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Discovering Genes that Enhance Yield in Drought Conditions within Turkish Winter Wheat

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On April 10, 2024, a collaborative research result by the International Maize and Wheat Improvement Center in Mexico, Syngenta's Jealott's Hill International Research Center, and Kazakhstan's Scientific Production Grain Center was published in the journal Scientific Reports. The paper, authored by D. Sehgal as the first author and A. Morgounov as the corresponding author, is titled "Genomic wide association study and selective sweep analysis identify genes associated with improved yield under drought in Turkish winter wheat germplasm." This research was jointly funded by the FAO's International Treaty on Plant Genetic Resources for Food and Agriculture (W2B-PR-41-TURKEY) and the BMGF/FCDO project on Accelerating Genetic Gains in Maize and Wheat for Improved Livelihoods (AGG) (INV-003439). The study employed genome-wide association studies (GWAS) and selective sweep analysis to explore genes and genomic regions related to drought resistance and increased yield within Turkish winter wheat germplasm. The research involved genotyping 84 local Turkish winter wheat varieties and 73 modern varieties using a 25K wheat SNP array and phenotyped agronomic traits in 2018 and 2019. The year 2018 was considered a drought environment due to extremely low rainfall, while 2019 was deemed a favorable environment. The results indicated several genomic regions associated with yield and yield-related traits.

1 Experimental Data Analysis

The GWAS results identified 18 genomic regions associated with grain yield (GY) and related traits, such as TaERF3-3A and TaERF3-3B. Selective sweep analysis revealed 39 selection signals, 15 of which were close to genes known to control flowering, yield, and yield components. The study also found that specific haplotype blocks exhibited a significant increase in yield (over 700 kg/ha) during the drought season.

Figure 1 clearly reflects the comparison between the wheat yield and related traits during the drought season of 2018 and the favorable season of 2019. In the drought season of 2018, the average wheat yield (shown in Figure a) significantly decreased, and its distribution showed a wide range, indicating considerable variability in performance under drought conditions among different local or modern varieties. At the same time, related yield parameters such as the number of spikelets per spike (Figure b) and thousand-grain weight (Figure c) also showed significant declines under drought conditions, suggesting that drought not only affects the overall wheat yield but also its constituent elements. Changes in spike length (Figure d) and the number of spikes (Figure e) also displayed significant differences between the two seasons, indicating that wheat growth and development were restricted under drought conditions, potentially affecting overall yield. However, these traits recovered under favorable conditions in 2019, indicating some adaptability of wheat varieties to environmental conditions. Additionally, the harvest index (Figure f), which is the ratio of the harvestable part weight to the total plant weight, also showed a downward trend in the drought year, reflecting a decrease in crop conversion efficiency under drought conditions. Although the response to these traits varied significantly among different varieties, the overall trend is consistent: drought conditions significantly affect wheat growth and yield.

