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Morpho-physiological trait distribution and correlation analysis in half diallel crosses, parents and check genotypes of bread wheat under water deficit stress

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ABSTRACT

Water deficit stress significantly impacts wheat productivity, so identifying key morpho-physiological traits that contribute to yield stability is essential. This study examined the distribution patterns and associations of 17 morpho-physiological traits in half diallel crosses, parental lines, and check genotypes of bread wheat (*Triticum aestivum* L.) under water deficit conditions. Box plot analysis visually represented trait dispersion, highlighting distinct distributional trends. Traits such as days to heading, days to maturity, and thousand grain weight showed broad interquartile ranges and outliers, suggesting considerable diversity. In contrast, canopy temperature depression, awn length, and spikelets per spike showed more compact distributions, indicating relative stability. Outliers in yield-related traits suggest the potential to identify high-performing genotypes for selection. Findings observed strong positive correlations between biological yield and grain yield. Significant associations were also observed between plant height and peduncle length, and between grains per spike and spikelets per spike. Moderately correlated traits such as normalized difference vegetation index and canopy temperature depression may serve as indicators for indirect selection. The findings highlighted the importance of integrating diverse morpho-physiological traits to improve selection efficiency in wheat breeding programs targeting water deficit tolerance.

Keywords: Bread wheat, Water deficit stress, Half diallel, Morpho-physiological traits, Box plot analysis, Correlation

1. Introduction

Bread wheat (*Triticum aestivum* L.) is an important cereal crop contributing substantially to global food security. However, water deficit is a major abiotic stress limiting wheat productivity, particularly in rainfed and water-limited environments. The extent of yield reduction depends on the intensity, duration, and timing of stress, as well as the genotype's genetic background (Nouri *et al.*, 2011; Ahmed *et al.*, 2020) [1, 2].

Water deficit adversely affects several physiological and morphological processes, including water relations, photosynthesis, biomass accumulation and grain development. Traits such as relative water content, chlorophyll content, canopy temperature, flag leaf characteristics, plant height and yield components have been reported to vary considerably among wheat genotypes under drought conditions. They may contribute to differences in grain yield (Ahmed *et al.*, 2020; Chen *et al.*, 2012; Pour-Aboughadareh *et al.*, 2020; Sewore *et al.*, 2023) [2, 3, 4, 5].

Because grain yield is a complex quantitative trait strongly influenced by the environment, selection based solely on yield may be less effective under water-limited conditions. Evaluating associated morpho-physiological traits can provide useful information for identifying genotypes better adapted to water deficit. Correlation analysis helps determine the direction and magnitude of associations among traits and can identify characters useful as indirect selection criteria (Sewore *et al.*, 2023; Rahman *et al.*, 2016; Sewore *et al.*, 2024) [5, 6, 7].

Half-diallel mating designs provide an opportunity to generate and evaluate diverse genetic combinations from selected parents. Assessing parents, their crosses, and suitable check genotypes under a common water-deficit environment can reveal the extent of trait variation and provide insight into relationships among morpho-physiological characteristics and grain yield.

Therefore, this study evaluated the distribution of morpho-physiological and yield-related traits in bread wheat half-diallel crosses, their parents, and check genotypes under water-deficit stress, and determined the associations among these traits and grain yield. The study aimed to identify traits with useful relationships to grain yield that could support selection for improved wheat performance under water-limited conditions.

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2. Materials and Methods

2.1 Experimental material and site

The experimental material comprised 38 genotypes: eight parental lines (PBW660, WH1080, UP2572, VL967, VL829, C306, UP262, and WH1142); their 28 F_1 crosses developed through a half-diallel mating design; and two released varieties, HD2967 and UP2903, used as checks.

The field experiment was conducted at the Norman E. Borlaug Crop Research Centre, Pantnagar, Uttarakhand. We developed crosses during the rabi season of 2020–21. The experimental trial comprising all 38 genotypes was laid out in a randomized block design with three replications during the rabi season of 2021–22. The study area lies in the Tarai belt of the Shivalik range in the Himalayan foothills of India and has a semi-humid subtropical climate. The soils are medium to heavy in texture, dark in colour, rich in organic matter, and have high cation-exchange and nutrient-retention capacities.

