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EFFECT OF YELLOW RUST PUCCINIA STRIIFORMIS ON YIELD OF SUSCEPTIBLE WHEAT GENOTYPES

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Abstract

Wheat (Triticum aestivum L.) production in Pakistan is significantly threatened by yellow rust (Puccinia striiformis f. sp. Tritici), which leads to considerable yield reductions under conducive environmental conditions. A field experiment was conducted during 2024-2025 at the Cereal Crops Research Institute Pirsabak, Nowshera to quantify yield losses and evaluate the effectiveness of fungicide application across twelve bread wheat genotypes with varying resistance levels. The experiment was arranged in a randomized complete block design with three replications under treated and untreated conditions. Highly significant ($P \leq 0.01$) differences were observed among genotypes for disease severity and all yield-related traits. The coefficient of infection ranged from 0.0 in resistant lines i.e. Yr-57 and Yr-5+15 to 55.5 in susceptible genotype Inqalab-91 (untreated). Grain yield varied from 1,353 kg ha^{-1} in untreated Inqalab-91 to 4,306.7 kg ha^{-1} in treated Yr-57. Thousand grain weight ranged from 29.42 g (untreated Seher-06) to 49.42 g (treated Zarlashta-99). Fungicide application resulted in grain yield increase ranged from 0.38% (Yr-5+15) to 14.33% (Imdad-05), while thousand grain weight increased by up to 36.83% (Seher-06). Biological yield increase ranged from 1.21% to 16.24% across genotypes. Resistant lines maintained low infection levels (0–7.5 CI) and exhibited minimal yield reduction under disease pressure. Fungicide application at proper time could minimize yield losses even in conducive environment. Moreover, regarding yellow rust disease resistance the best genotype was wheat line YR-57 and the most susceptible was Inqalab-91.

INTRODUCTIO

Wheat is a staple and the most cultivated crop in Pakistan, contributing significantly to the country's agricultural economy and ensuring the dietary needs of its population. However, the productivity of wheat faces numerous challenges, one of the most persistent being yellow rust (*Puccinia striiformis* f. sp. *tritici*), and a fungal disease that severely impacts wheat yields worldwide. In Pakistan, where wheat is grown on over 9 million hectares, yellow rust outbreaks pose a significant threat to both agricultural sustainability and national food security (Bux et al., 2012)

Yellow rust can cause yield losses of up to 58% on susceptible cultivars if infection occurs very early in the crop development stage and the disease continues to develop during the growing seasons Grain yield loss of 71% has been recorded on susceptible bread wheat variety Wabe in Bale (Ayele and Muche, 2019). The use of foliar fungicide application on bread wheat genotypes with variable level of resistance planted under contrasting growing conditions can help farmers, increase grain yield, grain quality and biomass (Abdennour et al. 2018). The study will report the effect of yellow rust disease and fungicide application on yield, yield components and biomass using bread wheat genotypes having different level of resistance.The present study will be conducted to determine the effect of yellow rust on the qualitative traits of twelve widely cultivated bread wheat varieties through fungicide application and host resistance, thereby quantifying the losses. The present study will be conducted to determine the effect of yellow rust on the qualitative traits of twelve widely cultivated bread wheat varieties through fungicide application and host resistance, thereby quantifying the losses.Wheat stripe rust infection have not been well studied. Based on a 2 year investigation under natural infection conditions analysis of the area under the disease progress curves (AUDPC) differentiated the susceptible cultivars Mianmai 367 (MM367; 788.59), Jinmai 47 (JM47; 1,087.71), and Avocet Susceptible (AvS; 1,314.59) from resistant cultivars Xikemai 18 (XKM18; 177.50) and Xiaoyan 6 (XY6; 545.67). Stripe rust resulted in a 2-year mean yield loss of 32% for all tested varieties. The susceptible varieties JM47, AvS, and MM367 lost 64, 55, and 21% of grain yield, respectively. On the contrary, rust-resistant cultivars XKM18 and XY6 lost only 11 and 28%, respectively. In addition, stripe rust resulted in reduced kernel hardness, flour yield, and flour whiteness. Dough and gluten properties were also affected. Overall, results revealed that the grain yield and quality loss values of the resistant wheat cultivars were less than in the susceptible cultivars. Disease-resistant cultivars such as XKM18 should be promoted and recommended for application. It may also be suggested that growing a susceptible variety such as MM367 could be feasible in combination with fungicide application under high disease pressure (Almacellas et al., 2013).

2. Materials and Methods

Twelve diverse wheat varieties/lines i.e. Imdad-05, Sindhu, TD-1, Benazir-13, zarlashta-99, As-02, Seher-06, Inqalab-91, Khatakwal, Pakhtunkhwa-15, Line Yr-57 and Yr 5+15 with varying parentage, morpho-yield traits was be grown during 2024-2025 in a randomized, complete block (RCB) design with three replications at Cereal Crops Research Institute, Pirsabak (CCRI), Nowshera, Khyber Pakhtunkhwa-Pakistan. Two sets of these varieties was be sown in one with fungicide and other without fungicide application In order to estimate yield losses in wheat due to stripe rust in Pakistan.

Table 2.1 Twelve diverse Wheat varieties/lines

S.NO	Varieties/lines	Resistant/Susceptible	S.NO.	Varieties/lines	Resistant/Susceptible
1	Imdad-05	Susceptible	7	Seher-06	Susceptible
2	Sindhu	Susceptible	8	Inqalab-91	Susceptible
3	TD-1	Susceptible	9	Khatakwal	Susceptible
4	Benazir-13	Susceptible	10	Pakhtunkhwa-15	S2.1sceptible
5	zarlashta-99	Susceptible	11	Line Yr-57	Resistant
6	As-02	Susceptible	12	Line Yr-5+15	Resistant

2.1 Coefficient of infection

Coefficient of Infection (CI) was calculated by using data on disease severity and host reaction by multiplying the severity value by the arbitrary constant value for field response, where R=0.2, MR=0.4, M=0.6, MS=0.8 and S=1 and used to classify genotypes in to three groups based on disease severity such as 1-20 high adult plat resistance, 21-40 intermediate and 41-100 low adult plant resistance .The Area Under Disease Progress Curve (AUDPC) value was calculated as

2.2 Days to Heading

From the date of planting until the appearance of spikes and exposure of peduncle node, the days till heading of each experimental plot will be recorded.

2.3 Plant Height (cm)

Plants was be chosen at random from normal conditions and measured using meter rods from the bottom to the top.

2.4 Flag Leaf Area (cm^2)

Various wheat plant leaves was be chosen at random, and the area of the flag leaf will be measured using a ruler or meter rod. The measurement of the flag leaf will follow the following formula:

Flag leaf area = Length × Maximum leaf area × 0.75

2.5 Spike Length (cm)

Each genotype's ten selected spikes was be measured in millimeters from the first spikelet's base on the rachis to the spike's tip, excluding awns. For data analysis, the average length of 10 spikes will be used.

2.6 Spike Weight (g)

Each of the 10 randomly chosen spikes was be used to measure each spike's weight using a sturdy, sensitive electronic balance.

