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# Studies on correlation for yield and its contributing traits in bread wheat (*Triticum aestivum* L. em. Thell) under normal and stress condition

**Guman Singh, Dhirendra Singh and Naresh Parashar**

**Abstract**
The present study intended to assess the correlation among various traits in wheat genotypes, including days to heading, grain filling duration, days to maturity, plant height, number of tillers per plant, flag leaf area, number of grains per spike, peduncle length, spike length, 1000-grain weight, biological yield per plant, and grain yield per plant. The experiment was conducted in randomized block design with three replications during *rabi* 2016-17. The analysis of correlation revealed that at phenotypic level, the grain yield per plant was positively and significantly correlated with tillers per plant, spike length, number of grains per spike, test weight and biological yield per plant in both the environments. There was a strong association of grain yield per plant with number of tillers per plant, spike length, number of grains per spike, 1000-grain weight and biological yield per plant in heat stress environment. hence these characters should be considered for selection in breeding for heat stress environment.

**Keywords:** Bread wheat, correlation analysis and stress condition

## Introduction
*Triticum aestivum* L., often known as bread wheat, is a very significant cereal crop in India and ranks second, behind rice, in terms of its importance as a food grain. Throughout human history, this traditional cereal grain has been the main source of food for humanity. It is widely renowned for its propensity to decrease hunger. This crop belongs to the Poaceae family and is a self-pollinating plant species. This species is hexaploid, meaning it has six sets of chromosomes (2n=6x=42: AABBDD genomes), resulting in a total of 21 pairs of chromosomes. It made a substantial contribution to the success of the "Green Revolution" and played a crucial role in shifting our nation from relying on food imports to attaining self-sufficiency.

Wheat is a very nutritious food for humans due to its composition, which includes 14.7% protein, 78.1% carbohydrate, 2.1% fat, and 2.1% minerals (Kumar *et al*., 2011) [7]. Wheat grains undergo processing to produce a kind of flour known as atta, which is then eaten. Approximately 80-85% of wheat that is eaten in India is mostly consumed in the form of chapatee. Soft wheat is used in the production of chapatee, bread, cake, biscuits, pastry, and other bakery items. Rawa, suji, and sewaya are derived from durum wheat. In regions where rice is a predominant staple in the diet, wheat is consumed in the form of puri and uppumav. Additionally, it is used in the production of flakes and confections, such as kheer and shira. Wheat grain is used in the production of starch. Given its high starch content and substantial grain yield, it has the potential to serve as a feedstock for bioethanol production in the future. Notably, a considerable quantity of wheat flour is already subjected to fermentation for the purpose of alcohol production, which is then used in the production of a range of drinks, including beer and whiskey. Wheat straw has a dual function, serving as both animal feed and a protective barrier for the soil to retain moisture and prevent the growth of undesirable vegetation. The citation is Singh *et al.*, 2009 [11].

Globally, the cultivation of this crop spans around 222.19 million hectares, resulting in a total output of 779.2 million tonnes and an average productivity of 3507 kg/hectare (Anonymous, 2022a) [1]. Europe, Russia, North and South America, Australia, and China are the primary locations for world wheat production.

In the 2021-2022 year, India's wheat cultivation spanned over 31.13 million hectares, with a total output of 109.59 million tonnes. The reported mean yield per hectare was 3520 kg/ha (Anonymous, 2022a) [1].

According to Anonymous (2022b) [2], Uttar Pradesh in India has attained the maximum output of 33.95 million tonnes, with Madhya Pradesh following closely behind at 22.42 million tonnes. The state of Punjab produced a total of 14.62 million tonnes, Haryana produced 10.42 million tonnes, Rajasthan produced 9.48 million tonnes, and Bihar produced 6.22 million tonnes. The combined wheat production of these six states accounted for around 90 percent of the country's total output.

The cultivation of wheat in Rajasthan during the 2021-22 season included a land area of 2.58 million hectares and resulted in a total output of 9.48 million tonnes. The average wheat yield in this region was 3792 kg per hectare (Anonymous, 2022b) [2]. The primary wheat-producing districts in Rajasthan are Shri Ganganagar, Hanumangarh, Alwar, Bharatpur, Chittorgarh, Bundi, Jaipur, Kota, Baran, Bikaner, Bhilwara, Jhalawar, Dausa, Banswara, Sikar, and Udaipur.

