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Studies on correlation coefficient for grain yield and its attributing traits in bread wheat (*Triticum aestivum* L.)

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Abstract
Wheat (*Triticum aestivum* L. Em. Thell.) is a staple food crop and a vital source of nutrition for millions globally, particularly in India, where it ranks second in importance after rice. The study investigates the genetic relationships between various quantitative traits affecting grain yield in wheat, employing a Line × Tester mating design with 22 genotypes to generate 72 F1s and F2s. Fourteen traits were evaluated, revealing significant phenotypic and genotypic correlations. Key findings include strong positive associations between grain yield and biological yield per plant and harvest index, indicating that enhancing biomass is critical for improving yield. Conversely, protein content showed a significant negative correlation with grain yield, highlighting the trade-off between grain quality and quantity. Other traits such as days to 50% heading exhibited notable relationships with maturity and protein accumulation, while plant height and 1000 grain weight showed negative correlations with grain yield in the F2 generation. These results emphasize the complexity of selecting for yield and quality traits, underscoring the need for balanced breeding strategies that consider both agronomic performance and nutritional quality.

Keywords: Correlation, wheat, F1s and F2s

Introduction

Wheat (*Triticum aestivum* L. Em. Thell., 2n=42) is a self-pollinated crop belonging to the *Poaceae* family and integral part of daily diet in different geographic regions of the world including India. It has been described as the 'King of cereals' because of the versatile nature, acreage occupies, high productivity and the prominent position in the International food grain trade. It is the most important food crop of India and is a main source of protein and energy for vegetarian people. In India, wheat is the second most important food crop after rice both in terms of area and production.

In India, mainly three species of wheat *viz., Triticum aestivum, Triticum durum* and *Triticum dicoccum* are grown. Bread wheat, is an annual crop of medium height with flat leaf blades and a terminal floral spike comprising perfect flowers. Its vegetative structure, characterized by tillers carrying axillary leafy culms, typically consists of 5-7 nodes with 3-4 foliage leaves. The uppermost leaf, known as the flag leaf, defines the inflorescence (Lersten, 1987) [14].

Most of the wheat grown throughout the world is hexaploid (2n=6x=42) A number of biometrical techniques are extensively used for genetic evaluation of plants. *Triticum aestivum*, which is commonly referred to as bread wheat, covering about 95% of the total wheat growing area in the country. It is used for various food products such as chapatti, bread, biscuits, cakes and noodles etc. *Triticum durum*, an allotetraploid (2n=4x=28), is used for making pasta products, such as macaroni, spaghetti, puffed breakfast cereals etc. It is also referred as durum or macaroni wheat and is grown in about 4% area of wheat in the country. *Triticum dicoccum* (2n=4x=28) is commonly known as emmer wheat and confined only to some parts of Gujarat and southern regions of the country (Paroda *et al.*, 2013) [20].

Wheat is consumed in a variety of ways such as *bread, chapatti, porridge, flour, suji* etc. Wheat has relatively high content of niacin and thiamine which are mainly concerned in providing the special protein called '*Gluten'*. Wheat proteins are of special significance because *Gluten* provides the framework of spongy cellular texture of bread and baked products. It has numerous uses, good storage quality and nutritive value; thus, accepted as a major foodstuff for one third global population (Sleper and Poehlman, 2006) [30]. Wheat is a strategic and major cereal crop around the globe. Wheat provides about 55% and 20% carbohydrates and calories, respectively (Aravind and Prasad, 2005) [4].

In India, wheat has been under cultivation in 30.54 million hectares during 2021-22 *Rabi* season. In the production season (2021-22), the wheat output was pegged at 106.84 million tonnes with national average productivity of 3484 kg. per ha. (4^{th}Advance Estimates from Directorate of Economics and Statistics (DES), Ministry of Agriculture and Farmers Welfare (MoA and FW), India.

In India, among the wheat-producing states, Uttar Pradesh accounted for the highest share of crop output estimated at 34.16 million tonnes (32%) followed by Madhya Pradesh (22.42 million tonnes; 21%), Punjab (14.46 million tonnes; 14%), Haryana (10.62 million tonnes; 10%), Rajasthan (9.82 million tonnes; 9%) and Bihar (5.60 million tonnes; 5%).

