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Research Article

Determination of Combining Ability and Heterosis of Some Cotton Crosses

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Abstract:

The present study was carried out at Sakha Agricultural Research Station, Cotton Research Institute, Agricultural Research Center, Egypt, during 2023 and 2024 seasons. The results showed highly significant mean squares due to the genotypes, parents, crosses, parents vs. crosses, lines, tester and line x tester for all studied traits, except Micronair reading for the crosses and boll weight for the testers. Three crosses had the best heterosis effect over both mid and better-parent (Giza 88 x 10229, Giza 96 x 10229 and Giza 96 x Suvine) for the most studied traits. The results also revealed that the lines Giza 86 and Giza 96 were significant desirable GCA effects, while the testers Karshenky and Australy 13 had significant desirable GCA effects for most studied traits. On the other side, the cross combinations Giza 88 x 10229, Giza 89 x Karshenky, Giza 89 x Suvin and Giza 86 x C.B.58 were significant desirable SCA effects for some studied traits. Proportion contribution of lines was higher than testers contribution and lines x tester interaction for all traits studied, except uniformity index for testers. Non-additive of genetic parameters was larger than additive genetic variance with respect to all studied traits. The highest broad sense heritability estimates was observed in case of seed index with values of 88.02% and the lowest was for boll weight with value of 57.68%, while for narrow sense heritability, it was ranged from 5.26% to 17.30% for upper half mean and lint cotton yield/plant, respectively. Generally, Giza 96 and Australy13 could be used in breeding programs for improving high yielding varieties, while Giza 96 and Suvine could be considered as excellent parents for breeding programs to produce new varieties characterized with best fiber properties.

1. Introduction

Line × tester analysis is a modified form of a top cross by Kempthorne (1957) for measuring the combining ability effects of parents and crosses and estimating gene actions of selection criteria in crop breeding (Jain and Sastry, 2012 and Rashid et al., 2013).

The ratio of general and specific combining ability variance (σ^2GCA / σ^2SCA) helps estimate gene action for quantitative traits in line × tester analysis. GCA and SCA components are mainly functions of additive and dominance gene action, respectively.

The concept of combining ability plays a crucial role in the design of plant breeding programs. It is particularly beneficial in testing procedures where the performance of lines in hybrid combinations needs to be evaluated and compared. Combining ability, or productivity in crosses, refers to the capability of parent plants or cultivars to merge effectively during hybridization so that advantageous genes or traits are passed on to their descendants. In quantitative genetics, two types of combining ability are identified: general and specific. Specific combining ability refers to the deviation in hybrid performance from the anticipated productivity based on the average performance of the lines involved in the cross. Meanwhile, general combining ability is defined as the average performance of a line across various crosses. According to Sprague and Tatum (1942), general combining ability arises from genes that largely exhibit additive effects, while specific combining ability is influenced by genes with dominance or epistatic effects.

Al-Hibbiny et al. (2020) demonstrated that the mean squares for both general and specific combining ability were significant for all traits studied, with the exception of micronair reading at specific combining ability. The parental genotypes Giza 96 and Giza 89 exhibited significant and desirable GCA effects for most yield traits. Additionally, Giza 96 and Suvin showed positive GCA effects for certain fiber properties. The hybrid Giza 89 x Pima S4, Giza 96 x Pima S6, and Giza 96 x Suvin displayed notable and positive SCA effects for most yield traits. In contrast, the crosses Giza 89 x Giza 96, Giza 96 x Suvin, and Giza 89 x Suvin revealed significant SCA effects for some fiber properties.

Dimitrova et al. (2024) found that non-additive variance was greater than additive variance for plant productivity and fiber length, highlighting the significance of non-additive gene action in these traits. Consequently, selecting desirable forms should be reserved for later hybrid generations. Non-additive genetic variance also played a larger role in boll weight, while additive gene action was more important for lint percentage, allowing effective selection for this trait in early segregated generations. Line 266 emerged as a strong general combiner for productivity per plant and fiber length, while line 346 was notable for lint percentage and fiber length. The Turkish cultivar Nazili 954 can enhance productivity through crosses, whereas the Spanish cultivar FRH-1001 is suitable for increasing lint percentage and fiber length. The hybrids 191 × Nazili 954 and 266 × FRH-1001 achieved the highest productivity per plant with high SCA effects and heterosis between 30.7-31.7%. Hybrids from Nazili 954 × 266 and 346 ×

FRH-1001 registered the highest lint percentage, achieving a range of 42.1-42.3% with positive heterosis of 2.4 - 9.0%. Meanwhile, hybrids from FR-H-1001 × 266 and 346 × FR-H-1001 presented the longest fiber lengths, exhibiting heterosis of 8.4% and 5.7%, respectively. The cross combination 346 × FR-H-1001 showed tremendous promise for lint percentage and fiber length with high mean levels for both traits, accompanied by strong SCA effects and positive heterosis.

The main objective of this study was to evaluate heterosis, combining ability, gene action and heritability for yield, yield components and fiber quality properties using Line x Tester analysis in cotton (*Gossypium barbadense* L.).

2. Materials and Methods

The present study was carried out at Sakha Agricultural Research Station, Cotton Research Institute, Agricultural Research Center, Egypt, during 2023 and 2024 seasons.

The selfed seeds of the eleven parental cotton genotypes were sown in the growing season of 2023 using line x tester mating design. Six Egyptian cotton varieties were used as lines (females) i.e, Giza 88, Giza 89, Giza 86, Giza 80, Giza 96 and Giza 94, while, the other five genotypes used as testers (males) 10229, C.B.58, Karshenky, Suvin and Australy 13 to produce 30 F_1's and the parental varieties were also selfed to increase their seeds.

Thirty cotton crosses and eleven parents were evaluated in a randomized complete block design with three replications in the growing season of 2024. Each plot consists of two rows for each genotype. Each row was 4m long, 0.60 cm wide and 0.40 cm within hills. The hills were thinned to one plant per hill.

Origin, pedigree where characterization of the parents in Table 1.the eleven cotton varieties are presented in Table (1).

Table 1. Origin, pedigree and category of the eleven cotton varieties used in the study.