The wheat crop cultivated in Northern India experiences harsh cold weather until the booting stage, when it is planted late. Subsequently, it undergoes elevated temperatures, which expedite its growth and result in a diminished crop output. The reproductive and ripening periods of late-seeded wheat crops are generally subjected to severe temperature stress over the months of March through April, with temperatures ranging from 35-40ºC. Every genetic variant within a plant species requires a certain temperature range that is ideal for the plant's growth and development at various stages. The optimal temperature range for germination is between 20 and 25 degrees Celsius, for tillering it is between 16 and 20 degrees Celsius, and for grain production in wheat it is between 20 and 23 degrees Celsius. Wheat is quite vulnerable to temperatures over 32-33 °C during extended periods of time. High temperatures may have negative effects on wheat plants at several stages of their growth, including seedling emergence, reproductive development, stem elongation, heading, and blooming.

Enhancing agricultural productivity has been a primary goal in breeding initiatives. Wheat breeders worldwide have used the existing genetic resources to accomplish this objective. Therefore, it is crucial for a breeder to evaluate genetic traits, such as heritability and genetic advancement. This assessment enhances comprehension of the scale, characteristics, and interplay between genotype and environmental variation of the traits. Correlation studies enhance comprehension of yield components, hence aiding plant breeders in the process of selection. This aids breeders in assessing the components of crop production and comprehending the causal relationship between two variables. The aim of this study was to determine the correlation coefficient between wheat yield and its contributing factors, under both normal and stressful settings.

## Methods and Materials

The study was conducted during the *rabi* seasons of 2015-16 and 2016-17 at the Agronomy Farm of S.K.N. College of Agriculture, Jobner. The farm is located at a latitude of 260 05’ North, longitude of 750 20 East, and an altitude of 427 meters above mean sea level in the Jaipur district of Rajasthan. The materials used in the current investigation included 10 genetically different wheat types.

Crosses were performed in a diallel manner, eliminating reciprocals, among the 10 varieties during the *rabi* season of 2015-16 at Agronomy Farm SKNCOA, Jobner, Jaipur. The 45 $F_1$ plants were cultivated in a plot of 2 meters in length at the Wheat Breeding Regional Station (IARI), Wellington, Nilgiris (Tamil Nadu) during the summer of 2016. The purpose was to get $F_2$ seeds for testing. The date of sowing was manipulated to generate a high temperature stress environment in the field condition. The experimental materials, which included 10 parents and their 45 $F_1$ and 45 $F_2$ progenies, were cultivated in a randomized block design with three replications. This was done under both normal and high temperature circumstances during the *rabi* season of 2016-17 at Agronomy Farm, SKNCOA, Jobner, Jaipur.

Data was collected by recording observations on 10 plants chosen at random from each of the $F_1$ progenies, as well as from each parent. In the $F_2$ population, 30 plants were picked from each replication. Measurements were taken on various plant characteristics including plant height (cm), number of tillers per plant, flag leaf area ($cm^2$), peduncle length (cm), and spike length (cm). These measurements were recorded while the plants were in the field. Additionally, data for the number of grains per spike, 1000-grain weight (g), biological yield per plant (g), grain yield per plant (g), and harvest index (%) were recorded after uprooting randomly selected plants for yield. These measurements were taken on randomly tagged plants of each genotype under each environment, excluding border plants. However, measurements for days to heading, grain filling duration, and days to maturity were taken on a plot basis.

## Results and Discussion

The character-wise pooled analysis of variance revealed considerable variations across the surroundings, demonstrating their diverse impact on the expression of distinct characteristics being studied. Except for grain filling length, days to maturity, plant height, 1000 grain weight, and biological yield per plant, there were significant differences seen between parents and the $F_1$ and $F_2$ generations in all the examined characteristics. The mean squares attributed to parents were statistically significant for all the tested characteristics, except for days to heading, peduncle length, and 1000 grain weight. Similarly, the mean squares attributed to $F_1$ versus $F_2$ were likewise statistically significant for all the analyzed characteristics, except for days to heading. The genotype x environment interaction exhibited statistical significance for all the examined traits. An analysis of variance was conducted independently for each individual environment, taking into account the substantial gene-environment interaction for all the traits (Table 1).

The genotypic and phenotypic correlation coefficients between various pairs of traits were calculated for the $F_1$ and $F_2$ generations in both $E_1$ and $E_2$ environments. The results are shown in Table 2. Significance was assessed only at the phenotypic level.

