Evaluation of Wheat Genotypes and their F1 Progenies for Waxiness and Pubescence related Traits

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Abstract

Wheat (Triticum aestivum L.) is the third largest cereal crop but its yield is constantly challenged by different biotic and abiotic factors. Wheat domestication shaped the evolution of waxiness and pubescence as defensive barriers against biotic and abiotic stresses, and indirectly contribute to better wheat yield potential. Understanding the role of these traits in the realm of biotic and abiotic stresses tolerance and their relationship to yield is pivotal for stable wheat production. This study was designed to evaluate indigenous and exotic wheat germplasm and F1 progenies for waxiness and pubescence, and their relationship to better yield potential. The wheat germplasm was sown in Randomized Complete Block Design (RCBD) with three replications at the Agriculture Research Field of Gomal University, Dera Ismail Khan. Data collected for waxiness, pubescence, leaf rust, yellow rust and yield related traits was subjected to R-package for graphical and tabula presentation. Results revealed that out of 100 wheat germplasm used in this study, majority of them possessed waxy leaves (59%) while glossy germplasm accounted for 41%. The high number of glossy lines among durum and landraces and the absence of glossy leaf line in modern Pakistani cultivars suggest that waxy attribute has been continuously selected by breeders to develop modern cultivars to combat drastic heat and drought stresses. The presence of abundant number of hairy germplasm both in landraces and modern varieties suggests that pubescence of flag leaf, auricle and glumes might be attributed to natural and artificial selection. Flag leaf hairiness, glume hairiness and flag leaf waxiness traits showed highly significant correlation (0.1546**,0.2986** and 0.1308**) with 1000GW at p-vale = 0.01 respectively, thus suggesting this trait to be used for breeding for disease resistance. Flag leaf waxiness and glume hairiness showed high heritability and the F1 progenies constructed exhibited heritable waxiness and pubescence traits which may be further extended to F2 generation for genetic mapping of novel genes controlling waxiness and pubescence.

Keywords: Wheat, Waxiness, Pubescence, Durum Wheat, Landraces, F1

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Introduction

Bread wheat (*Triticum aestivum* L.) is one of the three most extensively cultivated and consumed cereal crop, and contribute hugely to global food security in the fast changing climate. Globally, it covers more than 30% area under cereals cultivation and contribute about 20% of the nutrients for daily human diet (Bi *et al.,* 2017). Global human population is expected to reach up to 8.5 billion till 2050. Such fast growing human population warrants to enhance wheat production to ensure both food and nutritional security (FAO, 2014). Previous studies have shown that different abiotic and biotic stresses contribute differently to global wheat yield losses with highest losses contributed to heat stress (20%), followed by low temperature (7%), salinity (10%), drought (9%) and the rest of the 4% losses being caused by biotic factors especially rust, powdery mildew and fusarium head blight (Ziyaev *et al*. 2011; Sharma and Ravi, 2013). Wheat production is highly affected by biotic and abiotic stress worldwide, among the Asian countries, Pakistan and India faces more challenges through abiotic stresses, caused by water scarcity, over flooding, soil erosion and climate changes, and different biotic factors include pathological diseases, fungi diseases, attack of nematodes, viral and bacterial diseases, causing severe losses in yield and quality of wheat. (Absattarova *et al*. 2002; Nazari *et al*. 2008).

Among abiotic stresses, drought stress and heat stress severely affect wheat yield, especially at heading and grain-filling stages. Both these stresses not only limit kernel number per spike but also the size and weight of grains. The current situation is further aggravated by the constantly changing climate and decreasing water table and water resources, especially in drought-prone regions (Lobell and Gourdji, 2012). In most severe situations, drought causes 10-70% wheat yield losses. Thus, there is a constant need to evaluate available wheat germplasm for the evolved physiological and morphological traits that can in turn contribute to better yield potential by combating the adverse effects caused by drought stress (Mardeh *et al*., 2006; Foulkes *et al*., 2007; Li *et al*., 2011; FAO, 2013). Similarly, heat stress happening during sudden high temperature at the time of pollination (terminal heat stress) adversely affect seed setting, grain-filling, and ultimately causes decrease in wheat yield. Global climate change studies have predicted an approximate 1.8-5.8°C increase in temperature that is expected to adversely affect wheat yield production globally (Akter and Rafiqul, 2017; IPCC, 2007). Similarly, among biotic stresses different rust disease (leaf rust, stem rust and yellow rust) cause severe yield losses during pandemics (Prasad *et al*. 2020). To combat these different biotic and abiotic stresses, wheat has evolved several structures and traits that can help tolerate drought and heat stress and defend against different types of pathogens. Two such important traits are waxiness and pubescence.

