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Research Article

Combining ability and heterosis for fiber color and quality in cotton (*Gossypium hirsutum* L.)

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Abstract

The interest in organic cotton (colored) has been increased due to high contamination and environmental pollution during fabric dying process. However, detailed studies are needed to determine the genetic and yield related traits. Eight different cotton genotypes (3 green, 3 brown and 2 white) with known fiber color values were used in the current study to record combining ability and heterosis for fiber colour and quality traits. An 8×8 half diallel hybrid population containing 28 F_1 hybrids was analysed in the experimental area of GAP Agricultural Research Institute, Şanlıurfa, Turkey. The study including parents and hybrids was established in a randomized complete block design with three replications. The main aim was to examine the genetic structure for studied traits in the populations developed and detecting F_1 hybrid vigour. Finding appropriate parent and hybrid combinations for breeding studies was the second major aim of the study. Sufficient variations were noted for the studied traits in hybrid population formed. Genetic parameters such as general and special compatibility abilities, heterosis and heterobeltiosis values were recorded in the formed population. Fiber length (mm), fiber fineness (micronaire), fiber strength (g tex^{-1}), fiber uniformity (%), fiber color values L* (brightness), a* (red-greenness) and b* (yellow-blueness) values were recorded. It was noted that additive genetic effects were important for fiber length, fiber fineness, fiber strength, L*, a* and b* traits.

Keywords: cotton; diallel analysis; fiber color properties; inheritance
Abbreviations: HVI: high volume instrument; GCA: General Combining Ability; SCA: Specific Combining Ability

Introduction

Cotton with colored lint (other than white) is commonly regarded as colored cotton. The colored and white cotton types are found in the nature since the time immemorial. Colored cotton is being grown and used by mankind since 2500 B.C. Colored cotton is receiving increased importance due to eco-friendly character. The awareness regarding the toxicity and pollution caused by synthetic dyes has revived interest in the cultivation of organic cotton. Eco-friendly cotton production can be achieved by growing colored cotton, which would reduce the impact of harmful chemicals used in dying and processing on the environment. Positive impacts on human health, reduced environmental pollution and fabric production cost are some of

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the advantages of colored cotton (Handayani *et al.*, 2018; Singh *et al.*, 2001). However, low yield, low quality fiber, limited colors, unstable color distribution, contamination, and low market demand are the disadvantages associated with colored cotton (Gotmare *et al.*, 2021).

The main target of plant breeding studies is to develop the crop varieties that are resistant to diseases and pests, early maturing, have good adaptability to adverse environmental conditions, efficiently use resources and produce superior quality. The methods of introduction, selection, hybridization and mutation are used to achieve/introduce these traits in target crop plants (Kaiser *et al.*, 2020).

Hybridization is one of the plant breeding methods aimed at gathering the desired characteristics of two or more lines, varieties, or species in one variety. Sometimes, the new combination of genetic factors because of crossing can lead to the emergence of new and desired characters that were absent in the parents (Şehirali and Özgen, 2013). Crossbreeding is a gene transfer under natural conditions; however, it is impossible to prevent unwanted genes' transfer to next generation (Oğlakçı and Tiryaki, 2014). Crossbreeding includes detailed studies including selection of lines, performing crossbreeding and processing of crossbred materials (Şehirali and Özgen, 2013). Top cross, line × tester, diallel (double match), three way (triallel) and double-way cross methods are used for the choice of parents (Oğlakçı and Tiryaki, 2014).

Diallel analysis method has many advantages for determining the adaptability of the parents used in crossing with the information obtained in F_1 generation, selection of appropriate parent for the desired character, and revealing the genetic structure of the hybrid population (Çiçek and Kaynak, 2008). Diallel analysis method is widely used in many plant species (both self and cross-pollinated). This method is used to investigate the genetic structures of hybrid populations, select promising hybrid combinations and suitable parents, and determine general and specific combination abilities. Two types of analysis, i.e. "Jinks-Hayman" and "Griffing" type of diallel analysis method have been developed to achieve this goal (Yıldırım *et al.*, 1979).

Colour is the basic criterion for cotton grade classification according to Universal Cotton Standards (Matusiak and Walawska, 2010). Color grade is one of the major components of current cotton classification system. Reproducibility and spatial uniformity of the color imeter's data are reported, and the results are directly compared to colorimeters and human classers (Xu et al., 1998). Information about cotton color distributions in the CIE (The International Commission on Illumination) L*, a*, b* is critical for developing new cromatic technology of color grading, since this is more standardized system than Rdab system currently used in the cotton industry (Xu and Huang, 2001). Fiber color parameters are L*(L=0 black, L= 100 white), a*: red- green (+ red, - green); b*: indicates yellow-blue (-+ yellow, - blue).