**Table 1**: Pooled analysis of variance showing mean sum of squares of parents, $F_1$'s and $F_2$'s for yield and its attributes

| Source of variation | df | Days to heading | Grain filling duration (days) | Days to maturity | Plant height (cm) | No. of tillers per plant | Flag leaf area ($cm^2$) | Peduncle length (cm) | Spike length (cm) | No. of grains per spike | 1000-grain weight (g) | Biological yield per plant (g) | Grain yield per plant (g) | Harvest index (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Env. | 1 | 12973.45** | 8340.28** | 42117.88** | 25695.67** | 512.45** | 3282.86** | 5569.61** | 323.11** | 4270.40** | 10723.65** | 4606.62** | 1844.89** | 2208.06** |
| Replication | 4 | 1.73** | 1.58 | 1.23 | 1.19 | 0.6** | 0.37 | 0.44 | 0.04 | 3.02 | 1.77 | 1.55 | 0.29 | 1.10 |
| Genotypes | 99 | 6.58** | 30.39** | 23.15** | 35.56** | 1.02** | 4.39** | 7.16** | 1.31** | 27.70** | 12.74** | 79.10** | 8.04** | 32.56** |
| Parents | 9 | 2.96 | 21.08** | 26.82** | 36.24** | 0.68** | 2.84* | 2.82 | 0.67** | 12.62** | 2.86 | 25.19** | 3.33** | 9.10** |
| Generations | 89 | 6.5** | 31.51** | 22.94** | 35.85** | 1.06** | 4.13** | 7.29** | 1.33** | 27.27** | 13.75** | 85.33** | 8.34** | 33.60** |
| $F_1$'s | 44 | 5.88** | 26.87** | 18.66** | 34.28** | 0.77** | 3.87** | 5.68* | 1.34** | 28.56** | 8.03** | 79.63** | 5.59** | 33.10** |
| $F_2$'s | 44 | 7.16** | 35.21** | 25.11** | 36.91** | 1.13** | 2.69** | 8.69** | 1.24** | 21.71** | 17.11** | 85.70** | 6.61** | 25.21** |
| $F_1$ vs $F_2$ | 1 | 4.82 | 73.34** | 115.74** | 58.48** | 13.29*** | 78.92** | 16.56* | 5.03** | 215.21** | 117.70** | 319.84** | 205.73** | 425.26** |
| Par. vs Geno. | 1 | 45.92** | 14.21 | 9.04 | 3.75 | 0.66** | 41.36** | 4.90** | 4.77** | 201.26** | 11.55 | 10.01 | 24.05*** | 150.65** |
| $F_1$ Vs Parent | 1 | 50.74** | 1.02 | 37.35** | 17.24 | 3.52** | 77.63* | 47.06** | 7.61** | 322.19** | 42.10** | 70.71** | 81.00** | 321.14** |
| $F_2$ Vs Parent | 1 | 33.64** | 38.14** | 0.14 | 0.21 | 0.10 | 11.93** | 19.42* | 1.98** | 82.87** | 0.01 | 5.64 | 0.12 | 30.09** |
| Geno. x Env. | 99 | 5.67** | 18.00** | 13.63** | 42.85** | 0.96** | 5.36** | 8.23** | 1.17** | 21.41** | 11.49** | 45.63** | 5.44** | 15.65** |
| Error | 396 | 0.86 | 2.28 | 1.75 | 1.49 | 0.03 | 0.46 | 1.18 | 0.03 | 1.15 | 1.04 | 2.92 | 0.24 | 1.22 |

*, **Significant at 5 per cent and 1 per cent levels, respectively.