Waxiness is an important trait evolved in land plants as an outer cuticle or waxy layer acting as a contact zone between outer environment and plant. Waxy cuticle is the extension of upper epidermal layer cell of the plant that acts as hydrophobic sheet covering the upper surfaces of the organs of the plant. The waxiness trait governed by waxy cuticle provides important function to tolerate drought, radiations stress, heat stress and protection against different plant pathogens and insects (Delwiche *et al*., 2011; Wu *et al*., 2013; Wang *et al*., 2015). This waxy layer controls non-stomatal water loss by limiting transcription rate and enhance drought tolerance. Different genes and transcription factors that modulate wax synthesis and control drought and heat stress have been documented (Eigenbrode *et al*., 2000; Wang *et al*., 2024; Yadav *et al*., 2024). Another important trait evolved in wheat and other plant as a defensive mechanism is pubescence which is associated with low moisture and desert environment (Luo *et al*. 2016). Pubescence or hairiness is common on several organs of the wheat such hairy glumes, hairy leaf, hairy auricles and hairy culm. Previously, pubescence or hairiness have been documented to play a vital in water and temperature stress, resistance against aphids and fungal pathogens, and tolerate radiation dose (Hu *et al*., 2024; Simonov *et al*., 2024; Artemenko *et al*., 2024).

Very few reports are available to screen wheat germplasm, especially Pakistani wheat landraces, for the variation in waxiness and pubescence, and to determine the relationship between these two traits with yield. The current designed to evaluate indigenous and exotic wheat germplasm (varieties, landraces, durum advanced lines and F_1 progenies) for waxiness and pubescence, and their relationship to better yield potential.

Material and Method

Current research was conducted in the Research Field of Faculty of Agriculture, Gomal University Dera Ismail Khan in the wheat growing season of 2022-2023. The F_1 developed for waxiness and pubescence were sown and evaluated in wheat growing season 2023-2024.

Research Design

Research design for this study was standardized as RCBD (randomized complete block design) using three replications in the design. Experimental plot area was kept $90m^2$ with 100 wheat genotypes per replication. The length of each row was kept 5 meter and row to row length was kept 30cm. Total of 15 seeds per row were sown using dibbler method and seed to seed distance was kept 30cm.

Agronomic Practices

Land was prepared using ploughing, rotavator and laser leveler. Regular recommended doses of different nitrogen and phosphorous fertilizers followed by irrigation and hoeing was applied at different stages of wheat development.

Material

In this study, seventy wheat landraces and eighteen varieties were acquired from National Agricultural Research Centre (NARC), Islamabad while twelve durum advanced lines were acquired from Agriculture Research Institute (ARI) Ratta Kulachi, D.I.Khan.

Detailed information of the germplasm used in this study is given in Table 1.

Data was recorded keeping selection intensity at 5% from every line. Protocol for data collection of parameters is as under.

Parameters

Waxiness

Waxiness was scored as waxy (W) and non-waxy (NW) of the three randomly selected leaves. Waxiness was visually scored as the intensity of the purple waxy color versus no-waxy color of the leaves, culm and glume.

Pubescence

Pubescence was scored visually as non-hairy (0), medium-hairy (1) and dense-hairy (3) of the three randomly selected leaves.

