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GENOTYPIC PERFORMANCE EVALUATION OF ELITE COTTON STAINS BASED ON PLANT TRAITS RELATED TO COTTON YIELD, FIBER QUALITY, AND INSECT/DISEASE TOLERANCE UNDER HEAT STRESS

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Abstract *The current study was designed to compare the performance of twelve cotton strains based on their key agronomic and fiber quality-related traits under heat stress conditions. The experiment was laid out under RCBD with three replicates and a 75 cm row-to-row distance was maintained. The data was recorded for plant height, nodes per plant, monopods per plant, sympods per plant, bolls per plant, CLCuV percentage, whitefly occurrence percentage, total chlorophyll contents, peroxidases, fiber length, fiber fineness, and cotton yield. The results revealed the occurrence of significant variations for agronomically important and fiber quality-related traits in cotton strains under heat stress conditions except for CLCuV percentage. The correlation coefficient analysis revealed a strong positive correlation of cotton yield between bolls per plant, nodes per plant, and sympods per plant. The PC-1/PC-2 based biplot analysis reconfirms the results obtained through the correlation analysis and further unveiled that most of the variations in the data were due to transpiration rate, peroxidases, sympods per plant, nodes per plant, bolls per plant, and fiber fineness. The cluster analysis categorizes twelve cotton strains into three clusters, comprising four strains each, respectively, and found that cotton strains GR-4, GR-9, GR-2, and GR-5 were the most productive strains under heat stress conditions. Therefore, these genotypes must be tested in multilocation trials and potential genotypes must be found for heat-prone areas.*

Keywords: *Heat stress; Antioxidants; ROS; Photosynthesis; Fiber Quality; Abiotic Stresses*

Introduction

Cotton is a critical agricultural commodity with significant economic implications both globally and in Pakistan. Worldwide, cotton supports the livelihoods of millions of farmers and workers involved in its cultivation, processing, and trade, contributing substantially to the textile industry, which is a major economic sector (ICAC, 2021). In Pakistan, cotton is often referred to as "white gold" due to its pivotal role in the national economy. It accounts for a considerable portion of the country's agricultural GDP and export earnings, with the textile sector comprising a significant part of Pakistan's industrial base (Government of Pakistan, 2020). Cotton is used extensively in the production of

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textiles, clothing, and other goods such as medical supplies and industrial products. Its by-products, like cottonseed oil and meal, further enhance its economic value. Pakistan is one of the world's largest cotton producers, but the sector faces challenges such as pest infestations, water scarcity, and climate change, necessitating improvements in agricultural practices and technology to sustain and enhance production (Khan et al., 2018). Hence, cotton remains an indispensable crop, driving economic activity and development both globally and in Pakistan.

Cotton production is a cornerstone of the agricultural economy in many countries, including major producers like the United States, China, India, and Pakistan. The crop is cultivated on millions of hectares globally, providing raw materials for the textile industry, employment for millions of farmers, and by-products for various industries (ICAC, 2021). However, sustainable cotton production faces several significant challenges. Pests and diseases, such as the bollworm, pose persistent threats to yield and quality, often necessitating the use of chemical pesticides which can lead to environmental and health issues (Kranthi, 2021). Water scarcity and inefficient irrigation practices exacerbate the problem, especially in arid and semi-arid regions where cotton is commonly grown (WWF, 2020). Additionally, climate change brings about unpredictable weather patterns, including extreme temperatures and altered precipitation, further complicating cotton farming (Raza et al., 2019). Soil degradation due to monoculture practices also impacts long-term productivity. Addressing these challenges requires integrated pest management, adoption of drought-resistant cotton varieties, efficient water use technologies, and sustainable agricultural practices to ensure the viability and sustainability of cotton production for future generations.

The genotypic performance evaluation of elite cotton strains using multivariate analysis approaches is crucial for enhancing breeding programs and ensuring superior crop traits. Multivariate analysis, including techniques like Principal Component Analysis (PCA) and cluster analysis, allows researchers to comprehensively assess and interpret the complex relationships between multiple agronomic traits simultaneously (Jolliffe & Cadima, 2016). This method facilitates the identification of key traits that contribute to yield and quality, enabling the selection of genotypes with optimal performance across diverse environmental conditions. For instance, a study by Khan et al. (2020) utilized PCA to evaluate cotton genotypes and identified significant variations in fiber quality and yield components, leading to the selection of high-performing strains. Such analyses not only enhance the efficiency of breeding programs by pinpointing desirable genetic traits but also aid in understanding the genetic diversity and stability of cotton strains under various biotic and abiotic stresses (Azhar et al., 2019). Consequently, multivariate analysis stands as a powerful tool in advancing cotton breeding, driving the development of resilient and high-yielding cotton varieties.

