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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Inter-and intrageneration associations for agronomic traits in cotton (*Gossypium hirsutum* L.)

Pamukta (*Gossypium hirsutum* L.) tarımsal özellikler için generasyonlar arası ve generasyon içi ilişkiler

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ABSTRACT

Estimating the performance of late-generation populations in early generations increases breeding achievement but reduces effort. The primary objective of this study was to estimate the extent to which the genetic potentials of the character are transmitted to the next generations through intergenerational correlation. Simple Pearson correlations between traits studied both within and between generations in F_3, F_4, and F_5 multiparental cotton (*Gossypium hirsutum* L.) hybrids were evaluated. Thirteen different hybrid combinations were arranged in a split-plot design in 2022 for the F_3 and F_4 generations and in 2023 for the F_4 and F_5 generations. Basic statistics for generations indicated a decrease in minimum, maximum and mean values from F_3 to F_5 for all traits except fiber fineness. Intergenerational correlations were calculated between F_3 and F_4, and F_4 and F_5. Significant intergenerational correlations were positive for fiber length, fiber strength and seed index and negative for plant height in both $F_{3:4}$ and $F_{4:5}$. Significant and positive correlations were recorded for seed cotton yield, ginning out-turn and fiber fineness only in $F_{4:5}$. It was concluded that many of the F_4 populations with desirable values also performed well in the F_5 generation. Intrageneration correlations indicated that increasing boll number and boll weight for high yield and decreasing seed index for high ginning yield can be effective for selection.

ÖZET

İleri generasyonlardaki popülasyonların performansını erken generasyonlarda tahmin etmek işgücünü azaltarak ıslah başarısını artırmaktadır. İncelenen özelliklerin genetik potansiyellerinin generasyonlar arası korelasyon yoluyla sonraki generasyonlara ne ölçüde aktarıldığını tahmin etmek bu çalışmanın temel amacıydı. Pamukta (*Gossypium hirsutum* L.) F_3, F_4 ve F_5 çok ebeveynli melezlerde basit korelasyon kullanılarak verim, verim bileşenleri ve lif kalitesi parametreleri arasındaki ilişkiler hem generasyonlar içinde hem de generasyonlar arasında araştırılmıştır. 2022 yılında F_3 ve F_4, 2023 yılında ise F_4 ve F_5 generasyonlarında 13 farklı melez kombinasyon Bölünmüş Parseller Deneme Deseninde ekilmiştir. Generasyonlara ilişkin temel istatistikler lif inceliği dışında tüm özellikler için F_3 ten F_5 doğru minimum, maksimum ve ortalama değerlerdeki azalışı gösterdi. F_3-F_4 ve F_4-F_5 olmak üzere generasyonlar arası korelasyonlar saptandı. Generasyonlar arası önemli korelasyonlar, hem $F_{3:4}$ hem de $F_{4:5}$ de lif uzunluğu, lif dayanıklılığı ve tohum indeksi için pozitif, ancak bitki boyu için negatif bulunmuştur. Pozitif ve önemli korelasyonlar sadece $F_{4:5}$'te kütlü pamuk verimi, çırçır randımanı ve lif inceliği için saptanmıştır. Üstün özelliklere sahip F_4 popülasyonlarının çoğunun F_5 generasyonunda da iyi performans sergilediği sonucuna varılmıştır. Generasyon içi korelasyonlar yüksek verim için koza sayısı ve koza ağırlığının artırılmasının ve yüksek çırçır randımanı için tohum indeksinin azaltılmasının seleksiyon için etkili olabileceğini göstermiştir.

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INTRODUCTION

The breeding objectives of cotton, the world's most important natural fiber source, have focused on developing new cotton varieties with high yield, superior fiber quality traits, earliness (Yang et al., 2023), and tolerance to biotic and abiotic stresses (Kamburova et al., 2022). The narrowing of the germplasm genetic base in cotton makes breeding difficult (Anam et al., 2024).

As in all cultivated plants, the general steps of classical breeding in cotton are shown as the creation/combination of variability, selection, evaluation, and variety registration (Acquaah, 2015). It was emphasized that the most commonly used selection methods in cotton breeding are pedigree, reselection, and bulk (Bowman, 2000). The pedigree selection method allows the selection of the best traits with high heritability, whereas to improve traits with low heritability, such as yield, the bulk-pedigree method is applied and selection is performed in later generations (Wynne & Gregory, 1981).

