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COMBINING ABILITY IN RELATION TO HETEROSIS EFFECTS AND GENETIC DIVERSITY IN COTTON USING LINE X TESTER MATING DESIGN

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ABSTRACT

The aim of this study was to investigate the relationship between specific combining ability, genetic diversity of parents and heterosis over better parent effects. This research, having eighteen F1 crosses derived from crossing between six lines and three testers, was conducted in order to estimate combining ability, to determine the nature of gene action and heterosis for yield and fiber quality traits and to detect the appropriate crosses for cotton breeding program. The experiment was conducted on randomized complete block design with three replications. The analyses of variance showed significant differences among the genotypes, parents (lines and testers) and crosses for all the studied traits. Estimates of both general and specific combining ability effects were significant for most traits, indicating the importance of both additive and non-additive gene effects for these traits. While, specific was higher than general combining ability variances, for all traits, showing non-additive gene action controlling and therefore, heterosis breeding may be rewarding. The heterosis value varied from cross to cross and from trait to trait. This dissimilarity coefficient was ranged from 3.234 between Giza 85 and Giza 80 to 71.002 between Giza 96 and 10229. Association between heterosis over better parent and specific combining ability was positive and significant for all the studied traits except lint yield / plant. No correlations were found between SCA and GD for all the studied traits. Similarly, heterosis effects was negatively significantly correlated with GD only in the case of boll weight, lint yield / plant and uniformity ratio %, while showed positive and significant correlation for fiber strength and micronaire value. Four crosses showed both positive and significant heterosis and specific combining ability for most yield traits. The parents of these crosses belong to different clusters. Crossing diverse parents could produce high heterotic performance in hybrids. So, breeder should select parents from genetically diversified clusters.

Keywords: Combining ability, Heterosis, cotton, correlation, genetic diversity, dissimilarity coefficient

INTRODUCTION

The priority aim of many plant breeding programs is to produce high yield verities. Hybridization followed by selection in early transgreesive segregation to select the superior pure lines is a very useful technique in many breeding programs. The most important factor to determine breeding program success is how to select parents to buildup new crosses. to do this step the plant breeder need to know more knowledge about combining ability, gene action, genetic variation of the economic traits in the initial phases of plant breeding program.

Line x tester mating design was first proposed by Kempthorne in 1957. This design involves hybridization between lines (as females) and wide based testers (as males) in one to one fashion. It is the simplest mating design that provides both full-sibs and half-sibs (Nduwumuremyi *et al.*, 2013). Also, used to predicting general combining ability (GCA) of parents and determined the suitable parents and crosses with high specific combining ability (SCA), also to provide information about genetic mechanisms controlling important quantitative traits. The clear knowledge about both general and specific combining abilities and gene actions could help plant breeder to decide the best breeding methods to be followed and select desirable genotypes. Also, general combining ability is attributed to additive type of gene effects, while specific combining ability is attributed to non-additive type of gene actions (Sharma 1998 and Singh and Narayanan, 2013).

The breeders define combining ability or productivity of crosses as the combination of potential line concerning the transmission of desirable genes to their offspring. The aptitude of combination between two parents has been classified into general and specific combining ability. General combining ability is the average performance of a parent in a series of cross-combinations producing hybrids, whereas SCA is the deviation of a parent from its GCA in a specific cross combination (Bernardo, 2002). The breeder used GCA and SCA as an important tool to select the best inbreed parent and the superior single-cross hybrid, respectively. So, many cotton breeders have studied the combining ability effects of cotton by using line × tester analysis for various economic traits (Mahrous, 2018; Sultan *et al.*, 2018 and Yehia and El-Hashash, 2019).

Heterosis or hybrid vigor is a complex phenomenon defined as the superiority of the hybrid over their mid or better parents (heterobeltiosis). Heterosis is depending on the balance between additive and dominance gene action and interacting traits as well as distribution of genes in parental lines (Bernardo, 2002). To establish breeding program for producing commercial exploitation of heterosis for hybrid crop development or variety development, the patents should be characterized by genetically superior, physiologically efficient, possess better general and specific combining ability (Talpur *et al.*, 2016). Also, Singh and Narayanan, 2013 reported that heterosis has positive association with specific combining ability (SCA) variance because SCA is a measure of dominance variance and existence of a significant amount of dominance variance. This is essential for undertaking heterosis breeding program.

The present study was designed to assess both types of combining ability, to determine the nature and magnitude of gene action and heterosis over better parent for yield and fiber quality traits using line x tester mating design. Also, the study extended to estimate genetic diversity between the nine parental genotypes and classified them according dissimilarity coefficient using cluster analysis. The study discovers the relationship between specific combining ability, heterosis over better parent and genetic diversity.