No artificial irrigation was applied during the crop growth period, ensuring rainfed conditions. Wheat generally requires approximately 450–650 mm of water for optimal yield, depending on climate and crop duration. During the experimental period, only 235.10 mm of rainfall was recorded, which was substantially below the crop water requirement. The crop therefore experienced water deficit conditions throughout the growing season.

2.2 Trait recording

We recorded data for 17 morpho-physiological and yield-contributing traits on five randomly selected plants from each plot. The traits included days to 75% heading, days to maturity, grain filling duration, normalized difference vegetation index, canopy temperature depression ($^{\circ}\text{C}$), plant height (cm), peduncle length (cm), flag leaf area (cm^2), number of tillers per plant, spike length (cm), awn length (cm), spikelets per spike, grains per spike, thousand grain weight (g), biological yield (g/plot), grain yield (g/plot), and harvest index.

2.3 Statistical analysis

We generated box plots using the Seaborn and Matplotlib libraries in Python version 3.9 for graphical representation and data visualization. We calculated phenotypic correlation coefficients among the recorded traits. To further understand trait relationships, we partitioned correlation coefficients into direct and indirect effects using path coefficient analysis, as suggested by (Wright) [8] and elaborated by (Dewey and Lu) [9]. We performed Karl Pearson's correlation analysis in RStudio.

3. Results

3.1 Box plot analysis

Box plot analysis visually demonstrated the distributional patterns of 17 morpho-physiological traits, showing trait dispersion, median shifts, and potential high-performing genotypes under water deficit conditions. The graphical approach highlighted variation in trait performance among the genotypes.

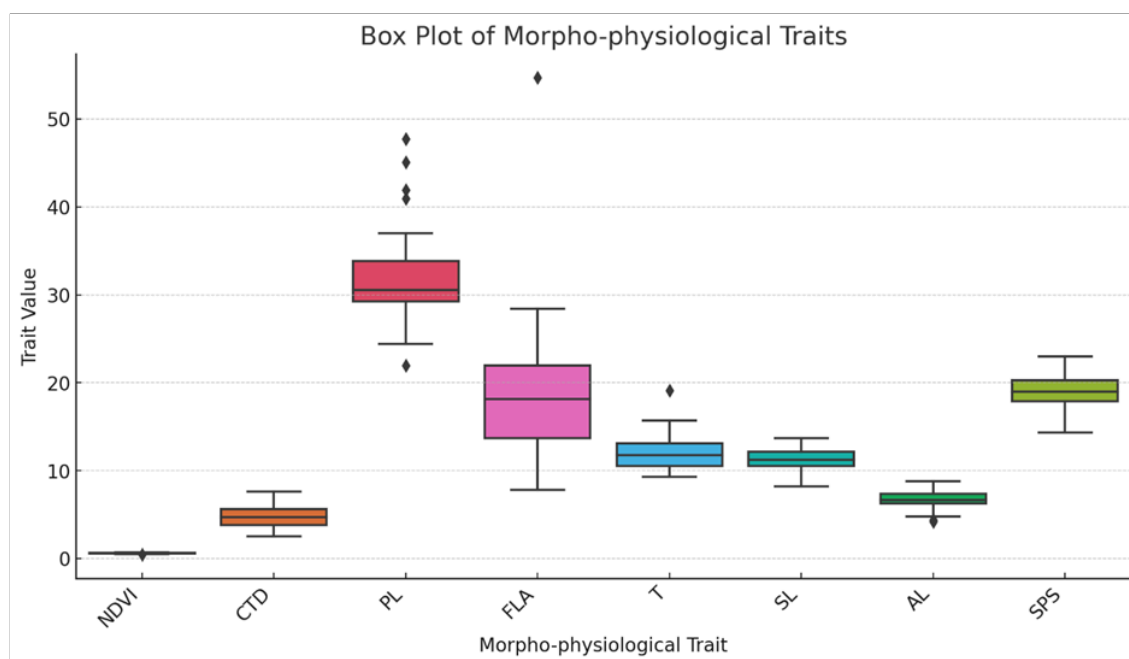


Figure 1. Box plots showing the distribution of morpho-physiological traits among parental lines, F_1 crosses, and check genotypes under water deficit conditions.