With the ongoing expansion of population in the nation, there will be requirement of more than 140 million tons of wheat grain to be produced by 2050, which is about 40% increase from our present production scenario (Singh *et al.*, 2019) [28]. Also, the world's demand for cereals is projected to grow by 56% while demand in the developing world is projected to increase by 60% by 2050 compared to the demand in 2000 and 26% of that demand is expected to be for wheat (FAO, 2015) [5]. To achieve this target there is an urgent need to improve the yield per unit area as the crop acreage cannot be expanded beyond a certain limit. Hence, it is important to increase the genetic potential of the varieties to increase the overall productivity of the crop.

Wheat breeding in India is confronted with several significant challenges that affect productivity and adaptability. One of the foremost issues is the limited genetic gains made in recent years, with wheat yields having plateaued. Developing high-yielding hybrid varieties has proven difficult due to wheat's self-pollinating nature, which complicates the breeding process. Additionally, efforts to breed for heat and drought tolerance, crucial given the increasing impact of climate change, have been slow, particularly when it comes to creating region-specific varieties capable of thriving in India's diverse agro-climatic zones. Resistance to evolving diseases like rust, especially the virulent Ug99 strain, continues to pose a threat to wheat production, with ongoing efforts to introduce disease-resistant traits into new varieties.

Correlation studies are pivotal in wheat breeding, as they elucidate the interrelationships among key agronomic traits and their collective influence on grain yield. By quantifying the degree of association among different traits with yield, breeders can simultaneously enhance multiple favorable traits. This approach improves selection efficiency by facilitating indirect selection for grain yield through easily measurable traits, which may exhibit high heritability and minimal environmental influence. Additionally, correlation analysis enables the identification of negative associations, such as between grain size and protein content, allowing breeders to balance trait improvement without compromising overall genetic gain. Furthermore, correlation serves as a precursor to path coefficient analysis, which dissects direct and indirect effects, thereby refining the understanding of trait contributions to yield. Ultimately, correlation studies provide a robust framework for informed selection decisions in wheat breeding, optimizing yield potential and trait improvement.

Materials and Methods

Basic material for this investigation, consisted of twenty-two genotypes *viz.*, K2012, K 1910, K 607, HD 2967, K 2007, HI 1612, PBW 644, DBW 398, PBW 386, HD 3171, DBW 252, K 2101, K 2105, DBW 173, DBW 222, HD 3059, WB 02, DBW 187, HI 1563, K 9423, K 307 and DBW 107. These were collected from section of *Rabi* cereals, C. S. Azad University of agriculture and technology, Kanpur. Out of these, 18 genotypes were used as lines and four (HI 1563, K 9423, K 307 and DBW 107) as testers.

These parental lines were crossed to develop 72 F_1s and F_2s using Line X Tester mating design. A total of 166 treatments (22 parents + 72 F_1s + 72 F_2s) were evaluated for the study of genetical analysis of fourteen quantitative characters in wheat.

Data was recorded for 14 characters *i.e.*, for days to 50% heading, days to maturity, plant height, number of productive tillers/plant, flag leaf area, number of leaves/main tiller, number of spikelets/ear, spike length, number of grains/ear, biological yield/plant, 1000 grain weight, harvest index, protein content and grain yield/plant.

Estimation of Correlation coefficients

The estimates of phenotypic and genotypic correlation were worked out as given under:

(a) Genotypic correlation

$$r_{xy}(g) = Cov._{xy}(g) / [V_x(g).V_y(g)]^{0.5}$$

Where,

$Cov._{xy}(g)$ = genotypic covariance between character X and y was obtained as follows:

$Cov._{xy}(g) = [Cov._{xy}(p) – Cov._{xy}(e)]$

$V_x(g)$ and $V_y(g)$ = Genotypic variance for the characters x and y respectively.

r = number of replications.

(b) Phenotypic correlation

$$r_{xy}(p) = Cov._{xy}(p) / [V_x(p). V_y(p)]^{0.5}$$

Where,

$Cov._{xy}(p)$ = Phenotypic correlation between the character x and y and this was obtained as follows:

$Cov._{xy}(p) = Cov._{xy}(g) + Cov._{xy}(e)$

$V_x(p)$ and $V_y(p)$= Phenotypic variance for the characters x and y, respectively.

xy (e) = the error variance obtained from the ANNOVA of x and y characters.

