Variability and Character Association Studies in Wheat (*Triticum aestivum* L. em. Thell) for Seed Yield and its Contributing Traits

Comment [D1]: What variability.Please Add "Genetic"

ABSTRACT

This study investigated genetic variability, correlation and path analysis in wheat across 55 treatments, including 40 F_1 hybrids, 14 parental lines, and a standard check variety (HD-3086). The parental lines consisted of 10 females and 4 males, with the hybrids evaluated using a randomized block design (RBD) during the 2019-2020 *rabi* season. Analysis of Variance (ANOVA) revealed significant differences among genotypes for most traits, indicating considerable genetic variability. Genotypic correlation analysis identified strong positive relationships between grain yield per plant (GYPP) and key agronomic traits, such as spike length, spikelets per spike, grains per spike, grain yield per spike, harvest index, and test weight. Conversely, negative correlations with days to 50% flowering and plant height suggested that early flowering and shorter plants are beneficial for yield enhancement. Path coefficient analysis revealed that harvest index and biological yield had the most substantial positive direct effects on GYPP, while traits like protein content and days to maturity showed negative direct effects.

Comment [D2]: What are the purpose of these parental lines?? Is that they are part of your treatment??

Comment [D3]: Where is your recommendation and future work line?

Keywords: Wheat, Variability, correlation, path analysis

1. INTRODUCTION

Wheat is a vital global food crop and holds a significant place in Indian agriculture, ranking second after rice. As a key cereal, it supports food security, poverty alleviation, and livelihoods (Kumar *et al.*, 2017). Contributing around 30% to the nation's food basket, wheat is cultivated extensively as a staple crop (Singh *et al.*, 2023). Grain yield components show varied relationships with yield and each other (Edae *et al.*, 2014).

Comment [D4]: Why you are interested to deal with Variability?/

Simple correlation analysis indicates the degree of association between the traits, but it can't provide reasons for the association. The better understanding of the association is provided by the path coefficient analysis (Shah *et al*., 2010; Desheva, 2016). It helps in partitioning of correlation coefficients into direct and indirect effects and in the assessment of the relative contribution of each component character to the yield (Verma *et al*., 2019). Noopur *et al*. (2019) noted that the information related to the nature and extent of association among the various yield attributes, the direct and indirect effects of each component on the yield are helpful in formulating an effective breeding strategy. The aim of the study was to determine the interrelationship and the direct and indirect effects of some yield components among themselves and with the grain yield in the common winter wheat.

2. MATERIALS AND METHODS

Comment [D5]: Where your study area with map,weather data

The experimental materials for this study consisted of 54 wheat treatments, including 40 F_1 hybrids, 14 parental lines (10 females and 4 males), and one standard variety used as a check. The parental lines included 10 lines *viz*., K-1006, NW-2036, HD-2888, PBW-343, DBW-14, RAJ-4120, PBW-550, PBW-502, HD-2643 and DBW-107, with 4 testers (males) *viz*., HD-2967, HD-3171, K-1317, K-9107. The hybrids, along with their 14 parental lines and the standard check variety HD-3086, were evaluated using randomized block design (RBD) with three replications during *rabi* seasons in 2019-20.

Comment [D6]: Where Data collected?

3. STATISTICAL ANALYSIS

The analysis of variance (ANOVA) for the design of experiment was carried out following the procedure outlined by Panse and Sukhatme (1967). The genotypic variance was calculated using the formula suggested by Burton and Devane (1953). The coefficient of genotypic and phenotypic variation was calculated using Burton's (1952) formula, providing a measure of the extent of variation within the population. The genetic advance as a percentage of the mean was calculated using the formula given by Robinson and Comstock (1949). The association among different characters at both genotypic and phenotypic levels was determined using the method outlined by Searle *et al.* (1971). Direct and indirect effects were estimated using path coefficient analysis as suggested by Wright (1921) and elaborated by Dewey and Lu (1959).