Breeding performance increases when the probability of success of populations in later generations is estimated in early generations (Barut, 1998). Percy (2003) compared pedigree and bulk populations and found that F_2 and pedigree-developed advanced population traits were weakly correlated. The weak correlations between early-generation yield test and later-generation performance test yields were explained by the breeder's selection for fiber quality (Jones & Smith, 2006). It has been reported that if unsuitable lines are discarded as a result of early generation selection for lint percentage, yield, and quality and the selected lines are better evaluated in later generations, a line that breaks the negative relationship between yield and fiber quality characteristics can be obtained (Clement et al., 2015).

It was emphasized that genetic degradation, defective segregation, selective elimination of desirable genes during self-fertilization, and high epistasis level could be the reason for the negative correlation between yield components and fiber quality traits in developed populations (Saha et al., 2004; Zhang et al., 2014). It was stated that the values of the correlation coefficients changed as we progressed from F_3 to F_4, the link between high yield and low quality was broken and yield progressed from F_2 to F_4 without a decrease in quality (Preetha & Raveendren, 2008).

To breed cotton genotypes with high yield and quality, it is necessary to identify yield components that are governed by few genes, have high heritability, and have significant relationships with yield. Several studies with homozygous-homogeneous genotypes have revealed the relationships between traits, but there are very few studies in the segregated generations such as F_3, F_4, and F_5. Therefore, this study aimed to discover the inter-generation correlations in terms of traits and the relationships between traits within generations.

MATERIALS and METHODS

The breeding of the hybrid combinations constituting the material of the study was initiated with a 4 × 3 reciprocal line × tester mating design. According to the results of F_2 generation, diallel crosses were made between the best 10 hybrid combinations. Population characteristics have been described in previous studies (Balcı et al., 2021). This study was initiated with the best F_3 seeds as a result of recurrent selection. The study included bulk populations of 13 different hybrid combinations (Table 1) in F_3 and F_4 generations in 2022 and F_4 and F_5 generations in 2023. In 2021, half of the F_3 seeds obtained were planted and the other half were reserved. Likewise, half of the F_4 seeds obtained in 2022 were planted and F_5 seeds were obtained, while half were reserved for F_4 and F_5 plantings. Thus, trials of two different years, $F_{3:4}$ and $F_{4:5}$, were arranged according to a split-block design with 3 replications. In both years, hybrid combinations were placed in single-row and 6 m long plots. Sowing was performed in the first half of May with 0.7 m × 0.12 m of sowing norm. Cultural practices such as fertilization, irrigation, and pesticides were carried out following cotton cultivation in the Aegean Region.

Meteorological data for the years of the study demonstrated that mean, maximum, and minimum temperatures were higher than long-term temperatures in 2022 (Table 2). Although 2023 temperatures fluctuated, average and maximum temperatures were generally below long-term temperatures, whereas minimum temperatures increased. The April-June period of 2023 was rainy compared to the long term and 2022. The study was conducted in soil with a clayey-loamy texture. The alkaline soil characteristics showed that salt level and organic nitrogen were low, while phosphorus and potassium were high.

Table 1. Code and pedigrees of the hybrids in the study
Çizelge 1. Çalışmada yer alan melez kombinasyonları soyağaçları

Code	**Pedigree**
I	(Julia × ST-468) × (Gloria × Carisma)
II	(Carisma × Carmen) × (Gloria × Flash)
III	(Carmen × ST-468) × (ST-468 × Claudia)
IV	(ST-468 × Claudia) × (Gloria × Flash)
V	(Julia × ST-468) × (Carmen × Carisma)
VI	(Julia × ST-468) × (Gloria × Flash)
VII	(Gloria × Flash) × (Gloria × Flash)
VIII	(Julia × ST-468) × (ST-468 × Claudia)
IX	(Carmen × ST-468) × (Gloria × Carmen)
X	(Julia × ST-468) × (Julia × ST-468)
XI	(Carisma × Carmen) × (Gloria × Carisma)
XII	(Carmen × Carisma) × (Julia × ST-468)
XIII	(Julia × ST-468) × (Carmen × ST-468)