2.7 Spikelets $Spike^{-1}$

In each experimental plot, spikelets $spike^{-1}$ was be counted at random from a selection of plants.

2.8 Grain $Spike^{-1}$Each genotype of wheat grown under normal conditions will have its grain $spike^{-1}$ measured at random. Additionally, the replication of the normal condition's spike will be gathered, and it was be manually measured.

2.9 Thousand Grain Weight (g)

Following the manual count of the thousand grains, an electronic balance was be used to weigh them.

2.10 Grain yield (Kg/ha)

An electronic balance was be used to calculate the grain yield (kg ha-1). Grain can be taken from several wheat plants.

Statistical Analysis

Table 2.2; ANOVA table for RCBD

S.O.V	Dt	Ss	Ms	FSSS
Block (reps)	r-1	SSB	MSB	F-Block
Treatment	t-1	SSt	MSt	F-treatment
Error	(r-1)(t-1)	SSE	MSE	
Total	Rt-1	SST		

H_0: , H_a: , $\sum Y_t$, $\sum Yj$, CF = $(Y_{11})^2$ /rt ,SST=$\sum\sum Yij2$- Cf , df for total = rt -1 , SSt = $\sum Yi^2/r$-CF , df for treatment =t-1 , MSt =SSt/df t ,SSB= $\sum Yj_2/t$ - CF, df for Blocks (Reps)= r-1 , MSB= SSB/df B ,SSE=SST – SSt-SSB, df E = df T- df t – df B, MSE =SSE/df E , Fc =MST/MSE Ftable=df t, df E

Result and Discussion

3. Results

3.1.1 Coefficient of infection

The statistical analysis showed significant differences among wheat genotypes for coefficient of infection. Moreover, the CV value for coefficient of infection was 0.58 which showed credibility of the experiment and LSD value was 9.93. Moreover, coefficient of infection for studied genotypes ranged from (0.0-55.5). Furthermore, maximum coefficient of infection was observed for land race wheat genotype Inqalab -91-untreated (55.5), Zarlashta -99-untreated (52.5) and TD-1-untreated (48.0). However, minimum coefficient of infection was reported for variety line Yr-57-untreated (4.5) and Line Yr -5 + 15 - treated (0.0).

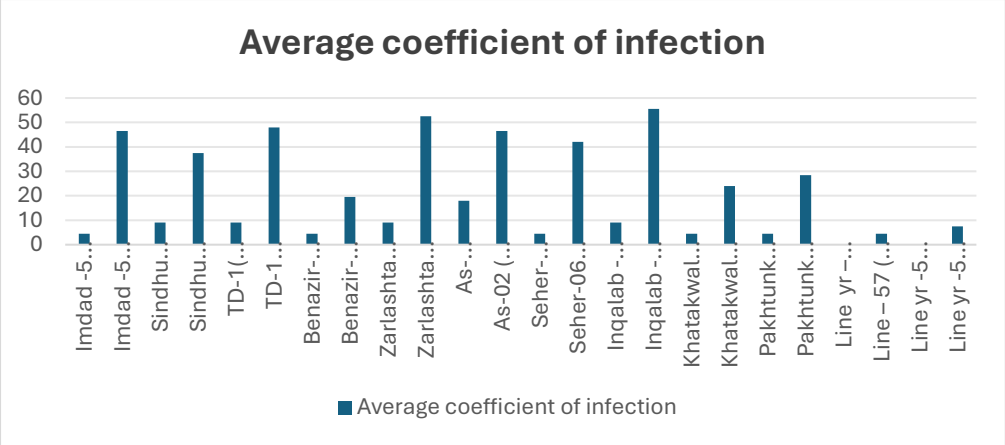


Figure 3.1.1. Mean performance of wheat genotypes for yellow rust ACI

Days to heading

The statistical analysis showed significant differences among wheat genotypes for days to heading. Moreover, the CV value for days to heading was 0.58 which showed credibility of the experiment and LSD value was 1.63. Moreover, days to heading for studied genotypes ranged from 112-115 days. Furthermore, maximum days to heading was observed for land race wheat genotype khattakwal untreated, Pakhtunkhwa-15 and YR-5+15 treated (120 days). However, minimum days to heading was reported for variety As-02 treated and untreated (112.00 days).

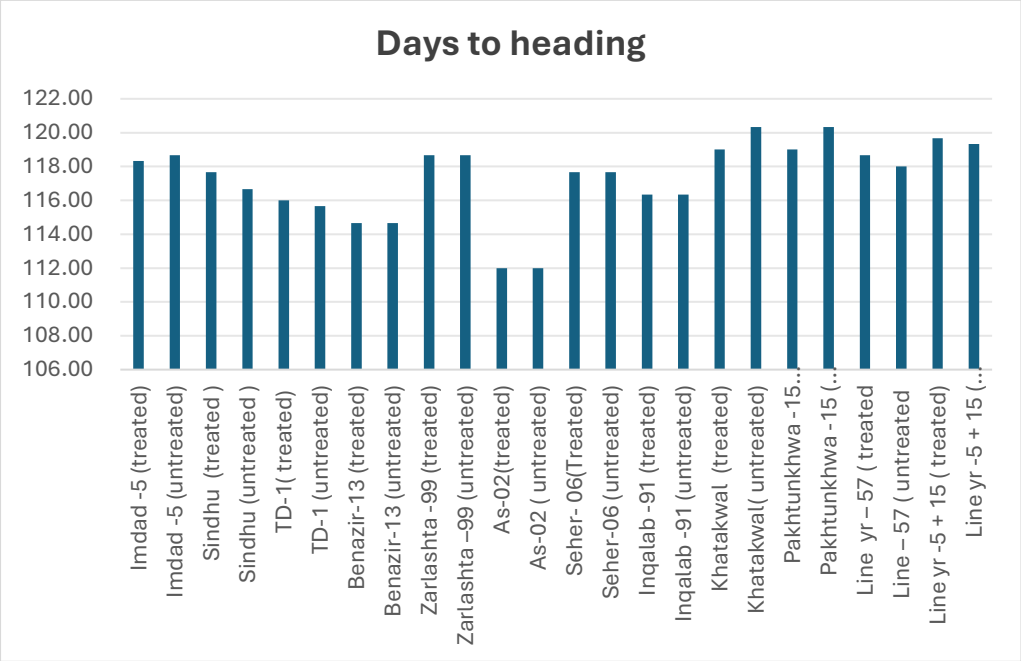


Figure 3.1.3. Mean performance of wheat genotypes for day to heading.