**Table 2:** Correlation between different characters in $F_1$ ($P + F_1$) under normal environment ($E_1$)

| Characters | Correlation. | Grain filling duration (days) | Days to maturity | Plant height (cm) | Flag leaf area ($cm^2$) | Number of tillers per plant | Peduncle length (cm) | Spike length (cm) | Number of grains per spike | 1000- Seed weight | Biological yield/plant (g) | Grain yield/plant (g) | Harvest Index (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Days to heading | g | -0.26 | 0.18 | -0.04 | -0.24 | -0.27 | 0.06 | -0.21 | -0.23 | -0.17 | -0.22 | -0.39 | -0.25 |
| | p | -0.43** | 0.20** | -0.03 | -0.15* | -0.13 | 0.10 | -0.17* | -0.18* | -0.07 | -0.11 | -0.22** | -0.13 |
| Grain filling duration (days) | g | | 0.94 | 0.80 | 0.38 | -0.08 | 0.59 | 0.05 | 0.07 | -0.48 | -0.49 | -0.23 | 0.38 |
| | p | | 0.77** | 0.34** | 0.28** | -0.05 | 0.23** | 0.12 | 0.14 | -0.10 | -0.11 | -0.01 | 0.13 |
| Days to maturity | g | | | 0.76 | 0.25 | -0.23 | 0.62 | -0.05 | -0.05 | -0.57 | -0.61 | -0.44 | 0.25 |
| | p | | | 0.37** | 0.20** | -0.13 | 0.31** | 0.01 | 0.03 | -0.15 | -0.19* | -0.15 | 0.06 |
| Plant height (cm) | g | | | | 0.56 | -0.26 | 0.54 | -0.02 | -0.04 | -0.01 | -0.31 | -0.23 | 0.12 |
| | p | | | | 0.34** | -0.20* | 0.20* | -0.02 | -0.04 | -0.11 | -0.23** | -0.21** | 0.05 |
| Flag leaf area ($cm^2$) | g | | | | | 0.08 | 0.81 | 0.29 | 0.28 | 0.27 | 0.11 | 0.29 | 0.33 |
| | p | | | | | 0.06 | 0.34** | 0.19** | 0.19* | 0.15* | 0.11 | 0.20** | 0.13 |
| Number of tillers per plant | g | | | | | | 0.06 | 0.69 | 0.69 | -0.55 | 0.73 | 0.89 | 0.33 |
| | p | | | | | | -0.06 | 0.49** | 0.48** | -0.35** | 0.60** | 0.77** | 0.17* |
| Peduncle length (cm) | g | | | | | | | 0.77 | 0.78 | -0.28 | -0.16 | 0.29 | 0.78 |
| | p | | | | | | | 0.25** | 0.25** | 0.03 | 0.00 | 0.08 | 0.13 |
| Spike length (cm) | g | | | | | | | | 1.00 | -0.40 | 0.56 | 0.85 | 0.52 |
| | p | | | | | | | | 0.99** | -0.15* | 0.48** | 0.72** | 0.30** |
| Number of grains per spike (g) | g | | | | | | | | | -0.38 | 0.57 | 0.85 | 0.52 |
| | p | | | | | | | | | -0.13 | 0.50** | 0.73** | 0.29** |
| 1000- Seed weight (g) | g | | | | | | | | | | -0.02 | -0.22 | -0.36 |
| | p | | | | | | | | | | 0.26** | 0.20** | -0.15 |
| Biological yield /plant (g) | g | | | | | | | | | | | 0.82 | -0.24 |
| | p | | | | | | | | | | | 0.80** | -0.44** |
| Grain yield/plant (g) | g | | | | | | | | | | | | 0.36 |
| | p | | | | | | | | | | | | 0.18* |

$r_g$: Genotypic correlation coefficient, $r_p$: Phenotypic correlation coefficient, * and ** represents significant at 5% and 1% level of significance respectively

**Table 3:** Correlation between different pairs of characters in $F_1$ (P + $F_1$) under high temperature stress environment ($E_2$)

| Characters | Correlation | Grain filling duration | Days to maturity | Plant height (cm) | Flag leaf area ($cm^2$) | Number of tillers per plant | Peduncle length (cm) | Spike length (cm) | Number of grains per spike | 1000- Seed weight (g) | Biological yield /plant (g) | Grain yield/plant (g) | Harvest Index (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Days to heading | $r_g$ | -0.51 | -0.12 | -0.10 | -0.11 | -0.13 | 0.56 | -0.38 | -0.43 | -0.52 | -0.19 | -0.36 | -0.17 |
| | $r_p$ | -0.55** | 0.11 | -0.03 | 0.01 | -0.05 | 0.13 | -0.12 | -0.14 | -0.20* | -0.11 | -0.17* | -0.02 |
| Grain filling duration (days) | $r_g$ | | 0.91 | -0.21 | -0.32 | -0.08 | -0.26 | 0.04 | -0.05 | -0.20 | -0.09 | -0.12 | -0.01 |
| | $r_p$ | | 0.77** | -0.14 | -0.18* | -0.01 | -0.11 | 0.00 | -0.03 | -0.13 | -0.02 | -0.06 | -0.08 |
| Days to maturity | $r_g$ | | | -0.29 | -0.42 | -0.16 | -0.04 | -0.13 | -0.26 | -0.48 | -0.20 | -0.31 | -0.09 |
| | $r_p$ | | | -0.18* | -0.20** | -0.05 | -0.03 | -0.09 | -0.14 | -0.30** | -0.11 | -0.20** | -0.11 |
| Plant height (cm) | $r_g$ | | | | 0.03 | 0.27 | 0.02 | 0.24 | 0.24 | 0.42 | 0.35 | 0.36 | -0.14 |
| | $r_p$ | | | | 0.02 | 0.18* | 0.06 | 0.20** | 0.20* | 0.18* | 0.26** | 0.24** | -0.13 |
| Flag leaf area ($cm^2$) | $r_g$ | | | | | -0.08 | 0.03 | 0.11 | 0.08 | 0.05 | -0.05 | 0.02 | 0.10 |
| | $r_p$ | | | | | -0.01 | -0.08 | 0.08 | 0.09 | 0.05 | 0.00 | 0.02 | 0.06 |
| Number of tillers per plant | $r_g$ | | | | | | 0.00 | 0.39 | 0.52 | 0.19 | 0.65 | 0.85 | -0.06 |
| | $r_p$ | | | | | | 0.00 | 0.29** | 0.36** | 0.09 | 0.60** | 0.73** | -0.08 |
| Peduncle length (cm) | $r_g$ | | | | | | | -0.07 | -0.05 | 0.13 | -0.22 | -0.01 | 0.38 |
| | $r_p$ | | | | | | | -0.06 | -0.06 | 0.01 | -0.11 | -0.01 | 0.17* |
| Spike length (cm) | $r_g$ | | | | | | | | 0.75 | 0.22 | 0.40 | 0.60 | 0.08 |
| | $r_p$ | | | | | | | | 0.75** | 0.10 | 0.38** | 0.53** | 0.04 |
| Number of grains per spike (g) | $r_g$ | | | | | | | | | 0.48 | 0.64 | 0.86 | -0.02 |
| | $r_p$ | | | | | | | | | 0.17* | 0.56** | 0.69** | -0.03 |
| 1000- Seed weight (g) | $r_g$ | | | | | | | | | | 0.56 | 0.62 | -0.13 |
| | $r_p$ | | | | | | | | | | 0.45** | 0.5** | -0.07 |
| Biological yield /plant (g) | $r_g$ | | | | | | | | | | | 0.83 | -0.66 |
| | $r_p$ | | | | | | | | | | | 0.78** | -0.66** |
| Grain yield/plant (g) | $r_g$ | | | | | | | | | | | | -0.09 |
| | $r_p$ | | | | | | | | | | | | -0.10 |

