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GENETIC DIVERGENCE AND TRAITS ASSOCIATION STUDY ON STRAW YIELD IN EARLY SOWN WHEAT

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SUMMARY

The present investigation aimed to evaluate the association between straw yield and its component traits, and to assess genetic divergence through cluster analysis under early sowing conditions in bread wheat. Substantial variability was observed for straw yield, with mean values ranging from 17.15 g/plant (HD 2888) to 31.10 g/plant (WH 1021). Straw yield exhibited a strong and positive correlation with biological yield ($r = 0.97$, $p < 0.01$), indicating its major contribution to total biomass accumulation. A significant positive association was also observed between straw yield and grain yield ($r = 0.68$, $p < 0.01$), whereas significant negative correlations were recorded with harvest index ($r = –0.56$, $p < 0.01$) and plant height ($r = –0.33$, $p < 0.01$). Cluster analysis grouped the genotypes into distinct clusters, with Cluster IV recording the highest mean straw yield (29.47 g/plant) and grain yield (15.38 g/plant). The lowest and highest intra-cluster distances were observed in Cluster IV (11.58) and Cluster I (40.60), respectively. High inter-cluster distances reflected substantial genetic divergence, suggesting promising opportunities for heterosis breeding. Crosses between genotypes belonging to Cluster I and Cluster V (61.06), Cluster I and Cluster III (48.96), and Cluster III and Cluster V (48.95) are therefore expected to generate superior recombinants with wider variability.

Key words: wheat, straw yield, correlation, genetic distance, cluster

Wheat (*Triticum aestivum* L.) is the dominant staple crop of the north-western Indo-Gangetic Plains, including Haryana, which provides a major share of livestock feed, particularly in regions where green fodder availability is limited (Kumar *et al.,* 2013). India sustains nearly 20% of the world's livestock and 17.5% of the global human population despite occupying only 2.3% of the world's geographical area. At present, substantial deficits persist in feed resources, including shortages of 35.6% in green fodder, 10.5% in dry crop residues, and 44% in concentrate feed components (Dhamodharan *et al.,* 2024). This situation is further aggravated by the growing pressure on already limited agricultural land to support both human and livestock populations. India produces vast quantities of agricultural residues, particularly from rice and wheat, a significant proportion of which is burned in situ due to inadequate management, leading to severe particulate emissions and air pollution in northern regions (Bhuvaneshwari *et al.,* 2019). Promoting alternative residue utilization pathways, such as composting, livestock feed, biochar production, and anaerobic digestion, is the solution. Limited adoption of residue management technologies has prompted a shift toward improving crop residues through plant breeding and selection at the source (Samireddypalle *et al.,* 2019). The wheat improvement programs become more efficient when straw attributes are prioritized once the straw-to-grain price ratio exceeds 0.17. In the Western Indo-Gangetic Plains of India, a key wheat-producing region, this ratio ranged from approximately 0.30 to 0.48 during periods of peak straw demand, and from about 0.19 to 0.35 under normal market conditions.

Empirical data on straw yield remain scarce, largely because such yields are seldom measured. This gap arises partly from the low economic priority assigned to straw, which is generally treated as a minor by-product rather than a primary output, limiting efforts to document its yield. Additionally, the measurement process itself presents substantial challenges. Unlike grain, straw is prone to losses and displacement during the transition from combining to baling. Obtaining reliable measurements in research plots often requires specialized equipment capable of compensating for variable terrain to produce consistent stubble heights. Together, these factors limit the availability of robust data on straw yield (Townsend *et al.*, 2017). Roth *et al.* (2021) also included straw yield as a response variable in a four-year evaluation of 20 wheat varieties.

MATERIALS AND METHODS

The experiment was conducted at the Research Farm of the Wheat and Barley Section at CCS Haryana Agricultural University, Hisar, during the *Rabi* seasons of 2019-20 and 2020-21 to estimate genetic parameters for several morphological traits in wheat. The genotypes were assessed under an early-sown regime, with planting conducted on 15 October 2019 in the first season and 14 October 2020 in the second season.