Materials and Methods

The current experimental study was carried out during the cotton crop season, 2023 at Cotton Research Station, Bahawalpur. The sowing was done during the last week of May, so that the flowering phase of the crop may experience a high temperature (above 45 ºC). The experimental material comprised twelve cotton strains i.e., DR-1, DR-2, DR-3, DR-4, DR-5, DR-6, DR-7, DR-8, DR-9, DR-10, DR-11 and DR-12. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The plant-to-plant distance was maintained at 45 cm while a 75cm distance will be maintained between lines/beds, respectively. At 2 weeks after sowing, thinning was done to achieve optimum plant population. These cotton strains were sown in four-rowed, 10-meter-long rows with a net plot size of 15cm^2. Standard agronomic and plant protection measures were taken for all the strains in all three replications. The properties of soil and irrigation water used are given in Table 1.

Table 1: Properties of Irrigation water and Soil used for Cotton sowing under heat stress

Properties of Irrigation water used in the study	
Parameter	**Value**
Total Soluble Salts (TSS)	1130 ppm
Sodium Adsorption Ratio (SAR	6.8
Residual Sodium Bicarbonate (RSB)	1.45
Chloride	4.3 meL
Properties of Soil on which the experiment was carried out	
Soil Texture	Sandy Loam
pH	7.9
EC	4.8 dSms
Organic Matter	0.73
Available P	7.5 ppm
Available K	85 ppm
Zinc	1.34 ppm

Data for Recording

The data was recorded from ten different, fully-guarded, fully-matured plants per strain per replication. The data was recorded for several morphological, physiological, and Ferber related

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parameters including plant height, nodes per plant, monopods per plant, sympods per plant, bolls per plant, CLCuV percentage, whitefly occurrence percentage, total chlorophyll contents, peroxidases, fiber length, fiber fineness, and cotton yield. Moreover, the CLCuV incidence percentage (CLCuV) was calculated as below according to the formula used by Aslam et al. (2022). The whitefly attack was estimated by counting the adult whiteflies per 10 leaves per plant in July and August.

Statistical Data Analysis

The obtained data will be subjected to analysis of variance (ANOVA) and correlation coefficient analysis as given by Steel et al., 1997. The PC-1/PC-2-based biplot analysis and agglomerative hierarchal cluster analysis were used to characterize and categorize cotton strains based on their performance and insect/disease tolerance as used by Hussain et al., 2024. To perform these analyses, three statistical packages i.e., Statistix 8.1, XLSTAT, and OriginPro were used.

Results and Discussion

The results obtained from the analysis of the variance (ANOVA) showed the presence of significant variations among cotton strains for the plant traits including plant height, nodes per plant, monopods per plant, sympods per plant, bolls per plant, whitefly occurrence percentage, total chlorophyll contents, peroxidases, fiber length, fiber fineness, and cotton yield while the variations among cotton strains for CLCuV percentage was found to be non-significant (Table 2). The occurrence of non-significant variations in CLCuV percentage among cotton strains depicts their tolerance against cotton leaf curl virus. Several researchers also showed that variations among cotton genotypes for key agronomic traits will provide a strong base to run a breeding program to improve an existing genotype or to develop a new cotton variety (Yousaf et al., 2023; Aslam et al., 2022; Hussain et al., 2023a; Manan et al., 2022; Munir et al., 2020; Rahman et al., 2022).