MATERIALS AND METHODS

The present investigation was carried out at Sakha Experimental Station; Agriculture Research Center, Kafr El-Sheikh government; Egypt, during two growing seasons of 2019-2020. Six line cotton varieties (Giza 80, Giza 85, Giza 90, Giza 94, Giza 95 and Giza 96) and three foreign testers (Suvin, 10229 and Pima S6) belonging to *Gossypium barbadense L*., were selected on the basis of their agronomic and fiber quality traits. Origin and pedigree of the studied parental genotypes were illustrated in Table 1. The selfed seeds of these genotypes were kindly supported from the Cotton Breeding Department; Cotton Research Institute, Agriculture Research Center, Giza, Egypt.

The lines which were used as female were emasculated and pollinated by testers as males following line × tester mating design to produce the hybrid seeds of eighteen cotton crosses in 2019 growing season. The seeds of each individual cross were harvested separately. The F1 hybrids of the eighteen crosses along with the nine parental genotypes (six lines and three testers) were grown in randomized complete block design (RCBD) with three replications in 2020 growing season. Each replicate consists of four rows for each genotype. The row was 7 m long, with 70 cm between rows and 70 cm between plants within rows to insure 10 plants per row. Hills were thinned to keep a constant stand of one plant per hill at seedling stage. All agronomic cultural practices were applied as recommended by the Ministry of Agricultural for cotton cultivation.

At harvest all individual plants of nine parental cotton genotypes and their eighteen F1 crosses were harvested in order to evaluate four agronomic yield traits; i.e.; boll weight (BW) in grams as the average weight of ten bolls per plant, seed cotton yield per plant (SCY/P) in grams, lint yield per plant (LY/P) in grams, lint percentage (L%). Also, four fiber quality traits i.e.; fiber length (FL) in mm, fiber strength (FS), micronaire value (Mic) and uniformity ratio (UR%) were estimated at Cotton Technology Laboratory, Cotton Research Institute, Agricultural Research Center, Giza, Egypt.

Analysis of variance (ANOVA) technique used to analyze the recorded data as outlined by Gomes and Gomes 1984. Also, mean values of parents was used to estimate heterosis relative to better parent according Fonsecca and Patterson 1968. The data were analyzed to estimate general combining ability (GCA) variance effects of the parents (lines and testers) and specific combining ability (SCA) variance effects of the crosses by the using line x tester mating design as described by Kempthorne, 1957 and Singh and Chaudhary, 1985. Cluster analysis using multivariate analysis based on quantitative yield and fiber quality traits. The dissimilarity coefficient based on Euclidean distance and dendrogram were done by using SPSS software version 20.

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) for agronomic and fiber quality traits used to detect the variability between studied cotton genotypes is presented in Table 2. Highly significant differences between genotypes showed that there is overall variability between these genotypes. This situation indicated that there was a significant variation among line x tester population (parents and crosses). The variance due to parents vs. crosses was also significant for all traits indicating presence of hybrid vigor or heterosis for these traits. However, line x tester were highly significant for all studied traits, showing the importance of both additive and nonadditive variance. The same results for barbadense cotton were obtained by Mahrous, 2018; Sultan *et al.*, 2018 and Yehia and El-Hashash, 2019. These results lead to compute general and specific combining ability effects between parent (lines and testers) and crosses, respectively.

Mean performance for formulating the breeding strategy of any crop is an important to know the genetics of breeding materials to be included in breeding programme. The mean performance of six lines, three testers and their eighteen F1 crosses for various traits under study is presented in Table 3. Five varieties out of six lines belonging to long staple cotton category and one (Giza 96) belonging to extra-long staple. Three varieties (Giza 95, Giza 94 and Giza 85) had high seed cotton yield / plant (179.5, 160.167 and 157.6 g) coupled with high lint % (40.473%, 39.971% and 38.848%), respectively. While, Giza 80 has low seed cotton yield / plant (117.2 g) and high lint % (40.297%) and Giza 90 showed high yield with low lint %. The fiber quality properties of these five lines fall in the long staple cotton category. On the other hand, the sixth line (Giza 96) has high seed cotton yield / plant (126.467 g) and lint % (36.036%) compared to the

Table 1: Origin and pedigree for the six lines and three testers

No.	Genotypes	Origin	Pedigree
L1	Giza 80	Egypt	Giza 66 x Giza 73
L2	Giza 85	Egypt	Giza 67 x CB58
L3	Giza 90	Egypt	Giza 80 x Dandara
L4	Giza 94	Egypt	10229 x Giza 86
L5	Giza 95	Egypt	(Giza 83 x (Giza 75 x 5844)) x Giza 80
L6	Giza 96	Egypt	Giza 84 x (Giza 70 x Giza 51b) x S62
T1	Suvin	Indian	Sujata x Vincent
T2	10229	Russian	Unknown
T3	Pima S6	American	5934-23-2-6 / 5903-98-4-4

