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Heritability and Path Analysis in F_2 Populations of Cotton (*Gossypium hirsutum* L.)

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Abstract: The estimation of heritability, genetic advance and direct effect of yield attributing components on seed cotton yield have been used to develop indirect selection criteria. For this purpose, seven parents and their F_2 populations were evaluated for the identification of superior populations to be transferred to further generations. Claudia x AGC-208, Claudia x AGC-85 and MD x AGC-85 combinations were superior F_2 populations for seed cotton yield and fiber quality. The highest heritability and genetic advance were recorded in boll number and fiber fineness. The results of correlation and path analysis indicated that boll number, days to first boll opening and boll weight could be used as selection criteria to improve seed cotton yield.

Keywords: Correlation, genetic advance, heritability, path analysis, segregation

F_2 Pamuk (*Gossypium hirsutum* L.) Populasyonlarında Kalıtım ve Path Analizi

Öz: *Kalıtım derecesi, genetik ilerleme ve kütlü pamuk verimi için doğrudan etkilerin tahminlenmesi dolaylı seleksiyon kriterinin belirlenmesi için önem taşımaktadır. Bu amaçla yedi anaç ve bunlara ait F_2 populasyonları ileri generasyonlara aktarılabilecek üstün populasyonların belirlenmesi yönünden değerlendirilmiştir. Kütlü pamuk verimi ve lif kalitesi yönünden Claudia x AGC-208, Claudia x AGC-85 ve MD x AGC-85 populasyonlarının üstün populasyonlar olduğu saptanmıştır. Koza sayısı ve lif inceliği yönünden yüksek kalıtım derecesi ve genetik ilerleme belirlenmiştir. Korelasyon ve path analizi sonucunda kütlü pamuk verimi için yürütülecek ıslah çalışmalarında koza sayısı, koza ağırlığı ve koza açma gün sayısının seleksiyon kriteri olarak kullanılabileceği sonucuna varılmıştır.*

Anahtar kelimeler: *Korelasyon, genetik ilerleme, kalıtım, path analizi, açılma*

INTRODUCTION

Cotton is one of the most important cash crops and accounts for more than half of all fiber used in textile industries (Wang, 2015). The sowing area and lint productions are 33.0 million ha and 26.2 million tons in the world, respectively (Anonymous, 2021a). The sowing area and lint production of Turkey are 359 thousand ha and 0.69 million tons, respectively (Anonymous, 2021b).

Breeding programs have continued to improve the yield and fiber quality in order to meet the global market requirements in cotton (*Gossypium hirsutum* L.). Genetic variability is very important to breed genotypes with high yielding and favorable fiber quality (Aziz et al., 2014). Superior plants are selected in the F_2 generation, in which the maximum segregations are occurring, and the selection continues until the advanced lines are reached in breeding programs (Gibely, 2021).

Estimation of heritability is important for the effective selection of target characters in order to achieve maximum genetic gain (Dhivya et al., 2014). Also, heritability is evaluated together with genetic advance, which coupled with high heritability is needed for an effective response to selection (Soomro et al., 2010). The association between heritability and genetic advance were evaluated for different generations in cotton breeding (Baloch et al., 2018; Komala et al., 2018; Balci et al., 2020; Gibely et al., 2021).

The relationships among yield, yield components and quality parameters were evaluated by using correlation and path analysis.

A complex character, seed cotton yield, is dependent on yield components. The relationships among the characters were determined to improve the cotton through breeding in many studies. Direct effects of boll number per plant and boll weight on seed cotton yield were found to be highest and positive (Ahmad and Azhar, 2000; Hazem and Bayaty, 2005; Salahuddin et al., 2010; Parmar et al., 2015; Srinivas et al., 2015; Abdullah et al., 2016; Ahmad et al., 2017; Nikhil et al., 2018; Deshmukh et al., 2019; Kumar et al., 2019).