No.	Genotypes	Origin	Pedigree	Category
P_1	Giza 88	Egypt	G. (77 x G. 45) B	Extra long staple
P_2	Giza 89	Egypt	(G.75 x R.6022)	Long staple
P_3	Giza 86	Egypt	G. 75 x G. 81	long staple
P_4	Giza 80	Egypt	(G.66 xG.73)	Long staple
P_5	Giza 96	Egypt	G.84xG70x G.51bxPima S_{62}	Extra Long staple
P_6	Giza 94	Egypt	10229 x G.86	Long staple
P_7	10229	Australian	Unknown	Long staple
P_8	C.B.58	American	Unknown	Long staple
P_9	Karshenky	Russian	Unknown	Long staple
P_{10}	Suvin	Indian	Sujata x Vincent	Extra Long staple
P_{11}	Australy 13	Australian	Unknown	Long staple

2.1. The studied traits were

- Seed cotton yield/plant
- Lint cotton yield per
- Lint percentage (L%)
- Boll weight (BW.g)
- Seed index (SI g)
- Lint index (LI.g)
- Fiber length (FL mm)
- Fiber strength (FS).
- Micronaire reading
- Uniformity index

All fiber properties were tested at cotton technology laborites, cotton Research Institute, Giza, Egypt.

2.12. Statistical analysis

The significance of means was determined using the least significant difference value (L.S.D $_{0.05}$ and $_{0.01}$ levels of significance), according to the equation, which outlined by Steel and Torrie (1985). Heritability was estimated in both broad (h^2_b%) and narrow (h^2_n%) senses from two formulas given by Allard (1960) and Mather (1949).

3. Results and Discussion

3.1. Analysis of variance

Results of the analysis of variance and the mean squares of all studied traits for the eleven parents and their 30 F_1's crosses are presented in Table (2). The results showed that the mean squares due to the genotypes, parents, crosses, parents vs. crosses, lines, tester and Line x Tester were highly significant for all studied traits, except microniare reading for crosses and boll weight in the testers. Hamed and Said (2021) indicated that mean squares due to the genotypes, parents, parents vs. crosses, crosses, lines, testers and Line x Tester were highly significant for all studied traits, except, for boll weight, seed index and lint index for tester and fiber strength for Line x Tester.

Table 2. Mean squares of line x tester analysis for yield, yield components and fiber quality properties.

S. O. V	d.f	SCY/P	LCY/P	LP%	BW	SI	LI	FL	FS	MIC	UI
Replications	2	9.54	0.89	0.16	0.002	0.001	0.01	2.25	0.01	0.01	0.40
Genotypes	40	527.30**	80.60**	2.99**	0.12**	0.84**	0.55**	3.48**	0.25**	0.13**	3.32**
Parents	10	153.79**	15.77**	4.47**	0.16**	0.85**	0.84**	5.59**	0.29**	0.11**	4.68**
Crosses	29	3404.35**	540.47**	0.25**	0.002	2.88**	1.35**	30.62**	0.25**	0.03	8.89**
P. *vs*. C	1	556.89**	87.10**	2.57**	0.12**	0.77**	0.42**	1.81**	0.23**	0.14**	2.66**
Lines	5	2147.41**	346.64**	9.66**	0.49**	3.36**	1.75**	5.48**	0.77**	0.56**	4.49**
Tester	4	892.63**	134.00**	4.18**	0.04	0.66**	0.33**	2.74**	0.32**	0.10**	8.97**
Line x Tester	20	92.11**	12.83**	0.48**	0.04**	0.14**	0.10**	0.71**	0.08**	0.05**	0.94**
Error	80	30.06	4.63	0.13	0.02	0.02	0.02	0.25	0.03	0.01	0.33

*, ** Significant and highly significant at 0.05 and 0.01 probability levels, respectively.

Where; Seed cotton yield/plant (SCY/P.g), Lint cotton yield per plant (LCY/P.g), Lint percentage (L%), Boll weight (BW.g) and Seed index (SI g) where; Lint index (LI.g) , Fiber length (FL mm), Fiber strength (FS), Micronaire reading (MIC), and Uniformity index (UI).

3.2. The mean performance of genotypes

Mean performances for parents and their crosses are presented in Tables (3 and 4). The lines Giza 88, Giza 89 had the highest values for uniformity index and seed cotton yield/plant, lint cotton yield/plant and micronaire reading, respectively. While, Giza 86 for lint percentage and lint index, Giza 80 for boll weight and seed index, Giza 96 for fiber length and Giza 94 for fiber strength. On the other side, the testers Karshenky had the best values for lint percentage, seed index, lint index, fiber strength and micronaire reading, Suvin for uniformity index, Australy 13 for seed cotton yield/plant, lint cotton yield/plant, boll weight and fiber length. The results also showed that the best mean performances were found for the cross combinations Giza 88 x 10229 for uniformity index, Giza 89 x 10229 for micronaire reading, Giza 86 x C.B.58 for lint percentage, Giza 86 x Australy 13 for fiber length, Giza 80 x 10229 for boll weight, Giza 96 x 10229 for seed index, Giza 96 x C.B.58 for seed cotton yield/plant and lint cotton yield/plant and Giza 96 x Karshenky for lint index and fiber strength.

Table 3. The mean performances of six parental lines, five testers for yield, yield components and fiber properties.

Genotypes	SCY/P	LCY/P	LP %	BW	SI	LI	FL	FS	MIC	UI
				Lines						
Giza 88	84.07	32.40	38.53	3.33	10.07	6.31	33.70	10.40	4.30	86.73
Giza 89	104.47	38.08	36.46	3.10	10.20	5.85	33.83	10.43	3.97	86.40
Giza 86	87.73	35.00	39.90	3.20	10.80	7.17	33.70	10.47	4.23	85.93
Giza 80	85.33	32.96	38.62	3.50	10.90	6.86	31.90	10.67	4.40	85.80
Giza 96	86.70	32.60	37.60	3.20	10.83	6.53	34.27	10.30	4.47	86.00
Giza 94	76.93	31.21	40.56	3.40	10.37	7.08	32.53	10.70	4.47	86.10
				Testers						
10229	85.83	32.22	37.53	3.02	9.27	5.57	30.37	9.73	4.57	83.40
C.B.58	91.73	35.16	38.32	2.90	9.67	6.01	31.17	9.97	4.40	83.37
Karshenky	89.30	35.57	39.83	2.77	10.00	6.62	31.07	10.17	4.00	84.57
Suvin	89.00	33.51	37.65	2.87	9.67	5.84	31.13	10.10	4.17	85.17
Australy 13	97.10	37.87	38.99	3.03	9.90	6.33	31.70	9.90	4.40	83.63
LSD 0.05	8.77	3.44	0.57	0.23	0.25	0.23	0.80	0.26	0.19	0.92
LSD 0.01	11.46	4.50	0.74	0.30	0.33	0.30	1.04	0.34	0.25	1.20

Where; Seed cotton yield/plant (SCY/P.g), Lint cotton yield per plant (LCY/P.g), Lint percentage (L%), Boll weight (BW.g), Seed index (SI g), Lint index (LI. g) , Fiber length (FL mm), Fiber strength (FS), Micronaire reading (MIC), and Uniformity index (UI).