The aim of this study was to determine the general combination abilities of parents, special combination abilities of hybrids, and heterosis and heterobeltiosis effects in terms of fiber quality and color characteristics of the population created from genetic analysis in genotypes with different colored fibers.

Materials and Methods

Biological material and experimental design

Three green (GS-223, GS-372, GS-741), three brown (GS-416, GS-273, GS-675) and two white (Candia, ST-498) colored genotypes were used as parents. The population formed 28 F_1 hybrid combinations obtained from half diallel mating design. The study was conducted in the experimental fields of GAP Agricultural Research Institute, Şanlıurfa, Turkey. The hybrids were produced during 2019 in accordance with the 8×8 half diallel analysis method, without reciprocating. All parents (8) and F_1 crosses (28) were planted according to randomized complete block design with three replications at the same experimental area on 14 May 2020. The study was conducted according to Griffing (1956), Method II, Model I (Singh and Chaudhary, 1985). The climate data the study area is given in Table 1. Similarly, soil characteristics of the experimental area are given in Table 2.

Table 1. Climatic data of experimental site for the crop year and long-term average (1929-2020)

Months	Minimum Temperature (˚C)		Average Temperature (˚C)		Maximum Temperature (˚C)		Rainfall (mm)	
	2020	**Long Term**	**2020**	**Long Term**	**2020**	**Long Term**	**2020**	**Long Term**
January	2.8	2.0	4.5	5.6	11.8	9.9	25.2	87.5
February	2.5	2.9	4.9	7.0	12.5	11.9	40.6	69.0
March	7.5	5.8	10.5	10.9	19.8	16.4	83.6	63.2
April	9.7	10.3	14.02	16.2	24.2	22.3	18.4	50.0
May	14.6	15.2	20.09	22.2	31.0	28.7	0.2	26.8
June	18.9	20.5	25.9	28.1	36.5	34.6	0.0	4.3
July	24.1	24.3	29.8	32.0	41.6	38.8	0.0	2.0
August	22.0	23.9	27.0	31.5	39.7	38.4	0.0	3.4
September	19.7	20.0	24.9	27.2	38.3	34.0	0.2	4.6
October	12.9	14.5	18.8	20.6	32.2	27.1	0.0	26.5
November	0.8	8.4	10.5	13.1	18.3	18.7	72.2	45.1
December	4.9	4.0	6.3	7.6	13.7	12.0	5.7	80.9

Turkish State Meteorological Service.

Table 2. Chemical properties of experimental soil

Texture	pH	$CaCO_3$ (%)	P_2O_5 (kg da^{-1})	Organic Mat. (%)	Water Saturation (%)
Clay	7.63	28.1	1.56	2.02	74

GAP Agricultural Research and Institute laboratory analysis, Şanlıurfa

Experimental procedures, collecting data and qualitative analysis

The length of the experimental unit was 10 m and 1 row was cultivated in each plot. The row-to-row and plant-to-plant spacing was 70 and 20 cm, respectively. All agronomic practices were kept optimum according to the regional recommendations. The crop was fertilized with 170 kg ha^{-1} N and 60 kg ha^{-1} ($P_2 0_5$). All plots were irrigated 6 times and the last irrigation was done on 4 September 2020. Weeds were controlled with a milling machine (with shaft) 2 times and a lister machine 3 times before planting and after emergence, respectively. Insecticide was used to control thrips (*Thrips tabaci*), spider mite (*Tetranychus urticae*), aphids (*Aphis gossypii*), *Empoasca* and *Helicoverpa armigera*. The crop was manually harvested two times. The first and second harvest was done on 9 and 28 October 2020, respectively.

Data relating to fiber length (mm), fiber fineness (micronaire), fiber strength (g tex^{-1}), and uniformity (%) were recorded by using USTER HVI 1000 device at Fiber Quality Analysis Laboratory, Nazilli Cotton Research Institute, Aydın, Turkey. Fiber colour brightness L*, fiber color a*, and fiber color b* values were measured with ColorFlex EZ Spectrophotometer device at Plant Physiology Laboratory, Faculty of Agriculture, Dicle University, Diyarbakır, Turkey.

Statistical procedures

Pre-variance analysis was performed for fiber length, fiber fineness, fiber strength, fiber uniformity, and L*, a* and b* values. Differences between parents and their hybrids were observed. Validity of previously accepted assumptions in the diallel cross analysis was checked (Hayman 1954) where significant differences were noted among parents and crosses. Genetic analyses were performed with the help of TarPopGen (Özcan and Açıkgöz, 1999) statistical package program. The effects of parents General Combining Ability (GCA) variance in terms of the traits examined and the effects of variance on the Specific Combining Ability (SCA) of hybrids were calculated and evaluated using the half diallel analysis method described by Method II, Model-

I (Griffing, 1956). Heterosis and heterobeltiosis values were calculated for each trait and evaluated according to Hallauer and Miranda (1981).