The current study was designed to estimate the heritability and genetic advance (1), determine the relationships among characters (2) and establish direct and indirect effects of earliness, fiber and yield-related traits on seed cotton yield (3).

In addition, this study aimed to select the promising F_2 populations to transfer further generations in successful cotton breeding (4).

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MATERIAL AND METHODS

Plant Material

Five parents including Claudia (CL), Gloria (GL), Carisma (CH), Stoneville 468 (ST-468) and MD (advanced line) were crossed with AGC-208 and AGC-85 to develop 10 F_1 populations in 2017. Claudia, Carisma, Gloria and MD were selected for high yield, adaptability and fiber quality, while Stoneville 468, AGC-208 and AGC-85 were included in the hybridization program in terms of high-temperature tolerance. F_1 plants were selfed and provided sufficient F_2 seeds in 2018. After delinting individual F_2 seeds for each genotype, 10 F_2 populations and 7 parents were sown in the field of Söke Seed Company (37°61' N and 27°36' E) in the cotton-growing season of 2019. The 17 genotypes were sown in a 10 m length with 6 rows adopting a spacing of 0.73 m between rows and 0.2 m between the plants in a row. Experimental management followed the established production techniques for Aegean Region.

Data Collection

For each of the 10 F_2 populations and 7 parents, 50 plants were randomly sampled from about 300 plants in the plots. The days to first squaring, days to first flowering and days to first boll opening were measured to evaluate earliness in cotton. The plant height (cm), boll number per plant, boll weight (g), and seed cotton yield per plant (g) were determined in the harvest. The seed cotton of single plants was separately ginned by a roller gin in the laboratory. The fiber fineness (micronaire), fiber length (mm) and fiber strength (g tex^{-1}) were determined using a High Volume Instrument (HVI).

Statistical Analysis

The t-test was used to compare the means of parents and F_2 populations (parents vs F_2 populations). Phenotypic correlations and path coefficient analysis for seed cotton yield per plant were computed according to the methods suggested by Kowon and Torrie (1964), and Dewey and Lu (1959), respectively. Genotypic (σ^2_g) and phenotypic variance (σ^2_p) were estimated to calculate the heritability degrees in a broad sense (h^2_{BS}) and genetic advance (GA) according to the method suggested by Singh and Chaudhary (1985).

$h^2_{(BS)} = [(\sigma^2_g) / (\sigma^2_p)] \times 100$

Where,

$\sigma^2_p = \sigma^2_{F2}$

$\sigma^2_g = \sigma^2_{F2} - \sigma^2_E$

σ^2_E = the mean of all parent's variance

Genetic Advance (GA) = i σ_p h^2_{BS}, genetic advance as percentage of mean (GAM) (GAM%) = (GA/grand mean) x 100 ; Where, i: standardized selection differential, a constant (2.06), σ_p: phenotypic standard deviation.

RESULTS AND DISCUSSION

The average values of F_2 populations compared with the average of parents indicated that F_2 populations were significantly superior for seed cotton yield, boll number per plant and boll weight, whereas earliness characters, plant height, ginning out-turn and fiber properties of F_2 populations and their parents were similar (Table 1 and 2).

The favorable values for all characters were recorded in Claudia x AGC-208, Claudia x AGC-85 and MD x AGC-85 combinations, whereas the performance of ST-468 x AGC-85 was unfavorable (Table 1). The seed cotton yield per plant of these superior F_2 hybrids changed from 57.0 (ST-468 x AGC 85) to 127.4 g (ST 468 x AGC 208). In addition, ST-468 x AGC-208 with high yield exhibited a low performance for ginning out-turn (41.8%). A successful selection mainly depends on heritability, which is an index for the transmission of a character from one generation to the next generation (Larik et al., 1999), and efficient selection is possible with high heritability and genetic advance (Kumar et al., 2019). It was defined as low when broad-sense heritability was below 30, medium 30-60 and high above 60 by Srivinias et al. (2014).

