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TRAIT CORRELATIONS AND IMPLICATIONS FOR YIELD POTENTIAL IN COTTON: A COMPREHENSIVE STUDY

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Abstract *Cotton (Gossypium hirsutum L.) yield improvement is a primary objective for breeders and researchers. This study explores trait correlations and their impact on cotton yield potential. Through field experiments and statistical analyses, relationships between traits and yield to provide insights for cotton breeding programs was investigated. Results revealed significant associations between traits and cotton yield. Plant height, number of nodes, monopodial branches and open ball showed positive correlations with yield. Taller plants, increased sympodial branches and more open balls were linked to higher yield potential. SS32 RH-668, NIAB-KIRAN and CIM-599 per form better among 19 genotypes. Further research is needed to establish causality. The study emphasizes that when selecting cotton genotypes for better yield potential, it's crucial to consider traits like sympodial branches, boll weight, open ball and green ball. Understanding their direct and indirect effects can help breeders develop varieties with desired characteristics and maximize yield. Additionally, the study found significant genetic variability among tested genotypes creating opportunities for breeding programs to enhance yield and desired traits. These findings offer valuable insights into trait correlations, paving the way for future research on genetics and developing better cotton varieties to meet global demand.*

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Introduction

Cotton (*Gossypium hirsutum* L.) is distinguished as one of the world's oldest and most vital crops. It has been crucial in numerous countries' economic and social progress throughout history (Snider et al., 2021). Having a fascinating history dating back to ancient times, cotton cultivation has expanded in India to become a prominent agricultural commodity, now grown in more than 100 countries worldwide (Chaudhary and Rathore, 2022). However, the pursuit of increasing cotton yield and productivity remains persistent challenge breeders, and researchers face (Guo et al., 2023). Yield improvement in cotton has been the subject of extensive research, and understanding the correlations between key traits and yield potential has been a fundamental aspect of cotton breeding programs (Kolhar and Jagtap, 2023; Kumar et al., 2020). The continuous demand for cotton has prompted researchers and breeders to explore strategies to enhance cotton yield and related traits by improving its morphological characteristics (Kayoumu et al., 2022; Sami et al., 2023). Morphological traits are crucial in determining cotton plants' overall performance and productivity, including plant architecture, branching pattern, and reproductive characteristics (Zaki and Hussein, 2022). One key morphological characteristic that has been extensively studied is plant height. Plant height influences light interception, photosynthetic efficiency, and boll development. Several studies have focused on developing cotton varieties with optimal plant height for improved yield potential. For instance, (Kumar et al., 2021) identified quantitative trait loci (QTL) associated with plant height in cotton. Through marker-assisted selection, they successfully developed cotton lines with reduced plant height and increased yield potential (Zafar et al., 2022; Puspito et al., 2015; Batool et al., 2023; Hafeez et al., 2021; Aaliya et al., 2016).

Another important morphological trait is branching pattern, specifically sympodial branches. Sympodial branches determine the number of fruiting positions and ultimately affect the yield potential of cotton plants (Magalhes and Cavalcante, 2023). Boll characteristics, such as size, shape, and position, are critical determinants of cotton yield and quality. Enhancing these morphological traits can significantly impact overall yield potential (Guo et al., 2023). Moreover, flower and fruit characteristics, including flowering time, fruiting period, and fruit retention, are vital for maximizing cotton yield (Godbold et al., 2021). Early and synchronous flowering and an extended fruiting period can increase the number of bolls per plant and enhance yield potential. A study by (Khokhar et al., 2017) found that certain morphological traits such as plant height, boll weight, and sympodial branches significantly influenced cotton yield in Pakistan. Therefore, focusing on these traits can improve substantially cotton production and help meet the increasing demand for cotton in Pakistan and globally. This paper evaluates the correlation of plant height, number of monopodial branches, number of sympodial branches, boll weight, green bolls, and number of open bolls with plant yield. The collected data was statistically analyzed to determine the differences among genotypes for various traits. Additionally, correlation coefficients (r) and path coefficient analysis were determined through the established procedures. Overall, the study provides valuable insights into the yield potential of different cotton genotypes, which can aid in selecting and developing more productive and sustainable cotton varieties for the cotton industry. By elucidating traits' direct and indirect effects on yield, breeders can make informed decisions regarding genotype selection and develop improved cotton varieties. The findings of this study will contribute to the ongoing efforts to enhance cotton yield potential, meet the increasing global demands for cotton, and ensure the sustainability and prosperity of the cotton industry.