Results and Discussion

The mean values of the studied traits are given in Table 3, whereas results of analysis of variance are summarized in Table 4. General Combining Ability (GCA) of parents is given in Table 5, Specific Combining Ability (SCA) of hybrid combinations is given in Table 6, and heterosis and heterobeltiosis values are given in Table 7.

Table 3. Mean values for parents and hybrid combinations

	Genotypes	Fiber length (mm)	Fiber fineness (mic)	Strength (g tex^{-1})	Uniformity (%)	L*	a*	b*
Parents	GS 223	26.43	2.80	19.43	78.70	61.34	-2.09	20.16
	GS 372	26.90	2.79	23.90	80.63	56.62	-1.37	14.10
	GS 416	25.43	4.60	24.60	82.27	50.84	9.95	23.21
	GS 273	25.09	5.45	24.93	82.03	58.62	6.32	18.80
	GS 675	26.89	4.96	24.47	80.70	53.12	8.35	78.36
	GS 741	24.17	3.52	23.07	80.10	59.42	-2.35	15.51
	Candia	31.96	4.82	35.33	86.50	81.29	0.30	8.51
	Stoneville 498	30.18	5.79	33.00	84.60	81.95	0.43	8.59
Hybrid combinations	GS-223 × GS-372	26.85	2.84	22.57	81.10	57.75	-1.45	20.05
	GS-223 × GS-416	28.65	4.27	27.87	82.30	60.71	5.46	19.45
	GS-223 × GS-273	28.56	4.71	28.67	83.67	64.48	-1.38	14.22
	GS-223 × GS-675	36.86	4.24	33.57	88.13	58.94	4.94	17.85
	GS-223 × GS-741	26.57	3.06	23.17	80.93	60.35	-3.11	15.84
	GS-223 × Candia	30.35	4.33	32.03	84.33	64.94	-2.49	11.83
	GS-223 × ST-498	29.16	4.28	30.63	83.73	68.37	-2.07	11.10
	GS-372 × GS-416	27.18	4.09	27.63	81.97	59.96	4.68	19.44
	GS-372 × GS-273	26.98	4.25	28.70	81.17	60.25	-1.82	14.06
	GS-372 × GS-675	32.16	3.98	32.00	84.90	54.06	3.85	19.37
	GS-372 × GS-741	26.12	3.35	24.83	81.53	54.81	-2.07	16.45
	GS-372 × Candia	28.51	3.77	32.03	84.40	62.69	-2.69	12.06
	GS-372 × ST-498	27.80	4.18	30.23	83.97	64.25	-1.91	11.95
	GS-416 × GS-273	24.60	5.74	26.10	82.47	53.34	9.31	22.17
	GS-416 × GS-675	33.18	4.63	33.93	85.00	56.79	7.02	19.98
	GS-416 × GS-741	26.09	4.82	28.67	81.60	56.04	5.07	18.32
	GS-416 × Candia	30.04	4.78	32.00	83.83	66.79	5.57	17.32
	GS-416 × ST-498	28.43	4.82	30.63	84.57	64.46	5.84	17.59
	GS-273 × GS-675	33.00	4.56	31.67	84.87	55.83	6.10	19.17
	GS-273 × GS-741	25.47	4.87	27.73	82.73	60.85	-0.38	12.47
	GS-273 × Candia	30.55	5.06	31.83	85.47	74.34	2.02	11.96
	GS-273 × ST-498	29.72	4.83	34.60	84.90	75.54	2.14	12.32
	GS-675 × GS-741	33.73	4.30	33.97	86.10	54.28	4.48	17.38
	GS-675 × Candia	34.55	4.69	34.63	86.97	57.15	5.86	18.74
	GS-675 × ST-498	35.31	4.52	35.27	87.10	59.00	5.75	18.19
	GS-741 × Candia	30.48	4.70	33.07	86.67	64.48	-2.12	10.64
	GS-741 × ST-498	28.92	4.80	31.63	84.87	62.44	-1.57	12.26

	Candia × ST-498	31.62	5.30	34.17	86.43	82.33	0.64	9.77
	Parent Means	27.13	4.34	26.09	81.94	62.90	2.44	23.41
	F_1 Means	29.69	4.42	30.49	84.13	61.97	1.99	15.78

Fiber length, fiber fineness, fiber strength, L*, a* and b* were significantly affected. In terms of fiber length, fiber fineness, fiber strength, L*, a* and b* properties, the effects of general and specific combining ability were significant at the 1% level (Table 4).

