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PATH COEFFICIENT ANALYSIS IN UPLAND COTTON (*GOSSYPIUM HIRSUTUM* L.)

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SUMMARY

The following study comprised an evaluation of 21 genotypes, which includes six parental genotypes and 15 half-diallel F_1 hybrids, applying the path coefficient analysis. The experiment, carried out in 2022 on upland cotton, used a randomized complete block design (RCBD) with three replications at the Musayyib Technical College of Babylon Governorate, Iraq. Path coefficient analysis enabled researchers to divide the correlation coefficient into direct and indirect effects, determining the relative contribution of each trait to seed cotton yield. The correlation analysis showed the seed cotton yield had a significant positive correlation with traits, such as the boll number, weight, ginning outturn, and seed index. The path coefficient analysis disclosed the seed cotton yield had considerable and direct effects from the ginning outturn and boll number. Correlation coefficient estimates indicated the ginning outturn contribution reached 21.12%, with the said trait becoming useful as a selection criterion to improve seed cotton yield. The coefficient contributions of the seed index and boll number were 11.49% and 8.83%, respectively, and the rest of the effects were 39.92%. The results revealed that the coefficient of determination of traits holds the highest relative importance as a major component of seed cotton yield. Breeders can use these estimates as selection criteria to enhance seed cotton yield in future breeding programs.

Keywords: Upland cotton (*G. hirsutum* L.), half-diallel cross, path analysis, yield-related traits, seed cotton yield

Key findings: Path coefficient analysis revealed the correlation coefficient of various traits holds the highest relative importance in managing seed cotton yield in upland cotton (*G. hirsutum* L.).

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INTRODUCTION

Upland cotton (*Gossypium hirsutum* L.) is the most widespread and profitable nonfood crop globally. Its production provides income for more than 250 million people worldwide and employs almost 7% of all labor in developing countries. Nearly half of all textiles are cotton-made. However, current cotton production methods are environmentally unsustainable, ultimately undermining the industry's ability to maintain future production. With a mean of 3,265.9 metric tons, Iraq was the fourth-largest producer of cotton in the world in 2022, followed by Yemen with a mean of 1,741.7 metric tons (FAOSTAT, 2022).

Seed cotton yield is a chief goal in cotton breeding and improvement programs, inherited by many genes. The cotton yield is also vital, with most influences from the environment. Several studies showed the seed cotton yield has a positive relationship with most other constituent traits (Al-Bayaty, 2005; Salahuddin *et al.*, 2010; Chaudhry *et al.*, 2022). Path analysis provides essential information by dividing correlation coefficients between seed cotton yield and its various components into direct and indirect effects, as well as determining the contribution of each trait in managing seed cotton yield (Waldia and Jatasra, 1980; Dawod, 1992; Al-Bayaty, 1999; Chapepa *et al.*, 2020).

Correlation coefficient analysis measures mutual relationships between various plant traits and determines component traits that can be effective for selection to improve yield. Correlating and analyzing the path coefficient of quantitative traits between cotton strains and their interchangeable crosses disclosed the seed cotton yield incurred intense and direct effects from the number of bolls, boll weight, and ginning outturn (Khan *et al*., 2010). Determination coefficient estimates showed the number of bolls and ginning outturn were among the most crucial traits.

Path analysis is a standardized partial regression coefficient that divides the correlation coefficient into measures of direct and indirect effects of a set of independent variables on a dependent variable (Kadam *et al*., 2024). Path analysis helps determine whether association of certain traits with yield is due to their direct effect on the seed cotton yield or due to indirect influences through other traits. If the correlation between seed cotton yield and a character is primarily due to a direct effect of that trait, it reflects a true relationship for yield improvement. However, if the correlation is mainly because of an indirect outcome of a character through another component trait, breeders need to select a trait through which an exertion of indirect effect happened.

Path coefficient analysis detailed the highest direct positive effects of mean boll weight and number of bolls on seed cotton yield, with the maximum indirect effect of mean boll weight being through the number of opened bolls (Al-Nuaimi, 2014). Their findings further revealed the premier positive indirect effect on fiber yield through the number of bolls on seed cotton yield. Ali *et al.'s* (2009) findings disclosed a direct positive effect of seed index, the number of nodes up to first fruiting of a branch, and the number of opened bolls on seed cotton yield.