Table 4. The mean performances of 30 F_1 hybrids for yield, yield components and fiber quality properties.

F_1 hybrids	SCY/P	LCY/P	LP %	BW	SI	LI	FL	FS	MIC	UI
Giza 88 x 10229	101.83	39.07	38.36	3.20	10.30	6.41	33.67	10.30	4.13	87.47
Giza 88 x C.B.58	97.90	39.26	40.10	3.31	10.20	6.83	32.57	10.00	4.30	86.70
Giza 88 x Karshenky	109.73	42.97	39.18	3.37	9.90	6.38	31.90	10.17	4.07	85.77
Giza 88 x Suvin	90.77	35.78	39.43	3.19	10.03	6.53	32.73	10.00	4.20	87.07
Giza 88 x Australy 13	96.83	38.09	39.33	3.31	9.93	6.44	33.97	9.97	4.17	84.83
Giza 89 x 10229	104.47	39.11	37.44	2.77	10.20	6.11	31.87	10.10	3.83	84.43
Giza 89 x C.B.58	105.27	39.32	37.35	2.79	10.07	6.00	32.07	10.23	4.03	84.47
Giza 89 x Karshenky	90.43	34.81	38.49	2.96	10.37	6.49	33.47	10.53	4.20	85.83
Giza 89 x Suvin	96.93	36.38	37.53	2.80	9.50	5.71	32.00	10.60	3.87	85.77
Giza 89 x Australy 13	104.27	39.37	37.77	2.78	9.60	5.83	33.30	10.80	3.97	84.90
Giza 86 x 10229	101.10	39.13	38.70	2.87	10.43	6.59	34.03	10.37	4.30	84.97
Giza 86 x C.B.58	105.63	42.56	40.30	2.91	10.60	7.16	34.00	10.50	4.33	85.83
Giza 86 x Karshenky	108.30	43.50	40.17	3.03	10.50	7.05	33.57	10.50	4.27	85.43
Giza 86 x Suvin	90.47	36.36	40.20	2.90	9.77	6.57	33.63	10.17	4.30	86.73
Giza 86 x Australy 13	111.07	44.54	40.11	3.31	10.30	6.90	34.97	10.43	4.30	83.90
Giza 80 x 10229	92.37	34.61	37.47	3.50	11.13	6.67	33.73	10.20	4.33	84.83
Giza 80 x C.B.58	92.10	35.18	38.20	3.19	10.67	6.59	34.23	10.10	4.20	86.07

Table 4. Continued.

Giza 80 x Karshenky	91.50	35.61	38.90	3.12	10.73	6.83	34.07	10.47	4.20	85.50
Giza 80 x Suvin	77.00	29.11	37.80	3.20	10.60	6.44	34.07	10.10	4.07	86.93
Giza 80 x Australy 13	99.30	37.81	38.08	3.21	10.53	6.48	34.00	10.40	4.40	84.13
Giza 96 x 10229	123.13	46.13	37.47	3.33	11.40	6.83	33.40	10.70	4.47	86.10
Giza 96 x C.B.58	130.13	49.96	38.39	3.18	11.30	7.04	33.23	10.43	4.43	86.67
Giza 96 x Karshenky	125.67	49.93	39.73	3.17	11.07	7.30	32.83	10.97	4.47	86.37
Giza 96 x Suvin	102.70	39.99	38.93	3.23	11.10	7.08	33.10	10.70	4.53	86.87
Giza 96 x Australy 13	129.87	49.43	38.07	3.22	11.20	6.88	33.97	10.90	4.87	85.20
Giza 94 x 10229	94.10	35.66	37.90	3.21	11.10	6.77	33.43	10.07	4.37	85.97
Giza 94 x C.B.58	87.00	33.48	38.48	3.17	10.30	6.44	34.00	10.13	4.50	86.20
Giza 94 x Karshenky	88.83	34.54	38.83	3.23	10.80	6.86	33.63	10.57	4.13	86.17
Giza 94 x Suvin	74.13	28.36	38.27	3.16	10.50	6.51	33.10	10.07	4.27	87.10
Giza 94 x Australy 13	101.20	38.89	38.43	3.30	10.77	6.72	34.43	10.30	4.60	85.73
LSD 0.05	7.60	2.98	0.49	0.20	0.22	0.20	0.69	0.23	0.17	0.79
LSD 0.01	9.92	3.89	0.64	0.26	0.28	0.26	0.90	0.30	0.22	1.04

Where; Seed cotton yield/plant (SCY/P.g), Lint cotton yield per plant (LCY/P.g), Lint percentage (L%), Boll weight (BW.g), Seed index (SI g), Lint index (LI.g) , Fiber length (FL mm), Fiber strength (FS), Micronaire reading (MIC), and Uniformity index (UI).

3.3. Heterosis

The genetic diversity and origin differences playing an important key source of genetic variability, which leading to the formation of new recombination's. This, in turn, results in the phenomenon of heterosis. Heterosis is typically measured as the percentage deviation of the F_1 generation's mean performance relative to both the mid-parent and better-parent values. It signifies the superiority of the F_1 hybrid in one or more traits compared to its parents, contributing to enhanced adaptability. In most cases, positive heterosis is regarded as beneficial across studied traits, with the notable, exception of micronaire reading.

The magnitude of heterosis for all traits studied over the mid-parents (MP) and better parent (BP) was presented in Tables (5 and 6). For seed cotton yield/plant relative heterosis versus mid-parent, seventeen crosses out of 30 F_1 crosses possessed significant and highly significant positive heterosis which ranged from 7.93% for Giza 80 x 10229 to 45.86% for Giza 96 x C.B.58, while twelve crosses showed significant and positive heterosis relative to better-parent which ranged from 9.63% for Giza 94 x 10229 to 45.02% for Giza 96 x 10229.