Materials and Methods

The study was carried out at Ghazi University, Dera Ghazi Khan, Pakistan, in 2021, to evaluate and characterize nineteen cotton genotypes for their phenotypic characters. These genotypes included z33, RH-Afnan, ss32, ss102, MNH-1020, MNH-1045, MNH-1035, RH-668, CIM-473, CIM-506, NIAB-Kiran, AGC-99, BH-160, CIM-482, CIM-496, CIM-534, CIM-698, CIM-599, and RH-662. The experiment was designed in a randomized complete block design (RCBD) with four replications, while the plant and row spacing were maintained at 30 and 75 cm, respectively. The application of fertilizer, including 125:75 kg N:P ha-1 in the form of urea and DAP, was done with a full dose of phosphorus and one-third of nitrogen at the time of land preparation. The remaining nitrogen was applied in three equal split doses with the first irrigation, peak flowering, and boll setting stages. Other cultural practices, including irrigation and insecticides, were also conducted at appropriate times to ensure optimal growth conditions. All cultural methods, including weeding, were consistently used throughout the growing season to reduce environmental changes. Average data on morphological traits, such as plant height, the number of monopodial branches, nodes, sympodial branches, number of green bolls, bolls per plant, boll weight (g), and plant yield (g), were recorded for ten randomly tagged plants per genotype from each replication. The same plants were individually harvested, and data was recorded on yield per plant (g).

Traits measurement and statistical analyses

Data was recorded on an individual plant basis on plant height, monopodia per plant, sympodia per plant, bolls per plant, and cotton yield per plan. All the data were subjected to analysis of variance (ANOVA) technique to test the null hypothesis of no differences between varieties. The simple correlation coefficient (r) of cotton yield with other yield components and path coefficient analysis were also worked out.

Results and Discussion

The Table-1 shows the mean comparison of various traits of 19 different cotton genotypes. These genotypes were evaluated based on plant height (PH), number of nodes (Nodes), number of monopodial branches (NMB), number of sympodial branches (NSB), boll weight (BW), ginning percentage (GB), seed cotton yield (OB) and lint yield (PY). The results show that there is considerable variation among the different genotypes for each of the traits evaluated. For instance, the plant height ranges from 68 cm for SS32 to 120.25 cm for RH-668, while the number of nodes ranges from 20.5 for SS32 to 32.25 for RH-668. Additionally, the number of sympodial branches ranges from 0 for MNH-1020 and MNH-1045 to 5 for NIAB-KIRAN.

It is worth noting that some genotypes perform better than others for specific traits. For instance, NIAB-KIRAN has the highest number of sympodial branches (5), while SS32 has the lowest (0.5). SS-102 has the highest boll weight (4.8 g), while MNH-1020 has the lowest (3.9 g). Furthermore, CIM-599 has the highest yield percentage (9.25%), while MNH-1045 has the lowest (1.25%).

Table 1: Mean comparison for all traits

Genotypes	PH	Nodes	NMB	NSB	BW	GB	OB	PY
G1	93.50	28.00	0.25	14.25	4.34	8.50	22.50	50.71
G2	88.75	29.25	0.25	13.75	4.25	7.00	15.50	34.81
G3	68.00	20.50	0.50	8.75	3.50	9.00	9.75	11.78

G4	117.50	29.25	2.25	8.25	4.80	7.50	11.50	24.27
G5	81.75	25.00	0.00	8.75	3.90	6.75	6.50	12.36
G6	92.00	26.50	0.00	9.00	3.76	1.25	5.25	9.35
G7	108.50	31.25	0.25	10.00	5.10	3.50	4.00	13.08
G8	120.25	32.25	0.50	9.00	3.46	2.25	5.75	5.72
G9	118.50	29.00	1.25	10.75	3.56	4.00	8.75	13.26
G10	109.50	31.75	0.50	6.50	4.95	3.00	8.25	12.63
G11	115.25	32.00	5.00	7.50	3.40	3.75	6.50	9.08
G12	110.50	32.00	1.25	7.25	3.67	3.00	11.25	19.07
G13	110.75	31.75	2.25	9.00	3.86	3.75	10.00	17.45
G14	97.25	28.50	0.25	9.50	3.67	2.00	7.25	14.11
G15	108.00	30.00	0.00	10.25	4.86	3.00	9.00	13.99
G16	109.00	30.50	0.00	9.00	3.36	4.75	10.25	11.95
G17	94.50	28.00	0.00	8.50	3.40	5.50	8.75	13.70
G18	101.50	29.50	1.00	9.00	2.65	9.25	10.25	18.17
G19	101.00	29.25	0.00	9.75	2.78	5.50	7.75	9.38