$r_g$: Genotypic correlation coefficient, $r_p$: Phenotypic correlation coefficient, * and ** represents significant at 5% and 1% level of significance respectively

**Table 4:** Character association and interrelationship between different characters in $F_1$ generation in both $E_1$ and $E_2$ environments

| Characters | Normal environment | | High temperature stress environment | |
|---|---|---|---|---|
| | **Significant (+) correlation** | **Significant (-) correlation** | **Significant (+) correlation** | **Significant (-) correlation** |
| Days to heading | Days to maturity | Grain filling duration, flag leaf area, spike length, number of grains per spike and grain yield per plant | - | Grain filling duration, 1000 seed weight and grain yield per plant |
| Grain filling duration (days) | Days to maturity, plant height, flag leaf area, peduncle and length | - | Days to maturity | Flag leaf area |
| Days to maturity | Plant height, flag leaf area and peduncle length | Biological yield per plant | - | Plant height, flag leaf area, 1000 seed weight and grain yield per plant |
| Plant height (cm) | Flag leaf area and peduncle length | Number of tillers per plant, biological yield and grain yield per plant | Number of tillers per plant, spike length, number of grains per spike, biological yield per plant, grain yield per plant | - |
| Flag leaf area ($cm^2$) | Peduncle length, spike length, number of grains per spike, 1000 seed weight and grain yield | - | - | - |
| Number of tillers per plant | Spike length, number of grains per spike, biological yield, grain yield and harvest index | 1000 seed weight | Spike length, number of grains per spike, Biological yield per plant and grain yield per plant | |
| Peduncle length (cm) | Spike length and number of grains per spike | - | Harvest index | - |
| Spike length (cm) | Number of grains per spike, Biological yield per plant, grain yield per plant and harvest index | 1000 seed weight | Number of grains per spike, Biological yield per plant and grain yield per plant | |
| Number of grains per spike | Biological yield per plant , grain yield per plant and harvest index | - | 1000 seed weight, biological yield per plant and grain yield pr plant | |
| 1000 Seed weight (g) | Biological yield per plant and grain yield per plant | - | Biological yield per plant and grain yield per plant | - |
| Biological yield per plant (g) | Grain yield per plant and harvest index | - | Grain yield per plant | Harvest index |
| Grain yield per plant (g) | Harvest index | - | - | Harvest index |
| Harvest index (%) | | - | | - |