Test of significance of correlation coefficients

The significance of phenotypic coefficient was tested against „r" values from r Table of Fisher and Yates (1938) for (n-2) degree of freedom where n is number of treatments.

Table 1: Estimates of Genotypic correlations among 14 characters in bread wheat for F1 generation

Parent/Hybrids	Days to 50% heading	Days to maturity	Plant height	Number of productive tillers/plant	Flag leaf area	Number of leaves/ main tiller	Number of Spikelets/ear	Spike length	Number of grains/ear	Biological yield/plant	1000 grain weight	Harvest index	Protein content	Grain yield/plant
Days to 50% heading	1.000	0.675**	-0.193**	-0.288**	-0.033	-0.159**	-0.211**	-0.275**	-0.161**	-0.123*	-0.071	0.058	0.170**	-0.116
Days to maturity			-0.003	-0.104	-0.117*	0.035	-0.167**	-0.283**	0.023	-0.118*	-0.162**	0.082	0.333**	-0.124*
Plant height				0.196**	0.171**	-0.004	0.153*	0.162**	0.080	-0.009	0.193**	-0.092	-0.128*	-0.082
Number of productive tillers/plant					0.226**	-0.063	0.212**	0.330**	0.051	0.229**	0.026	-0.033	-0.293**	0.221**
Flag leaf area						-0.114	-0.101	0.148*	0.029	0.206**	-0.017	-0.130*	-0.186**	0.157**
Number of leaves/ main tiller							0.029	-0.170**	-0.029	-0.210**	0.010	0.131*	0.010	-0.143*
Number of spikelets/ear								0.427**	0.357**	0.148*	0.090	-0.107	-0.199**	0.103
Spike length									0.236**	0.307**	0.186**	-0.257**	-0.245**	0.200**
Number of grains/ear										0.297**	-0.011	-0.063	-0.094	0.236**
Biological yield/plant											-0.106	0.017	-0.219**	0.889**
1000 grain weight												-0.058	-0.148*	-0.142*
Harvest index													0.035	0.416**
Protein content														-0.155**
Grain yield/plant														1.000

*, ** significant at 5% and 1% level, respectively

Table 2: Estimates of phenotypic correlations among 14 characters in bread wheat for F1 generation

Parent/Hybrids	Days to 50% heading	Days to maturity	Plant height	Number of productive tillers/plant	Flag leaf area	Number of leaves/ main tiller	Number of Spikelets/ear	Spike length	Number of grains/ear	Biological yield/plant	1000 grain weight	Harvest index	Protein content	Grain yield/plant
Days to 50% heading	1.000	0.606**	-0.182**	-0.262**	-0.032	-0.125*	-0.182**	-0.247**	-0.151*	-0.106	-0.053	0.059	0.159**	-0.089
Days to maturity			-0.003	-0.097	-0.104	0.024	-0.146*	-0.246**	0.020	-0.113	-0.138*	0.072	0.321**	-0.113
Plant height				0.192**	0.149*	0.002	0.127*	0.154**	0.073	-0.024	0.194**	-0.043	-0.121*	-0.078
Number of productive tillers/plant					0.203**	-0.061	0.188**	0.306**	0.051	0.215**	0.023	-0.009	-0.289**	0.215**
Flag leaf area						-0.122*	-0.107	0.123*	0.014	0.203**	-0.013	-0.119*	-0.170**	0.143*
Number of leaves/ main tiller							0.018	-0.116	-0.027	-0.152*	0.002	0.104	0.011	-0.099
Number of spikelets/ear								0.373**	0.330**	0.128*	0.072	-0.086	-0.181**	0.086
Spike length									0.219**	0.259**	0.158**	-0.155**	-0.228**	0.180**
Number of grains/ear										0.274**	-0.015	-0.043	-0.093	0.218**
Biological yield/plant											-0.102	-0.061	-0.211**	0.849**
1000 grain weight												-0.024	-0.139*	-0.122*
Harvest index													0.028	0.423**
Protein content														-0.148*
Grain yield/plant														1.000