Comment [D7]: Which software?

4. RESULTS AND DISCUSSION

4.1. Analysis of variance

The results of analysis of variance (ANOVA) indicated significant differences among the genotypes for most of the traits studied, suggesting a high degree of genetic variability. This variability is crucial for the selection and improvement of these traits in breeding programs. The significant differences among genotypes highlight the potential for selecting superior genotypes with desirable traits for further breeding (Shara *et al.*, 2016) (Table 1).

Comment [D8]: Is there any other findings support/oppose your result?

4.2. Genotypic correlation coefficient analysis

The coefficient correlation analysis revealed significant relationships between grain yield per plant (GYPP) and its component traits at both genotypic and phenotypic levels, with genotypic correlations generally being stronger (Table 2). Traits like spike length (0.826**), spikelets per spike (0.688**), grains per spike (0.618**), grain yield per spike (0.763**), harvest index (0.808**), and test weight (0.544) exhibited highly significant positive correlations with grain yield per plant, highlighting their critical contributions to yield improvement. Conversely, negative correlations were observed with days to 50% flowering (-0.783**) and plant height (-0.646**), suggesting that early flowering and shorter plant stature are favorable for yield enhancement. Traits such as flag leaf area, tillers per plant, and protein content also positively influenced yield but to a lesser extent. Notably, grain hardness correlated positively with yield (0.727**), although it showed negative associations with traits like days to 50% flowering (-0.415**) and spike length (-0.410**). These findings underscore the importance of selecting traits like spike length, harvest index, and spikelets per spike to optimize yield in breeding programs (Haydar *et al.*, 2020).

4.3. Phenotypic correlation coefficient analysis

The phenotypic correlation analysis revealed significant relationships between grain yield per plant (GYPP) and various agronomic traits (Table 3). GYPP exhibited strong positive correlations with spike length (0.771**), spikelets per spike (0.634**), grains per spike (0.579**), grain yield per spike (0.718**), harvest index (0.797**), and test weight (0.495**), highlighting their importance in yield improvement. Negative correlations were observed with days to 50% flowering (-0.732**) and plant height (-0.468**), suggesting that earlier flowering and shorter plants are favorable for higher yields. Traits like flag leaf area (0.398**), tillers per plant (0.407**), and protein content (0.392**) positively influenced yield, while grain hardness showed negative associations with several key traits, including DFF (-0.415**), plant height (-0.366**), and spike length (-0.410**). Other traits such as biological yield, peduncle length, and days to maturity demonstrated weaker or non-significant correlations, indicating a less direct role in yield formation. These findings underscore the importance of selecting traits such as spike length, spikelets per spike, and harvest index in breeding programs for yield optimization (Joshi *et al*., 2008).

4.4. Genotypic path coefficient analysis

The genotypic path coefficient analysis demonstrated the direct and indirect effects of agronomic traits on grain yield per plant (GYPP), elucidating complex trait interactions (Table 4). Traits like harvest index (0.886) and biological yield per plant (0.497) exhibited strong positive direct effects, emphasizing their critical role in yield improvement. Days to 50% flowering (0.137) and spike length (0.208) also showed significant positive direct impacts. Conversely, traits like protein content (-0.038), days to maturity (-0.069), and grains per spike (-0.073) had negative direct effects on GYPP, though their indirect contributions through other traits partially offset these impacts.

Indirectly, traits such as spike length, flag leaf area, and grains per spike positively influenced GYPP through pathways involving harvest index, biological yield, and test weight. However, negative indirect effects were noted for traits like grain hardness, which exhibited both a minimal positive direct impact (0.025) and negative indirect contributions through key yield-related pathways. Other traits, including test weight (0.033) and tillers per plant (0.002), had weak direct impacts but contributed positively via indirect effects (Shara *et al*., 2016).

