

THE GENETIC ARCHITECTURE OF MORPHO-PHYSIOLOGICAL, YIELD, AND GRAIN QUALITY PARAMETERS IN WHEAT

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INTRODUCTION

Terminal heat stress, a significant threat to global wheat production, necessitates a comprehensive genetic analysis of morpho-physiological, yield, and grain quality parameters. This investigation was conducted across two distinct environments: a normal-sown trial in Punjab (Rabi 2023-24) and a late-sown, heat stress trial in Andhra Pradesh (Rabi 2024-25). This study employed 43 diverse wheat genotypes, including three checks, laid out in a Randomized Block Design for field experiments and a Completely Randomized Design for laboratory evaluations. The objectives included assessing genetic variability, determining trait associations, estimating genetic divergence, evaluating grain protein content, and identifying heat stress effects.

RESULTS

ANOVA revealed highly significant ($P<0.01$) genetic variability among genotypes for all sixteen field and ten laboratory traits under both conditions, indicating a broad genetic base for selection. Heat stress significantly reduced most traits; the mean grain yield per plant plummeted from 9.02 g to 0.70 g, a decline underscored by a high Drought Intensity Index (DI) of 0.922. Genetic parameter estimates showed high heritability and high genetic advances for key traits. Grain yield per plant ($h^2 > 82\%$, $GAM > 41\%$), number of grains per spike ($h^2 > 89\%$, $GAM > 42\%$), and biological yield per plant ($h^2=93.8\%$, $GAM=73.7\%$ in normal conditions) suggested additive gene action. Grain protein content also exhibited high heritability (91-94%) and significant improvement potential (GAM up to 26.6%), with HD 2307 consistently showing the highest content (15.7-15.9%). Correlation and path analysis identified biological yield per plot as having the strongest positive direct effect on grain yield under optimal conditions ($P=0.693$). Under heat stress, the direct contribution of number of grains per spike ($P=0.821$) and grain weight per spike became paramount. Earliness (days to flowering) was consistently negatively correlated with yield, highlighting its importance as a heat escape mechanism under stress ($rg = -0.390^{**}$). Genetic divergence (D^2 analysis) grouped the 43 genotypes into six clusters under normal conditions and five under heat stress. Maximum inter-cluster distance occurred between Cluster II and Cluster VI (genotype G40) in the normal environment ($D=33.66$) and between Cluster II and Cluster V (genotype G40) under heat stress ($D=27.70$), indicating these as the most divergent parents. The number of grains per spike (contributing 11.2-19.8%) and test weight (9.3-12.3%) were the largest contributors to divergence. Based on stress tolerance indices, PBW 677 ($HSI=1.28$), HD 2307 ($YSI=0.25$), and HD 3386 ($HTI=25.13$) were identified as superior for heat

resilience. This investigation successfully identified significant genetic variability and key traits for targeted selection.

Table 1. Cluster means for morpho-physiological traits among different wheat genotypes for rabi seasons 2023-2024 and 2024-2025.

Cluster Means: Tocher Method (2023-24)																
	DF	DM	PH	PL	NTP	FLL	FLW	FLA	SL	NGPS	GWP S	BYP	GYP	GYP P	BYPP	TW
Cluster 1	91.56	132.1	3	98.11	18.65	4.73	28.36	1.48	31.20	11.63	53.99	1.99	18.56	8.71	342.0	873.8
Cluster 2	89.89	131.0	0	94.24	18.16	4.22	15.18	1.28	14.69	12.71	46.08	1.27	18.69	8.43	4	26.14
Cluster 3	95.00	133.6	7	3	16.60	3.87	31.90	1.90	45.07	11.37	38.30	2.50	12.23	6.17	3	27.87
Cluster 4	89.67	131.0	0	21.90	4.87	24.33	1.50	26.80	22.97	45.40	1.97	17.17	12.63	0	0	20.43
Cluster 5	90.00	131.0	0	85.30	16.63	4.60	25.07	1.80	34.00	17.20	60.93	2.57	23.00	13.00	0	29.03
Cluster 6	102.3	137.3	3	3	24.20	5.47	43.90	2.90	95.20	20.10	83.60	3.90	58.30	17.30	0	27.87
Cluster Means : Tocher Method (204-25)																
	DF	DM	PH	PL	NTP	FLL	FLW	FLA	SL	NGPS	GWP S	BYP	GYP	GYP P	BYPP	TW
Cluster 1	58.22	104.2	2	58.16	7.37	1.60	22.19	0.83	16.56	6.94	12.83	0.36	2.09	0.56	5.32	27.74
Cluster 2	54.80	106.7	3	65.39	8.43	2.18	21.07	0.84	16.55	8.31	29.38	0.87	2.87	1.71	11.01	29.59
Cluster 3	57.67	110.3	3	71.00	15.37	1.50	24.33	0.87	20.07	8.83	19.87	0.60	2.80	0.90	6.73	31.83
Cluster 4	54.67	110.6	7	65.13	12.77	2.67	16.73	0.83	12.53	7.87	14.87	0.50	4.97	1.07	9.50	34.63
Cluster 5	88.67	110.3	4	61.00	6.17	1.67	37.17	0.87	30.67	9.50	4.13	0.10	2.43	0.23	2.20	24.07

Genetic divergence (D^2 analysis) grouped the 43 genotypes into six clusters under normal conditions and five under heat stress.