For lint cotton yield/plant the results of heterosis versus mid-parent revealed that 25 crosses out of 30 F_1 crosses was found to be significant and positive heterosis which ranged from 3.31% for Giza 80 x C.B.58 to 47.48% for Giza 96 x C.B.58, while sixteen crosses showed significant positive heterosis relative to better-parent which ranged from 3.89% for Giza 86 x Suvin to 42.10% for Giza 96 x C.B.58. In this respect, for lint percentage, the results showed that thirteen crosses out of 30 F_1 crosses relative heterosis versus mid-parent were significant and positive which ranged from 0.75% for Giza 86 x Karshenky to 4.35% for Giza 88 x C.B.58, whereas, seven crosses showed significant positive heterosis relative to better-parent which ranged from 0.67% for Giza 86 x Karshenky to 4.07% for Giza 88 x C.B.58.

Regarding to boll weight the results of heterosis versus mid-parent revealed that nineteen crosses out of 30 F_1 exhibited highly significant and positive heterosis, which ranged from 0.52% for Giza 80 x Suvin to 10.38% for Giza 88 x Karshenky, whereas, heterosis relative to better-parent showed that five crosses had positive and highly significant heterosis, which ranged from 0.63% for Giza 96 x Australy 13 to 4.17% for Giza 96 x 10229.

Concerning seed index the results of heterosis versus mid-parent revealed that 24 of 30 crosses were exhibited highly significant positive heterosis which ranged from 0.96% for Giza 86 x Karshenky to 13.43% for Giza 96 x 102299, whereas, heterosis versus better-parent showed that thirteen crosses were positive and significant which ranged from 1.32% for Giza 88 x C.B.58 to 5.23% for Giza 96 x 10229. For lint index the results of heterosis versus mid-parent revealed that 25 crosses out of 30 F_1 crosses were found to be significant and positive heterosis which ranged from 0.20% for Giza 94 x Karshenky to 14.45% for Giza 96 x Suvin, but for heterosis versus better-parent showed that 10 out of 30 crosses were significantly positive and the largest amount of heterosis were found for Giza 96 x Suvin and Giza 96 x Karshenky with amounts of 8.41% and 10.21% respectively.

Regarding to fiber length the results of heterosis versus mid-parent revealed that 25 crosses out of 30 F_1 crosses were found to be significant and positive heterosis which ranged from 0.98% for Giza 88 x Suvin to 8.56% for Giza 80 x C.B.58, whereas, heterosis versus better-parent showed that 13 crosses out of 30 F_1 crosses were found to be significant and positive heterosis which ranged from 0.89% for Giza 86 x C.B.58 to 6.79% for Giza 80 x Karshenky.

Concerning fiber strength the results of heterosis versus mid-parent revealed that 18 of 30 crosses were exhibited highly significant positive heterosis which ranged from 0.33% for Giza 89 x C.B.58 to 7.92% for Giza 96 x Australy 13, whereas, heterosis versus better-parent showed that ten crosses were exhibited significant positive heterosis which ranged from 0.32% for Giza 86 x C.B.58 to 6.47% for Giza 96 x Karshenky. Regarding to micronaire reading the results of heterosis versus mid-parent revealed that 18 of 30 crosses were exhibited highly significant negative direction which is a desirable direction for the trait which ranged from -0.39% for Giza 86 x Australy13 to -10.16% for Giza 89 x 10229, whereas, heterosis versus better-parent showed that eight crosses were negative and significant which ranged from -1.52% for Giza 80 x 10229 to –4.55% for Giza 80 x C.B.58. For uniformity index the results of heterosis versus mid-parent revealed that 16 out of 30 crosses were exhibited significant positive heterosis which ranged from 0.98% for Giza 94 x Karshenky to 2.82% for Giza 88 x 10229, whereas, heterosis versus better-parent showed that Giza 86 x Suvin, Giza 80 x Suvin, Giza 96 x Suvin and Giza 94 x Suvin were exhibited significant positive heterosis with values of 0.93%, 1.32%, 1.01% and 1.16% respectively. Lingaraja (2017) results showed that range of economic heterosis varied from 1.58 to 32.91% of seed index, 11.15 to 31.85% of lint index, -11.06 to 3.37% of ginning outturn, -6.32 to 8.80% of 2.5 per cent span length, -2.73 to 18.27 of fiber strength, 17.69 to 21.23 of micronaire value, -2.08 to 1.66 of fiber uniformity and -60.38 to 48.32 of seed cotton yield per plant. Mahrous (2018) the results of heterosis noticed that 7 crosses had positive and highly significant heterosis in seed and lint cotton yield /plant and number of bolls/plant i.e., (Giza 80 x Giza 90), (G.86 x G.90), (G.86 x G.95), (G.87 x G.90), (G.90 x Australian)), and (G. 92 x G.90).

Table 5. Heterosis relative to the mid-parent (MP) for yield, yield components and fiber quality properties.