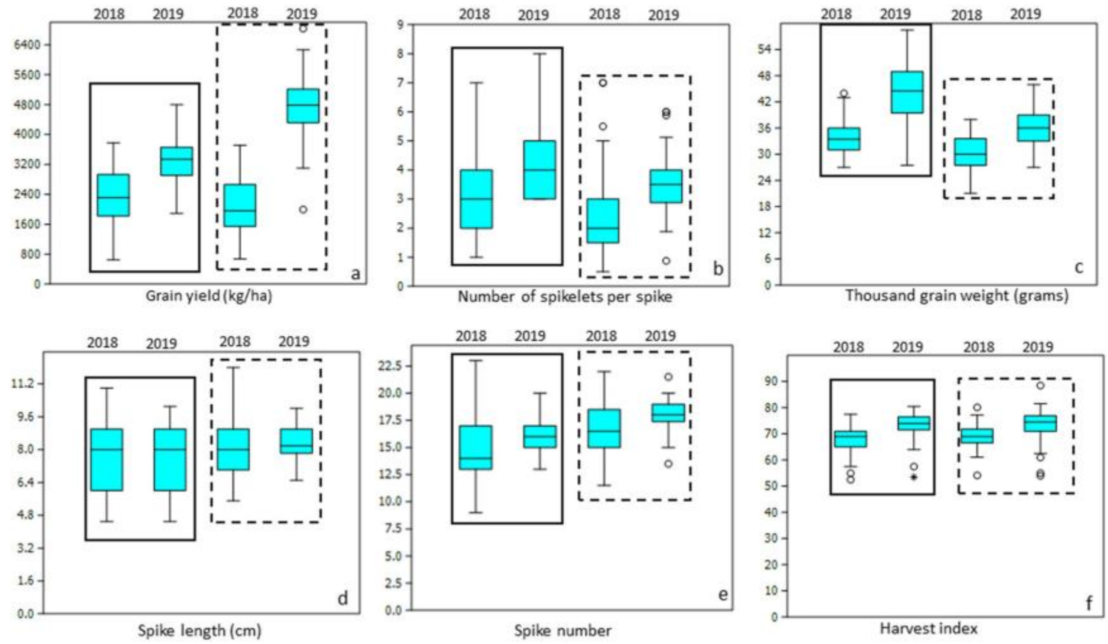

Figure 1 Wheat yield and yield-related traits in drought season of 2018 vs favorable season of 2019

The results of the statistical significance tests (p-values) further validated the credibility of these observations. For example, the significance level for the decrease in grain weight was less than 0.01, and the reduction in the number of spikelets was less than 0.001. Decreases in thousand-grain weight, spike length, and the number of spikes also showed varying degrees of statistical significance, indicating that drought has a statistically significant impact on wheat yield parameters.

Therefore, these data reveal the extensive negative impact of drought on wheat production traits, particularly yield-related traits. This finding is crucial for guiding future wheat breeding work for drought resistance because it provides direct evidence of wheat growth traits under drought conditions and emphasizes the importance of considering drought resistance and yield improvement in wheat breeding.

The relationship between the genetic diversity and geographic distribution of wheat varieties is depicted through a three-dimensional principal component analysis (PCA) plot (Figure 2). In Figure 2a, two broad groups are identified: local varieties (LR) and modern varieties (MV). The data points for the LR group are more dispersed within the PCA space, indicating greater genetic variability among these varieties; conversely, the MV group is relatively concentrated, suggesting higher genetic similarity among modern varieties. Figure 2b further subdivides the LR group into three subgroups based on geographical origin, consisting of local varieties from Afghanistan, Iran, and Turkey, while the MV group is shown as a separate cluster. It is observable that LR groups from different geographic origins are distinctly separated in the PCA plot, demonstrating genetic differences based on geographic distribution. Although the MV group is separated from the LR groups in the PCA plot, it also shows a tendency to be close to the Turkish LR group in Figure 2b, which may reflect that modern varieties have potentially retained or borrowed genetic traits from local varieties during the breeding process. Additionally, the lines between points in Figure 2b represent the fixation index (Fst) between groups, with Fst values providing a quantitative measure of genetic differentiation between populations. Higher Fst values indicate greater genetic differentiation. The Fst values in the figure indicate some level of genetic differentiation between different LR groups, and the Fst values between the MV group and each LR group further confirm the genetic distinction between modern and local varieties.

Therefore, the significant genetic diversity of local varieties reflects the genetic variations accumulated by wheat in different regions adapting to local environmental conditions. Although modern varieties exhibit lower genetic diversity, they may possess genetic connections across geographical boundaries, which is a valuable resource for future wheat breeding because these relationships can be utilized to introduce new, beneficial genetic traits.

Moreover, the integration of this genetic information helps us better understand and utilize wheat's genetic resources, especially in the face of climate change and environmental pressures. Protecting and exploiting this diversity is crucial for ensuring food security.

