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ASSESSING WHEAT GERMPLASM FOR RESISTANCE AGAINST STRIPE RUST, EVALUATING FUNGICIDES FOR ITS MANAGEMENT AND STUDYING ITS CORRELATION WITH EPIDEMIOLOGICAL FACTORS

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ABSTRACT

In Pakistan and around the world, stripe rust on wheat leads to substantial production losses. The current study was undertaken to assess different wheat genotypes at Hafizabad Research Farm, College of Agriculture, University of Layyah, during the 2022-23 cropping season. Among the 15 genotypes screened, three exhibited a resistant response to the yellow rust pathogen. The disease progress curve (AUDPC) was calculated for all genotypes in the area. Environmental factors significantly influenced the severity of yellow rust. A positive correlation was observed between environmental variables, such as maximum and minimum temperatures, relative humidity, rainfall, and disease severity. Simple linear regression analysis indicated that the severity of yellow rust increased with rising maximum temperature, minimum temperature, rainfall, and relative humidity: 15.3-24°C, 9.9-16.6°C, 8-16 mm, and 20.7-70.7%, respectively. In the subsequent study, four fungicides were employed to control yellow rust, mitigate yield losses, and enhance the marginal return of wheat varieties. Among these fungicides, Tilt and Score demonstrated the highest efficacy in yellow rust management. In conclusion, the screening and fungicidal management of yellow rust on wheat genotypes have the potential to foster rust resistance and maximize production.

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INTRODUCTION

The paramount cereal crop globally is wheat (*Triticum aestivum* L.). Wheat thrives across the globe, with approximately 35% of the world's population relying on it as a staple. The demand for wheat remains high due to the escalating population of Pakistan. Roughly 215 million hectares of arable land worldwide are dedicated to hexaploid and tetraploid wheat cultivation. Notably, China, India, and Pakistan alone account for 62 million hectares of this expansive cultivation (Singh et al., 2004). Within this framework, Pakistan's wheat cultivation covers an expanse of 8.80 million hectares, yielding a substantial 25.09 million tons of production (Anonymous, 2011). Owing to its economic significance, wheat is plagued by formidable challenges posed by fungal, bacterial, and viral diseases (Mehboob et al., 2014; Mukhtar et al., 2018). Rust, a prevalent affliction in wheat-growing regions globally, emerges as a prominent threat. Thus, three distinct rust types-wheat leaf rust caused by *Puccinia recondita* f. sp. *tritici*, stripe rust caused by *Puccinia striiformis* f. sp. *tritici*, and stem rust caused by *Puccinia graminis* f. sp. *tritici*-loom as substantial impediments, incurring substantial losses in wheat yield (Singh et al., 2004).

In Asia, particularly susceptible varieties render approximately 43 million hectares vulnerable to stripe rust (Aquino et al., 2002). The occurrence of wheat rusts varies across diverse agro-climatic zones in Pakistan. Notably, stripe rust thrives under the prerequisites of cool summers and moist springs. The distinctive symptoms of this rust manifest as yellow-hued uredia, forming strips along the leaf surface. As the crop matures, these morph into black telial spores arranged in strip formations (Smiley and Cynthia, 2003).

The repercussions of stripe rust are evident in its historical impact. In 1995, an outbreak of stripe rust ravaged wheat varieties Pak-81 and Pirsabak-85, inflicting a significant 20% loss in production across Islamabad, Rawalpindi, KPK, and other parts of Pakistan (Chaudhary et al., 1996). The scale of wheat production loss attributed to rust is substantial, ranging from 10% to 70%, contingent upon factors such as vulnerability of cultivars, early infection instances, disease progression rate, and the temporal span of affliction (Chen, 2005). During the years spanning from 1988 to 1990, stripe rust epidemics exacerbated substantial production losses, underscoring the persistent challenges posed by this virulent disease.

The primary risk to future wheat production lies in rust diseases, with production losses in susceptible varieties escalating by over 50% (Yaqoob, 1991). In the epidemic year of 1977-78, estimated losses attributed to rust totaled 30-40 million rupees (Hassan et al., 1979). Wheat rust manifests in five stages of spore development, wherein an abundance of uredospores during spring and summer triggers significant epidemics. Spore dissemination between plants is facilitated by the wind, giving rise to new infections and secondary uredospores (Wiese, 1987).