*, ** significant at 5% and 1% level, respectively

Table 3: Estimates of Genotypic correlations among 14 characters in bread wheat for F2 generation

Parent/Hybrids	Days to 50% heading	Days to maturity	Plant height	Number of productive tillers/plant	Flag leaf area	Number of leaves/ main tiller	Number of Spikelets/ear	Spike length	Number of grains/ear	Biological yield/plant	1000 grain weight	Harvest index	Protein content	Grain yield/plant
Days to 50% heading	1.000	0.381**	-0.365**	0.167**	-0.067	0.100	0.085	0.056	0.207**	-0.028	-0.410**	0.382**	0.271**	0.142*
Days to maturity			-0.265**	0.107	0.059	-0.018	0.090	0.030	0.092	0.002	-0.205**	0.230**	0.149*	0.088
Plant height				0.008	0.220**	-0.101	-0.011	0.177**	-0.219**	-0.222**	0.485**	-0.259**	-0.237**	-0.344**
Number of productive tillers/plant					0.044	0.424**	0.175**	0.157**	0.160**	-0.011	-0.378**	0.275**	0.117*	0.099
Flag leaf area						-0.123*	0.022	0.043	0.019	-0.047	0.110	-0.118*	-0.111	-0.111
Number of leaves/ main tiller							0.054	-0.062	-0.037	-0.039	-0.265**	0.094	0.072	0.012
Number of spikelets/ear								0.224**	0.421**	0.084	-0.157**	0.263**	0.114	0.179**
Spike length									0.645**	0.149*	0.123*	0.012	0.053	0.113
Number of grains/ear										0.210**	-0.086	0.204**	0.075	0.240**
Biological yield/plant											0.054	0.077	-0.099	0.804**
1000 grain weight												-0.436**	-0.291**	-0.181**
Harvest index													0.164**	0.591**
Protein content														0.066
Grain yield/plant														1.000

*, ** significant at 5% and 1% level, respectively

Table 4: Estimates of Phenotypic correlations among 14 characters in bread wheat for F2 generation

Parent/Hybrids	Days to 50% heading	Days to maturity	Plant height	Number of productive tillers/plant	Flag leaf area	Number of leaves/ main tiller	Number of Spikelets/ear	Spike length	Number of grains/ear	Biological yield/plant	1000 grain weight	Harvest index	Protein content	Grain yield/plant
Days to 50% heading	1.000	0.347**	-0.332**	0.152*	-0.075	0.088	0.080	0.036	0.197**	-0.007	-0.372**	0.301**	0.255**	0.138*
Days to maturity			-0.242**	0.101	0.052	-0.002	0.090	0.028	0.087	0.000	-0.194**	0.194**	0.142*	0.079
Plant height				0.006	0.205**	-0.097	-0.009	0.164**	-0.196**	-0.212**	0.467**	-0.211**	-0.230**	-0.322**
Number of productive tillers/plant					0.042	0.402**	0.162**	0.152*	0.150*	-0.009	-0.372**	0.239**	0.115	0.096
Flag leaf area						-0.117*	0.022	0.041	0.012	-0.056	0.111	-0.091	-0.107	-0.111
Number of leaves/ main tiller							0.049	-0.056	-0.038	-0.030	-0.249**	0.082	0.069	0.015
Number of spikelets/ear								0.179**	0.388**	0.081	-0.129*	0.210**	0.105	0.168**
Spike length									0.598**	0.130*	0.111	0.021	0.050	0.106
Number of grains/ear										0.198**	-0.080	0.187**	0.074	0.235**
Biological yield/plant											0.053	-0.017	-0.095	0.767**
1000 grain weight												-0.385**	-0.286**	-0.172**
Harvest index													0.147*	0.562**
Protein content														0.064
Grain yield/plant														1.000

*, ** significant at 5% and 1% level, respectively

Results and Discussion

Correlation study was carried out among all the fourteen characters at genotypic and phenotypic levels. The phenotypic and genotypic correlation coefficient of F1 and F2 computed among the fourteen characters under study has been presented in Table 1 and Table 2 respectively.