Yellow rust and leaf rust resistance

Leaf rust and yellow rust scores were recorded at three different time intervals. First scoring was performed at the initial rust appearance (t_1), corresponding to the growth stage of resistant wheat variety AZRC Dera (check) and susceptible wheat variety Punjab-11(check by the method devised by Zadoks *et al*. 1974). The scoring method considered the percentage of leaf area covered by spores on the three most heavily infested leaves, using a scale from 0 to 12. For each line, the area under the disease progress curve (AUDPC) was calculated using the formula: AUDPC = $(N_1 + N_2)(t_2 - t_1)/2 + (N_2 + N_3)(t_3 - t_2)/2$, where N_1 is the rust intensity recorded at t_1.

Days to 50% heading

Days to 50% heading were documented from the time of sowing of the crop to the moment when 50% plants in a line showing headings i.e., the time of emergence of spike from flag leaf.

Spike length (cm)

Spike length of the randomly chosen plants was calculated after measuring the spike from base to the panicle of spike and further analyzed on their average calculated.

Number of Spikelets spike^{-1}

The spikelet number spike^{-1} was recorded from the randomly chosen plants.

Number of grains spike^{-1}

All the spikes from the randomly selected plants of individual block were threshed by hand and their number of grains was calculated manually and average was obtained.

Grain yield plant^{-1} (g)

Data for grain yield plant^{-1} was recorded for five selected plants after threshing all the spikes by hand for each spike, after which they were cleaned whole grain yield of individual plant was recorded with the help of electric balance in grams.

1000-grain weight (g)

At the stage of physiological maturity, 1000-grains were calculated from the randomly selected plants and their weight was taken in grams.

Flag Leaf Length (cm)

Flag leaf length was calculated by measuring the distance from the base to the tip of the three randomly selected flag leaves.

Flag Sheath Length (cm)

Flag leaf sheath length was calculated by measuring the distance from the base of flag leaf sheath around the peduncle to the starting point of blade of three randomly selected flag leaves.

Flag Width (cm)

Flag leaf width was calculated by selecting and measuring width of three points of the flag leaf- base, mid and below tip of the three randomly selected flag leaves.

Traits transfer via hybridization

Parents with contrasting traits such waxy and non-waxy leaves, and hairy and non-hairy glumes were crossed using standard protocols of emasculation and pollination. The F_1 obtained in wheat growing season 2022-2023 were sown and evaluated in 2023-2024 for waxiness and pubescence traits.

Statistical Analysis

After collection of data, variance analysis was performed following the protocol provided by Singh and Chaudhry (1985) and R-package. Heritability was quantified through the formula suggested by Lush (1940).

Results

Waxiness distribution pattern

All 100 genotypes used in this study showed tremendous variation both for waxiness and pubescence. Three differetn levels of waxiness (normal, medium and strong) and sharp glossy phenotypes were observed among genotypes used in this study. Result showed that out of 100 wheat germplasm used in this study, majority of them possessed waxy leaves (59%) of which 28% was strong waxy while 31% had moderately waxy flag leaves. Glossy germplasm accounted for only 41% (Fig. 1). The trend of waxy and glossy phenotypes were not consistant in durum, landraces and varieties. The high number of glossy and minimum waxy lines were observed among durum and landraces (Fig. 2 and Fig. 4), while no glossy phenotype was observed in Pakistani wheat varieties (Fig. 3).

Stem and glume waxiness distribution pattern

Strong artificial selection trend was observed for stem and glume waxiness. Figures 5 and 6 also depict lowest number of strong waxy and highest number of glossy stem and spike glumes in Pakistani wheat landraces. The trend was contrary among 18 cultivars used in this study where all 18 cultivars possessed strong waxy stem and glumes.

Pubescence distribution pattern

Pubescence or hairiness was observed on flag leaf, auricles glume. All 100 genotypes used in this showed a diversity for hairiness on flag leaf, auricles and glumes. Majority of the genotypes (71%) exhibited pubescence in which 43% genotypes showed strong hairiness while 28% showed strong hairiness. The rest of the 29% of the genotypes lacked pubescence on flag leaf, auricles and glumes (Fig. 7). Results from figures 8 and 9 showed the presence of abundant number of hairy germplasm both in landraces and modern varieties. Among eighteen varieties tested, 12 showed moderate hairiness and rest of the 6 varieties lacked hairiness (Fig. 8). Similar hairiness trend was noted in 70 landraces tested in this study in which 10 landraces lacked hairiness while 32 showed moderate hairiness and 28 showed strong hairiness (Fig. 9).