The presented research aimed to study the correlation coefficient among various traits and analyze the path coefficient of six genotypes and their 15 half-diallel crosses to determine direct and indirect effects of the traits on seed cotton yield. Additionally, the study sought to determine the value of the coefficient of determination of studied traits and their impact on the seed cotton yield, using the most influential traits in improving the seed cotton yield in upland cotton.

MATERIALS AND METHODS

This study comprises 21 upland cotton genotypes, broken into six parental genotypes (Ashur, Reqa, deltabine, heleb, marsoomi-4, and lk-30) and 15 half-diallel F_1 hybrids. Their evaluation commenced in 2022 at the Musayyib Technical College of Babylon Governorate, Iraq. All the cotton genotypes, planted in fields in furrow, had a distance between rows of 100 and 40 cm between rows and plants, using a randomized complete block design (RCBD) with three replicates. Crop field operations ensued as per the usual recommendations for the cotton crop. At the end of the season, data recorded for studied traits came from a mean of 10 plants from each experimental unit, randomly selected, with the exclusion of terminal plants. The traits consisted of the ginning outturn (X4), seed index (X5), and days to first flowering (X6). Estimating the phenotypic correlation coefficient occurred for unique traits in all directions, with the path analysis also carried out (Wright, 1921; Dewy and Lu, 1959). The model testing includes six independent variables, i.e., X1, X2, X3, X4, X5, and X6 (Figure 1).

Various traits' designations with their symbols were as follows: Y: seed cotton yield, P: path coefficient, X1: plant height, X2: boll number, X3: boll weight, X4: ginning outturn, X5: seed index, X6: days to first flowering, W: remaining factors, and r: phenotypic correlation coefficient.

Path coefficient estimation used the matrix method as follows:

$$P = R^{-1} \times r$$

Where:

P = direct effects vector,

R^{-1} = Inverse of Matrix of correlation coefficients between all possible pairs of studied traits, and

r = Vector of phenotypic correlation coefficients between seed cotton yield trait and studied traits.

The coefficient of determination of interaction between independent variables and the percentage contribution of each trait to cotton yield bore estimation by the method, as described by Al-Bayaty (1999).

RESULTS

Simple phenotypic correlation coefficients revealed the seed cotton yield has a significant ($P \leq 0.01$) correlation with the traits' boll number, boll weight, ginning percentage, and seed index (Table 1). However, the said correlation values did not reach a level of significance with two traits, plant height and days to first flowering. The correlation of plant height was negative with all other traits and was significant ($P \leq 0.01$) with seed index and significant at $P \leq 0.05$ with the boll weight and ginning outturn. However, it was nonsignificant with the boll number and days to first flowering.

The correlation between the number of bolls and boll weight was significantly ($P \leq 0.01$) positive and significant ($P \leq 0.05$) with the variable of seed index, positive and nonsignificant with ginning outturn, and nonsignificantly negative with days to first flowering. The correlation of boll weight was significantly ($P \leq 0.01$) positive with two traits, ginning outturn and seed index, and positively nonsignificant with days to first flowering. The correlation was significantly ($P \leq 0.01$) positive between the seed index and days to first

Table 1. Phenotypic correlation coefficients between the yield and its component traits in upland cotton.

Traits	Plant height (cm)	Bolls plant^{-1}	Boll weight (g)	Ginning outturn	Seed index (g)	Days to first flowering (days).
Seed cotton yield plant^{-1} (g)	0.003	0.702**	0.652**	0.449**	0.501**	0.263
Plant height (cm)	-	- 0.337	- 0.361*	- 0.381*	- 0.461**	- 0.104
Boll plant^{-1}		-	0.707**	0.126	0.357*	- 0.009
Boll weight (g)			-	0.460**	0.593**	0.277
Ginning outturn				-	0.940**	0.625**
Seed index (g)					-	0.544**
Days to first flowering						-

*, **: Significant at 5% and 1% levels of probability, respectively.