Days to heading, days to maturity, and plant height exhibited moderate dispersion with relatively narrow interquartile ranges, suggesting comparatively stable performance across genotypes. The limited presence of outliers in these traits further indicated comparatively low variability under the experimental conditions. Peduncle length and flag leaf area exhibited broad interquartile ranges and numerous outliers, indicating considerable variation among genotypes. Canopy temperature depression and awn length showed tightly clustered distributions, indicating comparatively consistent performance.

Spike length and spikelets per spike showed moderate variability, suggesting a combination of genetic and environmental influences. Grain yield and biological yield showed considerable variation, with notable outliers indicating high-performing genotypes. Thousand

grain weight and harvest index also showed substantial dispersion, reflecting diversity among the evaluated material. Grains per spike and grain-filling duration showed moderate interquartile ranges, indicating intermediate stability with some genetic variation. Outliers in peduncle length, flag leaf area, grain yield, biological yield, thousand grain weight, and harvest index indicated potentially useful variation for selection under water deficit conditions.

3.2 Correlation coefficient analysis

We calculated correlation coefficients among the 17 morpho-physiological traits and presented the correlation matrix as a heat map (Figure 3). The matrix showed the correlation coefficient (r -value) between trait pairs together with statistical significance where reported. Correlation coefficients ranged from -1 (perfect negative cor

relation) to +1 (perfect positive correlation), with 0 indicating no correlation.

Biological yield and grain yield showed a strong positive correlation ($r = 0.87, p < 0.001$). Days to heading and days to maturity were positively correlated ($r = 0.62, p < 0.001$), while plant height and peduncle length showed a strong positive association ($r = 0.71, p < 0.001$). Grains per spike and spikelets per spike were also positively correlated ($r = 0.48$).

Grain yield showed moderate positive correlations with harvest index ($r = 0.46, p < 0.05$) and thousand grain weight ($r = 0.39, p < 0.05$). Flag leaf area and plant height exhibited a moderate positive correlation ($r = 0.43$). We observed weak positive correlations among spike length, awn length, and spikelets per spike.

Harvest index and plant height showed a negative correlation ($r = -0.22, p < 0.05$). Canopy temperature depression showed a weak negative correlation with grain yield ($r = -0.16$). Days to heading and days to maturity also showed negative associations with harvest index, grain yield, and thousand grain weight in the study material.

4. Discussion

The evaluated wheat material showed substantial phenotypic variation for most morpho-physiological and yield-related traits under water deficit stress, indicating useful genetic variability for selection. Greater variation was observed for grain yield, biological yield, thousand-grain weight, and flag leaf area, whereas days to heading and maturity showed comparatively narrow variation. Similar variability among wheat genotypes under drought has been reported previously (Sewore *et al.*, 2024; Makebe *et al.*, 2024; Mutanda *et al.*, 2025) [10, 11, 12]. The contrasting performance of genotypes and crosses further indicates the potential for identifying superior combinations for drought adaptation (Mutanda *et al.*, 2025; Ahmad *et al.*, 2022) [12, 13]. Grain yield showed a strong positive association with biological yield, while spike-related traits, harvest index, and thousand-grain weight also contributed positively to yield performance. These relationships suggest that both biomass production and efficient partitioning toward grain formation are important under water-deficit conditions (Azam *et al.*, 2025; Javed *et al.*, 2022; Pour-Aboughadareh *et al.*, 2020) [14, 15, 16]. The positive association of thousand-grain weight with grain yield further supports its potential usefulness as an indirect selection criterion.