Table 4. Analysis of variance for genotypes and combining ability for investigated traits

Source of variation	DF	Fiber length	Fiber fineness	Fiber strength	Uniformity	L*	a*	b*
Replication	2	0.18	0.01	0.34	1.96	1.50	0.06	307.18
Genotypes	35	396.82**	10.86**	380.02**	3584.90**	2197.02**	18.01**	604.38**
Error	70	0.19	0.01	0.66	0.49	4.39	0.25	311.14
GCA	7	150.03**	4.31**	147.45**	1345.47**	849.25**	11.08**	317.71**
SCA	28	148.28**	3.97**	140.39**	1343.85**	813.01**	4.90**	187.62**
Error	70	0.06	0.00	0.22	0.16	1.46	0.08	103.71
σ^2GCA/ σ^2SCA		1.012	1.085	1.050	1.001	1.045	2.261	1.693

σ^2GCA: variance of general combining ability, σ^2SCA: variance of specific combining ability * and **: significant at P ≤ 0.05 and P ≤ 0.01 respectively; DF: Degrees of freedom

Table 5. Predicted General Combining Ability effects (GCA) for investigated traits

Parents	Fiber length	Fiber fineness	Fiber strength	Uniformity	L*	a*	b*
GS-223	-0.140	-0.308	-1.332	-0.648	-0.313	-0.907	-0.649
GS-372	-0.046	-0.310	-0.438	-0.262	-1.256	-0.762	-1.862
GS-416	-0.340	0.052	-0.298	0.065	-2.413	1.501	-0.038
GS-273	-0.408	0.222	-0.232	0.018	-0.855	0.776	-0.921
GS-675	-0.049	0.124	-0.325	-0.248	-1.957	1.182	10.992
GS-741	-0.592	-0.164	-0.605	-0.368	-0.695	-0.959	-1.579
Candia	0.966	0.096	1.848	0.912	3.677	-0.428	-2.980
ST-498	0.610	0.289	1.382	0.532	3.811	-0.403	-2.963
SE (g_i)	0.074	0.016	0.139	0.120	0.358	0.085	3.012

SE: Standard error, * and **: significant at P ≤0.05 and P ≤0.01 respectively

Table 6. Predicted Specific Combining Ability effects (SCA) for investigated traits

Hybrid combinations	Fiber length	Fiber fineness	Fiber strength	Fiber uniformity	L*	a*	b*
GS-223 × GS-372	-5.843	-0.347	-4.028	-17.299	-12.409	1.126	-2.690
GS-223 × GS-416	-5.549	-0.709	-4.168	-17.626	-11.253	-1.137	-4.514
GS-223 × GS-273	-5.481	-0.879	-4.235	-17.579	-12.810	-0.412	-3.631
GS-223 × GS-675	-5.840	-0.781	-4.141	-17.313	-11.709	-0.818	-15.544
GS-223 × GS-741	-5.297	-0.493	-3.861	-17.193	-12.970	1.323	-2.973
GS-223 × Candia	-6.855	-0.753	-6.315	-18.473	-17.343	0.792	-1.572
GS-223 × ST-498	-6.499	-0.946	-5.848	-18.093	-17.476	0.767	-1.589
GS-372 × GS-416	-5.643	-0.707	-5.061	-18.013	-10.309	-1.282	-3.301
GS-372 × GS-273	-5.576	-0.877	-5.128	-17.966	-11.867	-0.557	-2.418

GS-372 × GS-675	-5.935	-0.779	-5.035	-17.699	-10.765	-0.963	-14.331
GS-372 × GS-741	-5.391	-0.491	-4.755	-17.579	-12.027	1.178	-1.760
GS-372 × Candia	-6.949	-0.751	-7.208	-18.859	-16.399	0.647	-0.360
GS-372 × ST-498	-6.594	-0.944	-6.741	-18.479	-16.533	0.622	-0.376
GS-416 × GS-273	-5.281	-1.238	-5.268	-18.293	-10.710	-2.820	-4.242
GS-416 × GS-675	-5.640	-1.141	-5.175	-18.026	-9.609	-3.226	-16.154
GS-416 × GS-741	-5.097	-0.852	-4.895	-17.906	-10.870	-1.084	-3.584
GS-416 × Candia	-6.655	-1.112	-7.348	-19.186	-15.243	-1.616	-2.183
GS-416 × ST-498	-6.299	-1.305	-6.881	-18.806	-15.376	-1.640	-2.200
GS-273 × GS-675	-5.573	-1.311	-5.241	-17.979	-11.166	-2.501	-15.272
GS-273 × GS-741	-5.029	-1.022	-4.961	-17.859	-12.427	-0.360	-2.701
GS-273 × Candia	-6.587	-1.282	-7.415	-19.139	-16.800	-0.891	-1.300
GS-273 × ST-498	-6.232	-1.475	-6.948	-18.759	-16.933	-0.916	-1.317
GS-675 × GS-741	-5.388	-0.925	-4.868	-17.593	-11.326	-0.766	-14.614
GS-675 × Candia	-6.946	-1.185	-7.321	-18.873	-15.699	-1.297	-13.213
GS-675 × ST-498	-6.591	-1.378	-6.855	-18.493	-15.832	-1.322	-13.230
GS-741 × Candia	-6.403	-0.896	-7.041	-18.753	-16.960	0.844	-0.642
GS-741 × ST-498	-6.047	-1.089	-6.575	-18.373	-17.093	0.820	-0.659
Candia × ST-498	-7.605	-1.349	-9.028	-19.653	-21.466	0.288	0.742
SE (S_{ij})	0.197	0.043	0.370	0.320	0.954	0.227	8.033