Crosses	SCY/P	LCY/P	LP %	BW	SI	LI	FL	FS	MIC	UI
Giza 88 x 10229	19.87**	20.94**	0.85**	0.52**	6.55**	7.93**	5.10**	2.32**	-6.77**	2.82**
Giza 88 x C.B.58	11.38**	16.24**	4.35**	6.10**	3.38**	10.87**	0.41	-1.80**	-1.15**	1.94**
Giza 88 x Karshenky	26.59**	26.46**	0.01	10.38**	-1.33**	-1.31**	-1.49**	-1.13**	-2.01**	0.14
Giza 88 x Suvin	4.89	8.57**	3.52**	2.80**	1.69**	7.57**	0.98**	-2.44**	-0.79**	1.30**
Giza 88 x Australy 13	6.90	8.41**	1.47**	4.08**	-0.50**	1.90**	3.87**	-1.81**	-4.21**	-0.41
Giza 89 x 10229	9.79*	11.28**	1.22**	-9.78**	4.79**	6.93**	-0.73*	0.17	-10.16**	-0.55
Giza 89 x C.B.58	7.31	7.38**	-0.10	-7.11**	1.34**	1.23**	-1.33**	0.33**	-3.59**	-0.49
Giza 89 x Karshenky	-6.66	-5.46**	0.91**	0.91**	2.64**	4.05**	3.13**	2.27**	5.44**	0.41
Giza 89 x Suvin	0.21	1.65	1.29**	-6.15**	-4.36**	-2.34**	-1.49**	3.25**	-4.92**	-0.02
Giza 89 x Australy 13	3.46	3.68*	0.11	-9.46**	-4.48**	-4.34**	1.63**	6.23**	-5.18**	-0.14
Giza 86 x 10229	16.50**	16.41**	-0.04	-8.02**	3.99**	3.42**	6.24**	2.64**	-2.27**	0.35
Giza 86 x C.B.58	17.72**	21.34**	3.04**	-4.48**	3.58**	8.61**	4.83**	2.77**	0.39**	1.40**
Giza 86 x Karshenky	22.35**	23.28**	0.75**	1.68**	0.96**	2.20**	3.65**	1.78**	3.64**	0.22
Giza 86 x Suvin	2.38	6.15**	3.67**	-4.40**	-4.56**	0.94**	3.75**	-1.13**	2.38**	1.38**
Giza 86 x Australy 13	20.18**	22.24**	1.67**	6.31**	-0.48**	2.19**	6.93**	2.45**	-0.39**	-1.04*
Giza 80 x 10229	7.93*	6.20**	-1.60**	7.14**	10.41**	7.36**	8.35**	0.01	-3.35**	0.28
Giza 80 x C.B.58	4.03	3.31*	-0.70**	-0.21**	3.73**	2.52**	8.56**	-2.10**	-4.55**	1.75**
Giza 80 x Karshenky	4.79	3.93**	-0.83**	-0.43**	2.71**	1.42**	8.21**	0.48**	0.01	0.37
Giza 80 x Suvin	-11.66**	-12.42**	-0.88**	0.52**	3.08**	1.48**	8.09**	-2.73**	-5.06**	1.70**
Giza 80 x Australy 13	8.86*	6.77**	-1.86**	-1.63**	1.28**	-1.72**	6.92**	1.13**	0.001	-0.69
Giza 96 x 10229	42.74**	42.33**	-0.27**	6.95**	13.43**	12.93**	3.35**	6.82**	-1.11**	1.65**
Giza 96 x C.B.58	45.86**	47.45**	1.13	4.26**	10.24**	12.34**	1.58**	2.96**	0.01	2.34**
Giza 96 x Karshenky	42.80**	46.49**	2.63**	6.15**	6.24**	10.98**	0.51	7.17**	5.51**	1.27**
Giza 96 x Suvin	16.90**	20.96**	3.47**	6.59**	8.29**	14.45**	1.22**	4.90**	5.02**	1.50**
Giza 96 x Australy 13	41.31**	40.29**	-0.60*	3.32**	8.04**	7.08**	2.98**	7.92**	9.77**	0.45
Giza 94 x 10229	15.63**	12.42**	-2.94**	-0.10	13.07**	7.16**	6.31**	-1.47**	-3.32**	1.44**
Giza 94 x C.B.58	3.16	0.89	-2.43**	0.74**	2.83**	-1.49**	6.75**	-1.94**	1.50**	1.73**
Giza 94 x Karshenky	6.88	3.44*	-3.40**	4.65**	6.06**	0.20*	5.77**	1.28**	-2.36**	0.98*
Giza 94 x Suvin	-10.65**	-12.35**	-2.14**	0.85**	4.83**	0.86**	3.98**	-3.21**	-1.16**	1.71**
Giza 94 x Australy 13	16.30**	12.59**	-3.38**	2.59**	6.25**	0.28**	7.21**	2.32**	3.76**	1.02*
LSD 0.05	7.60	2.98	0.49	0.20	0.22	0.20	0.69	0.23	0.17	0.79
LSD 0.01	9.92	3.89	0.64	0.26	0.28	0.26	0.90	0.30	0.22	1.04

*, ** Significant and highly significant at 0.05 and 0.01 probability levels, respectively.

where; Seed cotton yield/plant (SCY/P.g), Lint cotton yield per plant (LCY/P.g), Lint percentage (L%), Boll weight (BW.g), Seed index (SI g), Lint index (LI.g) , Fiber length (FL mm), Fiber strength (FS), Micronaire reading (MIC), and Uniformity index (UI).

Table 6. Heterosis relative to the better-parents (BP) for yield, yield components and fiber quality properties.

Crosses	SCY/P	LCY/P	LP %	BW	SI	LI	FL	FS	MIC	UI
Giza 88 x 10229	18.64**	20.61**	-0.46	-4.00**	2.32**	1.58**	-0.10	-0.96**	-3.88**	0.85
Giza 88 x C.B.58	6.72	11.68**	4.07**	-0.80**	1.32**	8.20**	-3.36**	-3.85**	0.01	-0.04
Giza 88 x Karshenky	22.88**	20.82**	-1.63**	1.00**	-1.66**	-3.62**	-5.34**	-2.24**	1.67**	-1.11*
Giza 88 x Suvin	1.99	6.76**	2.34**	-4.40**	-0.33**	3.54**	-2.87**	-3.85**	0.80**	0.38
Giza 88 x Australy 13	-0.27	0.58	0.87**	-0.60**	-1.32**	1.75**	0.79	-4.17**	-3.10**	-2.19**
Giza 89 x 10229	0.001	2.72	-0.24	-10.75**	0.01	4.34**	-5.81**	-3.19**	-3.36**	-2.28**
Giza 89 x C.B.58	0.77	3.26	-2.54**	-10.11**	-1.31**	-0.08	-5.22**	-1.92**	1.68**	-2.24**
Giza 89 x Karshenky	-13.43**	-8.58**	-3.36**	-4.52**	1.63**	-1.99**	-1.08**	0.96**	5.88**	-0.66
Giza 89 x Suvin	-7.21	-4.45*	-0.32	-9.68**	-6.86**	-2.45**	-5.42**	1.60**	-2.52**	-0.73
Giza 89 x Australy 13	-0.19	3.40	-3.15**	-10.43**	-5.88**	-7.95**	-1.58**	3.51**	0.01	-1.74**
Giza 86 x 10229	15.24**	11.78**	-3.01**	-10.42**	-3.40**	-8.14**	0.99*	-0.96**	1.57**	-1.12*
Giza 86 x C.B.58	15.15**	21.08**	1.00**	-8.96**	-1.85**	-0.21**	0.89*	0.32*	2.36**	-0.12
Giza 86 x Karshenky	21.28**	22.31**	0.67*	-5.21**	-2.78**	-1.72**	-0.40	0.32*	6.67**	-0.58
Giza 86 x Suvin	1.65	3.89*	0.75**	-9.38**	-9.57**	-8.43**	-0.20	-2.87**	3.20**	0.93*
Giza 86 x Australy 13	26.60**	17.61**	0.52	3.54**	-4.63**	-3.81**	3.76**	-0.32*	1.57**	-2.37**