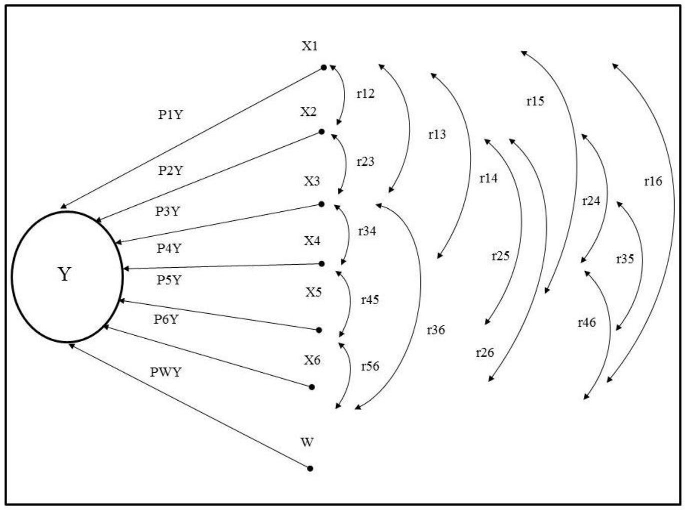

Figure 1. Path relationship of the traits affecting seed cotton yield in upland cotton.

flowering, indicating to find out more information about the nature, size, direction, and importance of the correlation between seed cotton yield and all other traits. Moreover, segmenting the values of correlation coefficients used the path analysis relationship (Figure 1).

The results of the path analysis of the direct and indirect effects of the studied traits in upland cotton are notable in Table 2. On seed cotton yield, it was apparent that a direct positive and medium influence of the trait plant height existed on seed cotton yield, with a positive value of +0.3069. Even if a positive and weak correlation of such a trait surfaced with seed cotton yield (+0.003). However, indirect effects were positive and high for the seed index (+0.4589), highly undesirable for ginning outturn (-0.5142), and medium negative for the number of bolls (-0.2068). These values reflect a relationship between traits, plant height, and seed cotton yield, along with a negative correlation for plant height and all other features, while the rest of the indirect effects were low (Table 2).

The correlation between the traits of the number of bolls and seed cotton yield was highly positive (0.7020), revealing direct favorable effects of the boll number on seed cotton yield. For indirect effects, most were small, except for an indirect influence of the seed index, with a mean negative value (-0.3554). The highest positive correlation emerged between the characteristics of boll weight and seed cotton yield because of the high positive and indirect impacts of the boll number and ginning outturn, amounting to +0.6169 and +0.6208, respectively. Meanwhile, an indirect effect was highly negative for the seed index, amounting to -0.5903. A direct effect of the boll weight was positive and small (+0.1234), while other indirect effects were nonsignificant. The correlation between traits, ginning outturn and seed cotton yield was highly positive because of positive and high direct effects as well.

For the traits of seed index and ginning outturn, path analysis results were significant with an inverse relationship, contrasting the results of the phenotypic correlation analysis (Table 1). Despite the highest positive correlation between the seed index and seed cotton yield (+0.5010), a direct effect of the seed index was highly negative. Positive indirect effects of the ginning percentage and number of bolls were accountably raising the value of the correlation coefficient between the seed index and seed cotton yield. On analyzing the path to the complex nature of inheritance of quantitative traits on one hand and the size and direction of relationship between yield components instead, indirect effects of the rest of the traits were nonsignificant.

Table 2. Path coefficient analysis of factors affecting seed cotton yield in upland cotton.