4.4. Phenotypic path coefficient analysis

The phenotypic path analysis revealed the direct and indirect effects of various traits on grain yield per plant (GYPP), highlighting their contributions to yield formation (Table 5). Harvest index (0.846) and biological yield per plant (0.546) exhibited the strongest positive direct effects, underscoring their critical roles in determining grain yield. Traits like days to 50% flowering (0.093) and spike length (0.092) also had notable positive direct impacts, with significant indirect contributions through traits such as flag leaf area, grains per spike, and test weight. Conversely, days to maturity (-0.035) and grain hardness (-0.002) had negative direct effects on GYPP, although traits like days to maturity exhibited partial compensation via positive indirect pathways. Other traits, such as plant height (0.006) and test weight (0.022), had minimal direct impacts but contributed positively through indirect paths involving key traits like harvest index and biological yield. Interestingly, protein content (1.342) showed an exceptionally high direct effect, indicating its dominant influence on GYPP in this analysis. The indirect contributions of traits like spikelets per spike, grains per spike, and grain yield per spike, although weaker, also supported yield improvement through their associations with biological and harvest index (Shrief *et al.*, 2019).

CONCLUSION

The study highlighted significant genetic variability among the wheat genotypes, with key traits like spike length, spikelets per spike, grains per spike, harvest index, and test weight showing strong positive correlations with grain yield per plant (GYPP) at both genotypic and phenotypic levels. Negative correlations with days to 50% flowering and plant height suggested that early flowering and shorter plants are favorable for yield enhancement. The genotypic and phenotypic path coefficient analyses further revealed the direct and indirect effects of these traits on GYPP. Traits such as harvest index and biological yield per plant exhibited strong direct positive effects, while days to maturity and grain hardness had negative direct effects, though their indirect contributions through other traits provided some compensation. These findings underscore the importance of selecting traits like spike length, spikelets per spike, harvest index, and biological yield in breeding programs to optimize yield potential. The complex interactions among traits and their direct and indirect effects on grain yield offer valuable insights for breeders aiming to improve wheat productivity and overall performance in future breeding programs.

Comment [D9]: Where is your recommendation and what you pointed out for future researcher?

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Table: 1 Analysis of variance for yield and its contribution to 16 characters in wheat germplasm

Source of Variation	Replicate (df=2)	Treatments (df=54)	Error (df=108)
Days to 50% flowering (DFF)	9.67	67.22**	4.14
Plant height (PHT)	66.56	82.66**	39.22
Days to maturity (DTM)	17.46	71.88**	5.73
Tillers per plant (TPP)	0.69	2.26**	0.23
Flag leaf area (FLA)	11.46	32.64**	16.32
Peduncle length (PL)	1.13	33.25**	2.38
Spike length (SL)	0.11	15.17**	1.02
Spikelet per spike (SPP)	7.08	26.25**	2.36
Grains per spike (GPS)	5.52	56.44**	6.77
Grains yield per spike (GYPS)	0.12	0.82**	0.04
Biological yield per plant (BYPP)	7.16	24.86**	3.41
Harvest Index (HI)	22.65	94.02**	7.56
Test weight (TW)	6.04	21.36**	2.66
Grain yield per plant (GYPP)	2.31	9.89**	0.76