Table 2: Analysis of variance for all the studied yield and fiber quality traits

		Mean Squares							
SOV	**d.f**	**BW**	**SCY/P**	**LY/P**	**L%**	**FL**	**FS**	**Mic**	**UR %**
Replications	2	0.004	22.919	3.039	0.022	0.290	0.045	0.002	0.158
Genotypes	26	0.070	1673.730	345.269	6.668	11.144	0.511	0.439	7.486
Parents (P)	8	0.083	1510.755	288.609	7.667	13.435	0.621	0.507	12.491
P vs. C	1	0.061	9663.589	2643.768	67.543	11.414	0.338	1.043	9.729
Crosses (C)	17	0.064	1280.432	236.727	2.616	10.051	0.469	0.371	4.998
Lines (L)	5	0.149	3534.212	642.248	2.099	31.136	1.046	0.536	12.289
Testers (T)	2	0.022	402.208	132.467	11.778	2.174	0.565	1.141	6.134
L x T	10	0.030	329.187	54.818	1.043	1.083	0.161	0.134	1.126
Error	52	0.005	11.187	2.018	0.138	0.158	0.015	0.005	0.577

Table 3: Mean performance for parents and their eighteen crosses for yield and fiber quality traits

Traits / Genotypes	BW g	SCY/P g	LY/P g	L%	FL mm	FS	Mic	UR %
Lines								
Giza 80	3.283	117.200	47.231	40.297	30.767	9.567	4.467	82.567
Giza 85	3.183	157.600	61.230	38.848	33.033	9.867	3.800	86.700
Giza 90	3.267	144.133	54.010	37.474	30.167	9.733	4.733	82.800
Giza 94	3.633	160.167	64.020	39.971	34.333	10.267	4.167	86.000
Giza 95	3.607	179.500	72.652	40.473	30.167	9.100	4.700	83.033
Giza 96	3.233	126.467	45.570	36.036	36.800	10.633	4.067	86.767
Lines mean	3.368	147.511	57.452	38.850	32.545	9.861	4.322	84.645
Testers								
Suvin	3.267	117.200	44.123	37.644	32.700	10.133	3.333	86.967
10229	3.433	114.033	45.348	39.776	32.533	10.267	4.067	84.433
Pima S6	3.467	144.100	58.272	40.439	34.333	10.133	4.133	85.567
Testers mean	3.389	125.111	49.248	39.286	31.855	10.178	3.844	85.656
Parental mean	3.375	140.044	54.717	38.995	32.759	9.967	4.163	84.982
Crosses								
Giza 80 x Suvin	3.470	137.700	54.726	39.743	32.867	10.200	3.533	86.467
Giza 80 x 10229	3.293	124.867	51.976	41.621	32.633	10.067	4.067	85.433
Giza 80 x Pima S6	3.383	147.933	59.921	40.507	33.100	10.267	3.900	85.000
Giza 85 x Suvin	3.250	157.933	61.865	39.173	33.233	9.900	3.367	87.233
Giza 85 x 10229	3.150	167.700	68.184	40.658	31.967	9.767	4.033	85.700
Giza 85 x Pima S6	3.077	162.933	65.876	40.433	33.533	9.633	3.867	87.400
Giza 90 x Suvin	3.350	145.733	58.315	40.014	31.767	10.000	3.533	84.133

Giza 90 x 10229	3.497	151.833	64.456	42.453	32.067	10.067	3.733	83.967
Giza 90 x Pima S6	3.233	168.567	69.907	41.472	31.433	9.633	4.367	85.567
Giza 94 x Suvin	3.300	156.733	62.540	39.896	35.900	10.000	4.167	87.667
Giza 94 x 10229	3.467	183.533	77.022	41.966	34.000	10.067	4.300	86.533
Giza 94 x Pima S6	3.333	153.200	63.673	41.559	35.067	10.356	4.067	87.267
Giza 95 x Suvin	3.150	196.967	79.838	40.543	31.067	10.600	3.733	84.867
Giza 95 x 10229	3.070	192.467	81.827	42.512	31.900	10.333	4.333	83.800
Giza 95 x Pima S6	3.257	203.533	83.050	40.803	31.167	10.533	4.500	85.200
Giza 96 x Suvin	3.500	153.500	63.733	41.519	36.867	10.633	3.333	87.933
Giza 96 x 10229	3.543	153.700	63.593	41.373	35.967	10.833	3.633	86.233
Giza 96 x Pima S6	3.377	169.033	68.526	40.540	35.467	10.067	3.733	86.500
Crosses mean	3.317	162.659	66.613	40.933	33.556	10.104	3.900	85.939
Overall mean	3.336	155.121	62.648	40.287	33.142	10.098	3.988	85.620
LSD at 0.05	0.113	5.462	2.320	0.606	0.648	0.199	0.116	1.240
LSD at 0.01	0.150	7.264	3.085	0.806	0.862	0.264	0.155	1.649

Table 4: Combining ability variances and proportional contributions of lines, testers and their interaction for yield and fiber quality traits

Parameters / Traits	Combining ability variances			Proportional contributions %		
	σ2gca	σ2sca	σ2gca/σ2sca	Lines	Testers	Lines x Testers
Boll weight	0.001	0.01	0.123	68.668	3.971	27.361
Seed cotton yield / plant	28.521	106	0.269	81.182	3.696	15.123
Lint yield / plant	5.454	17.6	0.31	79.795	6.583	13.622
Lint %	0.047	0.302	0.156	23.596	52.960	23.444
Fiber length	0.269	0.309	0.871	91.114	2.545	6.341
Fiber strength	0.009	0.049	0.189	65.604	14.178	20.217
Micronaire value	0.007	0.043	0.165	42.504	36.208	21.287
Uniformity ratio %	0.116	0.183	0.634	72.314	14.438	13.248