No.	Component effects on seed cotton yield	The symbol	Path coefficient
1	Direct effect of plant height	P_1Y	+0.3069
	Indirect effect of boll number	$r_{12}P_2Y$	-0.2068
	Indirect effect of boll weight	$r_{13}P_3Y$	-0.0444
	Indirect effect of ginning outturn	$r_{14}P_4Y$	-0.5142
	Indirect effect of seed index	$r_{15}P_5Y$	+0.4589
	Indirect effect of days to first flowering	$r_{16}P_6Y$	+0.0029
	Total effects	r_1Y	+0.0030
2	Direct effect of boll number	P_2Y	+0.8725
	Indirect effect of plant height	$r_{21}P_1Y$	-0.0727
	Indirect effect of boll weight	$r_{23}P_3Y$	+0.0872
	Indirect effect of ginning outturn	$r_{24}P_4Y$	+0.1700
	Indirect effect of seed index	$r_{25}P_5Y$	-0.3554
	Indirect effect of days to first flowering	$r_{26}P_6Y$	+0.0003
	Total effects	r_2Y	+0.7020
3	Direct effect of boll weight	P_3Y	+0.1234
	Indirect effect of plant height	$r_{31}P_1Y$	-0.1114
	Indirect effect of boll number	$r_{32}P_2Y$	+0.6169
	Indirect effect of ginning outturn	$r_{34}P_4Y$	+0.6208
	Indirect effect of seed index	$r_{35}P_5Y$	-0.5903
	Indirect effect of days to first flowering	$r_{36}P_6Y$	-0.0064
	Total effects	r_3Y	+0.6530
4	Direct effect of ginning outturn	P_4Y	+1.3496
	Indirect effect of plant height	$r_{41}P_1Y$	-0.1169
	Indirect effect of boll number	$r_{42}P_2Y$	+0.1099
	indirect effect of boll weight	$r_{43}P_3Y$	+0.0568
	Indirect effect of seed index	$r_{45}P_5Y$	-0.9358
	Indirect effect of days to first flowering	$r_{46}P_6Y$	-0.0176
	Total effects	r_4Y	+0.4460
5	Direct effect of seed index	P_5Y	-0.9955
	Indirect effect of plant height	$r_{51}P_1Y$	-0.1415
	Indirect effect of boll number	$r_{52}P_2Y$	+0.3115
	Indirect effect of boll weight	$r_{53}P_3Y$	+0.0732
	Indirect effect of ginning outturn	$r_{54}P_4Y$	+1.2686
	Indirect effect of days to first flowering	$r_{56}P_6Y$	-0.0153
	Total effects	r_5Y	+0.5010
6	Direct effect of days to first flowering	P_6Y	-0.2822
	Indirect effect of plant height	$r_{61}P_1Y$	-0.0319
	Indirect effect of boll number	$r_{62}P_2Y$	-0.0079
	Indirect effect of boll weight	$r_{63}P_3Y$	+0.0280
	Indirect effect of ginning outturn	$r_{64}P_4Y$	+0.8435
	Indirect effect of seed index	$r_{65}P_5Y$	-0.5416
	Total effects	R_6Y	+0.2620
	Remaining effects	P_WY	+0.2114

The correlation between days to first flowering and seed cotton yield was low and positive (0.2620), while a direct effect of this trait was negative and nonsignificant. The indirect effects of ginning outturn were highly positive (+0.8435), which were liable for the positive correlation between these two traits. An indirect influence of seed index was highly negative (-0.5416), and indirect outcomes of other traits were nonsignificant and minimal. Two features of ginning outturn and the number of bolls have the highest direct impact on the seed cotton yield, besides their positive and high indirect effect on most other traits. It confirms these two traits were considerably major components of the seed cotton yield.

The values of the coefficient of determination sought to identify the relative importance of each parameter of the seed cotton yield (Table 3). The six traits and their interaction were accountable for 97.55% of differences in the seed cotton yield, which signifies this study included most components of yield. However, the residual effects of other components were small (2.45%). Estimates of coefficient of determination signify the parameter of ginning outturn was one of the crucial traits playing a vital role in the seed

Table 3. Sources of variation, their direct effects, and the percentage of their contributions to differences in seed cotton yield in upland cotton.