Correlation of waxiness and pubescence with 1000GW

Correlation analysis in research is a statistical method used to measure the strength of the linear relationship between two variables and compute their association. Similarly, among other yield related attributes, 1000 Grain Weight (1000GW) is key determinant of wheat yield attribute. Flag leaf hairiness (FLGLH), glume hairiness (GHR) and flag leaf waxiness (FLGLW) traits showed highly significant correlation (0.1546**,0.2986** and 0.1308**) with 1000GW at 0.01 level of probability. All other traits correlations were non-significant (Table 2).

Yellow rust and leaf rust status

Majority of the landraces and modern cultivars used in this study possessing hairy flag leaf and glumes had reduced incidence of yellow and leaf rust (Fig. 10).

Hybridization for waxiness and pubescence

The cross of glossy landrace (parent-P1) with waxy landrace (parent-P2) produced F1 progenies with waxy flag leaves (Fig. 11). Similarly, the cross of non-hairy variety (P1) with hairy landrace (P2) produced F1 progenies with hairy glumes (Fig. 12),

Heritability estimates and genetic advance of various traits

In the current study, Flag leaf wax (FLGLW) and glume hairiness (GHR) showed high heritability while leaf rust (LR) show moderate heritability (Table 3). These traits can be effectively advanced to next generations via hybridization.

Discussion

To combat these different biotic and abiotic stresses, wheat has evolved several structures and traits that contribute to tolerance against drought and heat, and defend against different types of pathogens. Two such important traits are waxiness and pubescence. Result showed that out of 100 wheat germplasm used in this study, majority of them possessed waxy leaves (59%) of which 28% was strong waxy while 31% had moderately waxy flag leaves. Glossy germplasm accounted for 41%. The results are in accordance with the findings of Ma *et al.* (2015) that modern verities possess waxy broad leaves owing to better adaptations to changing climate bringing biotic and abiotic stresses. The high number of glossy lines among durum and landraces (Fig. 2 and Fig. 4), and the absence of glossy leaf line in modern Pakistani cultivars (Fig. 3) suggest that waxy attribute has been continuously selected by breeders to develop modern cultivars to combat drastic heat and drought stresses.

Strong artificial selection trend was observed for stem and glume waxiness. Figure 5 and 6 also depict lowest number of strong waxy and highest number of glossy stem and spike glumes in Pakistani wheat landraces. The trend was contrary in 18 cultivars used in this study where all 18 cultivars possessed strong waxy stem and glumes. These results are in agreement with Laskos *et al*., (2021).

Pubescence represents fine short hairs on the leaves and stems of plants. Many plants have pubescence designed to provide a tiny bit of shade to reduce the temperature of the leaves and stems and protect the leaves from losing too much water from transpiration. Results from figures 7-9 show the presence of abundant number of hairy germplasm both in landraces and modern varieties which in turn suggest that pubescence of flag leaf, auricle and glumes might be attributed to natural and artificial selection. Our results in agreement with the findings of Pshenichnikova *et al*., (2017) aimed to compare the diversity of the adaptive morphological trait-leaf pubescence among the relatives and the ancestors of hexaploid wheats to establish the variability of its phenotypic manifestation as a result of evolution and domestication. They found that the ploidy level affected only the trichome length and the index of pubescence. The density of the hairs was affected by the individual genomes A and B, whereas genome D significantly influenced all of the studied pubescence parameters.

Correlation analysis in research is a statistical method used to measure the strength of the linear relationship between two variables and compute their association. Similarly, among other yield related attributes, 1000 Grain Weight (1000GW) is key determinant of wheat yield attribute. Flag leaf hairiness (FLGLH), glume hairiness (GHR) and flag leaf waxiness (FLGLW) traits showed highly significant correlation (0.1546**,0.2986** and 0.1308**) with 1000GW at 0.01 level of probability. All other traits correlations were non-significant (Table 2). Majority of the landraces and modern cultivars used in this study possessing hairy flag leaf and glumes had reduced incidence of yellow and leaf rust (Fig. 10).