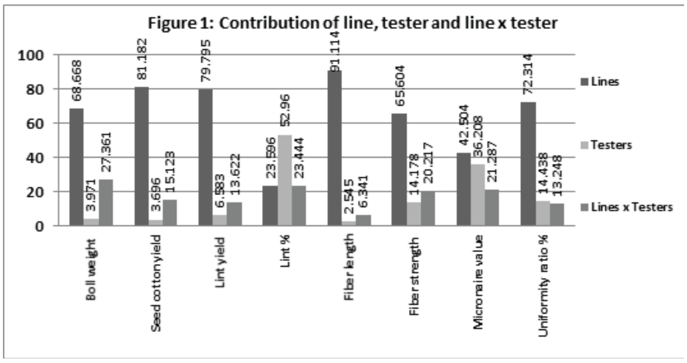
varieties belonging to this category.

The eighteen F1 crosses varied in their mean performance for all the studied traits. seven cotton crosses (Giza 85 x 10229, Giza 90 x Pima S6, Giza 94 x 10229, Giza 95 x Suvin, Giza x PIMA S6, Giza 95 x 10229 and Giza 96 x Pima S6) out of eighteen showed higher seed cotton yield / plant and lint cotton yield / plant more than the average crosses mean, while, lint % was more than 40% for the seven crosses. Fiber quality traits for the six crosses was ranged as long staple category and the seven one was extra-long staple but need more stress to increase fiber length trait more than 35.4mm because this is the minimum range of this category. On the other hand, the other two crosses (Giza 96 x Suvin and Giza 96 x 10229) showed high yield components traits but lower than crosses mean and express higher fiber quality traits as extra-long staple. So, the cotton breeder succeeded to break the negative linkage between yield and fiber quality traits. Five crosses (Giza 85 x 10229 x Giza 85 x Pima S6, Giza 85x Suvin and Giza 90 x Pima S6) had low fiber strength value less than 10 which need more stress in selection during later generations because these values not desirable by the Egyptian cotton breeder.

The proportional contributions of lines and testers and their interactions to the total variance for the studied yield and fiber quality traits were presented in Table 4 and Figure 1. The contribution of the lines was found higher than testers for all studied traits except lint %. Line x tester interaction contributed to combinations' variances was found higher than testers for the investigated traits expect lint %, micronaire value and uniformity ratio. According to these result, the maximum contributions to the total variance provided by the lines and line x tester interactions for all traits except lint % (tester contribution was 52.960 %). Specific combining ability variances are higher than general combining ability variances as presented in Table 4 for all the studied traits. These results indicated that there is preponderance of non-additive gene action (dominance and epistasis) and therefore, heterosis breeding may be rewarding.

Combining Ability (Variance and Effects)

General and specific combining ability effects are obtainable in Tables 5, 6, 7, 8 and 9 respectively. Whereas, highly significant mean squares for GCA indicated significant dissimilarity for all traits and additive gene effects. While, highly significant mean squares for SCA showed that non additive gene controlling the genetic behavior of these traits.



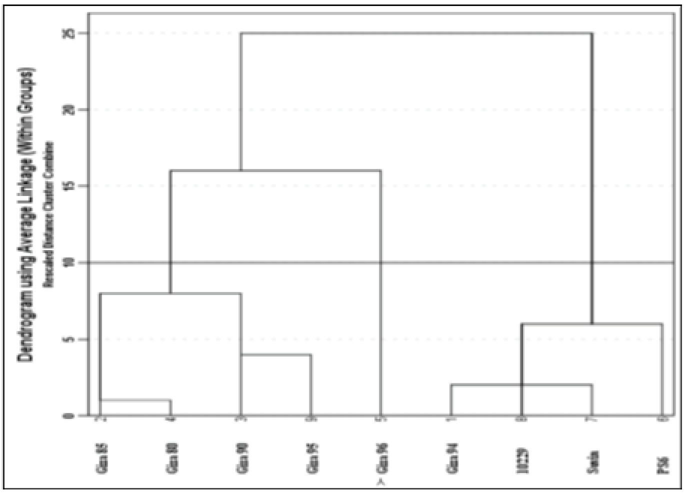


Figure 2: Dendrogram of the nine parental cotton genotypes

General Combining Ability effects (GCA)

General combining ability effects (GCA) was defined the average performance of line, tester in a series crosses. GCA effects of the lines and testers are present in Table 5. Among the parents the highest positive GCA effect were exhibited by the lines Giza 94 and Giza 95 for most of the studied traits. So, the breeder could consider these two lines as the best combiner. Especially, Giza 95 showed higher GCA values 34.996, 14.959 and 0.353 for seed cotton yield /plant, lint yield / plant and lint %, respectively. These results exhibit higher mean performance values for these traits overall the six lines (Table 3). Also, additive genes controlled these traits in these parents.