, ** significant at 5 and 1 per cent probability levels, respectively

Trait	Days to 50% flowering	Plant Height (cm)	Days to maturity	Tillers per plant	Flag leaf area (cm^2)	Peduncle length (cm)	Spike length (cm)	Spikelets per spike	Grains per spike	Grains yield per spike (g)	Biological yield per plant (g)	Harvest index (%)	Test Weight	Protein Content	Seed Hardness	Grain yield per plant (g)
D Days to 50% flowering	1.000	0.480**	0.256	0.456	0.592**	0.243	0.707**	0.526**	0.614**	0.628**	0.116	0.662**	-0.433**	0.440**	-0.415**	-0.783**
Plant Height (cm)		1.000	0.240	0.241	0.275	-0.074	0.469**	0.321	0.223	0.346*	0.135	0.581**	0.223	0.097	-0.366**	-0.646**
Days to maturity			1.000	-0.297	-0.251	0.165	0.123	0.481**	-0.258	0.331	0.533**	0.033	0.476**	-0.217	-0.014	0.313*
Tillers per plant				1.000	0.738**	-0.139	0.417**	0.007	0.653**	0.367*	-0.248	0.455**	0.110	0.140	0.141	0.339*
Flag leaf area (cm^2)					1.000	-0.079	0.678**	0.126	0.885**	0.397	-0.623**	0.784**	-0.016	0.394**	-0.191	0.457**
Peduncle length (cm)						1.000	-0.006	0.019	0.013	0.028	0.149	0.044	0.067	0.008	0.031	0.121
Spike length (cm)							1.000	0.723**	0.777**	0.779**	0.202	0.651**	0.605**	0.523**	-0.410**	0.826**
Spikelets per spike								1.000	0.390**	0.714**	0.598**	0.311**	0.831**	0.272	-0.333*	0.688**
Grains per spike									1.000	0.670**	-0.211	0.705**	0.393**	0.632**	-0.361	0.618**
Grains yield per spike (g)										1.000	0.368*	0.515**	0.674**	0.409**	-0.327*	0.763**
Biological yield per plant (g)											1.000	-0.309**	0.451**	-0.138	-0.158	0.289*
Harvest index (%)												1.000	0.243	0.392**	-0.237	0.808**
Test Weight													1.000	0.207	-0.205	0.544
Protein Content														1.000	0.396**	-0.149
Seed Hardness															1.000	0.727**
Grain yield per plant (g)																1.000

Table 2: Estimates of at genotypic correlation coefficient for component characters with grain yield in wheat germplasm

,**significant at 5 and 1 per cent probability levels, respectively

Table 3: Estimates of at phenotypic correlation coefficient for component characters with grain yield in wheat germplasm

Trait	Days to 50% flowering	Plant Height (cm)	Days to maturity	Tillers per plant	Flag leaf area (cm^2)	Peduncle length (cm)	Spike length (cm)	Spikelets per spike	Grains per spike	Grains yield per spike (g)	Biological yield per plant (g)	Harvest index (%)	Test Weight	Protein Content	Seed Hardness	Grain yield per plant (g)
D Days to 50% flowering	1.000	0.342**	0.267	0.407**	0.398**	0.224	0.657**	0.494**	0.570**	0.591**	0.105	0.621**	0.385*	0.543	-0.415**	-0.732**
Plant Height (cm)		1.000	0.170	0.178	0.156	-0.048	0.325**	0.236	0.153	0.265	0.086	0.425**	0.131	0.440**	-0.366**	-0.468**
Days to maturity			1.000	-0.277	-0.173	0.162	0.107	0.447**	-0.220	0.309**	0.491**	0.032	0.415**	0.097	-0.014	0.300*
Tillers per plant				1.000	0.485**	-0.140	0.398**	-0.004	0.564**	0.336**	-0.207	0.418**	0.119	-0.217	0.141	0.316**
Flag leaf area (cm^2)					1.000	-0.033	0.437**	0.100	0.579**	0.287	-0.417**	0.551**	-0.010	0.140	-0.191	0.333**
Peduncle length (cm)						1.000	-0.008	0.023	0.028	0.026	0.127	0.048	0.056	0.394**	0.031	0.120
Spike length (cm)							1.000	0.667**	0.718**	0.740**	0.176	0.608**	0.550**	0.008	-0.410**	0.771**
Spikelets per spike								1.000	0.411**	0.685**	0.538**	0.280	0.719**	0.523**	-0.333*	0.634**
Grains per spike									1.000	0.624**	-0.174	0.636**	0.326**	0.272	-0.361	0.579**
Grains yield per spike (g)										1.000	0.333**	0.491**	0.617**	0.632**	-0.327*	0.718**
Biological yield per plant (g)											1.000	-0.314	0.393**	0.409**	-0.158	0.287
Harvest index (%)												1.000	0.230	-0.138	-0.237	0.797**
Test Weight													1.000	0.392**	-0.205	0.495**
Protein Content														1.000	0.396**	-0.149
Seed Hardness															1.000	-0.067
Grain yield per plant (g)																1.000