**Table 5:** Correlation between different pairs of characters in $F_2$ (P + $F_2$) under normal environment ($E_1$)

| Characters | Correlation | Grain filling duration (days) | Days to maturity | Plant height (cm) | Flag leaf area ($cm^2$) | Number of tillers per plant | Peduncle length (cm) | Spike length (cm) | Number of grains per spike | 1000- Seed weight (g) | Biological yield /plant (g) | Grain yield/plant (g) | Harvest Index (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Days to heading | g | -0.51 | 0.00 | -0.02 | -0.26 | 0.02 | 0.10 | -0.12 | -0.12 | -0.44 | -0.19 | -0.24 | -0.04 |
| | p | -0.32** | 0.25** | -0.01 | -0.20* | 0.02 | 0.02 | -0.08 | -0.08 | -0.21** | -0.14 | -0.13 | 0.07 |
| Grain filling duration (days) | g | | 0.99 | 0.72 | 0.45 | -0.20 | 0.43 | 0.03 | 0.03 | -0.02 | -0.24 | -0.14 | 0.37 |
| | p | | 0.75** | 0.41** | 0.30** | -0.14 | 0.21** | 0.02 | 0.01 | -0.11 | -0.21** | -0.14 | 0.19* |
| Days to maturity | g | | | 0.80 | 0.33 | -0.22 | 0.64 | -0.05 | -0.06 | -0.35 | -0.45 | -0.34 | 0.49 |
| | p | | | 0.44** | 0.21** | -0.13 | 0.19* | -0.01 | -0.02 | -0.19* | -0.25** | -0.20* | 0.18* |
| Plant height (cm) | g | | | | 0.47 | -0.33 | 0.43 | -0.11 | -0.10 | -0.05 | -0.39 | -0.34 | 0.31 |
| | p | | | | 0.28** | -0.29** | 0.16* | -0.10 | -0.10 | -0.11 | -0.32** | -0.31** | 0.16* |
| Flag leaf area ($cm^2$) | g | | | | | -0.20 | 0.82 | 0.10 | 0.10 | 0.20 | -0.14 | -0.01 | 0.38 |
| | p | | | | | -0.09 | 0.27** | 0.11 | 0.11 | 0.12 | -0.02 | 0.06 | 0.15 |
| Number of tillers per plant | g | | | | | | -0.32 | 0.07 | 0.07 | -0.46 | 0.73 | 0.75 | -0.24 |
| | p | | | | | | -0.14 | 0.08 | 0.08 | -0.28** | 0.64** | 0.72** | -0.09 |
| Peduncle length (cm) | g | | | | | | | 0.01 | 0.02 | -0.18 | -0.58 | -0.30 | 1.00 |
| | p | | | | | | | -0.08 | -0.08 | 0.03 | -0.15* | -0.12 | 0.12 |
| Spike length (cm) | g | | | | | | | | 1.00 | 0.07 | 0.48 | 0.61 | 0.12 |
| | p | | | | | | | | 1.00** | 0.07 | 0.44** | 0.57** | 0.05 |
| Number of grains per spike (g) | g | | | | | | | | | 0.07 | 0.47 | 0.60 | 0.13 |
| | p | | | | | | | | | 0.07 | 0.44** | 0.57** | 0.06 |
| | | | | | | | | | | | | | |
| 1000- Seed weight (g) | g | | | | | | | | | | 0.14 | 0.02 | -0.41 |
| | p | | | | | | | | | | 0.34** | 0.28** | -0.24** |
| Biological yield /plant (g) | g | | | | | | | | | | | 0.95 | -0.57 |
| | p | | | | | | | | | | | 0.89** | -0.58** |
| Grain yield/plant (g) | g | | | | | | | | | | | | -0.29 |
| | p | | | | | | | | | | | | -0.15 |

$r_g$: Genotypic correlation coefficient, $r_p$: Phenotypic correlation coefficient, * and ** represents significant at 5% and 1% level of significance respectively

**Table 6:** Correlation between different pairs of characters $F_2$ diallel (P + $F_2$) under high temperature stress environment ($E_2$)