Table 2. Temperature and precipitation data for the trial years and long-term
Çizelge 2. Deneme yıllarına ve uzun döneme ait sıcaklık ve yağış verileri

	Mean Temp. (˚C)			**Maximum Temp. (˚C)**			**Minimum Temp. (˚C)**			**Total Precipitation (mm)**		
	Long	**2022**	**2023**	**Long**	**2022**	**2023**	**Long**	**2022**	**2023**	**Long**	**2022**	**2023**
April	16.18	18.00	15.90	30.48	33.10	26.50	5.27	5.40	5.80	50.22	16.10	53.80
May	21.13	22.60	20.40	35.64	38.10	36.00	9.58	10.20	10.00	37.43	15.50	73.40
June	25.89	27.00	25.60	39.82	38.50	35.80	14.15	18.80	16.20	12.71	70.40	48.80
July	28.62	30.06	31.00	41.34	41.10	40.00	17.87	20.60	19.00	3.43	0.00	4.70
August	28.00	28.89	19.20	40.73	40.60	38.10	18.03	20.80	21.90	3.26	0.03	2.50
September	23.94	25.11	26.50	37.59	38.00	36.50	12.99	11.60	19.90	12.54	0.00	31.10
October	18.83	20.51	21.50	32.81	36.90	28.80	7.72	10.50	18.10	40.02	0.03	6.00

Source: Turkish State Meteorological Service

Each plot was represented by 20 consecutive plants in the harvest period (November 8, 2022, and November 18, 2023). Plant height (cm), monopodial branches per plant (MBN), sympodial branches per plant (SBN), boll number per plant (BN), and boll weight (BW; g) were recorded. The seed cotton yield per plant (SCY) of individual plants was weighed and the mean was calculated (g $plant^{-1}$). In the plots where 20 plants were bulked, ginning out-turn (GOT; %) was determined in the set obtained by bulking single plant seed cotton yields. Fiber fineness (FF; mic), fiber length (FL; mm), and fiber strength (FS; g tex^{-1}) were determined with the device of HVI-1000 (High Volume Instruments) in the fiber analysis laboratory of Nazilli Cotton Research Institute. Basic statistics were calculated using Microsoft Excel®. Correlation coefficients and graphs were obtained with the 'ggally' package (Schloerke et al., 2018) in the R studio (R Studio Team, 2020).

RESULTS and DISCUSSIONS

Seed cotton yield per plant ranged from 46.4 g (F_4 in 2023) to 100.8 g (F_3) and average SCY reduced from F_3 to F_5 (Table 3). The decrease in GOT, FL, FS, BN, BW, SI, and PH from F_3 to F_5 was generally reflected in the minimum, maximum, and mean values. FF remained constant at about 4.8 mic. between generations. When the effect of the year is neglected from F_3 generation to F_5 generation, a negative improvement is observed in all traits examined except fiber fineness with the effect of homozygosity. From F_3 generation to F_5 generation, when the effect of year is ignored, a negative development is observed in all traits examined except fiber fineness with the effect of homozygosity. It can be said that especially the decrease in the number of fruit branches and the number of bolls brings along the decrease in SCY (Worley et al., 1974; Constable & Bange, 2015). From early generations to later generations, variability and performance decrease due to homozygosity and inbreeding depression (Meredith et al., 1979; Cole et al., 2009). In order to examine these changes in more detail, it was concluded that it is useful to evaluate the intergenerational and intra-generational relationships.