****, ** significant at 5 and 1 per cent probability levels, respectively***

Table 4: Estimates of at genotypic path coefficient for component characters with grain yield

Trait	Days to 50% flowering	Plant Height (cm)	Days to maturity	Tillers per plant	Flag leaf area (cm^2)	Peduncle length (cm)	Spike length (cm)	Spikelets per spike	Grains per spike	Grains yield per spike (g)	Biological yield per plant (g)	Harvest index (%)	Test Weight	Protein Content	Seed Hardness	Grain yield per plant (g)
D Days to 50% flowering	**0.137**	0.066	0.035	0.062	0.081	0.033	0.097	0.072	0.084	0.086	0.016	0.091	0.059	-0.140	0.137	-0.783**
Plant Height (cm)	-0.020	**-0.042**	-0.010	-0.010	-0.012	0.003	-0.020	-0.013	-0.009	-0.014	-0.006	-0.024	-0.009	0.194	-0.078	-0.646**
Days to maturity	-0.018	-0.016	**-0.069**	0.020	0.017	-0.011	-0.008	-0.033	0.018	-0.023	-0.037	-0.002	-0.033	-0.002	-0.008	0.313*
Tillers per plant	0.001	0.000	-0.001	**0.002**	0.001	0.000	0.001	0.000	0.001	0.001	0.000	0.001	0.000	-0.013	0.011	0.339*
Flag leaf area (cm^2)	-0.040	-0.019	0.017	-0.050	**-0.068**	0.005	-0.046	-0.009	-0.060	-0.027	0.042	-0.053	0.001	-0.010	0.013	0.457**
Peduncle length (cm)	-0.005	0.002	-0.004	0.003	0.002	**-0.022**	0.000	0.000	0.000	-0.001	-0.003	-0.001	-0.002	-0.005	-0.015	0.121
Spike length (cm)	0.147	0.098	0.026	0.087	0.141	-0.001	**0.208**	0.151	0.162	0.162	0.042	0.136	0.126	-0.169	0.189	0.826**
Spikelets per spike	-0.033	-0.020	-0.030	0.000	-0.008	-0.001	-0.045	**-0.063**	-0.025	-0.045	-0.038	-0.020	-0.052	0.116	-0.105	0.688**
Grains per spike	-0.067	-0.024	0.028	-0.071	-0.096	-0.001	-0.084	-0.042	**-0.109**	-0.073	0.023	-0.077	-0.043	0.137	-0.152	0.618**
Grains yield per spike (g)	0.022	0.012	0.012	0.013	0.014	0.001	0.027	0.025	0.023	**0.035**	0.013	0.018	0.024	-0.006	0.006	0.763**
Biological yield per plant (g)	0.058	0.067	0.265	-0.123	-0.310	0.074	0.100	0.298	-0.105	0.183	**0.497**	-0.154	0.224	-0.185	0.049	0.289*
Harvest index (%)	0.587	0.516	0.029	0.404	0.696	0.039	0.577	0.277	0.625	0.457	-0.275	**0.886**	0.215	-0.337	0.268	0.808**

Test Weight	0.014	0.007	0.016	0.004	-0.001	0.002	0.020	0.027	0.013	0.022	0.015	0.008	**0.033**	0.092	-0.041	0.544
Protein Content	0.038	0.044	0.002	-0.037	0.020	-0.003	0.034	0.031	0.033	0.030	0.015	0.022	0.029	**-0.038**	-0.077	-0.149
Seed Hardness	-0.064	-0.031	0.012	0.051	-0.049	-0.013	-0.065	-0.048	-0.063	-0.050	-0.007	-0.031	-0.022	0.018	**0.025**	0.727**