| Characters | Correlation | Grain filling duration | Days to maturity | Plant height (cm) | Flag leaf area ($cm^2$) | Number of tillers per plant | Peduncle length (cm) | Spike length (cm) | Number of grains per spike | 1000- Seed weight (g) | Biological yield/plant (g) | Grain yield/plant (g) | Harvest Index (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Days to heading | $r_g$ | -0.53 | -0.21 | 0.00 | -0.22 | 0.15 | 0.41 | -0.16 | -0.09 | 0.15 | 0.02 | 0.14 | 0.15 |
| | $r_p$ | -0.6** | -0.06 | -0.03 | -0.04 | 0.02 | 0.07 | -0.05 | -0.01 | 0.06 | 0.05 | 0.08 | 0.05 |
| Grain filling duration (days) | $r_g$ | | 0.98 | -0.21 | -0.03 | -0.24 | -0.49 | -0.17 | -0.15 | -0.15 | 0.05 | -0.26 | -0.38 |
| | $r_p$ | | 0.79** | -0.14 | 0.04 | -0.14 | -0.22** | -0.12 | -0.06 | -0.09 | 0.00 | -0.19* | -0.24** |
| Days to maturity | $r_g$ | | | -0.28 | -0.07 | -0.22 | -0.43 | -0.26 | -0.20 | -0.09 | 0.05 | -0.25 | -0.38 |
| | $r_p$ | | | -0.15 | -0.03 | -0.16* | -0.19* | -0.19* | -0.10 | -0.10 | 0.05 | -0.17* | -0.27** |
| Plant height (cm) | $r_g$ | | | | 0.09 | 0.28 | 0.03 | 0.21 | 0.06 | -0.02 | 0.05 | 0.18 | 0.09 |
| | $r_p$ | | | | 0.00 | 0.23** | 0.06 | 0.18* | 0.06 | 0.05 | 0.08 | 0.15 | 0.05 |
| Flag leaf area ($cm^2$) | $r_g$ | | | | | 0.29 | 0.33 | 0.39 | 0.37 | 0.17 | 0.43 | 0.49 | -0.06 |
| | $r_p$ | | | | | 0.08 | 0.01 | 0.18* | 0.13 | 0.14 | 0.06 | 0.14 | 0.03 |
| Number of tillers per plant | $r_g$ | | | | | | 0.04 | 0.17 | 0.09 | 0.17 | 0.61 | 0.76 | -0.05 |
| | $r_p$ | | | | | | 0.05 | 0.15 | 0.08 | 0.10 | 0.53** | 0.66** | -0.05 |
| Peduncle length (cm) | $r_g$ | | | | | | | 0.22 | 0.17 | 0.22 | -0.01 | 0.17 | 0.19 |
| | $r_p$ | | | | | | | 0.11 | 0.04 | 0.08 | -0.02 | 0.08 | 0.14 |
| Spike length (cm) | $r_g$ | | | | | | | | 0.95 | 0.44 | 0.46 | 0.60 | -0.02 |
| | $r_p$ | | | | | | | | 0.88** | 0.28** | 0.42** | 0.54** | -0.04 |
| Number of grains per spike (g) | $r_g$ | | | | | | | | | 0.47 | 0.48 | 0.58 | -0.04 |
| | $r_p$ | | | | | | | | | 0.22** | 0.41** | 0.50** | -0.07 |
| 1000- Seed weight (g) | $r_g$ | | | | | | | | | | 0.55 | 0.78 | 0.10 |
| | $r_p$ | | | | | | | | | | 0.42** | 0.63** | 0.05 |
| Biological yield /plant (g) | $r_g$ | | | | | | | | | | | 0.79 | -0.67 |
| | $r_p$ | | | | | | | | | | | 0.76** | -0.63** |
| Grain yield/plant (g) | $r_g$ | | | | | | | | | | | | -0.02 |
| | $r_p$ | | | | | | | | | | | | -0.05 |

$r_g$: Genotypic correlation coefficient, $r_p$: Phenotypic correlation coefficient, * and ** represents significant at 5% and 1% level of significance respectively

**Table 7:** Characters association and interrelationship between different characters in $F_2$ generation in both $E_1$ and $E_2$ environments

| Characters | Normal environment | | High temperature stress environment | |
|---|---|---|---|---|
| | **Significant (+) correlation** | **Significant (-) correlation** | **Significan (+) correlation** | **Significant (-) correlation** |
| Days to heading | Days to maturity | Gain filling duration, flag leaf area and 1000 seed weight | - | Grain filling duration |
| Grain filling duration | Days to maturity, plant height, flag leaf area, peduncle length and harvest index | Biological yield per plant | Days to maturity | Peduncle length, grain yield per plant and harvest index |
| Days to maturity | Plant height, flag leaf area, peduncle length and harvest index | 1000 seed weight, Biological yield per plant and grain yield per plant | - | Number of tillers per plant, Peduncle length, spike length, grain yield per plant and harvest index |
| Plant height (cm) | Flag leaf area, peduncle length and harvest index | Number of tillers per plant, Biological yield per plant and grain yield per plant | Number of tillers per plant and spike length | - |
| Flag leaf area ($cm^2$) | Peduncle length | - | Spike length | - |
| Number of tillers per plant | Biological yield per plant and grain yield per plant | 1000 seed weight | Biological yield per plant and grain yield plant | |
| **Characters** | **Normal environment** | | **Post anthesis heat stress environment** | |
| | **Significant (+) correlation** | **Significant (-) correlation** | **Significan (+) correlation** | **Significant (-) correlation** |
| Peduncle length (cm) | - | Biological yield per plant | - | - |
| Spike length (cm) | Number of rains per spike, Biological yield per plant and grain yield pr plant | - | Number of grains per spike, 1000 seed weight, Biological yield per plant and grain yield per plant | |
| Number of grains per spike | Biological yield per plant and grain yield per plant | - | 1000 seed weight, biological yield per plant and grain yield per plant | |
| 1000 Seed weight (g) | Biological yield per plant and grain yield per plant | Harvest index | Biological yield per plant and grain yield per plant, | Harvest index |
| Biological yield per plant (g) | Grain yield per plant | Harvest index | Grain yield per plant | Harvest index |
| Grain yield per plant (g) | - | - | - | |
| Harvest index (%) | - | - | - | - |