Pathologists and plant breeders have a primary focus on the meticulous screening of each variety and lineage. This approach aims to elevate farmers' income and wheat yield by implementing suitable measures and strategies to mitigate these severe threats. Due to the low market price of wheat and health considerations, chemotherapy for stripe rust is not extensively practiced on a large scale in Pakistan. The screening process stands out as the most effective and economically efficient approach for identifying varieties that demonstrate resistance to yellow rust. In the management of wheat stripe rust within field conditions, diverse fungicides are commonly employed. The efficacy of various commercial products and their concentrations varies (Conner and Kuzyk, 1988). Hence, the current study was formulated to evaluate the potency of fungicides in countering stripe rust and augmenting grain yield. Its objectives encompass identifying resistant cultivars against yellow rust and establishing a correlation between environmental factors and yellow rust response values.

MATERIALS AND METHODS

Establishment of stripe rust screening nursery

Fifteen wheat genotypes (Table 1) were collected from Arid Zone Research Institute Bhakkar (AZRI) and Ayyub Agriculture Research Institute (AARI) Faisalabad and sown in an augmented design during crop season 2022*23. All agronomic practices were used to keep the crop in healthy condition.

Table 1: List of genotypes used in current investigation.

Sr. No.	Name of genotype	Source
1	WL-711, Galaxy-13, Faislabad-85, AS-2002, Shahkar-95, Niab-81, Punjab-85, Blue silver, Rohtas-90	Ayyub Agricultural Research Institute, Faisalabad
2	TWS-1902, Subhani, Bhakkar-2002, TWS-19101, TWS-19125, TWS-1992	Arid Zone Research Institute, Bhakkar

Inoculation

The plants were artificially inoculated by rubbing, spraying, and dusting methods to develop high disease pressure. After the emergence of leaves and tillers, plants were inoculated at seven-day intervals. Different virulent race mixtures of *P. striiformis* consisting of uredinospores at 10^6/ml of water were sprayed at the booting stage (Roelf et al., 1992).

Data recording and calculation of AUDPC

The rust severity percentage and plant response to disease were recorded at the onset of disease symptoms for three consecutive observations at ten-day intervals. Modified Cobb's scale was used for the recording of field response and disease severity (Peterson et al., 1948) (Table 2). Up to the physical maturity of the crop, disease severity data were recorded, and final data were recorded when disease severity reached 80-90%. The formula developed by CIMMYT was used to determine the area under the disease progress curve (AUDPC).

AUDPC $=\sum_{i=1}^{n\_1}\left[\frac{xi+xi+1}{2}\right](ti+1\_ti)$

Where; Xi = rust intensity on data I; Ti = time in days between I and date I +1; N = number of dates on which disease was recorded.

Table 2. Disease rating scale (0-6) for wheat rust disease.

Reaction	Infection type	Field response
Immune	0	No visible infection
Resistant	R	Necrotic areas with or without minute uredia
Moderately resistant	MR	Small uredia present surrounded by necrotic area
Moderately resistant to moderately susceptible	MRMS	Small uredia present surrounded by necrotic areas as well as medium uredia with no necrosis but possible some distinct chlorosis
Moderately susceptible	MS	Medium uredia with no necrosis but possible some distinct chlorosis
Moderately susceptible-susceptible	MSS	Medium uredia with no necrosis but possible some distinct chlorosis as well as large uredia with little or chlorosis present
susceptible	S	Large uredia and little or no chlorosis present

Evaluation of fungicides for the management of stripe rust

Two moderately susceptible wheat varieties, Galaxy-13 and Blue Silver, were sown in a randomized complete block design (RCBD) with four replications for the evaluation of various fungicides (Table 3) against stripe rust. The single application of fungicides was applied during unfolded six to nine leaves, and the second application was applied when the first awns were visible and the emergence of the spike was complete. After the appearance of disease symptoms, fungicides were applied using a knapsack sprayer. When the crop was harvested, each variety's grain yield and weight were calculated. The potential decrease in grain yield loss was determined as the percentage difference in yield between the fungicides sprayed and the control treatment for each variety. The marginal return was calculated by subtracting the gross return of the unsprayed control treatment from the gross return of each fungicide treatment.

Table 3: Different fungicides for the management of stripe rust at Hafizabad Research Farm, University of Layyah.