Heritability is a statistic used in the fields of breeding and genetics that estimates the degree of variation in a phenotypic trait in a population that is due to genetic variation between individuals in that population. In the current study, Flag leaf wax (FLWX) and glume hairiness (GHR) showed high heritability while leaf rust (LR) show moderate heritability (Table 3). These traits can be effectively advanced to next generations via hybridization. Our results are in agreements with the findings of Wang *et al*., (2015), Huihui *et al*., (2017), Moghadam *et al*., (2013), Gulnaz *et al*., (2019) and Upadhyay *et al*., (2020).

The cross of waxy landrace (P2) with glossy landrace (P1) produced F1 progenies with waxy flag leaves (Fig. 11), suggesting that waxiness is controlled by single dominate gene. Similarly, the cross of hairy landrace (P2) with non-hairy variety (P1) produced F1 progenies with hairy glumes (Fig. 12), suggesting that pubescence is controlled by single dominate gene. These results are in agreements with the findings of Yoshiya et al., (2011) and Taketa et al., (2022). The cross of glossy landrace (parent-P1) with waxy landrace (parent-P2) produced F_1 progenies with waxy flag leaves (Fig. 11), suggesting that waxiness is controlled by single dominate gene. Similarly, the cross of non-hairy variety (P1) with hairy landrace (P2) produced F1 progenies with hairy glumes (Fig. 12), suggesting that pubescence is controlled by single dominate gene. These results are in agreements with the findings of Yoshiya *et al*., (2011) and Taketa *et al*., (2022).

Conclusion

Classical Pakistani wheat landraces possess glossy attributes while Pakistani modern wheat cultivars possess waxiness attributes; this trend is an indicator of breeder's choice of selection for waxiness to introduce into modern cultivars for drought and disease resistance. The equal proportion of pubescence in both classical landraces and modern cultivars suggest that selection of pubescence might be attributed to both natural and breeder's selection. The high correlation of waxiness and pubescence with 1000GW plus high heritability imply that both waxiness and pubescence can be conveniently transferred to next generation via hybridization.

Future Recommendations

The F_1 populations constructed for waxiness and pubescence can be advanced to F_2 segregating populations coming year to identify and map specific genes controlling these traits.

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Conflicts Of Interest

The authors declare no conflicts of interest.

Authors Contribution

Nasr Ullah Khan and Naimat Ullah conceived the idea, designed the study, conducted the field trial, collected the and analyzed the data and drafted the manuscript. Sundas Batool, Abul Muqeet Nawaz, Barira Tu Nisa helped in data collection. Sundas Batool helped in data analysis and provided critical evaluation of the manuscript.

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Table 1. Detail of Germplasm used

S. No.	Code	Germplasm type	Country of origin
1	GU1	Advanced Durum lines	Mexico
2	GU2	Advanced Durum lines	Mexico
3	GU3	Advanced Durum lines	Mexico
4	GU4	Advanced Durum lines	Mexico
5	GU5	Advanced Durum lines	Mexico
6	GU6	Advanced Durum lines	Mexico
7	GU7	Advanced Durum lines	Mexico
8	GU8	Advanced Durum lines	Mexico
9	GU9	Advanced Durum lines	Mexico
10	GU10	Advanced Durum lines	Mexico
11	GU11	Advanced Durum lines	Mexico
12	GU12	Advanced Durum lines	Mexico
13	GU13	Variety-Hashim08	Pakistan
14	GU14	Variety-AZRC Dera	Pakistan
15	GU15	Variety-Khaista	Pakistan
16	GU16	Variety-Wadan	Pakistan
17	GU17	Variety-Akbar19	Pakistan
18	GU18	Variety-Akbar Punjab	Pakistan
19	GU19	Variety-Shahkar	Pakistan
20	GU20	Variety-Gulzar19	Pakistan
21	GU21	Variety-Shahid17	Pakistan
22	GU22	Variety-Peer Sabaq13	Pakistan
23	GU23	Variety-Fakhre Bhakkar	Pakistan
24	GU24	Variety-Faisalabad Punjab	Pakistan
25	GU25	Variety-Faisalabad2008	Pakistan
26	GU26	Variety-PS15	Pakistan
27	GU27	Variety-PS19	Pakistan
28	GU28	Variety-Punjab11	Pakistan
29	GU29	Variety-Shalimar88	Unknown
30	GU30	Variety-Zamindar80	Unknown
31	GU31	Landrace	Pakistan
32	GU32	Landrace	Pakistan
33	GU33	Landrace	Pakistan
34	GU34	Landrace	Pakistan
35	GU35	Landrace	Pakistan
36	GU36	Landrace	Pakistan
37	GU37	Landrace	Pakistan
38	GU38	Landrace	Pakistan
39	GU39	Landrace	Pakistan
40	GU40	Landrace	Pakistan