Table 3. Summary basic statistics for generations

Çizelge 3. Generasyonlara ilişkin temel istatistikler

Year			SCY (g plant^{-1})	GOT (%)	FL (mm)	FF (mic.)	FS (g tex^{-1})	BN	BW (g)	SI (g)	PH (cm)	MBN	SBN
2022	F3	Min.	63.0	41.2	29.6	4.6	31.4	10.8	5.8	9.8	66.3	0.8	7.9
		Max.	100.8	43.9	31.5	5.1	34.7	13.4	8.3	11.2	77.7	1.4	9.3
		Ave.	87.0	42.6	30.5	4.8	33.1	12.0	7.3	10.6	72.4	1.0	8.5
	F4	Min.	73.7	40.4	29.2	4.5	31.4	10.8	5.7	10.4	63.6	0.8	7.7
		Max.	101.1	42.7	31.5	5.2	33.9	13.7	8.4	11.6	75.3	1.1	9.3
		Ave.	89.3	41.9	30.2	4.9	32.6	12.3	7.3	11.0	70.8	0.9	8.3
2023	F4	Min.	46.4	39.7	28.3	4.6	29.1	7.9	5.8	9.2	54.5	0.5	6.2
		Max.	80.1	42.1	30.8	5.0	33.4	12.4	7.5	10.8	69.4	1.3	7.4
		Ave.	67.0	41.0	29.3	4.8	31.1	10.4	6.5	9.8	63.6	0.9	6.8
	F5	Min.	54.9	39.1	27.4	4.5	29.2	8.3	5.1	9.2	61.1	0.8	5.6
		Max.	82.2	42.7	30.2	5.3	33.7	13.0	7.8	11.5	75.6	1.5	6.4
		Ave.	68.8	40.6	29.1	4.8	31.4	10.5	6.7	10.0	66.0	1.1	6.1

SCY: Seed cotton yield per plant, GOT: Ginning out-turn, FL: Fiber length, FF: Fiber fineness, FS: Fiber strength, BN: Boll number per plant, BW: Boll weight, SI: Seed index, PH: Plant height, MBN: Monopodial branches per plant, SBN: Sympodial branches per plant.

There was a significant and positive intergeneration correlation coefficient in $F_{4:5}$ for seed cotton yield but a non-significant correlation coefficient in $F_{3:4}$ (Table 4). Similarly, intergeneration correlations for fiber length, fiber strength, and seed index were positive and significant but negative and significant for plant height at both F3:4 and $F_{4:5}$. In addition, significant and positive correlation coefficients were found only at $F_{4:5}$ for fiber fineness, but significant and negative correlation coefficients were found only at $F_{3:4}$ for the number of monopodial branches. The fact that the intergenerational correlations found for each trait were different from each other for some traits was explained as the genotypes were not stable and heterozygosity was continued (Abbas et al., 2015; Patil et al., 2017). Inter-generation correlations between $F_{3:4}$ were generally lower than those between $F_{4:5}$. Most of the F_4 populations with high yield and quality traits also performed favorably in the F_5 generation. This result indicated the effectiveness and reliability of bulk selection for these characters (Kumar et al., 2020). On the other hand, for plant height, it was concluded that short genotypes in F_3 may be tall in F_5 or vice versa. Significant and positive intergenerational correlations were reported as an indication of heritability (Lungu et al., 1990; Hannachi et al., 2017; Yadav et al., 2020). Alkuddsi et al. (2013), found positive and significant correlation coefficients for fiber length, fiber fineness, and uniformity between selected F_3 lines and F_5 progeny.

Table 4. Intergeneration correlation coefficients for observed traits in $F_{3:4}$ and $F_{4:5}$