Upon examining Table 2, it was observed that in the $F_1$ generation, there were significant positive correlations between grain yield per plant and biological yield per plant (0.80), number of tillers per plant (0.77), number of grains per spike (0.73), spike length (0.72), flag leaf area (0.20), 1000 seed weight (0.20), and harvest index (0.18). Conversely, there were significant negative correlations between grain yield per plant and days to heading (-0.22) and plant height (-0.21) in both $E_1$ and $E_2$. Furthermore, the biological yield per plant (0.76), number of tillers per plant (0.73), number of grains per spike (0.69), spike length (0.53), 1000 seed weight (0.50), and plant height (0.24) exhibited a significant positive correlation with grain yield per plant in $E_2$. Conversely, days to heading (-0.17) and days to maturity (-0.20) displayed a significant negative phenotypic correlation with grain yield per plant (Table 3). One of the observed qualities is character association, which is displayed in the table. The number 4.

Upon examining Table 5, it was found that in $F_2$, there was a significant positive correlation between grain yield per plant and biological yield per plant (0.89), number of tillers per plant (0.64), spike length (0.57), number of grains per spike (0.57), and 1000 seed weight (0.28). Conversely, there was a negative phenotypic correlation between grain yield per plant and days to maturity (-0.20) as well as plant height (-0.31) in both $E_1$ and $E_2$. Furthermore, the biological yield per plant (0.76), number of tillers per plant (0.66), 1000 seed weight (0.63), spike length (0.54), and number of grains per spike (0.50) in $E_2$ exhibited a significant positive correlation with grain yield per plant. Conversely, days to maturity (-0.17) and grain filling duration (-0.19) displayed a significant negative phenotypic correlation with grain yield per plant (Table 6). One of the qualities that was observed is character association, which is shown in Table 7.

Regarding magnitude of correlation coefficient, strong association of grain yield per plant was observed with tillers per plant, spike length, number of grains per spike, 1000 grain weight and biological yield per plant in both the environments.

## Discussion

Study indicated that, overall, the link was more robust at the phenotypic level than to the genotypic level in both contexts. Phenotypic relationships are often regarded as there is no concrete technique to determine the statistical significance of correlations at the genotypic level. In a typical environment, the grain yield per plant showed a strong positive correlation with the flag leaf area, number of tillers per plant, spike length, number of grains per spike, 1000 grain weight, biological yield per plant, and harvest index. Conversely, there was a negative and significant correlation with days to heading and plant height in $F_1$. In $F_2$, the grain yield was significantly and positively associated with the number of tillers per plant, spike length, number of grains per spike, 1000-grain weight, and biological yield. On the other hand, there was a negative and significant correlation with days to maturity and plant height.

The grain yield per plant showed a positive and significant association with plant height, number of tillers per plant,

spike length, number of grains per spike, 1000-grain weight, and biological yield per plant. However, it had a negative and significant correlation with days to heading and days to maturity in $F_1$. In $F_2$, the grain yield per plant was positively and significantly correlated with the number of tillers per plant, spike length, number of grains per spike, 1000-grain weight, and biological yield. On the other hand, it had a negative and significant correlation with grain filling duration and days to maturity in a heat stress environment. Shah (1998) [10] also recognized biological yield as the characteristic to be chosen while dealing with high temperature conditions. Sharma (1993) states that the productivity gain under late sown conditions is contingent upon the biomass achieved by a particular genotype during anthesis. Consistent findings were achieved by Zhong-hu and Rajaram (1994) [13], Chowdhary *et al.* (1996) [4], Jaglam *et al.* (1997) [6]. Blum *et al.* (1997) [3] highlighted that selecting for high biomass output should result in beneficial enhancements in grain yield, effective tillers, and kernel count per spike under a heat stress setting. Nagarajan and Rane (2002) [8] have highlighted the ease of measuring biomass per square meter and spikes per square meter as characteristics that may be used to select genotypes appropriate for late planted circumstances. Therefore, selecting for biomass yield is a method to enhance productivity in bread wheat when subjected to heat stress conditions (Sarkar *et al*., 2001) [9].

In all conditions, there was a clear correlation between grain production per plant and tillers per plant, spike length, number of grains per spike, test weight, and biological yield per plant.

The significant correlation between grain yield per plant and the number of tillers per plant, spike length, number of grains per spike, 1000-grain weight, and biological yield per plant in a heat stress environment suggests that these traits should be considered as potential selection criteria for enhancing grain yield under high temperature conditions.

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