SE: Standard error, * and **: significant at P ≤ 0.05 and P ≤ 0.01 respectively

Table 7. Heterosis and heterobeltiosis of F_1 hybrid combinations for investigated traits

Hybrid Combinations	Fiber Length		Fiber Fineness		Fiber Strength		Fiber Uniformity		L*	a*		b*		
	Ht (%)	Hb (%)	Ht (%)	Hb (%)	Ht (%)	Hb (%)	Ht (%)	Hb (%)	Ht (%)	Hb (%)	Ht (%)	Hb (%)	Ht (%)	Hb (%)
GS-223 × GS-372	0.67	-0.21	1.49	1.31	4.15	-5.58	1.80	0.58	-2.09	-94.19	-16.10	611.93	31.75	-567.19
GS-223 × GS-416	10.49	8.40	15.26	-7.25	26.57	13.28	2.26	0.04	8.24	-59.73	38.91	74.00	28.50	-357.30
GS-223 × GS-273	10.88	8.07	14.05	-13.64	29.23	14.97	4.11	1.99	7.50	-43.53	-165.20	399.69	47.16	-315.93
GS-223 × GS-675	38.26	37.08	9.18	-14.57	52.92	37.19	10.58	9.21	3.00	18.71	57.85	566.62	-31.86	-76.12
GS-223 × GS-741	5.03	0.54	-3.11	-12.97	9.02	0.43	1.93	1.04	-0.05	-73.93	39.83	-685.88	29.89	-466.70
GS-223 × Candia	3.94	-5.05	13.69	-10.10	16.98	-9.34	2.10	-2.50	-8.93	-82.43	178.36	-3612.88	123.49	-508.86
GS-223 × ST-498	3.00	-3.40	-0.27	-25.98	16.85	-7.17	2.55	-1.02	-4.58	-74.74	149.30	188.64	113.10	-470.71
GS-372 × GS-416	3.86	1.02	10.73	-11.01	13.95	12.33	0.63	-0.36	11.60	-91.20	9.01	-132.61	48.13	-492.86
GS-372 × GS-273	3.76	0.27	3.03	-22.08	17.54	15.11	-0.20	-1.06	4.56	-88.59	-173.44	-181.21	74.49	-571.24
GS-372 × GS-675	19.56	19.53	2.62	-19.81	32.32	30.79	5.25	5.20	-1.47	-47.73	10.31	197.66	-30.78	-160.91
GS-372 × GS-741	2.28	-2.91	6.02	-4.92	5.75	3.91	1.45	1.12	-5.53	-94.93	11.11	453.72	67.76	-712.06
GS-372 × Candia	-3.14	-10.81	-0.88	-21.72	8.16	-9.34	1.00	-2.43	-9.08	-96.27	406.58	-3207.55	183.44	-782.94
GS-372 × ST-498	-2.60	-7.90	-2.56	-27.76	6.27	-8.38	1.63	-0.75	-7.27	-94.02	305.67	-42.27	166.53	-767.00
GS-416 × GS-273	-2.62	-3.26	14.23	5.32	5.38	4.68	0.39	0.24	-2.55	-103.41	14.48	-158.00	24.25	-545.48
GS-416 × GS-675	26.83	23.39	-3.24	-6.78	38.32	37.94	4.32	3.32	9.25	-19.23	-23.24	266.39	-33.19	-124.54
GS-416 × GS-741	5.20	2.60	18.80	4.86	20.28	16.53	0.51	-0.81	1.66	-81.67	33.45	-22.66	48.06	-451.83
GS-416 × Candia	4.68	-6.02	1.49	-0.83	6.79	-9.43	-0.65	-3.08	1.10	-95.08	8.62	-248.33	101.77	-509.59
GS-416 × ST-498	2.25	-5.80	-7.19	-16.71	6.37	-7.17	1.36	-0.04	-2.91	-84.70	12.53	-104.95	92.64	-464.90
GS-273 × GS-675	26.98	22.75	-12.42	-16.33	28.21	27.01	4.30	3.45	-0.07	-38.09	-16.92	203.64	-34.82	-148.61
GS-273 × GS-741	3.39	1.49	8.58	-10.64	15.56	11.23	2.06	0.85	3.09	-72.24	-119.14	142.06	61.66	-484.26
GS-273 × Candia	7.08	-4.42	-1.53	-7.22	5.64	-9.91	1.42	-1.19	6.27	-86.68	-39.03	-287.96	133.15	-561.08
GS-273 × ST-498	7.54	-1.52	-14.03	-16.53	19.45	4.85	1.90	0.35	7.47	-64.13	-36.59	67.49	152.65	-441.13
GS-675 × GS-741	32.13	25.45	1.30	-13.43	42.92	38.83	7.09	6.69	-3.54	-7.27	49.44	427.02	-27.63	-109.28
GS-675 × Candia	17.42	8.10	-4.12	-5.51	15.83	-1.98	4.03	0.54	-14.96	-73.80	35.46	-60.75	-20.26	-194.17
GS-675 × ST-498	23.75	17.00	-15.97	-21.95	22.74	6.87	5.38	2.96	-12.64	-52.59	31.06	236.14	-18.88	-167.11
GS-741 × Candia	8.59	-4.64	12.79	-2.42	13.24	-6.42	4.04	0.19	-8.35	-76.72	106.50	-1653.77	175.36	-594.63
GS-741 × ST-498	6.43	-4.17	3.15	-17.05	12.84	-4.14	3.06	0.32	-11.67	-75.94	62.98	650.46	162.52	-589.65
Candia × ST-498	1.75	-1.07	0.00	-8.35	0.00	-3.30	1.03	-0.08	0.87	-95.91	76.26	-1348.72	299.69	-1216.48
Means	9.55	4.09	2.54	-11.57	17.62	6.92	2.69	0.88	-1.11	-69.64	37.43	-259.36	70.31	-459.02