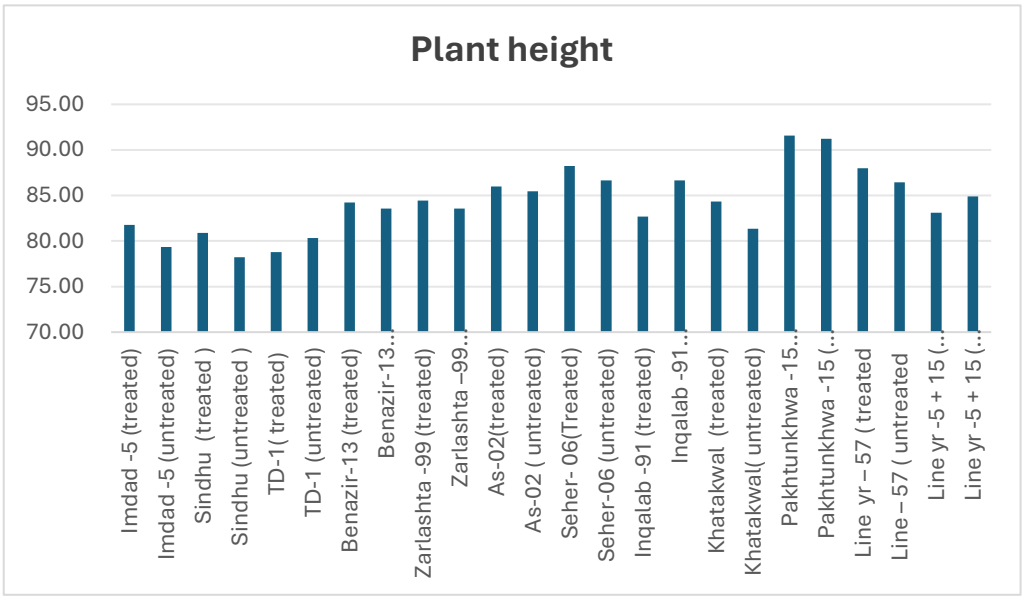


Figure 3 .1.5. Mean performance of wheat genotypes for plant height

3.1.3 Plant height

The statistical analysis showed significant differences among genotypes for plant height. The CV value for plant height was 3.23 which showed credibility of the experiment. Similarly, LSD value for plant height 4.47. Moreover, days to heading for studied genotypes ranged from 80.3-86. Furthermore, maximum plant height is observed for Pakhtunkhwa -15 treated (91.56) and Pakhtunkhwa-16 untreated. However, minimum was reported for varieties 78.223.

3.1.4 Flag leaf area

The statistical analysis showed significant differences among genotypes for flag leaf area. The CV value for flag leaf area was 8.08.which showed credibility of the experiment. Similarly, LSD value for flag leaf

area 3.48. Moreover, flag leaf area for studied genotypes ranged from 20.5-3303. Furthermore, maximum flag leaf area was observed for lmdad -05 treated (33.39) and lmdad 05 untreated. However, minimum flag leaf area was reported for varieties 20.540

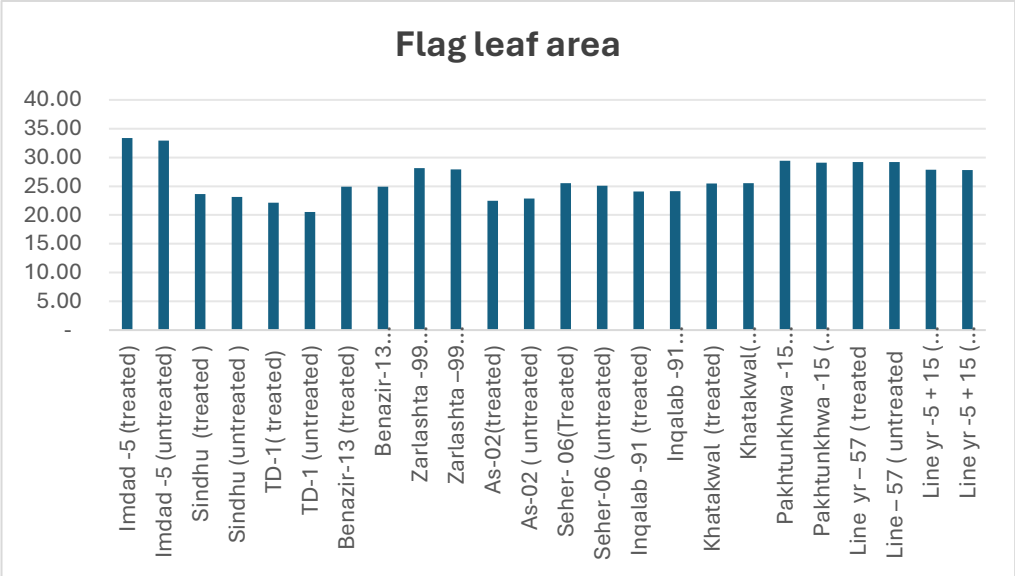


Figure 3.1.6: Mean performance of wheat genotypes for flag leaf area.

3.1.5 Spikelet per spike

The statistical analysis showed significant differences among genotypes for spike let per spike. The CV value for spike let per spike was 3.47.which showed credibility of the experiment. Similarly, LSD value for spike let per spike1.06. Moreover, spike let per spike for studied genotypes ranged from 18.0-18.22. Furthermore, maximum spike let per spike was observed for Pakhtunkhwa-15 treated (21.11) and Pakhtunkhwa -16 untreated. However, minimum spike let per spike was reported for varieties 17.223.

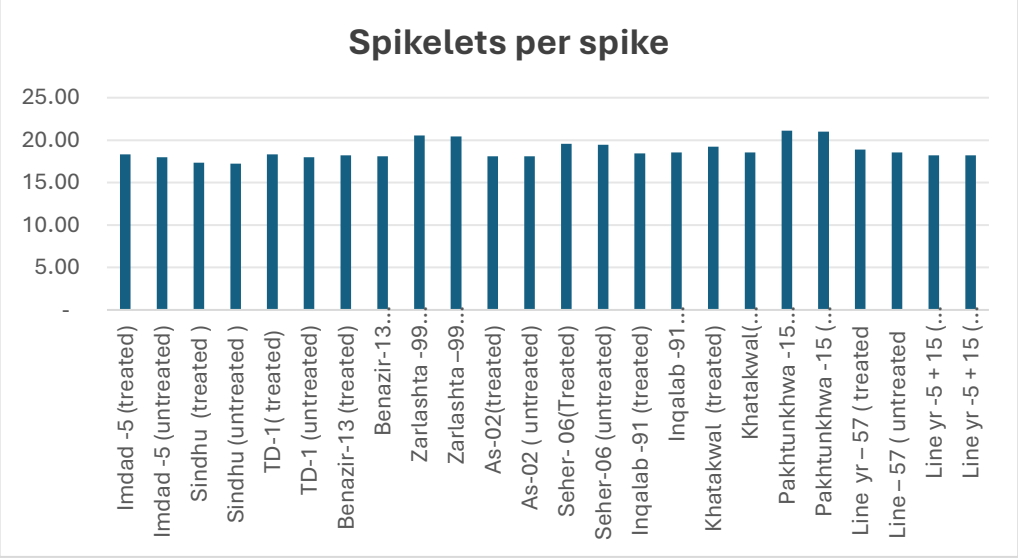


Figure: 3.1.8. Mean performance of wheat genotypes for spike lets per spike.