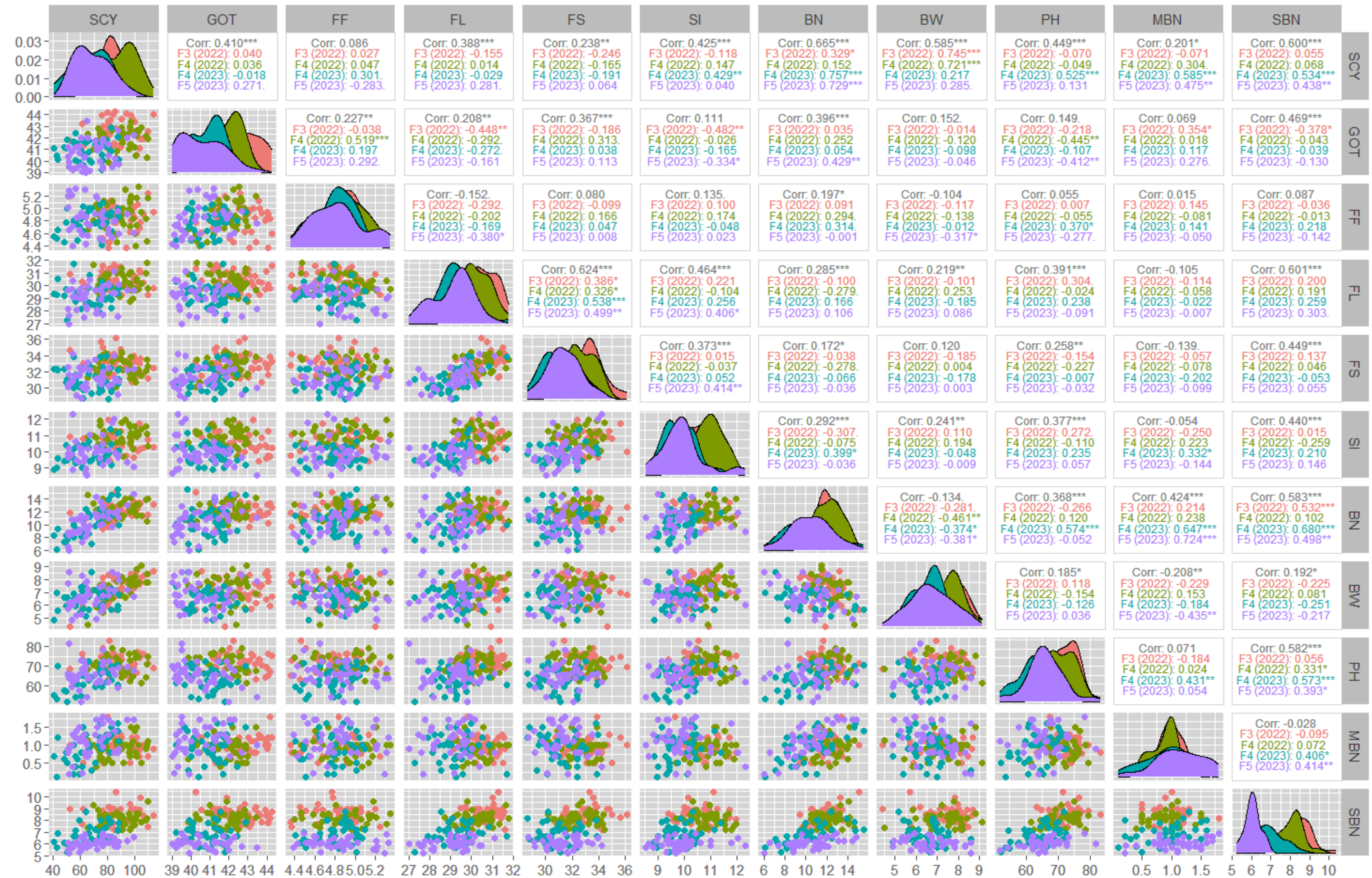
Çizelge 4. $F_{3:4}$ ve $F_{4:5}$'te gözlemlenen özellikler için generasyonlar arası korelasyon katsayıları

Trait	Generation	
	$F_{3:4}$	**$F_{4:5}$**
SCY (g plant^{-1})	0.221	0.457**
GOT (%)	-0.020	0.476**
FL (mm)	0.574**	0.711**
FF (mic)	0.163	0.625**
FS (g tex^{-1})	0.515**	0.726**
BN	-0.021	-0.119
BW (g)	0.050	0.208
SI (g)	0.651**	0.525**
PH (cm)	-0432**	-0.486**
MBN	-0.354**	-0.050
SBN	0.213	0.090

* and ** indicate significance at 5% and 1% level, respectively. SCY: Seed cotton yield per plant, GOT: Ginning out-turn, FL: Fiber length, FF: Fiber fineness, FS: Fiber strength, BN: Boll number per plant, BW: Boll weight, SI: Seed index, PH: Plant height, MBN: Monopodial branches per plant, SBN: Sympodial branches per plant.