Treatment	Trade name	Common Name	Dose	Company name
T_1	Metiram	Polyram DF	625 g/ha	Swat Agro Chemicals
T_2	Sulphur	Sulphur	2500 g/ha	Evyol Group
T_3	Propiconazole	Tilt	625 ml/ha	Sygenta
T_4	Difenoconazole	Score	375 g/ha	Sygenta
T_5	Control	-	-	-

Relationship of meteorological variables with disease severity

Data on meteorological variables, including maximum and minimum temperatures, relative humidity, and rainfall, were obtained from the meteorological department of the Agronomic Research Station, Karor-Layyah. Simple linear regression analysis was employed to establish the relationship between severity and environmental factors.

Statistical analysis

Correlation and simple linear regression analysis were used to determine the relationship between environmental factors and rust severity data. A strong relationship with stripe rust severity was graphically plotted, and critical ranges conducive to disease severity were determined. Minitab Ver. 17 was used during the present study.

RESULTS

The screening of wheat varieties in the 2022-23 season yielded diverse results concerning stripe rust. Among the

15 varieties tested, three exhibited resistance, as indicated by lower AUDPC values. Conversely, only one variety (WL-711) displayed susceptibility throughout the growing season, characterized by a higher AUDPC value. The remaining varieties exhibited a mixed response (Table 4).

Environmental factors such as temperature, relative humidity, wind speed, and rainfall played pivotal roles in the disease development and sporulation. Notably, a significant correlation emerged between the disease severity and all the epidemiological variables (Table 5). An analysis of environmental factors revealed that an escalation in maximum and minimum temperatures, along with increased rainfall and relative humidity within the ranges of 15.3-24℃, 9.9-16.6℃, 8-16 mm, and 20.5-70.7%, respectively, corresponded to heightened rust severity (Figure 1).

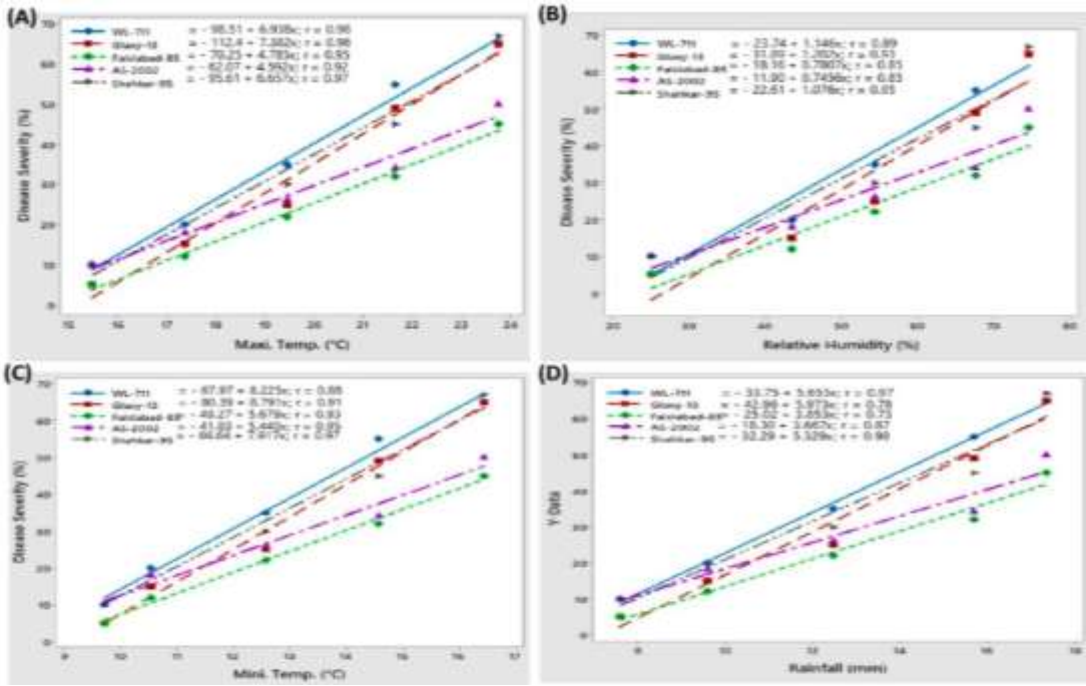

Figure 1: Relationship of (A) maximum temperature (B) minimum temperature (C) relative humidity and (D) rainfall with stripe rust disease severity.

Table 4. Response of different wheat genotypes against stripe rust.