The trial employed a randomized block design with three replications per environment, at a row-to-row and plant-to-plant spacing of 20 cm and 10 cm, respectively. The recommended agronomic and crop management practices for wheat, as prescribed by CCS HAU, were followed throughout the growing period. The study aimed to assess forty-eight bread wheat genotypes under field conditions by examining their phenology, yield components, and physiological characteristics. Observations were recorded for the following traits: straw yield (SY), grain yield (GY), days to maturity (DM), tillers per metre (TPM), plant height (PH), biological yield (BY), harvest Index (HI), Normalized Difference Vegetation Index at anthesis (NDVI1), Normalized Difference Vegetation Index at 15 days after anthesis (NDVI2), Canopy Temperature Depression at anthesis (CTD1), Canopy Temperature Depression at 15 days after anthesis (CTD2). For each genotype (treatment), data were taken from five randomly selected competitive plants per replication. SY was obtained after grains were threshed from the whole plant; the remaining part was then weighed and represented in grams.

Statistical analysis was performed using the R (4.3.1) statistical package for Analysis of Variance (ANOVA), correlation, and genetic divergence.

RESULTS AND DISCUSSION

The experiments were conducted over two consecutive years; however, Bartlett's test revealed no significant year-to-year variation, and therefore, the data were pooled across years for subsequent analysis.

Analysis of variance indicated the presence of significant genetic variability among the forty-eight bread wheat genotypes for all the traits evaluated in the study. Similar results for ANOVA were reported by Arya *et al.* (2017). The mean straw yield per plant ranged from 17.15 g in HD 2888 to 31.10 g in WH 1021, corresponding to 8.58 to 15.50 t ha{ ^{1}. These values exceed the range of 8.12 to 12.38 t ha{ ^{1} reported by Al-Otayk (2019), possibly due to the longer crop duration under early sowing conditions in the present study.

Correlation

Straw yield (Fig. 1) showed a highly significant and strong positive correlation with biological yield (BY) (r = 0.97, $p < 0.01$), indicating that straw yield is a major contributor to total biomass accumulation. This close relationship suggests that genotypes producing higher vegetative biomass inherently accumulate greater straw yield, a pattern commonly observed in wheat and other cereal crops. A strong positive correlation between straw yield and grain yield (r = 0.68, $p < 0.01$) indicates that higher biomass production contributes to enhanced grain productivity through improved source strength and assimilate supply. This finding aligns with reports that yield gains in modern wheat cultivars are largely driven by increased shoot biomass and spike number (Huang *et al.*, 2023). Additionally, straw yield was significantly and positively correlated with the number of effective tillers per metre (TPM) (r = 0.59, $p < 0.01$), reflecting the contribution of tiller density to overall vegetative biomass.

In contrast, straw yield exhibited a highly significant negative correlation with harvest index (HI) (r = –0.56, $p < 0.01$). This indicates that genotypes with excessive straw production beyond a certain limit may exhibit reduced partitioning efficiency towards grain yield. Straw yield was also significantly and negatively correlated with plant height (PH) (r = –0.33, $p < 0.01$), indicating that taller plants do not necessarily produce higher straw yield. This suggests that straw accumulation is more closely linked to tiller number and biomass density rather than plant height alone. The correlation between straw yield and days to maturity (DM) was positive but weak (r = 0.15) and statistically non-significant, indicating that extended crop duration does not substantially influence straw accumulation under the present experimental conditions. Similarly, correlation studies were also conducted by Ullah *et al.* (2021) and Devesh *et al.* (2021) in wheat, revealing biological yield and harvest index as important traits.