41	GU41	Landrace	Pakistan
42	GU42	Landrace	Pakistan
43	GU43	Landrace	Pakistan
44	GU44	Landrace	Pakistan
45	GU45	Landrace	Pakistan
46	GU46	Landrace	Pakistan
47	GU47	Landrace	Pakistan
48	GU48	Landrace	Pakistan
49	GU49	Landrace	Pakistan
50	GU50	Landrace	Pakistan
51	GU51	Landrace	Pakistan
52	GU52	Landrace	Pakistan
53	GU53	Landrace	Pakistan
54	GU54	Landrace	Pakistan
55	GU55	Landrace	Pakistan
56	GU56	Landrace	Pakistan
57	GU57	Landrace	Pakistan
58	GU58	Landrace	Pakistan
59	GU59	Landrace	Pakistan
60	GU60	Landrace	Pakistan
61	GU61	Landrace	Pakistan
62	GU62	Landrace	Pakistan
63	GU63	Landrace	Chagai
64	GU64	Landrace	Chagai
65	GU65	Landrace	Chagai
66	GU66	Landrace	Quetta
67	GU67	Landrace	Ziarat
68	GU68	Landrace	Pakistan
69	GU69	Landrace	Pakistan
70	GU70	Landrace	Pakistan
71	GU71	Landrace	Pakistan
72	GU72	Landrace	Pakistan
73	GU73	Landrace	Pakistan
74	GU74	Landrace	Pakistan
75	GU75	Landrace	Pakistan
76	GU76	Landrace	Pakistan
77	GU77	Landrace	Pakistan
78	GU78	Landrace	Pakistan
79	GU79	Landrace	Pakistan
80	GU80	Landrace	Pakistan
81	GU81	Landrace	Pakistan
82	GU82	Landrace	Pakistan
83	GU83	Landrace	Pakistan
84	GU84	Landrace	Faisalabad

85	GU85	Landrace	Faisalabad
86	GU86	Landrace	Pakistan
87	GU87	Landrace	Pakistan
88	GU88	Landrace	Pakistan
89	GU89	Landrace	Pakistan
90	GU90	Landrace	Pakistan
91	GU91	Landrace	Pakistan
92	GU92	Landrace	Pakistan
93	GU93	Landrace	Pakistan
94	GU94	Landrace	Pakistan
95	GU95	Landrace	Pakistan
96	GU96	Landrace	Pakistan
97	GU97	Landrace	Pakistan
98	GU98	Landrace	Pakistan
99	GU99	Landrace	Pakistan
100	GU100	Landrace	Pakistan

Table 2. Correlation analysis of waxiness, pubescence with leaf and yellow rust

	SWX	ARW	1000GW	FLGLHR	GHR	FLGLW
SWX	0.0057NS					
ARW	0.0622NS	0.024NS				
1000GW	-0.0326NS	0.0176 NS	-0.0204NS			
FLGLHR	-0.0084NS	-0.027 NS	0.1546**	-0.0148 NS		
GHR	-0.0874NS	-0.015 NS	0.2986**	0.0125 NS	-0.1383NS	
FLGLW	-0.0283NS	0.0476 NS	0.1308**	-0.0838 NS	0.0767 NS	0.0311 NS

SWX: stem waxiness, **ARW**: Auricle waxiness, **1000GW**: 1000 grain weight, **FLGLHR**: flag leaf hairiness, **GHR**: glume hairiness, **FLGLFW**: flag leaf waxiness**, **:** highly significant at p-value = 0.01; NS: non-significant.