Heritability was found to be low for plant height (34.6), seed cotton yield (31.8), days to squaring (33.8), flowering (36.9) and boll opening (32.5). Boll number (71.0), boll weight (68.9), ginning out-turn (83.7) and fiber characteristics such as fineness (72.7), length (69.8) and strength (75.1) exhibited high heritability. The genetic advance as a percentage of the mean (GAM) was found to be high for boll number (60.5) and fiber fineness (58.2), medium for boll weight (31,8) and fiber length (33.7). Boll number and fiber fineness had a high heritability coupled with genetic advance while high heritability and medium genetic advance were recorded in boll weight. These results are similar to Ahsan et al. (2015) and Gnanasekaran et al. (2018). The coefficient of variation (CV%) changed from 1.7% (GOT) to 25.5% (SCY) for parents, while CV value of F_2 populations was between 3.3% (DFB) and 40.5% (BN).

The differences among genotypes indicated that there are considerable variations for path and correlation analysis. Positive and significant correlation coefficients were found between single plant yield and the number of bolls (0.92**), boll weight (0.84**) and fiber length (0.61**) (Table 3). A positive and significant relationship was determined between plant height and fiber fineness (0.71**). The number of bolls showed a significant and positive correlation with boll weight (0.70**) and fiber length (0.53*).

Table 1. Mean performance, heritability (h^2_{BS}) and genetic advance (GAM) of yield, yield components and earliness.

Parents	PH	BN	BW	SCY	DFS	DFF	DFB
Claudia (CL)	94.9	15.6	4.8	75.7	30.1	50.4	108.1
Gloria (GL)	102.6	14.5	5.0	65.3	28.5	48.8	107.9
Carisma (CH)	112.6	11.5	4.8	53.9	31.0	52.4	112.3
AGC-208	107.8	14.3	4.6	68.2	30.8	51.0	103.2
AGC-85	100.0	12.6	4.8	69.5	29.0	48.7	107.3
ST-468	102.7	14.0	4.6	75.8	29.5	51.5	110.4
MD	103.2	11.1	4.2	53.2	31.6	51.6	101.1
Average	103.4	13.3	4.7	65.9	30.1	50.6	106.9
CV (%)	6.5	10.2	8.1	25.5	5.1	3.3	2.6
F_2							
CL x AGC-208	115.5	16.9	5.3	121.0	27.6	47.6	109.9
CL x AGC-85	106.0	18.8	6.0	117.1	28.9	50.7	107.2
GL x AGC-208	106.5	16.5	6.2	98.0	30.9	50.9	107.8
GL x AGC-85	108.7	13.7	6.2	93.3	30.9	50.8	106.6
CH x AGC-208	115.1	16.0	5.8	97.0	30.2	51.6	112.5
CH x AGC-85	113.4	17.0	6.4	103.9	29.4	51.0	111.3
ST-468 x AGC-208	110.9	20.9	6.6	127.4	30.0	51.0	108.3
ST-468 x AGC-85	84.4	13.6	4.4	57.0	30.0	49.6	102.1
MD x AGC-208	115.1	16.3	5.4	89.2	30.8	50.9	98.0
MD x AGC-85	111.6	20.0	5.0	97.1	31.4	52.3	100.6
Average	108.7	17.0	5.7	100.1	30.0	50.6	106.0
CV (%)	7.2	40.5	20.2	26.6	6.0	4.0	3.3
Parents vs F_2 (t p<0.05)	ns	**	**	**	ns	ns	ns
h^2_{BS}	34.6	71.0	68.9	31.8	33.8	36.9	32.5
GAM	5.0	60.5	31.8	17.3	14.7	3.6	2.7

* and **: significance at $p \leq 0.05$ and $p \leq 0.01$ respectively, ns: non-significant.
PH: Plant height, BN: Boll number, BW: Boll weight, SCY: Seed cotton yield per plant, DFS; Days to first squaring, DFF: Days to first flowering, DFB: Days to first boll opening.