Straw yield showed a significant negative correlation with NDVI at 15 days after anthesis (NDVI2) ($r = –0.44$, $p < 0.01$), suggesting that genotypes maintaining greener canopies during later stages, i.e., grain-filling stage, tend to allocate assimilates more efficiently towards grain rather than vegetative biomass. In contrast, the association between straw yield and NDVI at anthesis (NDVI1) was weak and non-significant ($r = 0.07$), indicating a limited influence of early canopy greenness on straw production. With respect to canopy temperature depression, straw yield exhibited moderate and significant positive correlations with CTD1 ($r = 0.32$, $p < 0.01$) and CTD2 ($r = 0.29$, $p < 0.01$). These relationships suggest that cooler canopies, indicative of better transpiration efficiency and physiological activity, contribute to increased vegetative biomass and straw accumulation. A similar trend was reported by Ahmed *et al.* (2023), who observed that canopy temperature depression displayed strong and predominantly positive associations with most of the evaluated traits.

Overall, straw yield in bread wheat was strongly influenced by biological yield, tillering capacity, and canopy temperature depression, while showing a pronounced trade-off with harvest index and late-stage canopy greenness (NDVI2). These findings indicate that straw yield reflects overall biomass production and physiological vigor but may negatively impact partitioning efficiency when in excess. Therefore, balanced selection for straw yield alongside grain yield and harvest index is essential for optimizing both productivity and biomass utilization in wheat breeding programs. In wheat breeding programs, it is essential to understand the performance of different traits and the relationships among them, particularly those traits that show positive correlations with yield (Singh *et al.*, 2023).

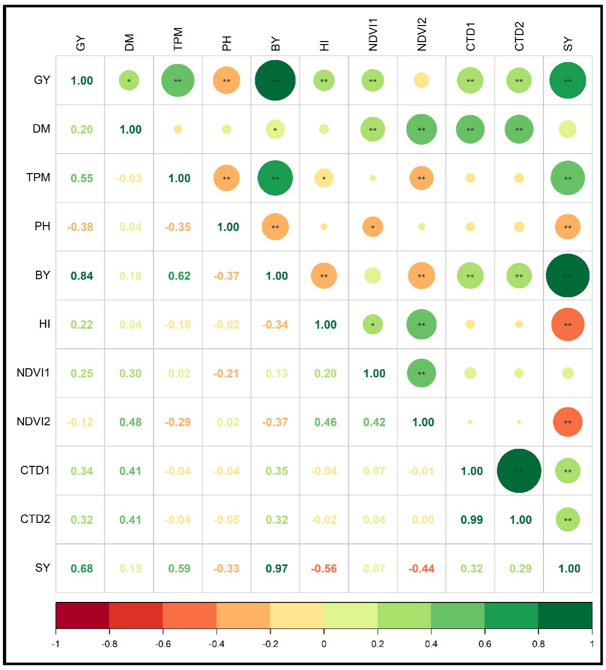

Fig. 1. Straw yield correlation with other traits.

Cluster Analysis

Hierarchical clustering using Ward's method and Euclidean distance reflects substantial genetic divergence for the eleven agro-morphological and physiological traits studied (Fig. 2). The clear separation of clusters in the dendrogram confirms the robustness of the clustering pattern, a finding consistent with earlier reports in wheat using multivariate techniques. Based on the genetic distance, 48 genotypes were clustered into five major clusters, with cluster 5 having only two genotypes, Barbat and C-306, as they both are tall and old varieties. Similarly, cluster 2 has two genotypes, UP2473 and WH730, as both varieties are of short-duration maturity. The clustering results were largely consistent with the observed phenotypic patterns, as also observed in a similar study by Al-Ashkar *et al.* (2023). Similarly, Nagar *et al.* (2015) classified genotypes into three clusters using Ward's method based on squared Euclidean distances derived from various physiological traits. The presence of both

TABLE 1

Inter and Intra-cluster distances of all five clusters

	c1	c2	c3	c4	c5
c1	**40.599**				
c2	38.740	**21.071**			
c3	48.958	33.782	**36.618**		
c4	27.392	23.783	31.794	**11.577**	
c5	61.057	48.710	48.948	46.790	**19.550**