3.1.6 Spike weight

The statistical analysis showed significant differences among genotypes for spike weight. The CV value for spike weight was4.50 which showed credibility of the experiment. Similarly, LSD value for spike weight0.23. Moreover, spike weight for studied genotypes ranged from 2.62-3.66. Furthermore, maximum spike weight was observed for Pakhtunkhwa -15 treated (4.45g) and YR7 treated. However, minimum spike weight was reported for varieties 2.3100.

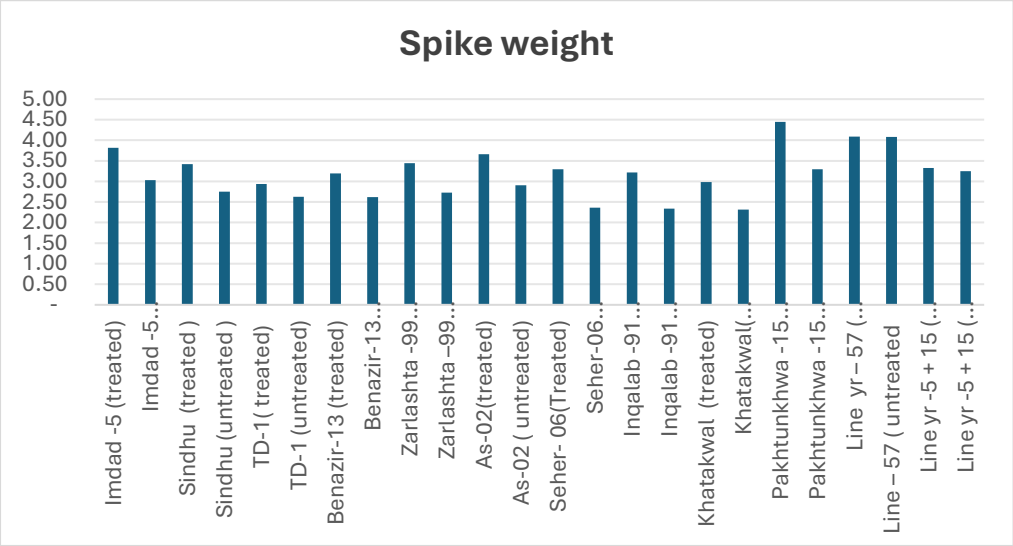


Figure: 3.1.10. Mean performance of wheat genotypes for spike weight.

3.1.7 Grain Weight per spike

The statistical analysis showed significant among genotypes for grain weight per spike. The CV value for grain weight per spike was 7.80 which showed credibility of the experiment. Similarly, LSD value for grain weight per spike 0.33. Moreover, grain weight per spike for studied genotypes ranged from 1.96-283. Furthermore, maximum grain weight per spike was observed for khattakwal untreated (2.99) and Pakhtunkhwa -15 treated. However, minimum grain weight per spike was reported for varieties 1.7113.

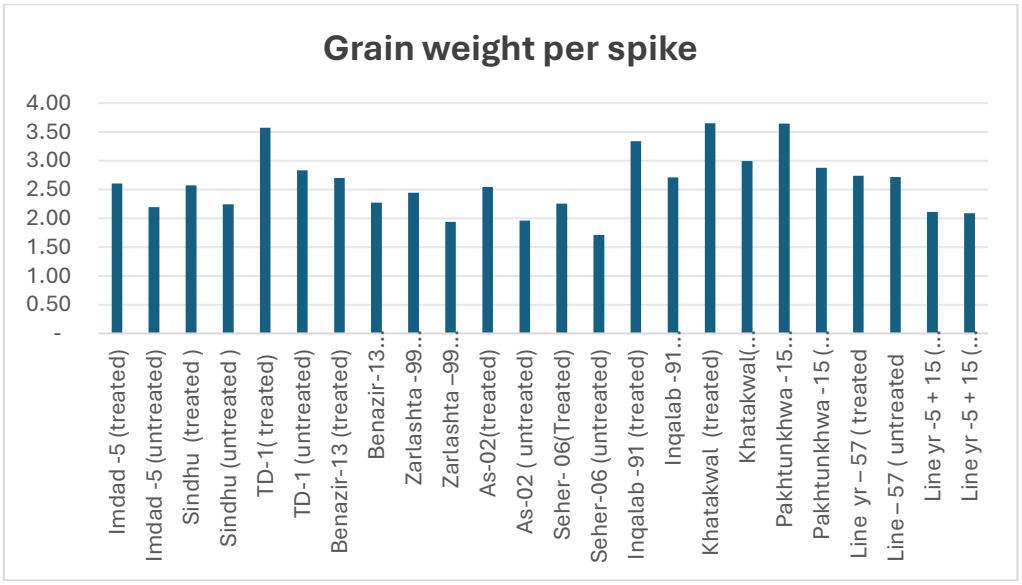


Figure: 3.1.12. Mean performance of wheat genotypes for grain weight per spike.

3.1.8 1000 grain weight

The statistical analysis showed significant among genotypes for days to maturity. The CV value for days to maturity was 0.58 which showed credibility of the experiment. Similarly, LSD value for days to heading

1.63. Moreover, days to heading for studied genotypes ranged from 112-115. Furthermore, maximum days to heading was observed for khattakwal untreated (39.42 g) and Pakhtunkhwa-16 untreated. However, minimum days to heading was reported for varieties 112.00. The increase in 1000 kernel weight may be attributed to the effects of foliar fungicide application in preventing stripe rust and thereby maintaining higher leaf greenness for long period of time.

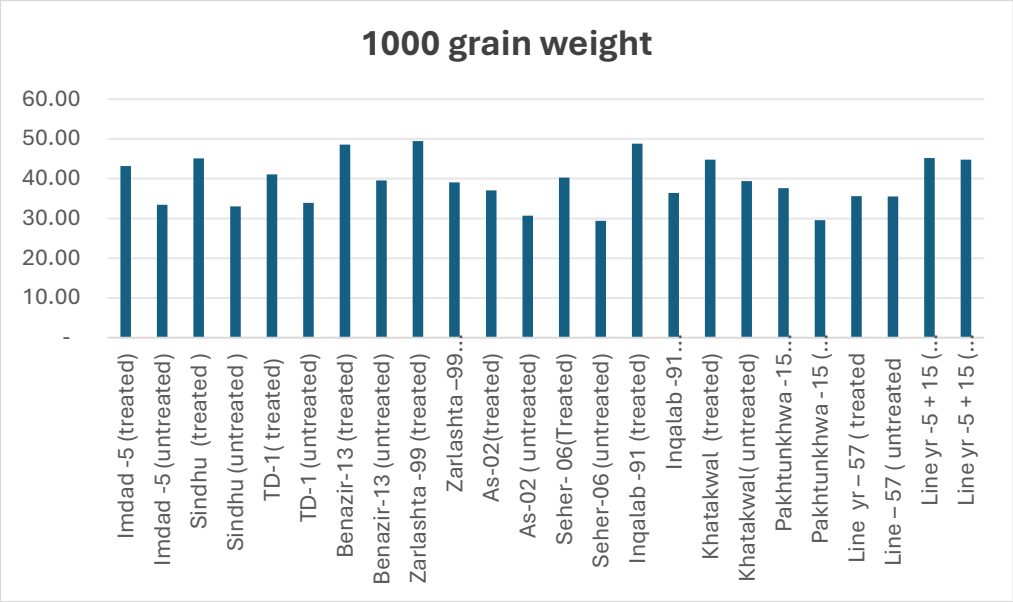


Figure 3.1.13. Mean performance of wheat genotypes for 1000 grain weight.