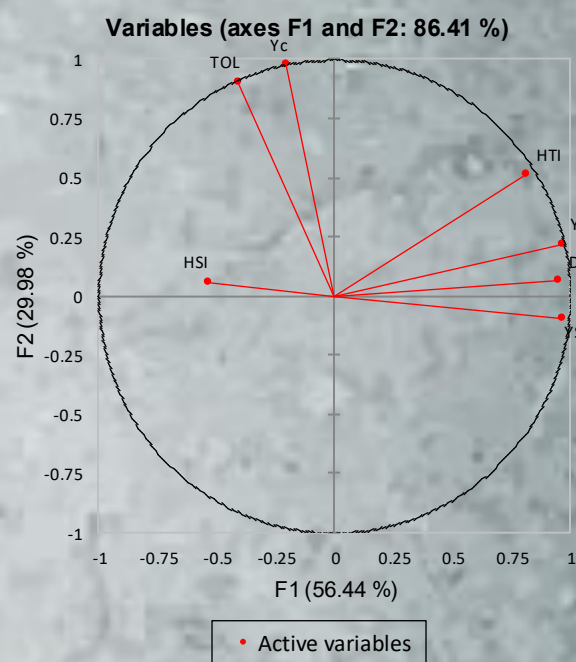


Fig. 1. Variables plot demonstrating heat stress indicators (active variables) distributed throughout the first two main components (F1 and F2), accounting for 86.41% of variability. F1 promotes performance and stability under stress, while F2 emphasizes controlled yield and stress sensitivity.

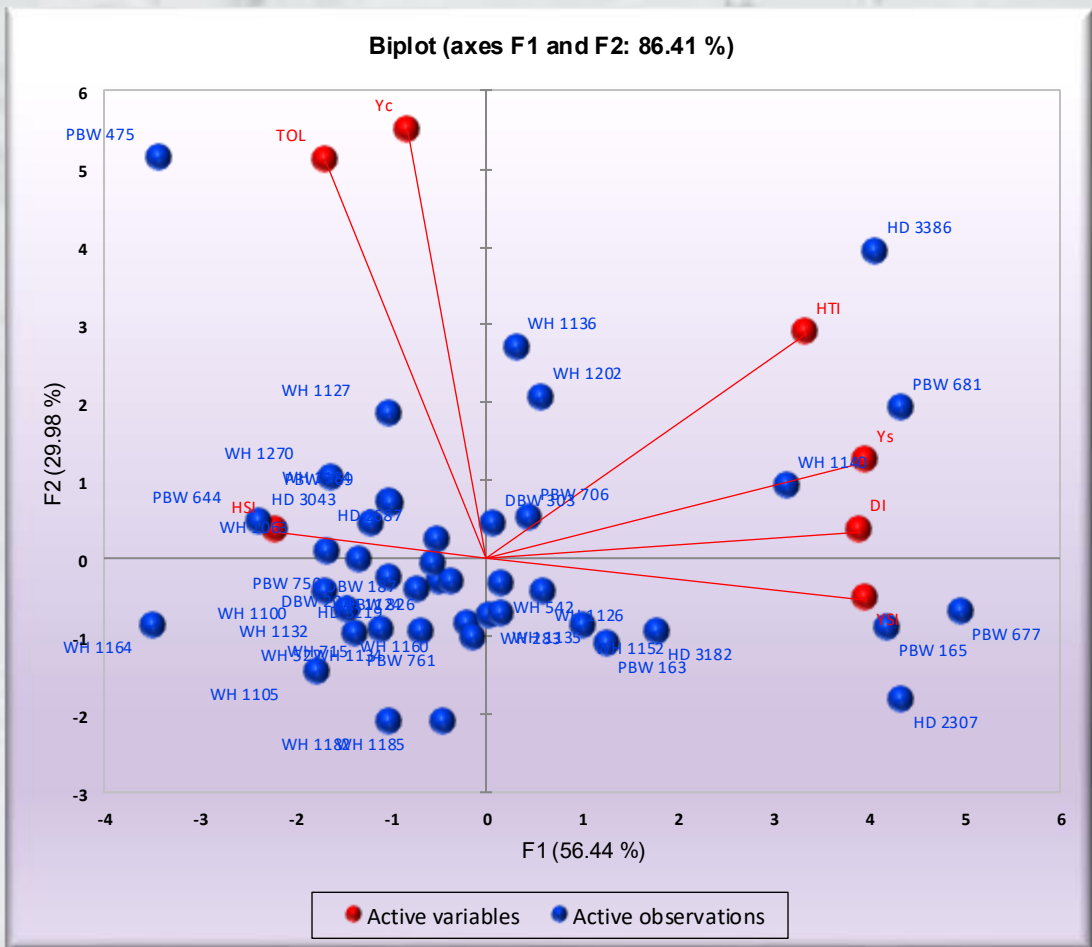


Fig. 2. Biplot illustrating the relationship between the first two principal components (F1 and F2), which collectively explain 86.41% of the variability in heat stress indices, and the active variables (stress indices) and active observations (wheat genotypes). F1 (56.44%) represents performance and stability under stress (associated with Ys, HTI, YSI, DI), while F2 (29.98%) represents yield under control conditions and stress sensitivity (associated with Yc, TOL).



Fig. 3. Experimental field images for 2023-2024 and 2024-2025.

CONCLUSION

This study pinpointed genetically diverse and heat-tolerant parents and identified traits like grain number, grain weight, and biological yield as critical selection criteria, providing a robust framework for developing high-yielding, climate-resilient wheat cultivars.

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Acknowledgments

This work was supported by a Department of Genetics and Plant Breeding, Guru Kashi University, Talwandi Sabo, Punjab 151302, India