Min.	-3.14	-10.81	-15.97	-27.76	0.00	-9.91	-0.65	-3.08	-14.96	-103.41	-173.44	-3612.88	-34.82	-1216.48
Max.	38.26	37.08	18.80	5.32	52.92	38.83	10.58	9.21	11.60	18.71	406.58	650.46	299.69	-76.12

Ht: Heterosis; Hb: Heterobeltiosis

Fiber length (mm)

Fiber length values varied between 24.60 mm and 36.86 mm in F_1 hybrid combinations. The highest fiber length (36.86 mm) was noted for GS-223 × GS-675, whereas the lowest (24.60 mm) value was noted for GS-416 × GS-273 (Table 3). The highest (+0.966) general combining ability (GCA) was noted for Candia and the lowest value (-0.592) was noted for GS-741 parent (Table 5). Since GCA effects of Candia and ST-498 parents were significant, these are suitable parents for high fiber length. The highest specific combining ability (SCA) in hybrid combinations was -5.029, while the lowest SCA effect was -7.605 (Table 6). The highest heterosis value (38.26%) and the highest heterobeltiosis value (37.08%) were recorded for GS-223 × GS-675 hybrid combination (Table 7). The average rate of heterosis and heterobeltiosis in hybrid combinations indicates that heterotic effects are not significant enough. The SCA effects of GS-223 × GS-675, GS-675 × GS-741, GS-675 × Candia, GS-675 × ST-498 hybrid combinations are significant and heterosis and heterobeltiosis values were high. It gives the impression that these are promising materials for increase this trait.

The GCA and SCA effects were significant for fiber length, and ratio of GCA to SCA variance was >1 (Table 4), which shows that additive gene effects were more effective in the management of this trait. This reveals the idea that individual selection may be more appropriate in the early generation (F_2-F_3).

Several studies on fiber length trait indicated that additive gene effects are important in the management of this trait. The results of the current study are similar to several earlier studies (Meredith and Bridge, 1972; Singh and Chaudhary, 1985; Kanoktip 1987; Gülyaşar 1987; Luckett 1989; Tariq et al. 1992; Ünay 1993; Temiz 2003; Karademir, 2005; Çiçek and Kaynak, 2008; Karademir *et al.*, 2009; Akgöl, 2012; Ekinci and Başbağ, 2018; Gergerli *et al.*, 2018; Ünay, 1993; Subhan *et al.*, 2003; Güngör and Efe, 2016). Ünay *et al.* (2019) reported that non-additive gene effects were more effective in terms of fiber length. This situation might be attributed to differences among populations.

Fiber fineness (mic.)