R SQUARE = 0.923 RESIDUAL EFFECT = 0.087

Table 5: Estimates of at phenotypic path coefficient for component characters with grain yield

Trait	Days to 50% flowering	Plant Height (cm)	Days to maturity	Tillers per plant	Flag leaf area (cm^2)	Peduncle length (cm)	Spike length (cm)	Spikelets per spike	Grains per spike	Grains yield per spike (g)	Biological yield per plant (g)	Harvest index (%)	Test Weight	Protein Content	Seed Hardness	Grain yield per plant (g)
D Days to 50% flowering	**0.093**	0.032	0.025	0.038	0.037	0.021	0.061	0.046	0.053	0.055	0.010	0.058	0.036	-0.002	-0.060	-0.732**
Plant Height (cm)	0.002	**0.006**	0.001	0.001	0.001	0.000	0.002	0.001	0.001	0.002	0.001	0.002	0.001	0.001	0.005	-0.468**
Days to maturity	-0.009	-0.006	**-0.035**	0.010	0.006	-0.006	-0.004	-0.016	0.008	-0.011	-0.017	-0.001	-0.015	0.001	0.002	0.300*
Tillers per plant	-0.012	-0.005	0.008	**-0.030**	-0.015	0.004	-0.012	0.000	-0.017	-0.010	0.006	-0.013	-0.004	0.006	0.010	0.316**
Flag leaf area (cm^2)	0.008	0.003	-0.004	0.010	**0.021**	-0.001	0.009	0.002	0.012	0.006	-0.009	0.011	0.000	-0.001	0.030	0.333**
Peduncle length (cm)	-0.002	0.000	-0.001	0.001	0.000	**-0.009**	0.000	0.000	0.000	0.000	-0.001	0.000	-0.001	-0.002	-0.003	0.120
Spike length (cm)	0.060	0.030	0.010	0.037	0.040	-0.001	**0.092**	0.061	0.066	0.068	0.016	0.056	0.051	0.010	0.011	0.771**
Spikelets per spike	-0.006	-0.003	-0.006	0.000	-0.001	0.000	-0.009	**-0.013**	-0.005	-0.009	-0.007	-0.004	-0.009	-0.006	-0.011	0.634**
Grains per spike	0.005	0.002	-0.002	0.005	0.006	0.000	0.007	0.004	**0.010**	0.006	-0.002	0.006	0.003	0.008	0.012	0.579**
Grains yield per spike (g)	0.001	0.001	0.001	0.001	0.001	0.000	0.002	0.001	0.001	**0.002**	0.001	0.001	0.001	0.006	-0.080	0.718**
Biological yield per plant (g)	0.057	0.047	0.268	-0.113	-0.228	0.069	0.096	0.294	-0.095	0.182	**0.546**	-0.171	0.215	0.173	0.368	0.287
Harvest index (%)	0.526	0.360	0.027	0.354	0.466	0.040	0.515	0.237	0.539	0.415	-0.266	**0.846**	0.195	-0.001	-0.001	0.797**

Test Weight (g)	0.009	0.003	0.009	0.003	0.000	0.001	0.012	0.016	0.007	0.014	0.009	0.005	**0.022**	0.004	0.002	0.495**
Protein Content	-0.001	0.032	0.012	0.015	0.004	0.007	-0.001	0.002	0.004	0.007	0.006	0.021	0.531	**0.001**	0.001	-0.149
Seed Hardness	0.005	0.002	-0.001	0.000	0.003	0.001	0.005	0.003	0.005	0.004	0.000	0.003	0.001	-0.001	**-0.002**	-0.067

R SQUARE = 0.969 RESIDUAL EFFECT = 0.177