Table 6. Continued

Giza 80 x 10229	7.61	5.02**	-2.98**	0.01	2.14**	-2.73**	5.75**	-4.37**	-1.52**	-1.13**
Giza 80 x C.B.58	0.40	0.08	-1.08**	-8.76**	-2.14**	-3.84**	7.31**	-5.31**	-4.55**	0.31
Giza 80 x Karshenky	2.46	0.12	-2.34**	-10.86**	-1.53**	-0.33**	6.79**	-1.87**	5.00**	-0.35
Giza 80 x Suvin	-13.48**	-13.14**	-2.11**	-8.57**	-2.75**	-6.06**	6.79**	-5.31**	-2.40**	1.32**
Giza 80 x Australy 13	2.27	-0.16	-2.33**	-8.19**	-3.36**	-5.51**	6.58**	-2.50**	0.01	-1.94**
Giza 96 x 10229	42.02**	41.50**	-0.35	4.17**	5.23**	4.62**	-2.53**	3.88**	0.01	0.12
Giza 96 x C.B.58	41.86**	42.10**	0.17	-0.63**	4.31**	7.85**	-3.02**	1.29**	0.76**	0.78
Giza 96 x Karshenky	40.72**	40.40**	-0.25	-1.04**	2.15**	10.21**	-4.18**	6.47**	11.67**	0.43
Giza 96 x Suvin	15.39**	19.33**	3.40**	1.04**	2.46**	8.41**	-3.40**	3.88**	8.80**	1.01*
Giza 96 x Australy 13	33.75**	30.54**	-2.38**	0.63**	3.38**	5.44**	-0.88*	5.83**	10.61**	-0.93*
Giza 94 x 10229	9.63*	10.66**	-6.57**	-5.49**	7.07**	-4.26**	2.77**	-5.92**	-2.24**	-0.15
Giza 94 x C.B.58	-5.16	-4.77**	-5.13**	-6.67**	-0.64**	-8.93**	4.51**	-5.30**	2.27**	0.12
Giza 94 x Karshenky	-0.52	-2.89	-4.27**	-5.10**	4.18**	-3.02**	3.38**	-1.25**	3.33**	0.08
Giza 94 x Suvin	-16.70**	-15.35**	-5.65**	-7.06**	1.29**	-7.95**	1.74**	-5.92**	2.40**	1.16*
Giza 94 x Australy 13	4.22	2.70	-5.25**	-2.94**	3.86**	-5.00**	5.84**	-3.74**	4.55**	-0.43
LSD 0.05	8.77	3.44	0.57	0.23	0.25	0.23	0.80	0.26	0.19	0.92
LSD 0.01	11.46	4.50	0.74	0.30	0.33	0.30	1.04	0.34	0.25	1.20

*, ** Significant and highly significant at 0.05 and 0.01 probability levels, respectively.
Where; Seed cotton yield/plant (SCY/P.g), Lint cotton yield per plant (LCY/P.g), Lint percentage (L%), Boll weight (BW.g), Seed index (SI g), Lint index (LI.g) , Fiber length (FL mm), Fiber strength (FS), Micronaire reading (MIC) and Uniformity index (UI).

3.4. Combining ability

The estimates of general combining ability and specific combining ability are presented in Table (7) and Table (8). The results revealed that the Giza 88 was significant and positive desirable for lint percentage, boll weight and uniformity index and negative desirable for micronaire reading. Giza 89 had significant and positive desirable GCA effects for fiber strength and negative desirable for micronaire reading. Giza 86 had significant and positive desirable GCA effects for lint cotton yield/plant, lint percentage, lint index and fiber length. Giza 80 had significant and positive desirable GCA effects for boll weight, seed index and fiber length, Giza 96 had significant and positive desirable GCA effects for seed cotton yield/plant and lint cotton yield/plant, boll weight, seed index, lint index, fiber strength and uniformity index. Giza 94 had significant and positive desirable GCA effects for boll weight, seed index, fiber length and uniformity index. In this respect, the results of testers showed that 10229 had significant and positive desirable GCA effects for seed index. C.B.58 had significant and positive desirable for lint cotton yield/plant and lint percentage. Karshenky showed significant and positive desirable GCA effects for lint cotton yield/plant, lint percentage, lint index and fiber strength. Suvin showed significant and positive desirable GCA effects for uniformity index and negative desirable for micronaire reading. Australy 13 had significant and positive desirable for cotton yield/plant, lint cotton yield/plant, fiber length and fiber strength. The results of specific combining ability effects for crosses Giza 88 x 10229, Giza 89 x Karshenky, Giza 89 x Suvin and Giza 86 x C.B.58 were significant desirable SCA effects for some studied traits. Lakho et al. (2016) found that among the parents, NIAB-78, Haridost and CRIS-134 were best general combiners for bolls per plant, boll weight, seed cotton yield per plant and seed index. the cross NIAB-78×Chandi-95 was best specific combiner for bolls per plant and the hybrid Chandi-95×CRIS-134 proved best specific combiner for seed cotton yield per plant, while NIAB-78×CRIS-134 gave maximum SCA effects for seed index. Hamed and Said (2021) The results revealed that the lines Giza 86 and Giza 94 were significant and positive desirable GCA effects for most yield traits. Giza 93 had significant desirable GCA effects for all fiber traits, in this respect, the results of testers showed that Pima S4 had significant desirable for some yield and fiber traits. However, estimates of specific combining ability (SCA) effects for crosses Giza 86 x Ustraly 13, Giza 90 x Pima S4, Giza 93 x Karshenky and Giza 95 x Pima S4 were significant desirable SCA effects for most yield traits, while, the crosses Giza 90 x Pima S4, Giza 93 x Karshenky and Giza 95 x Pima S4 were significant desirable SCA effects for most fiber traits.

Table 7. Estimates of general combining ability effects of the parental genotypes for yield, yield components and fiber quality properties.