3.1.9 Biological yield per plant

The statistical analysis showed significant differences among genotypes for biological yield per plant. The CV value for days to biological yield per plant is 4.16 which showed credibility of the experiment. Similarly, LSD value biological yield per plant 507.00. Moreover, biological yield per plant for studied genotypes ranged from 6453-7180. Furthermore, maximum biological yield per plant was observed for YR-57 treated (10, 71) and YR-5+SS15 treated. However, minimum biological yield per plant was reported for varieties 3367.

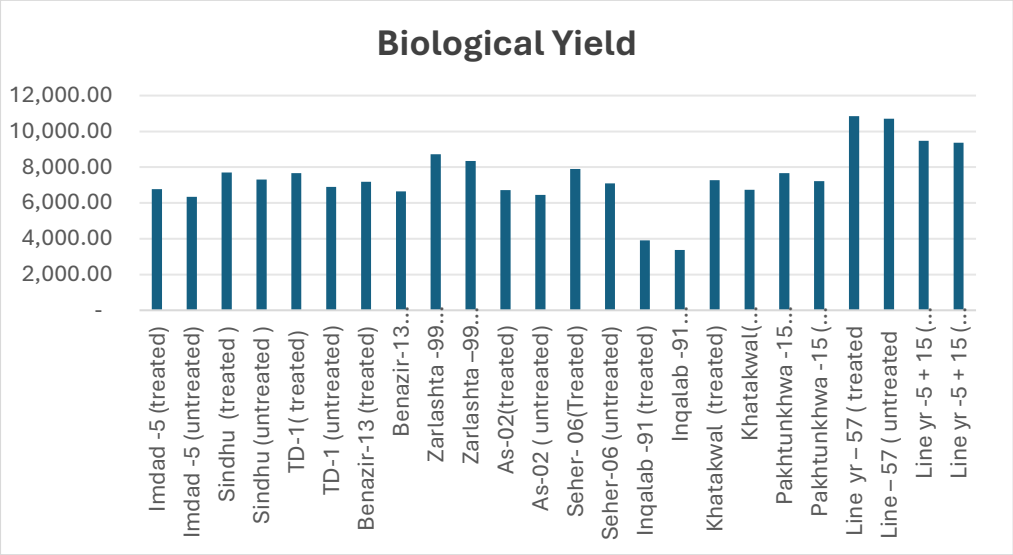


Figure: 3.1.15. Mean performance of wheat genotypes for biological yield per plant.

3.1.10 Grain yield

The statistical analysis showed significant variation among genotypes for grain yield. The CV value for grain yield was 6.87.which showed credibility of the experiment. Similarly, LSD value for grain yield 297.4. Moreover, grain yield for studied genotypes ranged from 1353-4306. Furthermore, maximum was grain yield was observed for genotype YR-57 treated (4306 kg/ha) and YR-57untreated. However, minimum grain yield was noted for varieties 1353.

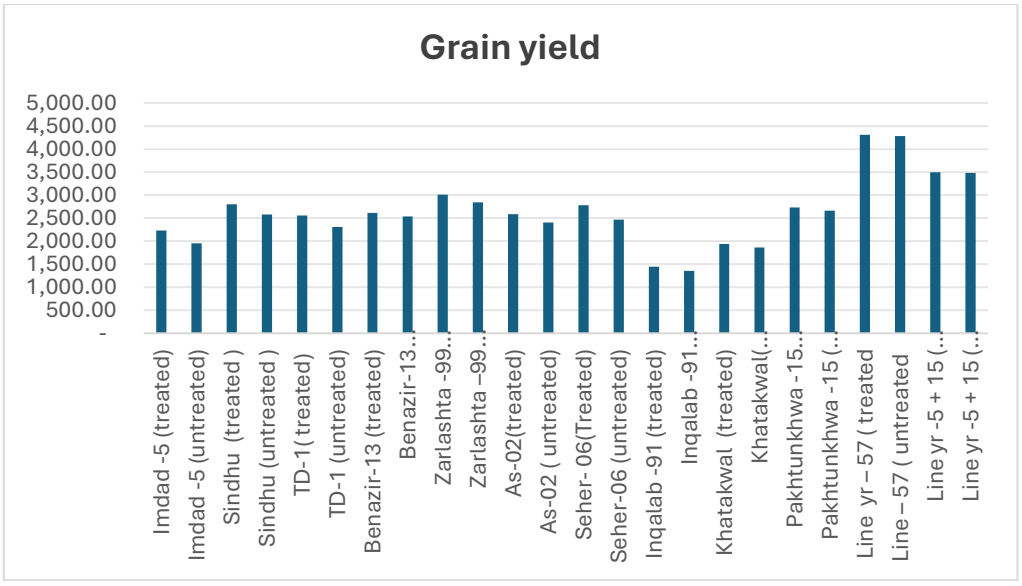


Figure: 3.1.17. Mean performance of wheat genotypes for grain yield.

3.1.11. Percent increase in yield and yield related traits over untreated plots

3.1.11.1 Percent increase of thousand grain weight

Percent increase in 1000 grain weight ranged from 0.23 to 36.83 % for treated vs non treated plots. Maximum % increase was recorded for famous wheat variety Seher-06 treated over untreated plot i.e. 36.83 which showed that yellow rust severely effected grain weight of wheat variety Seher-06. However, minimum percent increase for 1000 grain weight was reported fors wheat resistant line YR-57 i.e. 0.23 %, which showed resistance to yellow rust infestation during the season.

3.1.11.2 Percent increase of grain weight per spike

Percent increase in grain weight per spike ranged from 0.81 to 29.70% for treated vs non treated plots. Maximum % increase in grain weight per spike was recorded for Sindh wheat variety lmdad treated over untreated plot i.e. 31.67%, which showed that yellow rust severely affected grain weight per spike of wheat variety Imdad. However, minimum percent increase for grain weight per spike was observed for wheat line YR-57 i.e. 0.81%, which showed resistance to yellow rust severity during the season.

3.1.11.3 Percent increase of spike weight

Percent increase in spike weight ranged from 0.11 to 26.34% for treated vs non treated plots. Maximum % increase was exhibited by wheat variety lmdad treated over untreated plots i.e. 39.68% which revealed that the yellow rust adversely affected spike weight of wheat variety Imdad. However, minimum percent increase for spike weight was recorded for advance wheat line YR-57 i.e. 0.11%, which indicated resistance to yellow rust severity during the season.

3.1. 11.4 Percent increase of grain yield

Percent increase in economically important trait of wheat i.e. grain yield ranged from 0.38 t0 14.33% for treated vs non treated plots. Maximum % increase was recorded for Sindh wheat cultivar lmdad treated over untreated plot i.e. 12.70% which demonstrated that yellow rust greatly affected grain yield of Imdad. However, minimum percent increase for grain yield was witnessed for wheat advance line YR-5 + 15 i.e. 0.38%, which revealed resistance to yellow rust during the season.