Fiber fineness values varied between 2.84 and 5.74 mic. The highest value (5.74 mic.) was recorded for GS-416 × GS-273 combination, whereas GS-223 × GS-372 combination resulted in the lowest (2.84 mic.) value for fiber fineness (Table 3). The highest (+0.289) GCA effect was noted for ST-498 and the lowest (-0.310) for GS-372 parent (Table 5). The GCA effects of GS-416, GS-273, GS-675, Candia and ST-498 parents were significant showing that these are suitable parents for low fiber fineness. The highest and the lowest SCA effect in hybrid combinations was -0.347 and -1.475, respectively (Table 6). The highest (18.80%) heterosis value was noted for GS-416 × GS-741 hybrid combination and the highest (5.32%) heterobeltiosis value was recorded for GS-416 × GS-273 combination (Table 7). An average 2.54% heterosis and -11.57% heterobeltiosis values in hybrids combinations indicated that heterotic effects wer not significant enough. Since the effects of GCA and SCA were significant for fiber fineness, and the ratio of the GCA to SCA variance was greater than +1 (Table 4), additive gene effects are more effective in the management of fiber fineness.

According to SCA effects, GS-416 × GS-273 and GS-416 × GS-741 hybrid combinations are important with high heterosis and heterobeltiosis values. These combinations are promising in cotton breeding studies to increase fiber fineness. In the population formed the fact that additive gene effects are more effective in fiber fineness trait.

The earlier studies on fiber fineness trait indicated that additive gene effects are important in its management. The results of the current study are similar to several earlier findings (Kanoktip, 1987; Gülyaşar, 1987; Luckett, 1989; Al-Enani and Atta, 1990; Ünay, 1993; Toklu, 1999; Temiz, 2003; Karademir, 2005; Karademir *et al.*, 2009; Akgöl, 2012; Güngör and Efe, 2016; Gergerli *et al.*, 2018; Ünay *et al.*, 2019). However, results are different from Çiçek and Kaynak (2008) and Ekinci and Başbağ (2018), who stated that both additive and dominant gene effects are more effective in terms of the formation of the specified feature.

Fiber strength (g tex^{-1})

Fiber strength values varied between 22.57 and 35.27 g tex^{-1}. The highest (35.27 g tex^{-1}) and the lowest (22.57 g tex^{-1}) fiber strength values were recorded for GS-675 × ST-498 and GS-223 × GS-372 hybrid combinations, respectively (Table 3). Similarly, the highest (+1.848) and the lowest (-1.332) GCA effects were observed for Candia and GS-223 parents, respectively (Table 5). The GCA effects of Candia and ST-498 parents were significant, which indicated that these parents can be used as suitable parents to improve fiber strength.

The highest and the lowest SCA effects for hybrids were -3.861 and -9.028, respectively (Table 6). The highest (52.92%) and the lowest (38.83%) heterosis values were recorded for GS-223 × GS-675 and GS-675 × GS-741 hybrid combinations, respectively (Table 7). The SCA effects of GS-416 × GS-675, GS-273 × ST-498, GS-675 × GS-741, GS-675 × ST-498 and Candia × ST-498 hybrid combinations for fiber fineness indicated that these are promsing for improving this trait.

The GCA and SCA effects were significant for fiber strength and the ratio GCA to SCA variance was greater than +1 (Table 4).

Earlier studies on fiber strength trait reported that additive gene effects are important in management of this trait. Our results are similar to earlier studies in this regard (Kanoktip, 1987; Gülyaşar, 1987; Luckett, 1989; Cheatham *et al.*, 2003; Temiz, 2003; Çiçek and Kaynak, 2008; Akgöl, 2012; Güngör and Efe, 2016; Ekinci and Başbağ, 2018; Gergerli *et al.*, 2018). However, our results are also in contrast with several earlier studies reporting opposite findings (Al-Enani and Atta, 1990; Toklu, 1999; Karademir, 2005; Karademir *et al.*, 2009; Kumar *et al.*, 2013; Ünay *et al.*, 2019).

Fiber uniformity (%)

Fiber uniformity values ranged from 80.93% to 88.13%. The highest and the lowest fiber uniformity values were noted for GS-223 × GS-675 and GS-223 × GS-741 hybrid combinations, respectively (Table 3). The highest and the lowest GCA effects were recorded for Candia and GS-223 parent, respectively (Table 5). The highest and the lowest SCA values were -17.193 and -19.653, respectively (Table 6).

The highest heterosis and heterobeltiosis values were noted for GS-675 × GS-741 hybrid combination (Table 7). The SCA effects of GS-416 × GS-675, GS-273 × ST-498, GS-675 × GS-741, GS-675 × ST-498 and Candia × ST-498 hybrid combinations and their high heterosis and heterobeltiosis values indicated these combinations are useful for increasing fiber uniformity.

Our findings on fiber uniformity feature show that both additive and non-additive gene effects are important. Numerous studies (Meredith and Bridge, 1972; Luckett, 1989; Temiz, 2003) reported that additive gene effects are more effective in terms of the formation of the specified feature. On the other hand, (Toklu, 1999; Karademir, 2005; Karademir *et al.*, 2009; Güngör and Efe, 2016) stated that non additive gene effects are more effective in terms of the formation of the specified feature.

