanganga and Tilotamma, their yields were precisely acceptable suggesting that the genotypes are tolerant to heat and disease stress. At temperatures higher than 26^{o}C, even resistant varieties show some degree of disease susceptibility (Duveiller et al., 2005). RR21 even being the highly susceptible genotype among the test genotypes had higher yield than other susceptible genotypes under normal and late sown conditions. This might be because those genotypes had agronomic traits inferior to RR21. Timely seeded wheat reached flowering stage during early February and faced the progressive build-up of pathogen inoculum, while the late-seeded crop flowered in the third week of March and faced accumulated high inoculum pressure. The early-seeded wheat crop might even have served as a source of inoculum and contributed to the build-up of disease, causing overwhelming infection in late-seeded wheat at critical growth stages. Also, green leaf area duration in late-planted wheat is shorter and may be reduced further by the heavy inoculum load, which may have more impact because of the shorter grain-filling period.

CONCLUSION

The synthesis of our results advocates early sowing as an economic, easy and eco-friendly cultural method for curbing yield penalties due to spot blotch as early planting resulted lower disease severity and higher yield. Genotypes viz., NL 1207 and BL4341 outrivaled other test genotypes with substantially lower mean AUDPC values and higher mean yields under normal and late sown conditions, and thus could be effectively utilized as robust progenitor in spot blotch resistance breeding programs. Overall, the simultaneous adoption of early sowing and resistant genotypes could be a promising and economic avenue to reduce the disease pressure leading enhanced yield.

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REFERENCES

Aryal, L. (2013). Response of drought tolerant wheat genotypes to spot blotch under normal and late sowing condition at Rampur, Chitwan, Nepal. (Unpublished master thesis). Tribhuvan University, Rampur, Chitwan, Nepal.

CIMMYT. (2013). Research battles wheat spot blotch disease. Available on: https://www.cimmyt. org/research-battles-wheat-spot-blotch-disease/ [Retrieved on 17th June 2017].

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.

Duveiller, E. (2004). Controlling foliar blights of wheat in the rice-wheat systems of Asia. *Plant disease*, *88*(5), 552-556.

Duveiller, E., Chand, R., Singh, H. V., & Joshi, A. K. (2002). Physiological and morphological aspects of Bipolaris sorokiniana conidia surviving on wheat straw. *The Plant Pathology Journal*, *18*(6), 328-332.

Duveiller, E., Kandel, Y. R., Sharma, R. C., & Shrestha, S. M. (2005). Epidemiology of foliar blights (spot blotch and tan spot) of wheat in the plains bordering the himalayas. *Phytopathology*, *95*(3), 248–256. https://doi.org/10.1094/PHYTO-95-0248

FAO. (2019). World Food Situation. FAO Cereal Supply and Demand Brief.

Gurung, S., Sharma, R. C., Duveiller, E., & Shrestha, S. M. (2012). Comparative analyses of spot blotch and tan spot epidemics on wheat under optimum and late sowing period in South Asia. *European journal of plant pathology*, *134*(*2*), 257-266.

MoAD. (2017). Statistical Information on Nepalese Agriculture. Agri-Business Promotion and Statistics Division, Ministry of Agriculture and Cooperatives, Kathmandu, Nepal.

Mujeeb-Kazi, A., Villareal, R. L., Gilchrist, L. A., & Rajaram, S. (1996). Registration of five wheat germplasm lines resistant to Helminthosporium leaf blight. Crop Science, 36(1), 216-217.

Nema, K. G., & Joshi, L. H. 1973. Spot blotch disease of wheat in relation to host age, temperature and moisture. *Indian Phytopathol, 26,* 41-48.

Raemekers, R.H. (1991). Contribution to the epidemiology of Bipolaris sorokiniana disease and the development of rainfed wheat, a newcrop in Zambia. Diss. Land bouwwetenschappen, Katholicke Universiteitte Leuven, Belgium.

Regmi, A., Ladha, J., Pasuquin, E., Pathak, H., Hobbs, P., Shrestha, L., ... & Duveiller, E. (2002). The role of potassium in sustaining yields in a long-term rice-wheat experiment in the Indo-Gangetic Plains of Nepal. *Biology and Fertility of Soils*, *36*(*3*), 240-247.

Sharma, R. C., & Duveiller, E. (2006). Spot blotch continues to cause substantial grain yield reductions under resource limited farming conditions. *Journal of Phytopathology*, *154*(*78*), 482-488.

Wiese, M.V. 1998. Compendium of wheat diseases (3rd Ed). St. Paul, USA: APS Press, 112pp.