3.1. 11.5 Percent increase in biological yield

Percent increase in biological yield ranged from 1.21 to 16.24% for treated vs non treated plots. Maximum % increase was exhibited by wheat variety Inqilab-91 treated over untreated plot i.e. 16 .24%, which revealed that yellow rust adversely affected biological yield of wheat variety lnqilab-19 however, minimum percent increase for biological yield was recorded for wheat line YR-5+15 i.e. 1.21%, which showed resistance to yellow rust during the wheat season 2024-25.

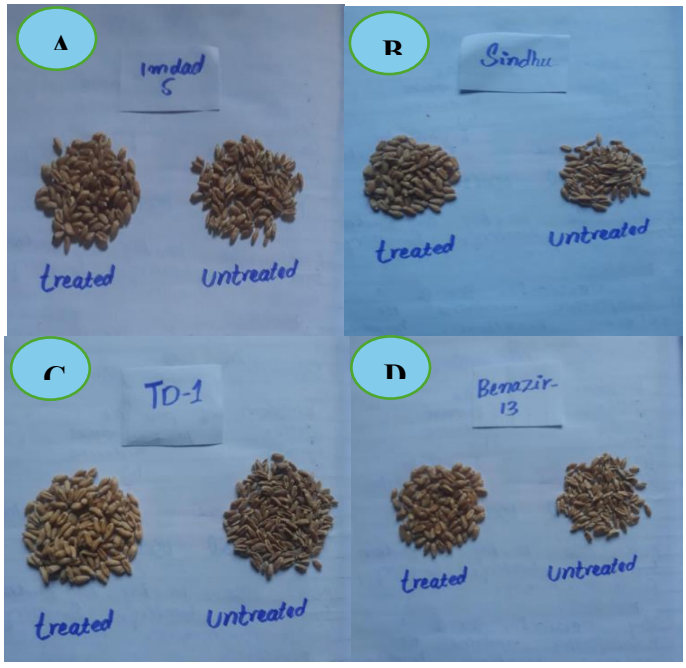


Figure: 3.1.18. Grain yield response of four wheat varieties lmdad -5 sindh TD-1 and Benazir -13under treated and untreated conditions showing differences in grain production between treatments.



Figure: 3.1.19. Grain yield performance of wheat varieties zarlashta-99 AS-02 seher-06 and Inqalab -91 under treated and untreated condition illustrating the effect of treatment on grain production.

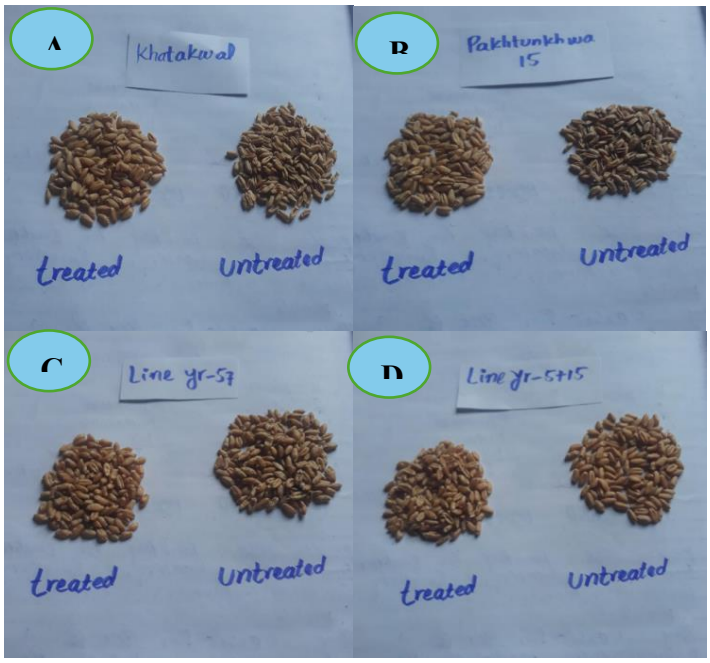


Figure: 3.1.20. Grain yield performance of wheat varieties khattakwal Pakhtunkhwa -15 line -57 and line YR-5+15 under treated and untreated conditions showing variation in grain production among varieties.

Table: 2.3. Mean performances of different agronomic traits.

S.NO	Varieties	DH	PH	FLA	SPS	ACI
1	Imdad -5 (treated)	118.33	81.78	33.39	18.33	4.5
2	Imdad -5 (untreated)	118.67	79.33	32.91	18.00	46.5
3	Sindhu (treated)	117.67	80.89	23.66	17.33	9
4	Sindhu (untreated)	116.67	78.22	23.11	17.22	37.5
5	TD-1(treated)	116.00	78.78	22.13	18.33	9
6	TD-1 (untreated)	115.67	80.33	20.54	18.00	48
7	Benazir-13 (treated)	114.67	84.22	24.93	18.22	4.5
8	Benazir-13 (untreated)	114.67	83.56	24.94	18.11	19.5
9	Zarlashta -99 (treated)	118.67	84.44	28.14	20.56	9
10	Zarlashta –99 (untreated)	118.67	83.56	27.95	20.44	52.5
11	As-02(treated)	112.00	86.00	22.45	18.11	18
12	As-02 (untreated)	112.00	85.44	22.88	18.11	46.5
13	Seher- 06(Treated)	117.67	88.22	25.51	19.56	4.5
14	Seher-06 (untreated)	117.67	86.67	25.11	19.44	42
15	Inqalab -91 (treated)	116.33	82.67	24.10	18.44	9
16	Inqalab -91 (untreated)	116.33	86.67	24.12	18.56	55.5
17	Khatakwal (treated)	119.00	84.33	25.46	19.22	4.5
18	Khatakwal(untreated)	120.33	81.33	25.52	18.56	24
19	Pakhtunkhwa -15 (treated)	119.00	91.56	29.42	21.11	4.5
20	Pakhtunkhwa -15 (untreated)	120.33	91.22	29.10	21.00	28.5
21	Line Yr-57 (treated	118.67	88.00	29.22	18.89	0
22	Line-Yr-57 (untreated	118.00	86.44	29.21	18.56	4.5
23	Line Yr -5 + 15 (treated)	119.67	83.11	27.84	18.22	0
24	Line Yr -5 + 15 (untreated)	119.33	84.89	27.83	18.22	7.5
LSD		**1.63**	**4.48**	**3.48**	**1.07**	**3.33**

Table: 2.4. Mean performances of different agronomic traits.