Parents	SCY/P	LCY/P	LP %	BW	SI	LI	FL	FS	MIC	UI
					Lines					
Giza 88	-1.39	0.07	0.63**	0.14**	-0.42**	-0.10**	-0.47**	-0.27**	-0.10**	0.57**
Giza 89	-0.53	-1.16*	-0.93**	-0.31**	-0.55**	-0.59**	-0.89**	0.09*	-0.29**	-0.72**
Giza 86	2.51	2.25**	1.25**	-0.13**	-0.18**	0.24**	0.61**	0.03	0.03	-0.42**
Giza 80	-10.35**	-4.50**	-0.56**	0.11**	0.24**	-0.01	0.59**	-0.11**	-0.03	-0.30*
Giza 96	21.50**	8.12**	-0.13	0.10**	0.72**	0.41**	-0.13	0.38**	0.28**	0.44**
Giza 94	-11.75**	-4.78**	-0.26**	0.08*	0.20**	0.05	0.29*	-0.13**	0.10**	0.44**
LSD 0.05	2.77	1.09	0.18	0.07	0.08	0.07	0.25	0.08	0.06	0.29
LSD 0.01	3.62	1.42	0.23	0.09	0.10	0.09	0.33	0.11	0.08	0.38

Table 7. Continued.

					Testers					
10229	2.03	-0.01	-0.76**	0.02	0.26**	-0.05	-0.08	-0.07	-0.03	-0.17
C.B.58	2.20	1.00*	0.16*	-0.04	0.03	0.06	-0.08	-0.13**	0.03	0.19
Karshenky	1.61	1.26*	0.57**	0.01	0.06	0.20**	-0.19	0.17**	-0.05	0.05
Suvin	-12.13**	-4.63**	0.05	-0.05	-0.25**	-0.14**	-0.33**	-0.09*	-0.06*	0.95**
Australy 13	6.29**	2.39**	-0.02	0.06	-0.11**	-0.07*	0.67**	0.11**	0.11**	-1.01**
LSD 0.05	2.53	0.99	0.16	0.07	0.07	0.07	0.23	0.08	0.06	0.26
LSD 0.01	3.31	1.30	0.21	0.09	0.09	0.09	0.30	0.10	0.07	0.35

*, ** Significant and highly significant at 0.05 and 0.01 probability levels, respectively.
where; Seed cotton yield/plant (SCY/P.g), Lint cotton yield per plant (LCY/P.g), Lint percentage (L%), Boll weight (BW.g), Seed index (SI g), Lint index (LI.g) , Fiber length (FL mm), Fiber strength (FS), Micronaire reading (MIC), and Uniformity index (UI).

Table 8. Estimates of specific combining ability effects of the 30 F_1 crosses for yield, yield components and fiber quality properties.

Crosses	SCY/P	LCY/P	LP %	BW	SI	LI	FL	FS	MIC	UI
Giza 88 x 10229	0.39	0.05	-0.17	-0.09	-0.04	-0.06	0.78**	0.28**	-0.01	1.27**
Giza 88 x C.B.58	-3.72	-0.77	0.66**	0.07	0.10	0.25**	-0.32	0.04	0.10	0.14
Giza 88 x Karshenky	8.71	2.68*	-0.67**	0.08	-0.24**	-0.34**	-0.88**	-0.09	-0.06	-0.65*
Giza 88 x Suvin	3.49	1.38	0.10	-0.04	0.21*	0.16*	0.09	0.00	0.09	-0.25
Giza 88 x Australy 13	-8.87**	-3.34**	0.07	-0.02	-0.03	-0.01	0.33	-0.23*	-0.12	-0.52
Giza 89 x 10229	2.16	1.33	0.49*	-0.07	-0.01	0.13	-0.60*	-0.28**	-0.12	-0.48
Giza 89 x C.B.58	2.79	0.52	-0.52**	0.01	0.09	-0.09	-0.39	-0.09	0.02	-0.80*
Giza 89 x Karshenky	-11.45**	-4.25**	0.20	0.13	0.36**	0.26**	1.11**	-0.09	0.27**	0.71*
Giza 89 x Suvin	8.79**	3.22**	-0.23	0.03	-0.20*	-0.18*	-0.21	0.23*	-0.05	-0.26
Giza 89 x Australy 13	-2.29	-0.82	0.07	-0.10	-0.24**	-0.13	0.09	0.24**	-0.13	0.83*
Giza 86 x 10229	-4.25	-2.08	-0.44*	-0.15	-0.15	-0.21**	0.07	0.04	0.03	-0.24
Giza 86 x C.B.58	0.12	0.35	0.25	-0.05	0.25**	0.24**	0.04	0.23*	0.00	0.27
Giza 86 x Karshenky	3.38	1.02	-0.30	0.01	0.12	-0.01	-0.29	-0.07	0.01	0.01
Giza 86 x Suvin	-0.71	-0.22	0.26	-0.05	-0.31**	-0.14	-0.08	-0.14	0.06	0.41
Giza 86 x Australy 13	1.47	0.93	0.23	0.25**	0.09	0.12	0.25	-0.07	-0.11	-0.46
Giza 80 x 10229	-0.12	0.16	0.14	0.24**	0.14	0.12	-0.21	0.02	0.12	-0.49
Giza 80 x C.B.58	-0.56	-0.28	-0.05	-0.01	-0.09	-0.07	0.30	-0.03	-0.07	0.38
Giza 80 x Karshenky	-0.56	-0.12	0.24	-0.14	-0.06	0.03	0.23	0.04	0.01	-0.04
Giza 80 x Suvin	-1.32	-0.72	-0.34	0.01	0.11	-0.02	0.37	-0.07	-0.11	0.49
Giza 80 x Australy 13	2.56	0.96	0.01	-0.09	-0.09	-0.05	-0.69*	0.04	0.05	-0.35
Giza 96 x 10229	-1.20	-0.94	-0.29	0.09	-0.08	-0.14	0.17	0.03	-0.06	0.03
Giza 96 x C.B.58	5.63	1.87	-0.28	-0.01	0.06	-0.05	0.01	-0.18	-0.15	0.24
Giza 96 x Karshenky	1.76	1.58	0.64**	-0.07	-0.21*	0.07	-0.29	0.05	-0.04	0.08
Giza 96 x Suvin	-7.47**	-2.47*	0.37	0.06	0.13	0.19*	0.12	0.05	0.04	-0.32
Giza 96 x Australy 13	1.28	-0.04	-0.44*	-0.07	0.09	-0.07	-0.01	0.05	0.20*	-0.03
Giza 94 x 10229	3.01	1.48	0.27	-0.02	0.14	0.16*	-0.21	-0.09	0.02	-0.10
Giza 94 x C.B.58	-4.26	-1.70	-0.06	0.01	-0.42**	-0.28**	0.36	0.03	0.10	-0.22
Giza 94 x Karshenky	-1.83	-0.91	-0.12	0.00	0.04	0.00	0.10	0.17	-0.19*	-0.11
Giza 94 x Suvin	-2.79	-1.19	-0.16	0.01	0.05	-0.01	-0.29	-0.07	-0.04	-0.08
Giza 94 x Australy 13	5.86	2.32	0.06	0.03	0.18*	0.13	0.04	-0.03	0.11	0.51
LSD 0.05	6.20	2.43	0.40	0.16	0.18	0.16	0.57	0.19	0.17	0.65
LSD 0.01	8.10	3.18	0.52	0.21	0.23	0.21	0.74	0.24	0.22	0.85