Sr. No.	Variety	Reaction	AUDPC
1	WL-711	S	1505
2	Galaxy-13	MS	479.5
3	Faisalbad-85	MRMS	287
4	AS-2002	MRMS	325.5
5	Shahkar-95	MS	514.5
6	Niab-81	MS	504
7	Punjab-85	MS	448
8	Blue silver	MRMS	252
9	Rohtas-90	MRMS	385
10	TWS-1902	R	91
11	Subhani	R	105
12	Bhakkar-2002	MS	381.5
13	TWS-19101	MRMS	262.5
14	TWS-19125	R	73.5
15	TWS-1992	MS	350

Table 5: Correlations between metrological variables and stripe rust.

Sr. No.	Variety	Maximum temperature	Minimum temperature	Min. relative humidity	Max. relative humidity	Rainfall	Windspeed
1	WL-711	0.93**	0.75*	0.96**	0.94**	0.94*	0.98*
		0.004	0.02	0.007	0.0005	0.07	0.02
2	Galaxy-13	0.52*	0.58**	0.87**	0.97*	0.67*	0.91*
		0.01	0.005	0.0003	0.04	0.01	0.02
3	Faisalbad-85	0.59**	0.54*	0.81**	0.99*	0.57*	0.89*
		0.0005	0.03	0.003	0.03	0.04	0.02
4	AS-2002	0.65**	0.62*	0.88*	0.94**	0.51*	0.97*
		0.002	0.01	0.01	0.0002	0.03	0.01
5	Shahkar-95	0.57**	0.66**	0.92**	0.95**	0.89*	0.94*
		0.0001	0.004	0.0001	0.001	0.02	0.02
6	Niab-81	0.29*	0.64**	0.90*	0.98*	0.69*	0.96*
		0.01	0.004	0.02	0.02	0.01	0.01
7	Punjab-85	0.64*	0.65*	0.91*	0.98*	0.61*	0.97
		0.01	0.06	0.02	0.03	0.02	0.01
8	Blue silver	0.55*	0.62**	0.90*	0.93*	0.76*	0.96**
		0.02	0.001	0.01	0.02	0.01	0.002
9	Rohtas-90	0.92*	0.86*	0.97*	0.88*	0.89*	0.98*
		0.02	0.03	0.02	0.02	0.04	0.06
10	TWS-1902	0.07**	0.73**	0.94**	0.91*	0.59*	0.98**
		0.0001	0.004	0.0001	0.02	0.09	0.004
11	Subhani	0.95**	0.72**	0.92**	0.95*	0.74*	0.99**
		0.0001	0.004	0.0001	0.01	0.02	0.0005
12	Bhakkar-2002	0.59**	0.60*	0.89**	0.97*	0.54*	0.93*
		0.0002	0.01	0.0007	0.02	0.08	0.01
13	TWS-19101	0.55**	0.56*	0.83*	0.99*	0.98**	0.91*
		0.0002	0.01	0.001	0.01	0.004	0.01
14	TWS-19125	0.24*	0.72**	0.95**	0.95**	0.52*	0.98**
		0.0001	0.003	0.002	0.001	0.03	0.004
15	TWS-1992	0.56*	0.57**	0.87*	0.95*	0.93*	0.90*
		0.01	0.003	0.0002	0.01	0.01	0.01

Upper values indicate Pearson's correlation coefficient; Lower values indicate the level of significance at 5%probability; * = Significant (P<0.05); ** = highly significant (P<0.01)

The evaluation of fungicides showed that both wheat genotypes, Galaxy-13 and Blue Silver, exhibited significant reductions in yield loss and increases in thousands of grain weight, grain yield, and marginal return. This was particularly evident with two sprays of Tilt, outperforming single and double applications of Score, Sulphur, and Polyram DF, as indicated in Table 6 and Table 7.

DISCUSSION

The four wheat genotypes exhibited a resistant response against stripe rust under field conditions, making them suitable candidates for integration into wheat breeding programs. Utilizing resistant genotypes is imperative for enhancing wheat yield (Admassu et al., 2012). Our findings align with Singh et al. (2004), who observed that numerous cultivated genotypes in Pakistan succumbed to the disease, resulting in substantial commercial losses (Kisana et al., 2003). Afzal et al. (2009) conducted a study to assess the status of wheat genotypes against yellow rust and discovered that a majority of the one hundred and eighty-eight genotypes exhibited a resistant response to stripe rust.

Table 6: Evaluation of different fungicides against stripe rust at Hafizabad Research Farm, University of Layyah on Galaxy-13.