Table 3. Heritability estimates and genetic advance of various traits.

Parameters	Vp	Vg	PCV	GCV	H=h2 (BS)	GA	GG
FLGLW	0.36	0.36	46.35	46.35	100%	0.75	0.57
GHR	1.13	1.13	40.86	40.86	100%	2.19	0.84
AHR	1.29	0.05	74.13	15.00	4.10%	0.10	0.06
FLGLH	4.44	1.91	56.94	37.28	42.87%	1.86	0.50
SWX	63.74	18.16	74.48	39.75	28.49	4.69	0.44
GWX	32.15	13.09	30.77	20.87	35.51%	20.10	2.28

Vp: phenotypic variance, **Vg**: genotypic variance, **PCV**: phenotypic co-efficient of variance, **GCV**: genotypic co-efficient of variance, **H(BS)**: broad-sense heritability, **GA**: genetic advance, **GG**: genetic gain.

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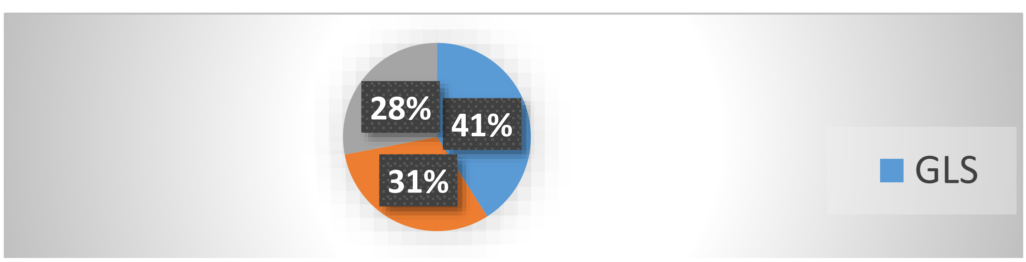

Fig 1. Distribution of waxiness and glossiness of flag leaf across germplasm used. **GLS**: glossy, **MW**: moderate waxy; **SW**: strong waxy

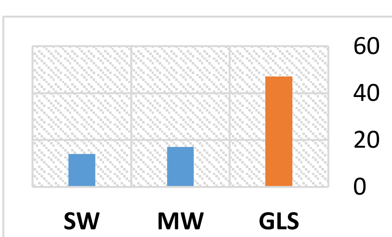

Fig 2. FL waxiness of durum lines. **GLS**: glossy, **MW**: moderate waxy; **SW**: strong

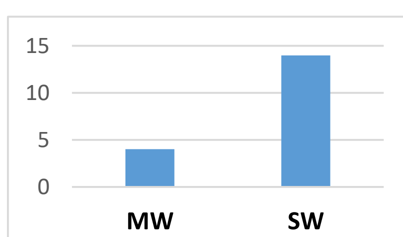

Fig 3. FL waxiness of Pakistani cultivars. **GLS**: glossy, **MW**: moderate waxy; **SW**: strong waxy