In the sum of four sets (F3 and F4 + F4 and F5), significant and positive correlation coefficients were found between seed cotton yield and all traits except fiber fineness (Figure 1). It was observed that the boll number, sympodial branches per plant, and monopodial branches per plant had positive and significant correlations with seed cotton yield in F4:5, whereas boll weight was realized in F3:4. It was reported that selection based on boll number and sympodial branches per plant and boll weight would be beneficial for cotton yield (Rauf et al., 2004; Soomro et al., 2008; Salahuddin et al., 2010). Boll number, sympodial branches per plant, and monopodial branches per plant became prominent with homozygotization. The most effective yield components on yield were determined as boll number and boll weight in early generation (Soliman et al., 2023), ginning out-turn, and fiber length within fiber traits in F_5 generation (Rasheed et al., 2020). Our study findings are consistent with the results of both groups of researchers.

It was reported that ginning out-turn made the greatest contribution to the performance of genotypes in seed cotton yield and was the most important indicator among yield components (Desalegn, 2016). Ginning out-turn had negative and significant correlation coefficients with sympodial branches per plant, fiber length, and plant height in F_3 generation; significant and positive correlation coefficients with boll number in F_5 generation, while it exhibited significant and negative correlations with seed index in both F_3 and F_5 generations. At the same time, there was generally a positive correlation between ginning out-turn and fiber fineness, which was significant in the F_4 generation. The above-mentioned associations indicate that types with short height, and few sympodial branches but carrying many bolls on one sympodial branch will increase the ginning out-turn but this will lead to short and thick fibers. In parallel with our study results, Monisha et al. (2018) reported a negative correlation between ginning yield and plant height, seed index, and all fiber traits. In contrast, Yaqoob et al. (2016), Malik (2018), and Nawaz et al. (2019) found positive and positive correlation coefficients between ginning yield and plant height, monopodial branches per plant, sympodial branches per plant, fiber fineness, and fiber strength.



Seed cotton yield (SCY), ginning out-turn (GOT), fiber length (FL), fiber fineness (FF), fiber strength (FS), boll number per plant (BN), boll weight (BW), seed index (SI), plant height (PH), number of monopodial branches (MBN), number of sympodial branches (SBN).

Figure 1. Correlation matrix among traits

Şekil 1. Özellikler arasındaki korelasyon matrisi

The negative relationships of fiber fineness with boll weight and fiber length were significant only in F_5. It was concluded that heavy bolls positively thinned the fibers, but not both long and fine fibers together. Previous studies have shown that the selection of coarse fibers increases fiber length and fiber strength (Echekwu, 2001). It was emphasized that the selection of genotypes with higher micronaire values indirectly leads to genotypes with fibers of the highest maturity (Reis et al., 2017). There were positive and significant relationships between fiber length and sympodial branches per plant, plant height, boll weight, boll number, seed index, and fiber strength in the sum of four sets ($F_{3:4}$ + $F_{4:5}$), while the positive and significant relationship between fiber length and fiber strength in all generations was noteworthy. The positive and important association between fiber length and fiber strength has been emphasized in many studies (Rao & Gopinath, 2013; Shruti et al., 2020; Çetin & Güvercin, 2022). It was observed that fiber length was positively correlated with a large number of yield components and that long and strong fiber traits were directed together. Fiber strength was significantly and positively correlated with sympodial branches per plant, plant height, boll number, and seed index in all sets, while the relationship with seed index was significant only in F5. In line with our results, the positive and significant effect of seed index on fiber strength has been emphasized in previous studies (Snider et al., 2016; Rathinavel et al., 2017; Nawaz et al., 2019). It was determined that the boll number increased with the increase in plant height, monopodial branches per plant, and sympodial branches per plant, but the increase in the boll number decreased the boll weight.

In conclusion, the study demonstrated that inter-generation correlations between $F_{3:5}$ were found to be higher. Most of the F_3 populations with high yield and fiber quality also performed well in the F_5 generation due to the effectiveness of bulk selection. Also, it was shown that selection based on boll number and sympodial branches per plant and boll weight would be beneficial for seed cotton yield. For the ginning out-turn, it was determined that the seed index should be reduced. However, it was recommended that the optimum values should not be exceeded due to the negative effects of the increase in the mentioned yield components, especially on fiber length and fiber strength.

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STATEMENT OF CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

AUTHOR'S CONTRIBUTIONS

The authors declare that their contributions are equal.

STATEMENT OF ETHICS CONSENT

Ethical approval is not applicable, because this article does not contain any studies with human or animal subjects.

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