Table 2: Mean Square (MS) of agronomically important cotton strains under heat stress condition

Traits/Source of Variance	Replication	Genotypes	Error
Degree of Freedom	**2**	**11**	**22**
Plant Height	166	1218^{**}	8
Nodes per plant	3.00	71.04^{**}	4.88
Monopods per plant	0.03	1.05^{**}	0.15
Sympods per plant	6.86	63.24^{**}	6.47
Bolls per plant	1.00	45.70^{**}	4.82
CLCuV Percentage	237.9	274.4^{NS}	269.9
Whitefly infestation percentage	6.19	3.56^{**}	0.15
Total Chlorophyll Contents	0.00	2.09^{**}	0.16
Transpiration Rate	0.00	0.01^{**}	0.00
Peroxidase	16762	15858^{**}	1055
Fiber length	0.43	1.29^{*}	0.45
Fiber fineness	0.02	0.08^{**}	0.00
Cotton Yield	669	51196^{**}	3977

The correlation coefficient analysis was applied to investigate the relationship between different agronomically important traits in cotton strains under heat stress conditions (Table 3 & Figure 1). The results revealed that cotton yield had a significantly positive correlation with bolls per plant ($r = 0.739^{**}$), nodes per plant ($r = 0.709^{**}$), and sympods per plant ($r = 0.625^{**}$) (Table 3 & Figure 1). However, a negative but non-significant correlation of seed yield was with CLCuV percentage ($r = -0.231^{NS}$), monopods per plant ($r = -0.199^{NS}$), and transpiration rate ($r = -0.128^{NS}$) (Table 3 & Figure 1). The results unveiled the significant contribution of bolls per plant, nodes per plant, and sympods per plant in parental selection. Similar results were also reported by many researchers who showed that these parameters must be included in the selection criteria of selection of parental material for any cotton breeding program (Singh et al., 2007; Xu et al., 2020; Zafar et al., 2021; Thompson et al., 2022; Zafar et al., 2022; Yousaf et al., 2023; Zafar et al., 2023, Hussain et al., 2024).

The multivariate analysis approaches have become a fundamental method in the characterization, classification, and categorization of crop varieties/strains/ecotypes under normal and stress conditions. In the current study, two multivariate approaches i.e., biplots and cluster analysis were used to classify the cotton strains based on their performance under heat stress conditions on clay loamy soil. The PC-1/PC-2-based biplot analysis

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showed a strong association of plant height, nodes per plant, sympods per plant, and bolls per plant with cotton yield as revealed by the angle of corresponding lines of these traits (Figure 2). Furthermore, most of the variations in the data were due to transpiration rate, peroxidases, sympods per plant.

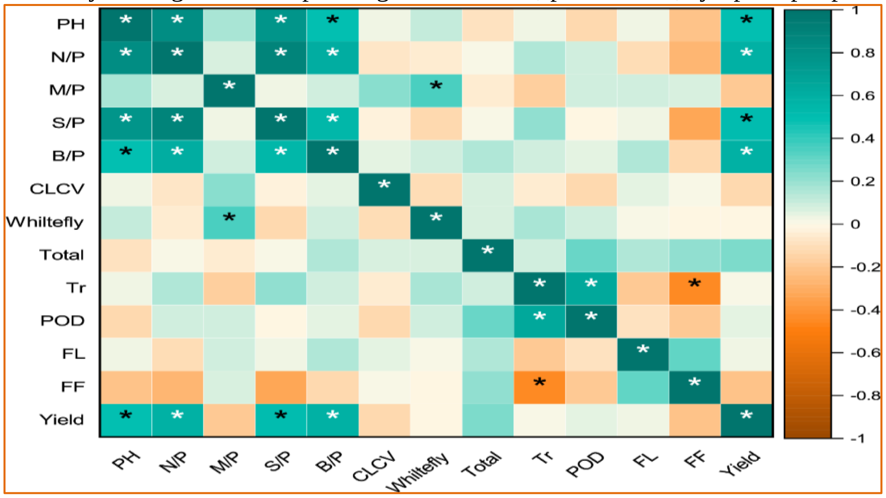

Figure 1: Correlation Matrix of agronomically important traits in cotton crop under heat stress conditions