Table 2. Mean performance, heritability (h^2_{BS}) and genetic advance (GAM) of ginning out-turn and fiber quality parameters.

Parents	GOT	FL	FF	FS
Claudia (CL)	47.8	31.1	4.7	31.8
Gloria (GL)	43.6	30.6	4.5	31.9
Carisma (CH)	44.2	29.3	4.5	25.9
AGC-208	42.2	30.1	4.7	30.6
AGC-85	40.7	29.2	4.8	29.0
ST-468	43.8	28.3	4.5	28.2
MD	42.5	27.6	4.7	28.7
Average	43.5	29.5	4.6	29.4
CV (%)	1.7	11.6	6.6	3.9
F_2				
CL x AGC-208	43.5	31.7	4.6	31.6
CL x AGC-85	43.6	30.8	4.6	31.2
GL x AGC-208	42.7	29.6	4.7	31.2
GL x AGC-85	42.5	30.5	4.7	32.9
CH x AGC-208	43.6	29.5	4.7	28.1
CH x AGC-85	42.5	30.4	4.6	29.4
ST-468 x AGC-208	41.8	30.5	4.7	30.1
ST-468 x AGC-85	44.0	28.7	4.9	28.6
MD x AGC-208	43.7	29.0	4.6	29.6
MD x AGC-85	43.3	29.8	4.6	30.2
Average	43.1	30.0	4.7	30.2
CV (%)	4.2	22.9	12.5	7.5
Parents vs F_2 (t p<0.05)	ns	ns	ns	ns
h^2_{BS}	83.7	69.8	72.7	75.1
GAM	7.3	33.7	58.2	11.6

* and **: significance at $p \leq 0.05$ and $p \leq 0.01$ respectively, ns: non-significant.
GOT: Ginning out-turn, FL: Fiber length, FF: Fiber fineness, FS: Fiber strength.

The relationship between boll weight and fiber length (0.49*) and fiber strength (0.49*) is positive and significant. The number of days to first squaring showed a significant positive correlation with the number of days to first flowering (0.79**), whereas it showed a negative and significant correlation with fiber length (-0.53*). The correlation between fiber length and fiber strength (0.68**) is positive and statistically significant.

Also, many researchers emphasized that correlation coefficients between boll number and boll weight and single plant yield were significant and positive (Deshmukh et al., 2019; Iqbal et al., 2019; Nawaz et al., 2019; Rehman et al., 2020). On the other hand, Araujo et al. (2012) stated that the boll weight negatively affects fiber yield. The results of our study are mostly similar to the comments made in previous studies. The most important direct effects on the seed cotton yield were boll number (72.11%) and days to first boll opening (59.23%). These characters were followed by the direct effects of boll weight (23.19%) and plant height (22.60%), respectively. On the other hand, it is noteworthy that days to first flowering (-41.62%) and the ginning out-turn (-12.24%) have a high but negative direct effect on single plant yield (Table 4). When the direct effects of the investigated characteristics on the seed cotton yield are examined collectively, it is clearly understood that the most important yield-attributing component that determines seed cotton yield is the number of bolls. In this case, it can be said that the flowering occurs early, but the conditions in which boll opening is prolonged have a positive effect on the yield.

Table 3. The correlation coefficient among observed characters

	PH	BN	BW	DFS	DFF	DFB	GOT	FL	FF	FS
SCY	0.45	0.92**	0.84**	-0.34	-0.10	0.21	-0.15	0.61**	0.32	0.43
PH		0.35	0.42	0.24	0.48	0.16	-0.23	0.13	0.71**	-0.11
BN			0.70**	0.20	-0.03	-0.04	-0.03	0.53*	0.19	0.41
BW				-0.18	-0.04	0.21	-0.28	0.49*	0.28	0.49*
DFS					0.79**	0.45	0.03	-0.53*	0.02	-0.28
DFF						0.05	0.08	-0.42	0.19	-0.44
DFB							0.01	0.34	0.25	-0.18
GOT								0.16	-0.17	0.07
FL									0.26	0.68**
FF										0.20

* and **: significance at $p \le 0.05$ and $p \le 0.01$ respectively.