S. NO	V. Names	TGW	%ITGW	GWPS	%IGWPS	SW	%ISW	GY	%IGY	B.Y	%IB.Y
1	Imdad-05.(treated)	43.17	29.18	2.61	18.78	3.82	25.82	2,233.3	14.33	6,773	6.95
2	Imdad-05.(untreated)	33.42	-	2.19	-	3.03	-	1,953.3	-	6,333	-
3	Sindhu (treated)	45.08	36.62	2.57	14.52	3.42	24.52	2,800.0	8.53	7,693	5.29
4	Sindhu (untreated)	33.00	-	2.25	-	2.75	-	2,580.0	-	7,307	-
5	TD-1 (treated)	41.08	21.13	3.57	26.00	2.94	11.86	2,560.0	10.98	7,660	11.01
6	TD-1 (untreated)	33.92	-	2.83	-	2.62	-	2,306.7	-	6,900	-
7	Benazir-13 (treated)	48.58	22.84	2.70	18.97	3.19	21.88	2,613.3	2.89	7,180	8.13
8	Benazir-13 (untreated)	39.55	-	2.27	-	2.62	-	2,540.0		6,640	-
9	Zarlashta-99 (treated)	49.42	26.44	2.45	26.26	3.45	26.34	3,006.7	5.87	8,713	4.31
10	Zarlashta-99 (untreated)	39.08	-	1.94	-	2.73	-	2,840.0		8,353	-
11	As-02 (treated)	37.08	20.92	2.54	29.70	3.66	25.92	2,586.7	7.63	6,713	4.03
12	As-02 (untreated)	30.67	-	1.96	-	2.91	-	2,403.3		6,453	-
13	Seher-06 (treated)	40.25	36.83	2.25	31.67	3.30	39.68	2,780.0	12.70	7,907	11.47
14	Seher-06 (untreated)	29.42	-	1.71	-	2.36	-	2,466.7		7,093	-
15	Inqilab-91 (treated)	48.83	34.10	3.34	23.15	3.22	37.59	1,443.3	6.65	3,913	16.24
16	Inqilab-91 (untreated)	36.42	-	2.71	-	2.34	-	1,353.3		3,367	-
17	Khattakwal (treated)	44.75	13.53	3.65	22.02	2.99	29.28	1,940.0	4.11	7,273	8.13
18	Khattakwal (untreated)	39.42	-	2.99	-	2.31	-	1,863.3		6,727	-
19	Pakhtunkhwa-15 (treated)	37.58	27.04	3.65	26.71	4.45	35.05	2,730.0	2.63	7,667	6.09
20	Pakhtunkhwa-16 (untreated)	29.58	-	2.88	-	3.29	-	2,660.0		7,227	-
21	line Yr-57 (treated)	35.58	0.23	2.74	0.81	4.09	0.11	4,306.7	0.62	10,847	1.24
22	line Yr-57 (untreated)	35.50	-	2.72	-	4.08	-	4,280.0		10,713	-
23	line Yr-5+15 (treated)	45.17	0.89	2.11	0.86	3.33	2.57	3,493.3	0.38	9,473	1.21

24	line (untreated)	Yr-5+15	44.77	-	2.09	-	3.25	-	3,480.00	9,360	-
LSD			**2.61**		**0.34**		**0.23**		**297.42**	**507.3**	

3.2 Discussion

3.2.1 Average coefficient of infection

At Bekoji, infection coefficients on unsprayed plots were 6% for the resistant variety (Wane) and 81% for the susceptible variety (Kubsa). After two fungicide sprays, these coefficients decreased to 0.2% for Wane and 27% for Kubsa. Similarly, at Meraro, unsprayed plots showed 4.7% infection for Wane and 83% for Kubsa, with fungicide application significantly reducing infection rates compared to unsprayed plots, though results varied with different fungicides and their frequencies of application.

3.2.2 Days to heading

However, no significant differences were observed among the moderately resistant and resistant varieties regarding head infection the findings of (Kumar et al. 2019), who observed significant variations for these attributes among various genotypes, are not consistent with our results. Given that their backgrounds are comparable; the lack of significant differences may be due to genetic similarities. There were significant differences in head infection between susceptible and moderately resistant/resistant varieties at both locations, Sinana and Ginirat these locations.

3.2.3 Plant hight

The positive correlation observed between these traits and grain yield may be attributed to enhanced photosynthetic assimilation and a greater proportion of photosynthesis being allocated to the developing kernels, ultimately increasing their weight. Similar findings were reported by (Berhanu et al. 2017), who reported significant associations of plant height.

3.2.4 Flag leaf area

Our result are similar to those (Iqbal et al. 2024) who reported that the substantial genetic variation among wheat genotypes for flag leaf area (FLA). Their study demonstrated that heritability estimates and coefficients of variation were notably high, confirming the presence of con Otane', stripe rust continues to develop, although slowly, on flag leaves when conditionsremain cool, and the crop is not under water stress, Under these conditions, up to 20% kleaf area can be affected. 'Otane' is also susceptible to stripe rust in the spike and inoculum from infected leaves can result in as many as 23%of florets becoming infected (Cromey 1989). On flag leaves, disease severity increased after 70 and 60 days after planting (DAP) for Millennium and Kubsa, respectively. Kubsa's mean disease severity was lower on flag leaves compared to all leaves, whereas Millennium's was higher. At Agarfa, maximum disease severities reached 15% for Kubsa and 10.8% for Millennium. A significant difference in yellow rust severity between Kubsa and Millennium was noted after 80 DAP. Disease severities on flag leaves were lower than those on all leaves across test varieties. The susceptible variety Kubsa exhibited the highest severity ratings consistently. Maximum severities at Sinana were 37.1% for Kubsa, followed by 18.3%, 2.6%, 1.3%, 0.5%, and 0% for Millennium, Dure, Digalu, MaddaWalabu, and Sofumar, respectively. A sharp disease increase was noted on flag leaves of Kubsa and Millennium after 61 days after planting (DAP), while Dure and Digalu showed the increase after 71 DAP, with MaddaWalabu maintaining stability. Resistant and moderately resistant varieties showed no significant differences in disease severity, but significant differences ($p \leq 0.05$) were noted among the susceptible, moderately resistant, and resistant varieties.

3.2.5 Spike weight

According to Emad & Asoda (2019) this results indicated a significant impact of yellowrust on the number of kernels per spike, particularly in susceptible cultivars. Kernel number was reduced by 13.0%, 10.7%, and 9.6% in Saber Beg, Al-8/70, and Araz, respectively, while moderately resistant to moderately susceptible cultivars (Tamuz 2 and AL-84) showed smaller reductions of 8.3% and 6.0%. In contrast, resistant genotypes AL-124 and AL-8/172 were not significantly affected. Despite disease pressure, highly

significant differences among genotypes were observed. AL-84 produced the highest kernels per spike (79.15), followed by Tamuz 2 (74.32), while Saber Beg had the lowest (39.32). Similar trends persisted under infection, with AL-84, Tamuz 2, and AL-124 maintaining higher kernel numbers, whereas Saber Beg again showed the minimum (36.57). Overall, the results clearly demonstrate strong varietal differences and the pronounced negative effect of yellow rust on susceptible cultivars.