G1=Z33, G2=RH-AFNAN, G3=SS32, G4=SS102, G5=MNH-1020, G6=MNH-1045, G7=MNH-1035, G8=RH-668, G9=CIM-473, G10=CIM-506, G11=NIAB-KIRAN, G12=AGC-99, G13=BH-160, G14=CIM-482, G15=CIM-496, G16=CIM-534, G17=CIM-698, G18=CIM-599, G19=RH-662, PH=plant Hight, Nodes, NMB=Number of monopodial branches, NSB=Number of sympodial branches, BW= Ball weight, GB=green balls, OB=open balls, PY=plant yield

The results suggest considerable potential for improvement in cotton breeding. By identifying and selecting genotypes that perform well for specific traits, breeders can develop new cotton varieties better adapted to specific growing conditions and provide higher yields. Overall, the results of this study can be used as a basis for further research aimed at identifying the genetic basis of the observed variation and developing new cotton varieties with improved traits.

Correlation Analysis

The Table-2 shows the correlation analysis of different traits concerning plant yield in cotton. The correlation coefficient ranges from -1 to 1, where 1 indicates a perfect positive correlation, -1 indicates a perfect negative correlation, and 0 indicates no correlation between the traits. Plant height (PH) positively correlates (0.818) with the number of nodes, which is expected as taller plants generally have more nodes. However, the correlation between PH and yield is insignificant (0.015). The number of monopodial branches (NMB) has a weak positive correlation (0.232) with plant height and a weak significant correlation (0.039) with yield. The number of sympodial branches (NSB) has no significant correlation with yield, but a weak positive correlation (0.179) with the number of nodes (Ali et al., 2013; Ali et al., 2016; Abbas et al., 2016).

Ball weight (BW) has a weak positive correlation (0.089) with plant height and a weak negative correlation (-0.085) with the number of monopodial branches. Green ball (GB) has a strong negative correlation (-0.349) with plant height and a strong negative correlation (-0.338) with the number of nodes. Open ball (OB) has a weak positive correlation (0.247) with the number of sympodial branches and a weak significant correlation (0.259) with yield.

Table 2: Correlation analysis for all traits

Traits	PH	Nodes	NMB	NSB	BW	GB	OB
Nodes	0.818**						
NMB	0.232*	0.300**					
NSB	0.018	0.179	-0.010				
BW	0.089	0.112	-0.085	-0.079			
GB	-0.349**	-0.338**	0.012	0.095	-0.142		
OB	-0.025	0.009	-0.026	0.370**	-0.105	0.247*	
PY	-0.015	0.039	-0.039	0.337**	-0.029	0.259*	0.813**

*=Highly significant, *=Significant, PH=Plant Hight, Nodes, NMB=number of monopodial branches, NSB=number of sympodial branches, BW=ball weight, GB=green ball, OB=open ball, PY=Plant yield*

The most important trait for yield is plant height, followed by the number of nodes, number of monopodial branches, and open ball. Green ball harms yield. These correlations suggest that selecting cotton genotypes with taller plants, more nodes, and more monopodial branches can increase yield. In contrast, selecting genotypes with a lower number of green balls and a higher number of open balls could also lead to higher yield. However, it is important to note that correlation does not imply causation and further experiments and analyses are needed to confirm these relationships (Ali et al., 2014; Ali et al., 2017; Abbas et al., 2016).

Analysis of Variance

The Table-3 shows the analysis of variance (ANOVA) for the experiment. The ANOVA tests the hypothesis that there is no significant difference among the means of the treatments. The sources of variation are listed in the first column as SOV (Source of Variation), followed by their corresponding degrees of freedom (DF), sum of squares (SS), mean square (MS), calculated F-value (F(cal)), and the p-value. The first source of variation is the replication (Rep) with 3 degrees of freedom (DF). The sum of squares (SS) for the replication is 85.63, and the mean square (MS) is 28.542. The second source of variation is the genotype with 19 degrees of freedom (DF). The sum of squares (SS) for the genotype is 7780.11, and the mean square (MS) is 409.479. The calculated F-value (F(cal)) is 6.25, with a p-value of 0, indicating a significant difference among the genotypes tested.

The third source of variation is the error, which represents the variation within the treatment groups and has 53 degrees of freedom (DF). The SS for the error is 3472.66, and the MS is 65.522. Finally, the total SS for all sources of variation is 11338.4.