GCA effects for the tester 10229 were significant and positive for lint yield / plant, lint % and fiber strength for 10229. While, tester Pima S6 has significant and positive GCA for seed cotton yield / plant and lint yield / plant. On the other hand, tester I (Suvin) showed significant and negative GCA for yield traits and micronaire value. While, has significant and positive GCA for fiber quality traits. These results reflected by it lower mean values for yield traits and higher values for fiber quality traits comparing to the other two testers (Table 2).

It was obvious that both lines and testers showed different response positive or negative GCA for variable traits. Sharma 1998, Singh and Narayanan, 2013 and Khokhar *et al.*, 2018 reported that high GCA effect is a result of the additive gene effects or additive x additive gene interaction effects (if epistasis is present). Therefore, the newly two cotton varieties Giza 94 and Giza 95 should be considered as the best combiner in cotton breeding program aimed to improve yield traits.

Specific combining ability (SCA) is defining as the performance of inbred parents in a specific combination. SCA is an important parameter to estimate and select superior cross combinations and indicated non-additive gene action (Nduwumuremyi *et al.*, 2013). The specific combining ability effects of eighteen cotton crosses for the studied yield and fiber quality traits were illustrated in Table 7. Two crosses (Giza 80 x Pima S6 and Giza 94 x 10229) out of eighteen showed significant and positive specific combining ability for all the studied traits except lint % and uniformity ratio %. Three crosses (Giza 80 x Suvin, Giza 85 x 10229 and Giza 90 x PIMA S6) had significant and positive SCA for seed cotton yield / plant and lint yield / plant. Only, two crosses (Giza 94 x Pima S6 and Giza 96 x Suvin) had significant and positive SCA for lint %. This may be related to the higher lint % mean values for the lines and testers for these crosses. Specific combining ability effects for fiber quality; two crosses (Giza 85 x Pima S6 and Giza 95 x Suvin) and anther two (Giza 95 x Pima S6 and Giza 96 x 10229) showed significant and positive SCA for fiber length and fiber strength, respectively. Only four crosses (Giza 85 x Suvin, Giza 90 x 10229, Giza 94 x Pima S6 and Giza 95 x Suvin) had significant and negative (desirable trend) SCA for micronaire value.

Finally, the crosses showed positive and significant SCA could had parents with good x good, good x poor and poor x poor general combining ability effects. The best combinations should have at least one parent with good or medium or poor GCA effects. The same findings were also reported in several cotton crosses by Mahrous, 2018; Sultan *et al.*, 2018, Khokhar *et al.*, 2018 and Yehia and El-Hashash, 2019.

Heterosis relative to better parent or heterobeltiosis values is important genetic parameter. Either positive or negative values for heterosis are useful but depending on the breeding program objectives or trait direction. Nowadays, some breeding programs aimed to increase yield productivity through producing hybrid vigor varieties. Heterotic estimates relative to better parent of the eighteen cotton cross for yield and fiber quality traits was presented in Tables 7 and 8. Cross (Giza 96 x 10229) has significant and positive heterosis over better parents for all the studied traits except fiber length, micronaire value (desirable direction) and uniformity ratio were negative. Also, the cross recorded higher heterosis values for these traits. Three crosses (Giza 90 x 10229, Giza 94 x 10229 and Giza 95 x 10299) had significant and positive heterosis for seed cotton yield / plant, lint yield / plant, lint % and fiber length, while negative micronaire value for cross Giza 90 x 10229 only. Cross (Giza 96 x Suvin) showed significant and positive heterosis for four yield traits only and recorded the highest heterosis values 7.143, 21.376, 39.858 and 10.294 for boll weight, seed cotton yield / plant, lint yield / plant and lint %, respectively.

Table 5: Estimates of general combining ability effects for the six lines and three testers for yield and fiber quality traits

Parents \ Traits	Role in cross	BW g	SCY/P g	LY/P g	L%	FL mm	FS	Mic	UR %
Group I									
Giza 80	Line	0.066**	-25.83**	-11.07**	-0.309*	-0.689*	0.074	-0.067**	-0.306
Giza 85	Line	-0.158**	0.196	-1.304**	-0.844**	-0.644*	-0.337**	-0.144**	0.839**
Giza 90	Line	0.043	-7.281**	-2.386**	0.380**	-1.800**	-0.204**	-0.022	-1.383**
Giza 95	Line	-0.159**	34.996**	14.959**	0.353**	-1.511**	0.385**	0.289**	-1.317**
Group II									
Giza 96	Line	0.157**	-3.915**	-1.329**	0.211	2.544**	0.407**	-0.333**	0.950**
Group III									
Giza 94	Line	0.050*	3.830**	1.132*	0.208	2.100**	0.326**	0.278**	1.217**
Suvin	Tester	0.020	-4.565**	-3.110**	-0.785**	0.394**	0.119**	-0.289**	0.444*
10229	Tester	0.020	-0.309	1.230**	0.831**	-0.133	0.085**	0.117**	-0.661**
Pima S6	Tester	-0.040*	4.874**	1.880**	-0.047	-0.26***	-0.204**	0.172**	0.217