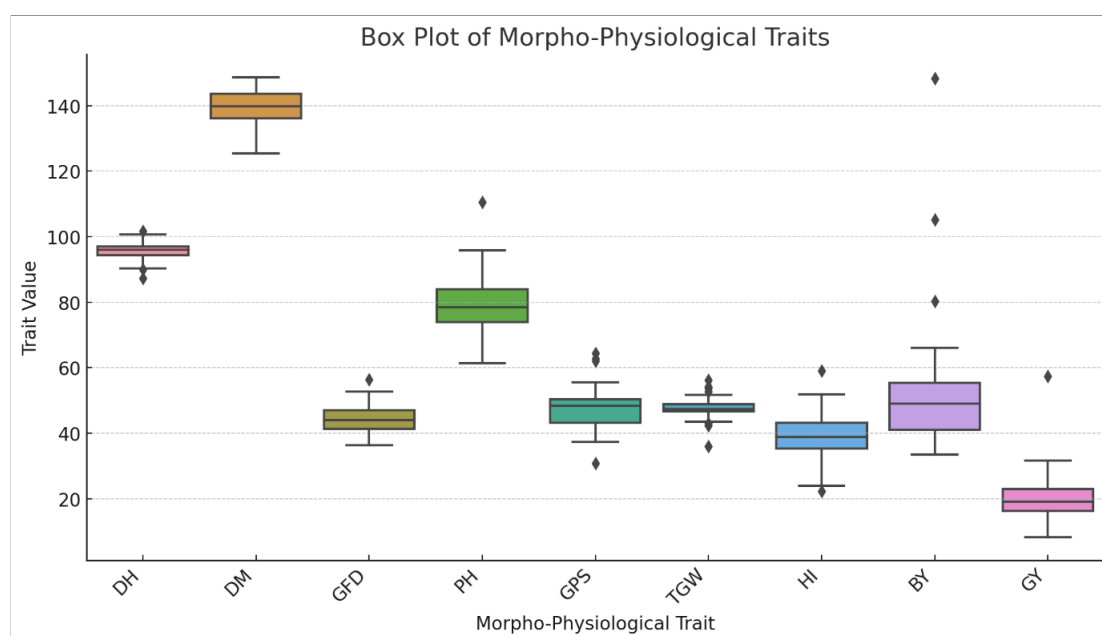


Figure 2. Additional box plot representation of morpho-physiological and yield-related traits under water deficit conditions.

The negative association observed between harvest index and plant height suggests that greater vegetative biomass may not always translate into efficient grain production. Similarly, the relationship between canopy temperature depression and grain yield was less consistent, reflecting its dependence on environmental conditions and crop growth stage (Sewore *et al.*, 2024; Lepekhov, 2022) [10, 17]. Therefore, selection based on a combination of yield, biomass, partitioning, and physiological traits may be more appropriate than relying on a single trait. Overall, the observed trait variation and correlation patterns indicate that biological yield, harvest index, thousand-grain weight and important spike traits can contribute to improved grain yield under water deficit stress. These traits may therefore be considered in selection programmes involving half-diallel-derived wheat populations and their parents.

5. Conclusion

The study revealed substantial variation among the evaluated wheat genotypes for several morpho-physiological and yield-related traits under water deficit conditions. Peduncle length, flag leaf area, and

major yield components showed greater variability, while phenological traits showed comparatively stable distributions. Biological yield exhibited a strong positive association with grain yield, while important relationships were also observed among plant height, peduncle length, grains per spike, and spikelets per spike. The negative association between harvest index and plant height indicated a potential trade-off between plant stature and assimilate partitioning. For breeding under water-deficit conditions, selection should emphasize high grain yield combined with greater biological yield, higher thousand grain weight, favourable harvest index, and desirable spike traits. The superior parents and crosses identified in this study can be prioritized as breeding material for advancement to subsequent generations, followed by replicated and multi-environment testing under water-limited conditions. This approach can facilitate the identification and development of wheat lines combining stable grain productivity with desirable morpho-physiological attributes for water-deficit environments.