PH: Plant height, BN: Boll number, BW: Boll weight, SCY: Seed cotton yield per plant, DFS; Days to first squaring, DFF: Days to first flowering, DFB: Days to first boll opening, GOT: Ginning out-turn, FL: Fiber length, FF: Fiber fineness, FS: Fiber strength.

Table 4. The percentage value of direct (diagonal) and indirect (off-diagonal) effects on seed cotton yield

	PH	BN	BW	DFS	DFF	DFB	GOT	FL	FF	FS
PH	**22.60**	42.69	14.87	0.20	-10.16	5.45	0.79	-1.79	-0.23	-1.25
BN	4.74	**72.11**	14.69	-0.11	0.40	-0.71	0.06	-4.29	-0.04	2.87
BW	6.33	56.31	**23.19**	-0.10	0.06	4.70	0.55	-4.35	-0.62	3.86
DFS	6.53	-32.67	-7.62	**1.03**	-20.74	-18.78	-0.12	8.76	0.01	-3.76
DFF	21.19	-7.53	-2.74	1.30	**-41.62**	-3.50	0.51	11.17	-0.12	-10.32
DFB	6.24	-7.32	12.64	0.65	1.92	**59.23**	-0.03	-8.07	-0.15	-3.76
GOT	-20.11	-14.50	-34.41	0.10	-6.56	0.65	**-12.24**	8.15	0.21	3.06
FL	2.34	50.45	13.34	-0.34	7.00	9.21	-0.40	**-10.59**	-0.07	6.30
FF	23.22	33.81	14.54	0.03	-5.85	12.56	0.79	-5.19	**-0.48**	6.53
FS	-2.25	46.38	16.30	-0.20	8.89	-5.89	-0.21	-8.62	-0.06	**11.21**

PH: Plant height, BN: Boll number, BW: Boll weight, SCY: Seed cotton yield per plant, DFS; Days to first squaring, DFF: Days to first flowering, DFB: Days to first boll opening, GOT: Ginning out-turn, FL: Fiber length, FF: Fiber fineness, FS: Fiber strength.

It has been determined that the indirect effects of boll weight, fiber length, fiber strength, plant height and fiber fineness on the boll number are high, whereas the indirect effects of the number of days to squaring on boll number and ginning out-turn on boll weight are high. In this case, it can be said that the seed cotton yield increases with the increase in fiber length, fiber strength and fiber fineness in plants with high plant height and boll weight and early squaring. However, it is also noteworthy that the increase in yield due to the high boll number and boll weight makes the fibers coarser. Similar to our results, Srinivas et al. (2015), Abdullah et al. (2016), Ahmad et al. (2017), Nikhil et al. (2018), Deshmukh et al. (2019) and Kumar et al. (2019) emphasized that boll number and boll weight had a positive and highest direct effect on the seed cotton yield. On the other hand, Dinakaran et al. (2012) explained that the direct effect of boll weight is high and negative. In the light of both correlation coefficients and direct effects resulting from path analysis, it can be said that the boll number and boll weight are the most important yield components for seed cotton yield.

CONCLUSION

The characters with high heritability, managed by few genes and highly correlated to the target character could be used for rapid screening of segregating populations and indirectly selecting for associated characters with low heritability and genetic advance. The current study showed that boll number, days to first boll opening and boll weight with high heritability coupled with high genetic advance and having positive correlation and direct effect with seed cotton yield should be given priority during selection in cotton breeding. In addition, considering F_2 hybrids, Claudia x AGC-208, Claudia x AGC-85 and MD x AGC-85 exhibited favorable performance for yield and fiber quality.

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