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

Table 6: Above average and poor general combing ability parents for different studied traits

Traits	Lines						Testers	
	Above average combiners				Poor combiners		Above average combiners	
	1st		2nd					
	Genotypes	Value	Genotypes	Value	Genotypes	Value	Genotypes	Value
BW	Giza 96	0.157**	Giza 80	0.066**	Giza 90	0.043	Pima S6	-0.040*
SCY/P	Giza 95	34.996**	Giza 94	3.830**	Giza 85	0.196	Pima S6	4.874**
LY/P	Giza 95	14.959**	Giza 94	1.32**	-	-	Pima S6	1.880**
L%	Giza 90	0.380**	Giza 95	0.353	Giza 96	0.211	10229	0.831**
FL	Giza 96	2.544**	Giza 94	2.100**	-	-	Suvin	0.394**
FS	Giza 96	0.407**	Giza 94	0.326**	Giza 80	0.074	Suvin	0.119**
Mic	Giza 96	-0.333**	Giza 85	-0.337**	Giza 90	-0.022	Suvin	-0.289**
UR%	Giza 94	1.217**	Giza 96	0.950**	Giza 80	-0.306	Suvin	0.444**

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

Table 7: Specific combining ability (SCA) and heterosis over better parent (HBP) effects for yield and its components traits

No.	Crosses \ Traits	Boll weight g		Seed cotton yield / plant g		Lint yield / plant g		Lint %	
		SCA	HBP	SCA	HBP	SCA	HBP	SCA	HBP
1	Giza 80 x Suvin	0.068	5.685**	5.431**	17.491**	2.295**	15.869**	-0.096	-1.373
2	Giza 80 x 10229	-0.11**	-4.078**	-11.65**	6.542**	-4.79**	10.047**	0.166	3.286**
3	Giza 80 x Pima S6	0.041	-2.404*	6.226**	2.660	2.500**	2.830	-0.070	0.167
4	Giza 85 x Suvin	0.071	-0.510	-0.357	0.212	-0.334	1.037	-0.131	0.834
5	Giza 85 x 10229	-0.029	-8.252**	5.154*	6.409**	1.645*	11.357**	-0.261	2.218*
6	Giza 85 x Pima S6	-0.042	-11.25**	-4.796*	3.384*	-1.312	7.589**	0.392	-0.015
7	Giza 90 x Suvin	-0.030	2.551*	-5.080*	1.110	-2.80**	7.971**	-0.515*	6.295**
8	Giza 90 x 10229	0.117**	1.845	-3.235	5.342**	-1.000	19.342**	0.309	6.731**
9	Giza 90 x Pima S6	-0.087*	-6.731**	8.315**	16.952**	3.801*	19.967**	0.206	2.554**
10	Giza 94 x Suvin	-0.087*	-9.174**	-3.191	1.010	-2.095*	0.861	-0.459*	-0.187
11	Giza 94 x 10229	0.080*	-4.587**	19.354**	18.281**	8.046**	24.217**	-0.006	4.990**
12	Giza 94 x Pima S6	0.007	-8.257**	-16.16**	-1.267	-5.95**	9.269**	0.465*	2.769**
13	Giza 95 x Suvin	-0.029	-12.66**	3.876	9.731**	1.376	9.891**	0.041	0.172
14	Giza 95 x 10229	-0.11**	-14.880**	-4.880*	7.224**	-0.975	12.629**	0.394	5.036**
15	Giza 95 x Pima S6	0.138**	-9.704**	1.004	13.389**	-0.401	14.313**	-0.436*	0.816

16	Giza 96 x Suvin	0.007	7.143**	-0.680	21.376**	1.559	39.858**	1.160**	10.294**
17	Giza 96 x 10229	0.050	3.204**	-4.735*	21.534**	-2.921**	39.550**	-0.602**	4.016**
18	Giza 96 x Pima S6	-0.057	-2.596*	5.415**	33.658**	1.362	17.596**	-0.557*	0.249

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

Table 8: Specific combining ability (SCA) and heterosis over better parent (HBP) effects for fiber quality traits