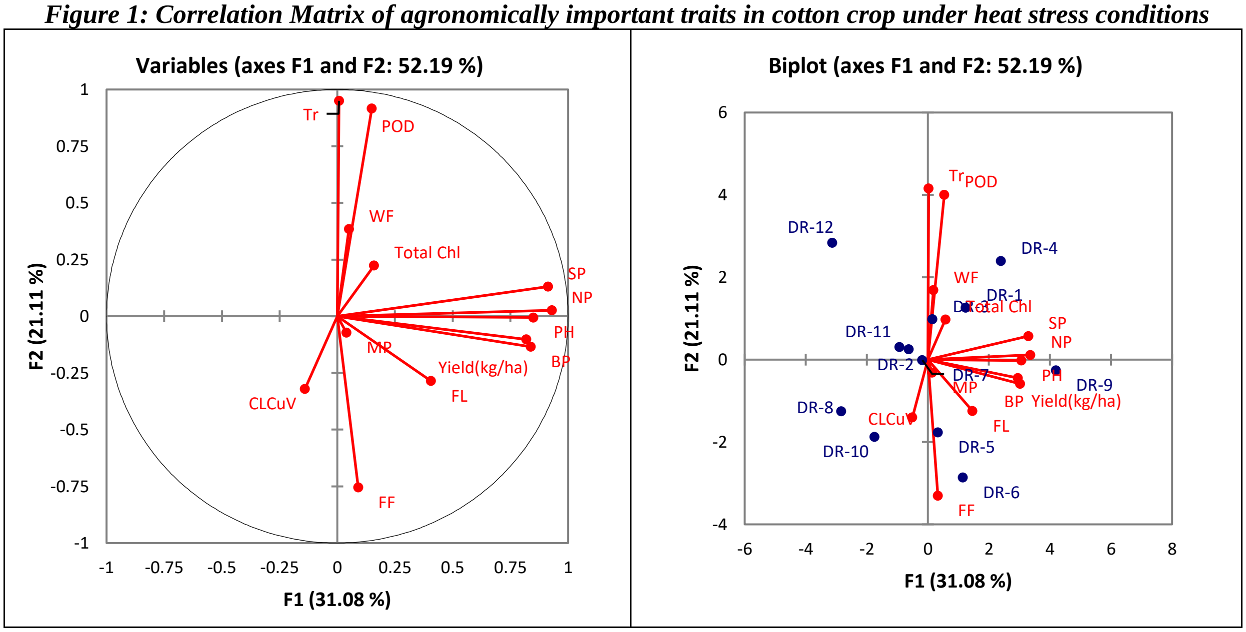

Figure 2: PC1/PC2 Cumulative Biplot between plant traits and cotton genotypes under heat stress

Table 4: Class means of three clusters in cotton strains under heat stress conditions

Class	1	2	3
Plant Height	91.783	107.033	98.117
Nodes per plant	26.100	31.100	25.850
Monopods per plant	0.617	0.450	0.867
Sympods per plant	21.347	24.847	20.263
Bolls per plant	19.083	22.917	18.750
CLCuV Percentage	3.837	5.333	13.876
Whitefly infestation percentage	6.858	6.450	6.508
Total Chlorophyll Contents	1.892	1.858	1.692
Transpiration Rate	0.384	0.340	0.298
Peroxidase	942.000	874.167	785.083
Fiber length	27.967	27.733	27.633

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Fiber fineness	4.637	4.636	4.718	Cotton Yield	829.593	1026.929	786.538

Table 3: Correlation coefficient between different agronomically important traits in upland cotton strains under heat stress conditions

Variables	PH	NP	MP	SP	BP	CLCuV	WF	T.C	Tr	POD	FL	FF	CY
PH	**1**	**0.885**	0.197	**0.866**	0.550	0.077	0.151	-0.096	0.010	0.041	0.217	0.002	0.519
NP	**0.885**	**1**	0.042	**0.964**	**0.666**	-0.076	-0.133	-0.106	0.022	0.132	0.132	-0.047	**0.709**
MP	0.197	0.042	**1**	0.012	0.092	**0.811**	0.422	0.144	-0.112	-0.027	0.188	-0.152	-0.199
SP	**0.866**	**0.964**	0.012	**1**	**0.635**	-0.110	-0.127	-0.012	0.147	0.210	0.173	-0.121	**0.625**
BP	0.550	**0.666**	0.092	**0.635**	**1**	-0.163	0.164	0.191	-0.140	0.012	0.477	0.200	**0.739**
CLCuV	0.077	-0.076	**0.811**	-0.110	-0.163	**1**	0.120	0.020	-0.282	-0.338	0.045	-0.015	-0.231
WF	0.151	-0.133	0.422	-0.127	0.164	0.120	**1**	0.367	0.362	0.299	0.135	-0.159	-0.024
T.C	-0.096	-0.106	0.144	-0.012	0.191	0.020	0.367	**1**	0.287	0.320	0.549	0.117	0.257
Tr	0.010	0.022	-0.112	0.147	-0.140	-0.282	0.362	0.287	**1**	**0.872**	-0.233	**-0.582**	-0.128
POD	0.041	0.132	-0.027	0.210	0.012	-0.338	0.299	0.320	**0.872**	**1**	0.010	**-0.595**	0.031
FL	0.217	0.132	0.188	0.173	0.477	0.045	0.135	0.549	-0.233	0.010	**1**	0.482	0.282
FF	0.002	-0.047	-0.152	-0.121	0.200	-0.015	-0.159	0.117	**-0.582**	**-0.595**	0.482	**1**	0.186
CY	0.519	**0.709**	-0.199	**0.625**	**0.739**	-0.231	-0.024	0.257	-0.128	0.031	0.282	0.186	**1**