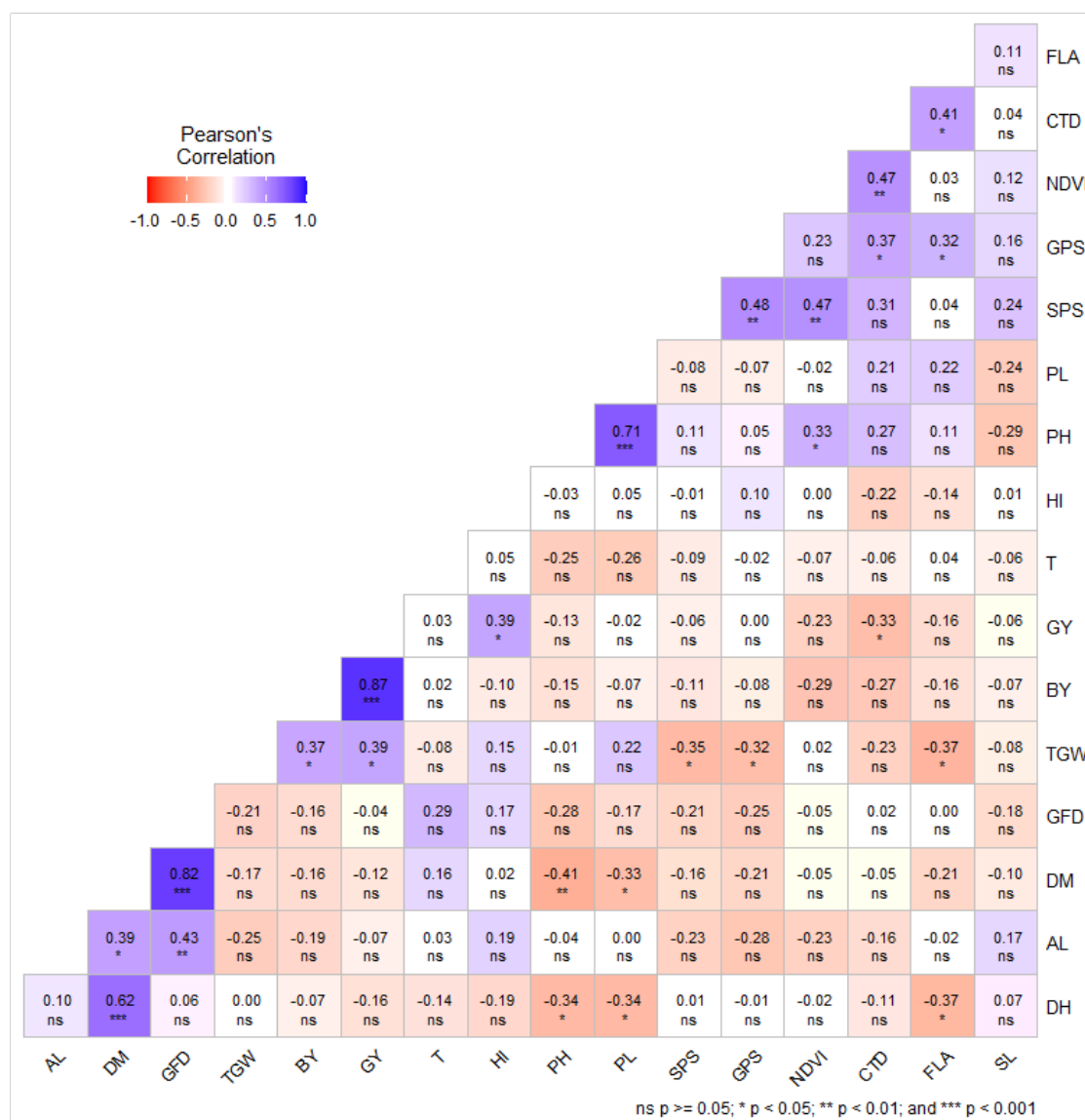


Figure 3. Heat map depicting the correlation matrix among the 17 traits under study.

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