No.	Traits / Crosses	Fiber length mm		Fiber strength		Micronaire value		Uniformity ratio %	
		SCA	HBP	SCA	HBP	SCA	HBP	SCA	HBP
1	Giza 80 x Suvin	-0.394	0.305	-0.096	0.658	-0.011	6.000**	0.389	-0.575
2	Giza 80 x 10229	-0.100	-0.407	-0.196**	-1.948*	0.117**	0.000	0.461	1.184*
3	Giza 80 x Pima S6	0.494*	1.017	0.293**	1.316	-0.106*	-5.645**	-0.850	-0.662
4	Giza 85 x Suvin	-0.072	0.605	0.015	-2.303**	-0.100*	1.000	0.011	0.307
5	Giza 85 x 10229	-0.81**	-3.229**	-0.085	-4.870**	0.161**	6.140**	-0.417	-1.153*
6	Giza 85 x Pima S6	0.883**	1.514	0.070	-4.934**	-0.061	1.754	0.406	0.807
7	Giza 90 x Suvin	-0.383	-2.854**	-0.019	-1.316	-0.056	6.000**	-0.867	-3.258**
8	Giza 90 x 10229	0.444	1.691*	0.081	-1.948*	-0.26**	-8.197**	0.072	-0.553
9	Giza 90 x Pima S6	-0.061	0.319	-0.063	-4.934**	0.317**	5.645**	0.794	0.000
10	Giza 94 x Suvin	-0.150	1.604*	0.104	-2.597**	0.278**	25.000**	0.067	0.766
11	Giza 94 x 10229	0.478*	1.887*	0.204**	-1.948*	0.006	5.738**	0.039	-0.536
12	Giza 94 x Pima S6	-0.328	-0.755	-0.307**	-9.740**	-0.28**	-1.613	-0.106	0.307
13	Giza 95 x Suvin	0.628**	1.121*	-0.007	4.605**	-0.17**	12.000**	-0.200	-2.415**
14	Giza 95 x 10229	-0.011	1.163*	-0.241**	0.649	0.028	6.557**	-0.161	-0.750
15	Giza 95 x Pima S6	-0.62**	-0.532	0.248**	3.947*	0.139**	8.871**	0.361	-0.429
16	Giza 96 x Suvin	0.372	0.181	0.004	0.000	0.056	0.000	0.600	0.190
17	Giza 96 x 10229	0.000	-2.264**	0.237**	1.881*	-0.050	-10.656**	0.006	-1.747**
18	Giza 96 x Pima S6	-0.372	-3.623**	-0.241**	-5.329**	-0.006	-8.197**	-0.606	-1.443*

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

Table 9: Above average and poor specific cross combination of various studied traits

Traits	1st		2nd			
	Genotypes	Value	Genotypes	Value	Genotypes	Value
BW	Giza 95 x Pima S6	0.138**	Giza 90 x 10229	0.117**	Giza 94 x Pima S6	0.007
SCY/P	Giza 94 x 10229	19.345**	Giza 90 x Pima S6	8.315**	Giza 85 x Suvin	-0.357
LY/P	Giza 94 x 10229	8.046**	Giza 90 x Pima S6	3.801**	Giza 85 x Suvin	-0.334
L%	Giza 96 x Suvin	1.160**	Giza 94 x Pima S6	0.465**	Giza 94 x 10229	-0.006
FL	Giza 85 x Pima S6	0.883**	Giza 95 x Suvin	0.628**	Giza 96 x 10229	0.000
FS	Giza 80 x Pima S6	0.293**	Giza 95 x Pima S6	0.248**	Giza 96 x Suvin	0.004
Mic	Giza 94 x Pima S6	-0.28**	Giza 90 x 10229	-0.26**	Giza 96 x Pima S6	-0.006
UR%	Giza 90 x Pima S6	0.974	Giza 96x Suvin	0.600	Giza 96 x 10229	0.006

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

On the other hand, this cross showed extra-long staple category as shown in Table 3. Four crosses had (Giza 85 x Pima S6, Giza 95 x Suvin, Giza 95 x Pima S6 and Giza 96 x Pima S6) significant and positive heterosis for seed cotton yield / plant and lint yield / plant only. Three crosses (Giza 80 x 10229, Giza 85 x 10229 and Giza 90 x Pima S6) had significant and positive heterosis for all yield traits except boll weight, while the cross (Giza 80 x Suvin) has significant and positive heterosis for the same traits except lint %. Our research findings are in conformity with Sultan *et al.*, 2018, Khokhar *et al.*, 2018 and Yehia and El-Hashash, 2019 for sign and direction. The differences in results between researchers with the present study may be attributed to the divergence of the breeding materials used in each study.

Ultimate, the breeding aim is to produce heterosis yield traits coupled with other heterotic traits. The maximum significant positive heterosis over better parent values for yield traits ranged from 6.409% to 33.658% for seed cotton yield / plant, from 7.589 % to 39.858% for lint yield / plant and from 2.218% to 10.299% for lint %. Four crosses (Giza 80 x Suvin, Giza 85 x 10229, Giza 90 x Pima S6 and Giza 94 x 10229) showed both positive

Table 10: Dissimilarity coefficient between nine parental genotypes based on Euclidean distance

Parents	Giza 94	Giza 85	Giza 90	Giza 80	Giza 96	Pima S6	Suvin	10229	Giza 95
Giza 94		43.046	27.925	41.050	67.294	12.733	6.434	4.596	29.457
Giza 85			16.115	3.234	25.218	35.175	43.895	46.442	14.027
Giza 90				14.841	40.099	21.128	29.139	31.549	7.248
Giza 80					27.083	33.411	42.085	44.444	11.699
Giza 96						60.220	68.761	71.002	38.537
Pima S6							10.402	13.873	22.349
Suvin								4.807	30.609
10229									32.803
Giza 95									

Table 11: Simple correlation between parental specific combining ability (SCA), heterosis effect over better parent (HBP) and genetic diversity (GD), for all the studied traits across eighteen cotton crosses

Variables		BW g	SCY/P g	LY/P g	L%	FL mm	FS	Mic	UR %
SCA	HBP	0.417*	0.479*	0.229	0.499*	0.686**	0.533*	0.530*	0.645**
	GD	-0.361	0.195	0.256	-0.199	0.152	-0.128	0.039	-0.231
HBP	GD	-0.699**	-0.281	-0.415*	-0.207	-0.028	0.646**	0.536*	-0.632**

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

and significant heterosis and specific combining ability for seed cotton yield / plant and lint yield / plant. These crosses may be use in breeding program to produce hybrid varieties.