3.2.6 Grain weight

The results of Sajid Ali et al. (2009) confirm that grains per spike is a highly genotype-dependent trait and varies significantly across environments, with some cultivars consistently outperforming others due to their superior genetic makeup for spike development and grain setting. Clear variation was observed in grains per spike among wheat varieties. Bahawalpur-95, Chakwal-86, and Tatara produced the highest values (62), while WL-711, Tandojam-83, and Faisalabad-85 showed the lowest (32–36). Site data also showed wide differences, with minimum grains spike^{-1} for Sarsabz (22), WL-711 (24), and Fakhre Sarhad (28), and maximum for Kaghan-93 (69), Chakwal-96 (86), and Shahkar-95 (68). These results highlight strong genetic and environmental influences on spike fertility. Greater severity (60) but with better grain yield and grain weight, which could be due to its tolerance behavior. Thus it was excluded from the analysis, considering it as an outlier. Similar was the case for Frontana, which was considered to be partially resistant but not adapted to our climate and had relatively poor yield potential. For the rest of varieties, a negative linear relationship was found between yield potential traits and rust severity. Varieties with lower yellow rust severity, like Tatara, Saleem 2000, and Fakhre-Sarhad had relatively higher grain yield and 1000-grain weight accordingly

3.2.7 1000 grain weight

This result of increased grain weight from foliar fungicide application was in agreement with previous findings (Ransom et al. 2008 & Bancal et al. 2007,) Kelly 2001 and Jesus et al.2001) similarly (Hawkesford et al. 2013 & Robert et al. 2005), this increase in mean kernel weight can be attributed to leaf area protection as foliar fungicide application leads to higher leaf area index, which enhances the efficiency of photosynthesis and therefore the grain filling. According to results of (sajjid Ali et al. 2009). Variation in 1000-grain weight was evident across locations, showing the strongest range at AUP, where Fakhre-Sarhad recorded the highest value (64.3 g) and Kohistan-97 the lowest (19.3 g). CCRI showed comparatively narrower variability (17.2–35.4 g), while NIFA presented moderately high values but a smaller range after excluding two outliers (35.3–56.0 g).Overall, varieties with greater yellow rust severity consistently showed lower 1000-grain weight. Analysis of variance showed highly significant between varieties ranged from 34-48 g. Maximum kernels weight (48.48 and 44 g) were obtained from varieties kakaba, hidasie and galil respectively. However, grains with minimum weight (34.37 and 39 g) were observed in wheat varieties medawelebu galema and Jeferson respectively.

3.2.8 Biological yield

Similar to The finding of (sajjid et al. 2009) the Biological yield varied, with the highest variability at NIFA and a generally negative skewness at all locations. At AUP, biological yield ranged from 7500 to 18,533 kg ha^{-1}, while NIFA and CCRI showed ranges of 6333–18,333 kg ha^{-1} and 8333–18,333 kg ha^{-1}, respectively. Across varieties, the highest mean biological yield (15,278 kg ha^{-1}) was observed in Kirin-95, WL-711, Blue Silver, Shahkar 95, Sariab 92, Saleem-2000, and Tatara, indicating their superior biomass production under varying yellow rust pressure.

Biological yield was relatively more variable across locations. A negative skewness was recorded for all the 3 locations with a maximum variability at NIFA. The skewness was most prominent at CCRI. The biological yield at AUP was in the range of 7500 kg ha-1 (Punjab-96) to 18533 kg ha-1 (Kirin-95, WL-711, Blue Silver, Shahkar-95, Sariab-92, Saleem-2000, and Tatara). It ranged from 6333 kg ha-1 (Pasban-90) to 18333 kg ha-1 (Faisalabad-93 and Shahkar-95) at NIFA. Similarly, at CCRI it was maximum for Tatara (18333) while minimum for Maxi-Pak, Faisalabad-93, and Watan-64 (8333 kg ha-1). Among the varieties, the maximum mean biological yield was 15278 (kg ha-1), which was recorded for Kirin-95, WL-711, Blue Silver, Shahkar-95, Sariab-92, Saleem-2000, and Tatara.

3.2.9 Grain yield

Our results corroborate those reported by Lopez et al. (2015) and Bhatta et al. (2018) which indicates that foliar fungicide application increase grain yield by about 10 to 50% in bread wheat. The increase of grain yield is the result of the efficacy of the foliar fungicide to control the disease and limits its effects.by AUP (4292 kg ha-1). CCRI had the minimum grain yield among the tested locations (3676 kg ha-1). Grain yield on untreated plots at Bekoji was 273.3 kgha-1 for susceptible (Kubsa), 2638.3 kgha-1 for moderately susceptible (Danda'a), 2938.3 kgha-1 for moderately resistant (Lemu), and 4688 kgha-1 for resistant varieties (Wane). The susceptible variety's grain production on treated plots was 3240.0 kgha-1, while the resistant variety's was 6085 kgha-1. Grain production on untreated plots at Meraro ranged from 2965 kgha-1 for resistant varieties to 106.7 kgha-1 for susceptible cultivars. Grain yields on treated plots at Meraro varied from 4920 kgha-1 on resistant varieties (Wane) to 3191.5 kgha-1 on susceptible types (Kubsa). Higher yields were achieved by applying both fungicides, Tilt 250 EC and Rex® Duo, twice.

The outcome was consistent with that of Reid D and swart J (2004) who found that applying foliar fungicides to wheat enhanced yield by 34% to 41% compared to untreated plots. In contrast, Wiik L & Rosenqvist H. (2010) Found that a single fungicide treatment throughout the years 1983–2007 increased yield over a number of research years.

This increase of grain yield is the result of the efficacy of the foliar fungicide to control the disease and limits its effects. The results corroborate those reported by (Lopez et al., 2005) and (Bhatta et al., 2018), which indicates that foliar fungicide application increase grain yield by about 10 to 50% in bread wheat. However, resistant genotypes showed similar grain yield between treated and untreated plots (belong to the same classes; consequently, using genetic resistance for yellow rust can substitute chemical alternative even under high pressure of the disease.

The maximum mean grain yield was produced at NIFA (5533 kg ha-1) followed The mean grain yield among the varieties ranged from 3174 kg ha-1 to 6718 kg ha-1. The maximum mean grain yield was produced by Sariab-92 (6718 kg ha-1), followed by Faisalabad-83 (6314 kg ha-1), and Tatara (6232 kg ha-1). However, Saleem-2000 (5980 kg ha-1), Pak-81 (5465 kg ha-1), and Tandojam-83 (5363 kg ha-1) also had relatively better grain yield. The maximum grain yield was recorded for Sariab-92 (7947 kg ha-

Conclusion

It was concluded that Fungicide application resulted in grain yield increases ranging from 0.38% (Yr-5+15) to 14.33% (Imdad-05), while thousand grain weight increased by up to 36.83% (Seher-06). Moreover, resistant lines maintained low infection levels (0–7.5 CI) and exhibited minimal yield reduction under disease pressure.

From the study it was concluded that for better wheat yield production resistant wheat varieties should be used. In case of diseased varieties proper fungicide application at proper time could also maintained wheat production.

Future Recommendations

The use of fungicide at the right time is a valuable disease management tool particularly when environmental conditions are conducive for the development of yellow rust.

Breeding programs for wheat should aim to introduce durable rust resistance genes in high yielding wheat cultivars.

More multi-location and multi-year testing should performed to select resistant wheat genotypes in a range of agro-climatic conditions

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