Table 3: Analysis of variance

SOV	DF	SS	MS	F(cal)	P.value
Rep	3	85.63	28.542		
Genotypes	19	7780.11	409.479	6.25	0
Error	53	3472.66	65.522		
Total	75				
Grand mean	16.329		**CV**	49.57	
Tukey's 1 Degree of Freedom Test for Non-additivity					
Source	**DF**	**SS**	**MS**	**F**	**P**
Nano-additivity	1	446.78	446.778	7.68	0.0077
Remainder	52	3025.88	58.19		

The grand mean of the experiment is 16.329, and the coefficient of variation (CV) is 49.57. The Tukey's one-degree-of-freedom test for non-additivity was also conducted to test the interaction between the genotype and other factors. The Nano-additivity source has 1 degree of freedom (DF), with an SS of 446.78, MS of 446.778, F-value of 7.68, and a p-value of 0.0077. This result indicates significant non-additivity interaction between the genotype and other factors. The results of this analysis provide important information for future breeding programs aiming to improve the yield and other traits in cotton.

Path Coefficient analysis

The path coefficient analysis shown in Table-4 represents each trait's direct and indirect effects on plant yield (PY). Among these traits, the number of sympodial branches (NSB) directly positively affected yield (PY). This means an increase in sympodial branches in cotton plants is associated with higher yield potential. On the other hand, plant height (PH), green ball (GB), and open ball (OB) had direct negative effects on yield. This implies that taller plants and a higher proportion of green or open balls can negatively impact cotton yield. These traits may be associated with resource allocation, competition for nutrients, or susceptibility to pests and diseases, leading to reduced yield (Ali et al., 2013; Ali et al., 2016; Abbas et al., 2016). Furthermore, there were indirect effects of some traits on yield through other traits. For instance, NSB had a strong positive indirect effect on yield through boll weight (BW) and open ball (OB). This suggests that the increased number of sympodial branches indirectly contributes to higher yield through larger boll weight and a higher proportion of open bolls. Similarly, green ball (GB) indirectly positively affected yield through NSB and OB. This indicates that green balls may influence the number of sympodial branches and the proportion of open bolls, ultimately impacting cotton yield.

Table 4: Path coefficient analysis for direct and indirect effects

Traits	PH	Nodes	NMB	NSB	BW	GB	OB	PY
PH	-0.03592	0.074312	-0.00791	0.000496	0.005264	-0.03144	-0.02005	-0.01524
Nodes	-0.02939	0.090801	-0.01022	0.004718	0.006671	-0.03048	0.007503	0.039597
NMB	-0.00835	0.0273	-0.034	-0.00029	-0.00505	0.001158	-0.02072	-0.03995
NSB	-0.00068	0.016314	0.000372	0.02626	-0.0047	0.008556	0.291195	0.33732
BW	-0.0032	0.01026	0.002907	-0.00209	0.05904	-0.01286	-0.08325	-0.02919
GB	0.012542	-0.03074	-0.00044	0.002495	-0.00843	0.090044	0.194265	0.259738
OB	0.000917	0.000867	0.000897	0.009736	-0.00626	0.022271	0.78544	0.81387

Diagonal line= Direct effects; PH=Plant Hight, Nodes, NMB=number of monopodial branches, NSB=number of sympodial branches, BW=ball weight, GB=green ball, OB=open ball, PY=Plant yield

These findings highlight the importance of considering traits such as NSB, BW, OB, and GB when selecting highly yielding cotton genotypes. By understanding these traits' direct and indirect effects on yield, breeders and researchers can focus on developing cotton varieties with desirable characteristics, such as increased sympodial branches, optimal boll weight, and appropriate boll maturity, on maximizing cotton yield (Ali et al., 2013; Ali et al., 2017; Abbas et al., 2016).

Conclusion

The study identifies specific traits such as plant height, number of nodes, and open ball that affect cotton yield potential and can be used for targeted breeding efforts. These results emphasize the importance of considering these traits when choosing genotypes to enhance cotton yield. However, further experiments are necessary to establish causal relationships and validate the results. The study also highlights the significant genetic variability among tested genotypes, creating opportunities for future breeding programs to enhance yield and desirable traits in cotton. Overall, understanding the direct and indirect effects of these traits on yield provides breeders with a scientific basis to develop cotton varieties with optimal characteristics and meet global cotton demand. This study contributes to the knowledge base in cotton breeding and can pave the way for future research on trait variation genetics and the development of superior cotton varieties.

Declarations

Data Availability statement

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

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

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Not applicable

Conflict of Interest

Regarding conflicts of interest, the authors state that their research was carried out independently without any affiliations or financial ties that could raise concerns about biases.

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