*, ** Significant and highly significant at 0.05 and 0.01 probability levels, respectively.
where; Seed cotton yield/plant (SCY/P.g), Lint cotton yield per plant (LCY/P.g), Lint percentage (L%), Boll weight (BW.g), Seed index (SI g), Lint index (LI.g), Fiber length (FL mm), Fiber strength (FS), Micronaire reading (MIC), and Uniformity index (UI).

3.5. Proportional contribution

Relative percentages of contribution of lines, testers and lines x testers interaction are shown in Table (9). The results showed that lines contribution was higher than testers contribution and lines x tester interaction for all traits studied except uniformity index for testers. However proportion contribution of lines x tester interaction was higher than of testers for most studied traits. Similar results were agreement with Chapara et al. (2020).

3.6. Genetic parameters

Knowledge of gene action helps in the selection of parents for using in the hybridization programs and also in the choice of appropriate breeding procedure for the genetic improvement of various quantitative characters. Hence, insight into the nature of gene action involved in the expression of various quantitative characters is essential to a plant breeder for starting a judicious breeding program. The genetic variance component and dominance degree ratio were calculated for all traits studied are presented in Table (10). The results indicated that the non-additive of genetic parameters were larger than additive genetic variance with respect to all studied traits. These results indicated that non-additive effects play a major role in the expression of these traits, while additive effects had a minor role. This indicated that the hybridization program would be effective in improvement of most studied traits. The importance of non-additive genetic variances was verified by the average degree of dominance which is more than one for all traits. This indicated that the overdominance played an important role of the dominance component. AL-Hibbiny et al. (2020) indicated that the non-additive of genetic variances were larger than the additive genetic variance with respect to all studied traits except, lint percentage, boll weight, fiber length and micronaire reading traits.

Table 9. Proportional contributions of lines, testers and their interaction for yield, yield components and fiber quality properties.

Traits	Lines	Testers	Lines x Testers
SCY/P	66.48	22.11	11.41
LCY/P	68.62	21.22	10.16
LP %	64.68	22.39	12.94
BW	73.15	4.28	22.57
SI	75.73	11.93	12.34
LI	71.89	10.86	17.26
FL	52.06	20.80	27.14
FS	57.57	18.80	23.63
MIC	67.43	9.19	23.38
UI	29.09	46.47	24.44

Where; Seed cotton yield/plant (SCY/P.g), Lint cotton yield per plant (LCY/P.g), Lint percentage (L%), Boll weight (BW.g), Seed index (SI g), Lint index (LI.g) , Fiber length (FL mm), Fiber strength (FS), Micronaire reading (MIC) and Uniformity index (UI).

Table 10. The partitioning of the genetic variance for yield, yield components and fiber quality properties.

Genetic parameters	SCY/P	LCY/P	LP %	BW	SI	LI	FL	FS	MIC	UI
GCA	10.19	1.63	0.05	0.002	0.01	0.01	0.02	0.003	0.002	0.04
SCA	20.68	2.73	0.12	0.006	0.04	0.03	0.15	0.02	0.011	0.20
σ^2A	20.38	3.26	0.09	0.003	0.03	0.01	0.05	0.01	0.004	0.08
σ^2D	20.68	2.73	0.12	0.006	0.04	0.03	0.15	0.02	0.011	0.20
$(\sigma^2D./\sigma A)^{½}$	1.007	0.915	1.154	1.414	1.154	1.01	1.73	1.41	1.66	1.58
H^2_b	77.43	75.42	81.84	57.68	88.02	86.10	72.76	73.75	77.60	73.11
H^2_n	15.30	17.30	13.22	7.22	13.63	9.38	5.26	6.45	6.47	6.16

Where; Seed cotton yield/plant (SCY/P.g), Lint cotton yield per plant (LCY/P.g), Lint percentage (L%), Boll weight (BW.g), Seed index (SI g), Lint index (LI.g) , Fiber length (FL mm), Fiber strength (FS), Micronaire reading (MIC), and Uniformity index (UI).

3.7. Heritability

The results of heritability in broad and narrow senses are illustrated in Table (10). The results revealed that broad sense heritability (h^2_b%) estimates were larger than the corresponding values of narrow sense heritability (h^2_n%) for all studied traits. The highest broad sense heritability estimates was observed in case of seed index with values of 88.02% and the lowest was for boll weight with value of 57.68%, while for narrow sense heritability, it was ranged from 5.26% to 17.30% for fiber length and lint cotton yield/plant, respectively. Sorour et al. (2013) found that heritability estimates in narrow sense were low to high for all the studied traits, ranged from 32.17% for seed cotton yield to 91% for boll weight. Hamed and Said (2021) The highest broad sense heritability estimates was observed in case of UHM with values of 88.47% and the lowest was for fiber strength with value of 32.24%, while for narrow sense heritability, it was ranged from 8.04% to 49.03% for boll weight and fiber length, respectively.

4. Conclusions

Giza 96 and Australy13 could be used in breeding programs for improving high yielding varieties, while Giza 96 and Suvine could be considered as excellent parents for breeding programs to produce new varieties characterized with best fiber properties.

Conflicts of Interest: The authors declare no conflict of interest.

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