TABLE 2

Cluster means of all five clusters for 11 traits

	GY	DM	TPM	PH	BY	HI	NDVI1	NDVI2	CTD1	CTD2	SY
c1	12.857	163.02	156.82	110.98	39.007	33.018	0.8415	0.696	4.1855	3.869	26.151
c2	11.215	151.67	154	109.17	35.185	31.9	0.825	0.63	1.84	1.51	23.97
c3	12.006	162.5	149.07	111.43	33.103	36.31	0.8505	0.764	3.137	2.827	21.098
c4	15.38	163.42	157.92	109.92	44.855	34.31	0.86	0.74	5.8075	5.2525	29.47
c5	9.475	162.83	137.83	137.33	30.76	30.975	0.825	0.735	3.64	3.215	21.285

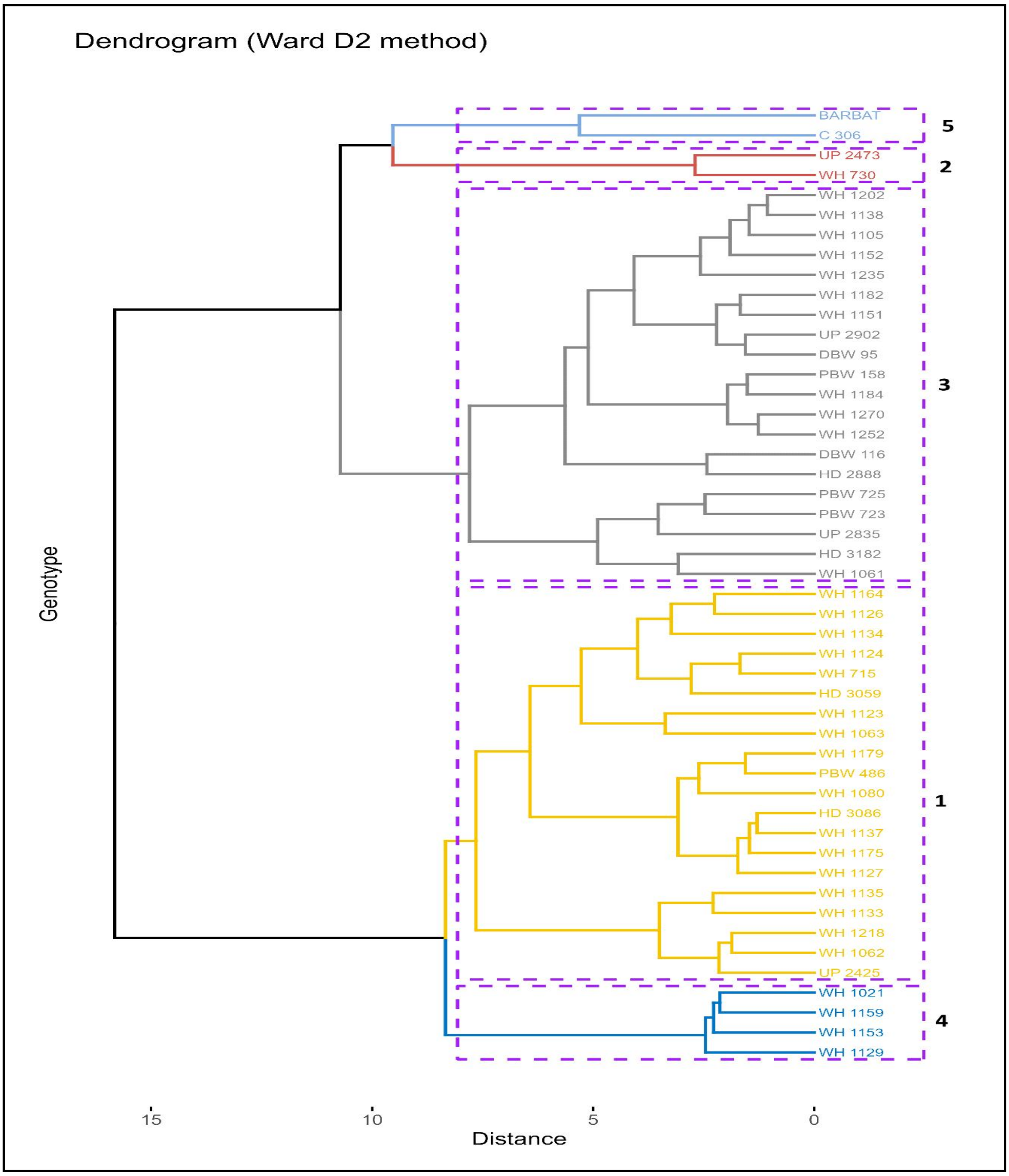

Fig. 1. Cluster dendrogram of 48 genotypes.

large and very small clusters suggests the existence of core groups of genetically similar material as well as highly divergent genotypes, a pattern commonly reported in bread wheat germplasm collections, which is also evident from the study by Ahmed *et al.* (2023).