No.	Sources of difference	Coefficient of Determination (C.D.)	Percent Contribution (P.C.%)
1	Plant height	+0.0941	1.09
2	Boll number	+0.7612	8.83
3	Boll weight	+0.0152	0.18
4	Ginning outturn	+1.8314	21.12
5	Seed index	+0.9910	11.49
6	Days to first flowering	+0.0008	0.01
7	Plant height x boll number	-0.1270	1.47
8	Plant height x boll weight	-0.0275	0.32
9	Plant height x ginning outturn	-0.3156	3.66
10	Plant height x seed index	+0.2816	3.27
11	Plant height x days to first flowering	+0.0016	0.02
12	Boll number x boll weight	+0.1522	1.77
13	Boll number x ginning outturn	+0.2966	3.44
14	Boll number x seed index	-0.6202	7.19
15	Boll number x days to first flowering	+0.0004	0.01
16	Boll weight x ginning outturn	+0.1532	1.78
17	Boll weight x seed index	-0.1456	1.69
18	Boll weight x days to first flowering	-0.0018	0.02
19	Ginning outturn x seed index	-2.5258	29.29
20	Ginning outturn x days to first flowering	-0.0476	0.55
21	Seed index x days to first flowering	+0.0304	0.35
22	Remaining effects	+0.2114	2.45
Total			1.0000

cotton yield (21.12%), followed by variables of seed index (11.49%) and the number of bolls (8.83%). The joint effects of these traits amounted to 40%. Approximately, these three traits and their common effects contribute to about 81% of the total variance in the seed cotton yield, while the direct and joint effects of the rest of the traits were minimal.

DISCUSSION

It is illustrative that seed cotton yield has a significant ($P \leq 0.01$) correlation with yield-related traits, i.e., boll number and weight, ginning outturn, and seed index. The correlation between the number of bolls and boll weight was significantly ($P \leq 0.01$) positive, considerably ($P \leq 0.05$) positive with the variable of seed index, and nonsignificantly positive with the days to first flowering trait. The correlation of the boll weight feature was remarkably ($P \leq 0.01$) positive with ginning outturn and seed index and nonsignificantly positive with the trait of days to first flowering. Past studies also reported a significant positive correlation coefficient between various earliness and yield-related qualities in cotton (Dawod, 1992; Chapepa *et al.*, 2020; Chaudhry *et al.*, 2022). Seed cotton yield receives a direct influence from the number of bolls, boll weight, and ginning outturn (Khan *et al*., 2010).

The ginning outturn showed a notably ($P \leq 0.01$) positive correlation with the traits of seed index and days to first flowering. The correlation was significant ($P \leq 0.01$) and positive between the seed index and days to first flowering. Moreover, the correlation between the number of bolls and the seed cotton yield was substantially ($P \leq 0.01$) positive, and it was the outcome of direct effects of the number of bolls on seed cotton yield as well. As for indirect effects, most of the traits were nonsignificant, except for indirect effects of the mean of the seed index. It segmented the values of correlation coefficients using the path analysis method according to the path relationship. Past studies have stated the seed cotton yield has a positive relationship with most other constituent traits (Al-Bayaty, 2005; Salahuddin *et al.*, 2010). These results agree to some extent with the previous research, as they also observed a significant positive correlation coefficient between various yield-related components in cotton (Al-Juboori and Dawod, 2006; Al-Nuaimi *et al.*, 2021).

The correlation between the number of bolls and the seed cotton yield was significantly ($P \leq 0.01$) positive. A positive and high correlation between the number of bolls and the seed cotton yield was because of indirect effects of the number of bolls and ginning outturn, which were high and positive. The correlation between ginning outturn and the seed cotton yield was positive and high, and this was due to direct effects, occurring also as positive and high. All indirect effects of various traits were nonsignificant, except for an indirect impact of the seed index, which was highly negative.

The correlation between days to first flowering and the seed cotton yield was positive, and the coefficient of determination detected a relative importance of each trait. These results were greatly analogous to past findings, which reported the same direct and indirect effects of various traits in upland cotton (Ali *et al*., 2009). Earlier studies disclosed direct positive effects of seed index, the number of nodes up to the first fruiting branch, and the number of opened bolls on the seed cotton yield (Waldia and Jatasra, 1980; Dawod, 1992).

CONCLUSIONS

Results revealed the seed cotton yield emerged as significantly and positively associated with the number of bolls, boll weight, ginning outturn, and seed index. The path analysis expressed the seed cotton yield received intense and direct influences from ginning outturn and boll number. The number of bolls and ginning outturn's coefficient of determination exhibited these traits were most important in variations found in the seed cotton yield. Therefore, these parameters can be beneficial as selection criteria to improve the seed cotton yield in future breeding programs.

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