Treatment	Disease severity (%)	Grain yield (ton/ha)	TGW (g)	Reduction (%) of yield loss	Reduction (%) of TGW Loss	Gross revenue ($/ha)	Marginal return over unsprayed control ($/ha)
Single spray Polyram DF	90	0.22	10.3	30.3	10.8	91.3	138.3
Two sprays of Polyram DF	71	0.47	13.2	40.3	16.5	91.2	101.3
Single spray Sulphur	53	0.28	15.2	36.2	23.2	121.4	160.5
Two sprays of Sulphur	60	0.52	20.2	46.5	31.3	149.3	118.3
Single spray Score	59	0.43	30.7	47.7	39.2	199.1	181.2
Two sprays of Score	41	0.62	32.8	55.1	49.2	221.5	192.3
Single spray Tilt	68	0.51	39.1	59.3	51.3	229.1	199.1
Two sprays of Tilt	16	0.81	49.1	77.3	71.2	277.4	239.1
Control	93	0.11	16.6				

Table 7: Evaluation of different fungicides against stripe rust at Hafizabad Research Farm, University of Layyah on Blue Silver.

Treatment	Disease severity (%)	Grain yield (ton/ha)	TGW (g)	Reduction (%) of yield loss	Reduction (%) of TGW Loss	Gross revenue ($/ha)	Marginal return over unsprayed control ($/ha)
Single spray Polyram DF	71	2.21	20.1	19.2	20.4	131.3	69.5
Two sprays of Polyram DF	81	2.39	31.3	44.2	39.1	158.3	91.2
Single spray Sulphur	49	2.31	28.1	29.2	29.1	149.5	87.8
Two sprays of Sulphur	59	2.61	40.3	50.3	58.1	161.3	139.1
Single spray Score	61	2.39	38.2	40.4	37.1	181.3	208.1
Two sprays of Score	45	2.78	50.1	60.0	71.1	200.3	171.2
Single spray Tilt	62	2.61	48.2	50.4	41.1	241.3	241.6
Two sprays of Tilt	11	2.91	66.2	86.1	81.2	288.1	271.3
Control	97	0.11	14.3				

During the current study, various environmental variables such as maximum and minimum temperatures, relative humidity, and rainfall were assessed in relation to stripe rust severity.

The results demonstrated significant and highly significant correlations between disease severity and all environmental factors. Disease severity increased with elevated minimum and maximum temperatures, relative humidity, and rainfall.

Temperature ranges of 10-18°C and 12-28°C facilitated lesion formation and spore production on mature plants. Notably, at a minimum temperature of 7-15°C, infected leaves displayed a considerable increase in lesion area, leading to rapid spore production (Milus et al., 2009).

Park et al. (1992) evaluated the response of eighty three wheat genotypes against stripe rust at the seedling stage and found that temperature ranges of 5-18°C and 15-24°C significantly impacted yellow rust development.

Singh and Tewari (2001) investigated the influence of meteorological variables on stripe rust development, noting that the pathogen's growth was influenced by a minimum temperature of 10.9°C, a maximum temperature of 25.7°C, and relative humidity ranging from 49.6% to 88.1%. Geagea et al. (2000) demonstrated the wind-borne spread of the yellow rust pathogen.

Our research underscored the effectiveness of tilt against the wheat stripe rust pathogen, aligning with Smith et al. (1986) and Iqbal and Mukhtar (2020) who emphasized the use of fungicides as a primary management strategy to combat yellow rust. Salman et al. (2006) highlighted a positive correlation between yellow rust severity and production losses, specifically identifying wheat genotypes such as WL-711, SA75, SA42, Chakwal, and Morocco as experiencing the highest losses (53-59%) against the stripe rust pathogen. Consequently, our results emphasize the necessity of consistent rust monitoring and the release of resistant varieties to safeguard the country's food security.

CONCLUSION

It is concluded that three wheat genotypes exhibited resistant response against yellow rust pathogen. Maximum wheat genotypes significantly and highly significantly correlate with yellow rust severity. Yellow rust severity increases with increase of maximum, minimum temperature, relative humidity and rainfall. Tilt fungicide was found to be the best for the management of yellow rust.

AUTHORS' CONTRIBUTIONS

SS, HMA, and YA designed, formulated and laid out the study; SS, YA, and SA conducted the experiments; CMSH, and AAK collected, arranged and analyzed the data; MAR, and MA provided technical assistance; HMA and RH supervised the work; SS and YA wrote the manuscript; SA proofread the paper.

CONFLICT OF INTEREST

The authors declare no conflict of interest

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