Intra-cluster distances provide an estimate of genetic homogeneity within clusters (Table 1). The lowest intra-cluster distance was observed for Cluster IV (11.58), indicating a high degree of similarity among its four genotypes. Cluster V (19.55) and Cluster II (21.07) also showed relatively low intra-cluster distances, reflecting compact grouping despite small cluster size. In contrast, Cluster I (40.60) and Cluster III (36.62) exhibited higher intra-cluster distances, suggesting greater genetic variability within these clusters. These results indicate that Clusters I and III harbor broad genetic diversity, which is desirable for selection and recombination breeding, as large clusters often contain diverse phenotypic expressions despite overall similarity.

Inter-cluster distances ranged widely, indicating variable levels of genetic divergence among clusters. The maximum inter-cluster distance was recorded between Cluster I and Cluster V (61.06), followed by Cluster I and Cluster III (48.96) and Cluster III and Cluster V (48.95). The minimum inter-cluster distance occurred between Cluster II and Cluster IV (23.78), suggesting closer genetic affinity between these two clusters. High inter-cluster distances imply greater genetic divergence and, therefore, higher potential for heterosis and generation of transgressive segregants when genotypes from such clusters are crossed (Kumar *et al.,* 2018; Arya *et al.,* 2017; Rajput *et al.,* 2025; Yadav *et al.,* 2025). This principle has been widely emphasized in wheat improvement programs.

Cluster means (Table 2) revealed clear differentiation among clusters for agronomic and physiological traits. Cluster IV recorded the highest mean straw yield (29.47 g/plant) and mean grain yield (15.38 g/plant), along with the highest biological yield (44.86 g/plant), and canopy temperature depression (CTD1 = 5.81!; CTD2 = 5.25!). This cluster represents high-yielding, physiologically efficient genotypes, particularly suitable for stress-prone environments. Cluster I showed moderately high straw yield (26.15 g/plant), as well as grain yield (12.86 g/plant) and relatively balanced performance across yield components and physiological traits, indicating general adaptability. Cluster III exhibited lower straw yield (21.1 g/plant) and moderate grain yield (12.01 g/plant), but relatively higher NDVI values, suggesting better canopy vigor. Cluster V showed the lowest grain yield (9.48 g/plant) and biological yield, but relatively higher plant height.

CONCLUSIONS

The association analysis indicates that straw yield largely reflects overall biomass production and physiological vigor, contributing positively to grain productivity through improved source strength. However, its inverse relationship with harvest index and late-stage canopy greenness suggests a trade-off between vegetative growth and assimilate partitioning efficiency. Therefore, balanced selection for biomass accumulation and partitioning efficiency is essential to optimize total productivity in wheat.

The hierarchical clustering based on Euclidean distance and Ward's D^2 method effectively partitioned bread wheat genotypes into genetically distinct groups. The integration of cluster means with inter- and intra-cluster distances provides a strong statistical basis for selecting diverse and complementary parents, thereby enhancing the efficiency of future wheat breeding programs. Clusters combining high mean performance and high inter-cluster distance are of prime importance in the present study. Cluster IV represents a valuable source of high-yielding and stress-adaptive genotypes. Cluster V, despite poor mean performance, is genetically highly divergent and may contribute novel alleles.

There is a need to keep a balance between grain yield attributes and non-grain shoot biomass to sustain wheat productivity. Accordingly, future breeding strategies should focus on sustaining high shoot biomass while enhancing harvest index to achieve further gains in grain yield.

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