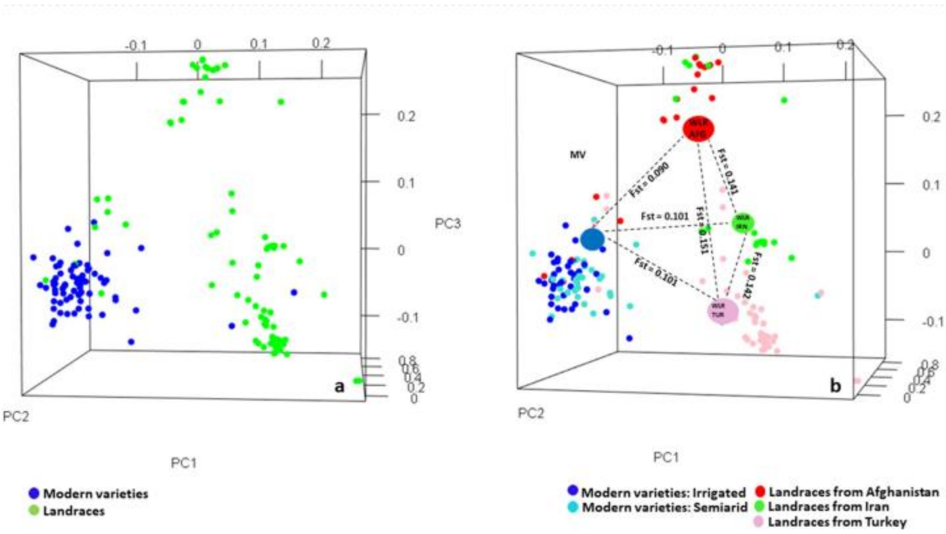

Figure 2 Three-dimensional PCA plot of LR subgroups and MV group

Figure 3 originates from the EigenGWAS analysis of Turkish local and modern wheat varieties, highlighting SNPs that exhibit selection signals. The x-axis represents chromosome numbers, while the y-axis represents the adjusted P-values, also known as PGC values. The Manhattan plot is a commonly used chart in genetics to visually display the results of genome-wide association studies (GWAS). Each point on the plot represents the statistical significance of an association between a specific SNP and a trait. In this plot, different colors of the points represent different chromosomes, and the vertical position of a point indicates its -log10 P-value; the higher the position, the greater the statistical significance of the association with the trait. A blue horizontal line across the chart represents the significance threshold, with SNPs above this threshold considered to exhibit selection signals. It is evident that points on certain chromosomes, particularly on chromosomes like 3B, 5A, and 5B, are notably high, suggesting that SNPs in these regions might have undergone strong selection during the evolution of wheat varieties, related to important agronomic traits.

Thus, this provides direct evidence of genetic selection within Turkish wheat varieties, revealing key genetic regions that affect important wheat traits. This information is crucial for guiding the genetic improvement and enhancement of crop performance in wheat.

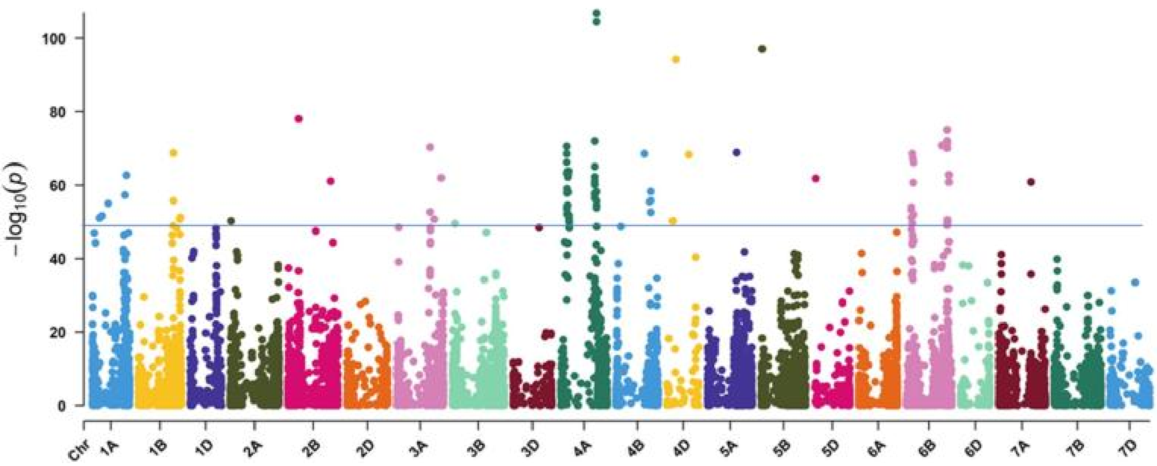

Figure 3 Manhattan plot from EigenGWAS showing distribution of SNPs with selection signals in turkish landraces and modern varieties

2 Research Results Analysis

This study effectively identified genes and genomic regions associated with drought resistance and yield improvement in wheat by combining GWAS and selective sweep analysis. It also highlighted the potential value of utilizing the genetic diversity in local varieties for modern breeding practices.

3 Research Evaluation

The study leveraged the genetic resources of Turkish winter wheat, utilizing advanced molecular marker technologies and statistical methods to effectively identify genes and genomic regions that contribute to drought resistance and yield enhancement. These findings provide valuable genetic resources for drought-resistant breeding in wheat.

4 Conclusion

The GWAS and selective sweep analysis of Turkish winter wheat germplasm successfully identified several key genes and genomic regions associated with improved drought resistance and yield, providing important molecular markers for future wheat breeding against adverse conditions.

5 Access the Full Text

Sehgal, D., Rathan, N.D., Özdemir, F. et al. Genomic wide association study and selective sweep analysis identify genes associated with improved yield under drought in Turkish winter wheat germplasm. Sci Rep 14, 8431 (2024). https://doi.org/10.1038/s41598-024-57469-1.

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