L (Fiber Colour Brightness)*

Fiber color brightness (L*) values ranged from 53.34 to 82.33. The highest and the lowest L* value were noted for Candia × ST-498 and GS-416 × GS-273 hybrid combinations, respectively (Table 3). Likewise, the highest and the lowest GCA effects were recorded for ST-498 and GS-416 parents, respectively (Table 5). The fact that the GCA effects of Candia and ST-498 parents are significant; these parents can be used as suitable parents in cotton breeding studies for high fiber uniformity. On the other hand, GS-223, GS-372, GS-416, GS-273, GS-675 and GS-741 parents can be used as suitable parents for low L* values.

The highest heterosis value was recorded for GS-372 × GS-416 and the highest heterobeltiosis value was noted for GS-223 × GS-675 hybrid combination (Table 7). The mean heterosis rate (-1.11%) and heterobeltiosis rate (-69.64%) in hybrid combinations indicated that heterotic effects were not significant enough. The SCA effects of GS-223 × GS-675, GS-675 × GS-741, GS-675 × Candia and GS-675 × ST-498 hybrid combinations indicated that these are promising to increase L* trait.

The GCA and SCA effects and ration of their variance for L* was greater than +1 (Table 4). This shows that additive gene effects are more effective in the management of this trait.

Red-Green (a)*

The fiber color a* values varied between -3.11 and 9.31. The highest and the lowest fiber color a* values were recorded for GS-416 L × GS-273 and GS-223 × GS-741 hybrid combinations, respectively (Table 3). Similarly, the highest and the lowest GCA effects were noted for GS-416 andGS-741 parents, respectively (Table 5). The highest and the lowest SCA effect was +1.323 and -3.226, respectively (Table 6).

The highest heterosis value was noted for GS-372 × Candia hybrid combination (Table 7). The SCA effects of GS-223 × GS-675, GS-675 × GS-741, GS-675 × Candia and GS-675 × ST-498 hybrid combinations for fiber color a* indicated that these are the suitable combinations for improving this trait.

Yellow-blue (b)*

Fiber color b* values varied between 9.77 and 22.17. The highest and the lowest fiber color b* value were noted for GS-416 × GS-273 and Candia × ST-498 hybrid combinations, respectively (Table 3). Similarly, the highest and the lowest GCA effects were recorded for GS-675 and Candia parents, respectively (Table 4). The GS-675 parent can be used as suitable parent in cotton breeding studies in terms of high fiber color b* value. The highest and the lowest SCA effects were +0.742 and -16.154, respectively (Table 6).

The highest heterosis value was noted for Candia × ST-498 and the highest heterobeltiosis value was noted for GS-223 × GS-675 hybrid combination (Table 7). The SCA effects of GS-223 × GS-675, GS-675 × GS-741, GS-675 × Candia and GS-675 × ST-498 hybrid combinations for fiber color b* indicated that these can be used for improving this trait.

Conclusions

The highest heterosis value was noted for fiber length, fiber strength, a* and b*. Candia and ST-498 proved better parents for fiber length, fiber strength, fiber colour L* properties. Similarly, GS-223, GS-372, GS-741 were good parents for fiber fineness, whereas Candia, ST-498, GS-416, GS-273 seemed better parents for fiber uniformity. Likewise, GS-416, GS-273, GS-675 proved better parents for fiber color a*, while GS-675 proved better parent for of fiber color b*. Hybrid combinations GS-223 × GS-675, GS-675 × GS-741, and GS-675 × Candia had better fiber length. Similarly, GS-675 × ST-498 and GS-223 × GS-372 had higher fiber fineness. Nonetheless, GS-416 × GS-675, GS-273 × ST-498, GS-675 × GS-741, GS-675 × ST-498, and Candia × ST-498 has better fiber strength. Likewise, GS-416 × GS-675, GS-273 × ST-498, GS-675 × GS-741, GS-675 × ST-498, and Candia × ST-498 had better fiber uniformity. In the same way, GS-223 × GS-675, GS-675 × GS-741, GS-675 × Candia, and GS-675 × ST-498 had better fiber color brightness (L*). The hybrid combinations GS-223 × GS-675, GS-675 × GS-741, GS-675 × Candia, and GS-675 × ST-498 resulted in higher fiber color a* values. Similarly, GS-223 × GS-675, GS-675 × GS-741, GS-675 × Candia and GS-675 × ST-498 had better fiber color b*. Hence, these combinations are recommended for use in the improvement of relevant trait.

Authors' Contributions

BÇ, conducted the trial and collected the data. OC and BÇ wrote the draft with together.
Both authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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