Genetic divergence between parents

The cluster analysis of eight qualitative traits was done based on Euclidean distances which formed the cluster by unweighted paired group method using the arithmetic average (UPGMA). The matrix data of dissimilarity coefficient based on Euclidean distance between nine parental genotypes is presented in Table 10. This dissimilarity coefficient was ranged from 3.234 between Giza 85 and Giza 80 to 71.002 between Giza 96 and 10229. This wide range of genetic distance among these genotypes reflected the presence of wide range of genetic variation and provides an opportunity to improve the cotton genetic basis using crossing technique. Cluster analysis classified nine parental cotton genotypes into three clusters based on dissimilarity coefficient as shown in Figure 2. Cluster I consist of four parents and classified into two sub-clusters, each one has two parents (Giza 80 and Giza 85) and (Giza 90 and Giza 95). Cluster II has only one parent Giza 96. While cluster III has four parents and classified into two sub-clusters; one has three parents (Giza 94, 10229 and Suvin) and the other one has only one parent (Pima S6). Abd El-Moghny *et al.*, 2015 and Akter *et al.*, 2019 classified some cotton genotypes into different clusters based on phenotypic mean performance.

Genetic distance was estimated between and within the three clusters as shown on Figure 2. The genetic distance between cluster I and II, I and III and Clusters II and III was 66.684, 34.230 and 32.570, respectively. While, genetic distance within these clusters was 7.319, 0.000 and 5.419 within cluster I, II and III respectively. The magnitude of the genetic diversity between these clusters indicates that clusters I and II were more diversified followed by I and II. The lowest genetic distance was observed to be between clusters II and III. The intra-cluster distances were always much smaller than inter-cluster distances suggesting a lower genetic diversity among the parents of the same cluster. So, hybridization between clusters more efficient than within clusters and could increase transgressive or heterosis. These results are in common harmony with Abd El-Moghny *et al.*, 2015 and Akter *et al.*, 2019.

Correlation between SCA, heterosis over better parent and genetic diversity

Correlation coefficients between specific combining ability (SCA), heterosis over better parent (HBP) and genetic diversity (GD) are presented in Table 11. The present investigation showed positive and significant correlation between heterosis over better parent (HBP) and specific combining ability (SCA) for all the studied traits except lint yield / plant. Simple correlation between heterosis and SCA was 0.417, 0.479, 0.229, 0.449, 0.686, 0.533, 0.530 and 0.645 for boll weight, seed cotton yield / plant, lint yield / plant, lint %, fiber length, fiber strength, micronaire value and uniformity ratio, respectively. Consequently, four crosses (Giza 80 x Suvin, Giza 85 x 10229 and Giza 90 x Pima S6 and Giza 94 x 10229) recorded positive and significant heterosis and specific combining ability (SCA) for most yield traits and fiber length for the fourth cross only. Also, the parents of these crosses derived from two diverse clusters; cluster I (Giza 80, Giza 85 and Giza 90) and cluster II (Suvin, 10229 Pima S6 and Giza 94). Singh and Narayanan, 2013 explain association between heterosis and specific combining ability effects (SCA) was positive and significant, because SCA is a measure of dominance gene action and heterosis could be explain as a dominance effects and considered as an effective tool for

SCA effects.

No correlations were found between SCA and GD for all the studied traits. Similarly, heterosis effects over better parent were negatively significantly correlated with GD only in the case of boll weight (-0.699), lint yield / plant (-0.415) and uniformity ratio % (-0.632), while positively significant correlation for fiber strength (0.646) and micronaire value (0.536). These results showed that choosing pairs of parents depending on both SCA and GD may be similar for heterosis breeding. This conclusion is confirmed by the values of correlation coefficient between GD of parents, SCA and heterosis effects.

CONCLUSIONS

The breeding program strategy should depending on selection high GCA values for both lines and testers coupled with higher SCA effects to improve major economic traits of the program. Particularly, out of eighteen only two crosses (Giza 80 x Pima S6 and Giza 94 x 10229) were defined as best combinations for high yield and fiber quality traits due to their higher and significant SCA values. The plant breeder should use the association between heterosis and specific combining ability before initiate heterosis breeding program. To existing non-additive gene action from the breeding population to obtain the best families and superior plants within families' selection should be delay to the early segregating generations like F4 and F5.

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