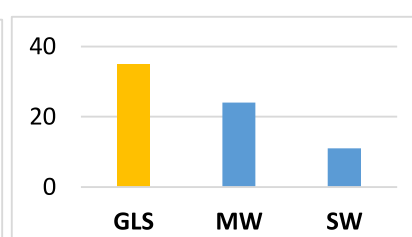

Fig 4. FL waxiness of landraces. GLS: glossy, MW: moderate waxy; SW: strong

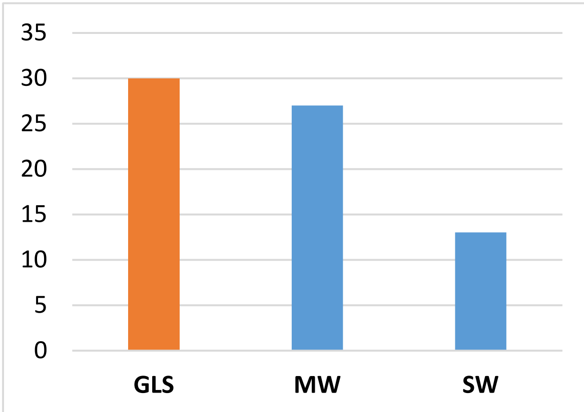

Fig 5. Stem waxiness of durum lines. **GLS**: glossy, **MW**: moderate waxy; **SW**: strong waxy

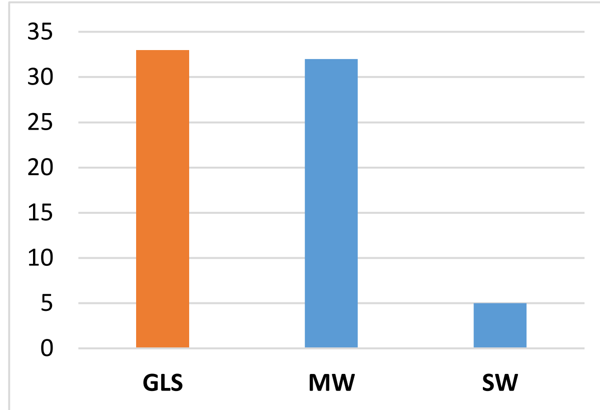

Fig 6. Glume waxiness of durum lines. **GLS**: glossy, **MW**: moderate waxy; **SW**: strong waxy

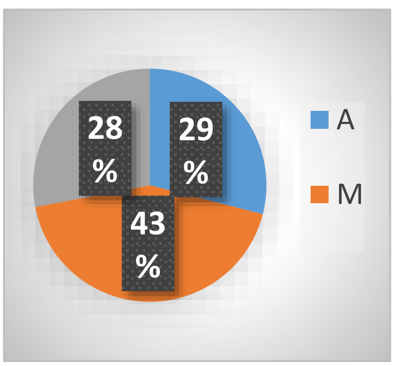

Fig 7. Distribution of FL, auricle and glume pubescence across 100 germplasm used. **A**: non-hairy, **M**: moderate hairy; **S**: strong hairy

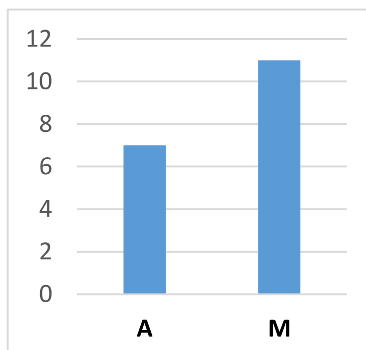

Fig 8. Distribution of FL, auricle and glume hairiness across 18 Pakistani wheat cultivars used. **A**: non-hairy, **M**: moderate hairy

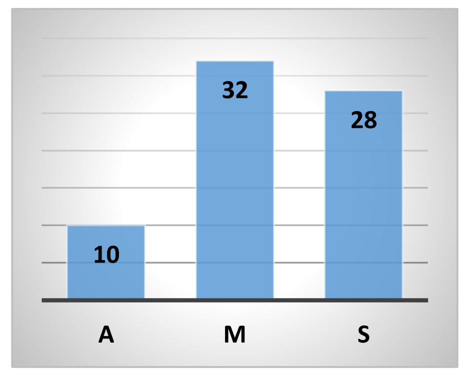

Fig 9. Distribution of FL hairiness across 70 wheat landraces used. **A**: non-hairy, **M**: moderate hairy; **S**: strong hairy

Fig 10. Response of hairy and non-hairy leaves of wheat to leaf rust

Fig. 11 Cross between glossy and waxy

Fig. 12 Cross between non-hairy and hairy