nodes per plant, bolls per plant, and fiber fineness as their corresponding lines were at maximum distance from the origin of the plot. However, monopods per plant, total chlorophyll, and whitefly attack showed the lowest variations in the data (Figure 2). Moreover, the cotton strains DR-9, DR-4, DR-5, and DR-6 were among the most productive cotton strains under heat stress conditions (Figure 2). The cluster analysis grouped twelve cotton strains into three groups, where cluster-1 comprised four strains (DR-12, DR-3, DR-1, and DR-7), cluster-2 comprised four strains (DR-4, DR-9, DR-2, and DR-5) and cluster-3 also consisted of four strains (DR-6, DR-8, DR-10 and DR-11), respectively (Table 4 & Figure 3). The most productive cluster was cluster-2, which produced 1026.9 kg per acre followed by cluster-2 (829.6 kg per acre) and cluster-3 (786.5 kg per acre), respectively (Table 4). Multivariate approaches were extensively used by plant scientists to categorize crop germplasm based on their performance under the given circumstances or stresses and found it very useful in characterizing the germplasm (Zafar et al., 2021; Aslam et al., 2022; Yousaf et al., 2023; Zafar et al., 2023 and Hussain et al., 2024).

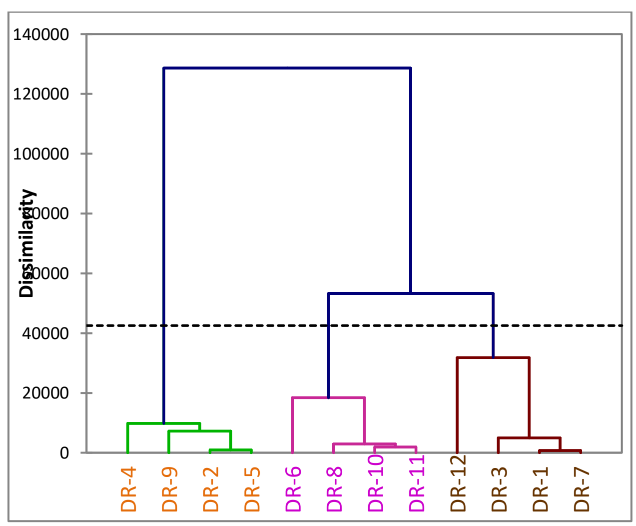

Figure 3: Cluster analysis based Dendrogram of twelve cotton strains under heat stress conditions

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Conclusion

The current study revealed the occurrence of significant variations for agronomically important and fiber quality-related traits in cotton strains under heat stress conditions except for CLCuV percentage. The correlation coefficient analysis revealed a strong positive correlation of cotton yield between bolls per plant, nodes per plant, and sympods per plant while a negative but non-significant correlation with CLCuV percentage, monopods per plant, and transpiration rate under heat stress conditions. The PC-1/PC-2 based biplot analysis reconfirms the results obtained through the correlation analysis and further unveiled that most of the variations in the data were due to transpiration rate, peroxidases, sympods per plant, nodes per plant, bolls per plant, and fiber fineness. The cluster analysis categorizes twelve cotton strains into three clusters, comprising four strains each, respectively, and found that cotton strains GR-4, GR-9, GR-2, and GR-5 were the most productive strains under heat stress conditions. Therefore, these genotypes must be tested in multiplication trials and potential genotypes must be found for heat-prone areas.

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Declaration

Data Availability statement

All data generated or analyzed during the study are included in the manuscript.

Ethics approval and consent to participate

Approved by the department concerned.

Consent for Publication

The study was approved by authors.

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Conflict of Interest

There is no conflict of interest among the authors regarding this case study.

Authors Contribution

All authors contributed equally.

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