The phenotypic correlation analysis in both F1 and F2 generations provides valuable insights into the complex relationships between yield components and other agronomic traits in wheat. Understanding these correlations is crucial for plant breeders seeking to improve grain yield while maintaining or enhancing other desirable traits such as grain quality, plant height, and biomass.

In the F1 generation, grain yield per plant exhibited a strong positive correlation with biological yield per plant (0.849) and harvest index (0.423), both of which are key contributors to overall productivity. Similar findings have been reported by Ali *et al.*, (2016) [3], where biological yield was a significant determinant of grain yield in wheat. The strong association between grain yield and biological yield suggests that increasing the plant's overall biomass is a viable strategy for boosting grain yield. However, the challenge lies in balancing this with grain quality traits such as protein content, which showed a significant negative correlation with grain yield (-0.148). This inverse relationship between yield and protein content has been widely documented in wheat (Kumar *et al.*, 2018) [13], reflecting a common trade-off between grain quantity and quality.

Interestingly, 1000 grain weight, a measure of seed size, also had a negative correlation with grain yield (-0.122), suggesting that genotypes with larger seeds may not necessarily produce higher yields. This could be due to a resource allocation trade-off between seed size and seed number, as supported by similar studies (Slafer & Andrade, 1993) [29]. Therefore, breeders need to consider both seed number and seed size when selecting for higher yield potential.

Days to 50% heading displayed a strong positive correlation with days to maturity (0.606) and protein content (0.159), indicating that later-maturing genotypes tend to accumulate more protein. However, it was negatively correlated with plant height (-0.182) and spike-related traits, such as spike length (-0.247) and number of spikelets per ear (-0.182). These findings are consistent with the work of Foulkes *et al.*, (2007) [6], who noted that earlier heading can be advantageous for yield but may reduce plant stature and spike size, limiting yield potential. This suggests that careful selection of heading and maturity traits is critical for optimizing yield in different environments.

In the F2 generation, the correlation between grain yield per plant and biological yield per plant (0.767) remained strong, underscoring the importance of biomass accumulation in yield performance. However, unlike in F1, grain yield showed a significant negative correlation with plant height (-0.322). This is in contrast to some earlier studies (Foulkes *et al.*, 2011) [6] that suggest taller plants with more biomass can lead to higher yields. The negative relationship observed here could be due to the specific genetic background or growing conditions, where shorter plants may have benefited from better lodging resistance or more efficient resource allocation to grain development.

One notable result in the F2 generation is the positive correlation between days to 50% flowering and harvest index (0.301) and the negative correlation with plant height (-0.332). These findings indicate that earlier flowering genotypes with a more efficient partitioning of biomass into grains tend to be shorter in stature, a trait that may enhance harvest efficiency and reduce lodging risk (Reynolds *et al.*, 2009) [24].

The challenge for breeders is to balance these traits to ensure high grain yield while maintaining desirable plant architecture.

Spike-related traits such as number of spikelets per ear, spike length, and number of grains per ear were positively correlated with grain yield in both generations. These findings are consistent with those of Sheoran *et al.*, (2018) [27], who observed that spike length and the number of spikelets were closely linked to yield potential. Improving these traits could be an effective strategy for increasing the grain yield potential in wheat breeding programs.

However, 1000 grain weight was negatively correlated with grain yield and other yield components, particularly in the F2 generation. This result highlights the need for careful selection to avoid excessive increases in seed size, which may reduce the number of grains per spike, ultimately limiting total yield. Previous studies, such as those by Fischer (2011), have emphasized the importance of striking a balance between grain number and grain weight for maximizing yield.

Another key observation is the negative correlation between protein content and yield-related traits, especially in the F2 generation, where protein content had a highly negative correlation with 1000 grain weight (-0.286) and harvest index (-0.385). These results align with findings from Mason *et al.*, (2007) [16], who noted that increasing protein content often comes at the cost of reduced yield. This presents a challenge for wheat breeders, as improving both yield and grain quality requires careful genetic selection and management practices.

Conclusion

The results of this study provide valuable information on the relationships between yield, yield components, and quality traits in wheat. While increasing biomass and spike-related traits offers a promising path for improving grain yield, breeders must carefully manage the correlation between yield, seed size, and protein content. A balanced selection approach, incorporating both agronomic and quality traits, is essential for achieving sustainable improvements in wheat production.

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