



## Original article

## Evaluation of genetic behavior of some Egyption Cotton genotypes for tolerance to water stress conditions



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## ABSTRACT

Water stress is a critical abiotic stress for plant reduction in arid and semiarid zones and, has been discovered to be detrimental to the development of seedlings as well as the growth and physiological characteristics of many crops such as cotton. The objectives of our study were to determine the combining ability and genetic components for five quantitative traits [(leaf area (LA), leaf dry weight (LDW), plant height (PH), fiber length (2.5 percent SL), and lint cotton yield/plant (LCY/P)] under water shortage stress, a half diallel cross between six cotton genotypes representing a wide range of cotton characteristics was evaluated in RCBD with four replications. The genotype mean squares were significant for all traits studied, demonstrating significant variation among genotypes for all characters under water shortage stress. LCY/P had the highest phenotypic and genotypic correlation co-efficient with PH, LDW, and LA shortage. The highest direct effect on lint cotton yield was exhibited by leaf area (3.905), and the highest indirect effects of all traits were through LA, with the exception of 2.5 percent SL, which was through LDW. The highest dissimilarity (Euclidean Distance) between parental genotypes was between G.87 and G.94, followed by G.87 and Menoufi. G.94 was also a well-adapted genotype, and the combinations G.87 x G.94 and G.87 x Menoufi may outperform their parents. The combining ability analysis revealed highly significant differences between parental GCA effects and F1 crosses SCA effects. The variation of GCA and SCA demonstrated the assurance of additive and non-additive gene action in the inheritance of all traits studied. In terms of general combining ability (GCA) effects, parental genotype G.94 demonstrated the highest significant and positive GCA effects for all traits studied, with the exception of 2.5 percent SL, where G.87 revealed the highest significant and positive GCA effects. The effects of specific combining ability (SCA) revealed that the cross (G.87 x G.94) revealed stable, positive, and significant SCA for all of the studied traits.

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## 1. Introduction

Drought tolerance is a complex agronomic trait with multiple genes that interact in the plant system holistically. If the variation

expressed for the trait is genetically regulated, plant materials with improved tolerance for water-stressed conditions can be developed more efficiently and effectively through breeding and selection. Water stress tolerance is genetically controlled, according to the evidence in the literature, and both additive and dominant types of genes were important for the expression of biomass recovery, water use efficiency, total leaf area, and yield per plant (Rakavi et al., 2021). Over the years, genetic research on Egyptian cotton has revealed that the genetic behaviour of cotton cultivars varies depending on the genetic material used and the surrounding environmental factors.

Cotton is one of the most important commercial crops in Egypt, and it plays a critical part in the country's agricultural and

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industrial development. The water deficiency has reduced the general cultivated area in recent years, necessitating the development of new varieties adapted to water shortage conditions. Breeders must create a new set of varieties adapted to water stress conditions (Hu et al., 2021); fundamental knowledge of gene action for various cotton properties helps determine the best breeding method (Mohamed et al., 2009). It is critical to investigate the genetic diversity of Egyptian cotton cultivars grown in water-stressed conditions, as this information might be exploited to produce new cotton genotypes. Plant breeders need to understand genetic diversity and interactions among breeding materials to improve yield and fiber characteristics under water-stressed environments (Chattha et al., 2021; Ergashovich et al., 2020). Heterosis is a valuable genetic tool for enhancing yield and enriching a variety of other quantitative attributes. Under normal conditions, significant positive heterosis over-mid and better parent was detected in cotton for both numbers of sympodial branches per plant and yield of seed cotton per plant for both lint yield and boll number per plant, indicating that heterosis relative to mid-parent and better parent was found to be significantly positive for boll number per plant, seed cotton yield, and lint yield per plant in the intra-barbadense cross, while it was negative in the intra-hirsutum cross. Crossings between genetically dissimilar parents are likely to have more genetic diversity across progenies than crosses between genetically similar parents (Burton, 1952). These studies' findings are applicable under specific settings and materials; however, repeating these experiments with the same genetic material may yield different results, making the applicability of these findings in cotton breeding under water stress situations erroneous. Shortage breeding should be conducted under water shortage conditions with specialized genetic materials. Cotton crop improvement necessitates an understanding of the interactions between various features. The correlation coefficient measures the relationship between components and can be used to distinguish between vital and non-vital relationships in breeding (Areej et al., 2021). When two characteristics are positively linked, one can benefit indirectly from the improvement of the other. Correlation coefficients are useful when using indirect selection of a secondary feature to improve the primary trait of interest (Hussain et al., 2010). Path coefficient analysis can also be used to determine which connections are direct and which are indirect (Kale et al., 2007). Path coefficient analysis has been widely used in cotton crop research by Larik et al. (1999); Azeem and Azhar (2006). When starting a breeding programme, the diallel system provides the most accurate information to plant breeders of all genetic analysis methods (Kiani et al., 2007).

As a result of the elaboration of the study, the Jinks-Hayman and Griffing approaches are regarded powerful enough for gene action analysis (Jinks and Hayman (1953), Hayman, (1954 a and b), Jinks, (1954) and Griffing, (1956)). The goal of this study was to investigate the genetic basis of water stress tolerance by evaluating parental genetic behavior, inheritance, the different genetic components, broad- and narrow-sense heritability, general and specific combining ability, and heterosis, as well as to discover information on the genetic control of studied traits in hybrid combinations obtained by all possible crosses of six selected genotypes under water shortage stress.

## 2. Materials and methods

### 2.1. Genetic materials and experimental procedures:

This study was conducted at Sakha Agricultural Research Station Kafr El-Sheikh Governorate during the 2015 and 2016 seasons. As parents, six genotypes encompassing a wide variety of cotton

properties are selected (Table 1). During the 2015 season, the parents were hand-crossed under normal conditions to form F1 partial diallel crosses. During the 2016 season, the parents and F1 crosses were evaluated using randomized complete blocks with four replicates under water shortage stress conditions by applying one irrigation at planting, three supplemental irrigations 25, 40, and 55 days after planting, and the ordinary practices of cotton cultivation were applied. Each plot had one row with a length of 5.0 m and a width of 0.70 m. Two plants per hill were left at thinning time after seeds were sowed in hills 30 cm apart. Leaf area (cm<sup>2</sup>), dry leaf weight (g) (LDW), and plant height (cm) (PH) were measured on five guarded plants. Plants were hand-picked, with the center ten guarded plants being used to calculate lint cotton yield g/plant (LCY/P). The High-Volume Instrument (HVI) was used to test 2.5 % span length (mm) samples of lint cotton yield (2.5 % SL).

### 2.2. Statistical and genetic analysis:

The data were subjected to the analysis of variance technique (Steel et al., 1997) to calculate phenotypic and genotypic coefficients of variation in order to determine the significance level among the genotypes (PCV and GCV) (Fisher and Yates, 1963) were used to determine phenotypic and genotypic correlations between the traits investigated. Path-coefficient analysis was used to evaluate the direct effects of the examined variables on lint cotton output, allowing the genetic correlation coefficient to be divided into direct and indirect impact (Dewey and Lu, 1959).

Multivariate analysis was used to calculate the dissimilarity between parental genotypes (Johnson and Wichern, 1988). A hierarchical clustering procedure utilizing Ward's minimum variance method was used to determine genetic divergence and distance, which minimize the sum of square inside each cluster across all partitions.

The percent deviation of F1 mean performance over either the better or mid parent was used to compute heterosis estimates (%).

Estimates of parents' general combining ability (GCA) and hybrids' specific combining ability (SCA) effects, as well as variances for GCAs and SCAs, were calculated using Griffing's (1956) method 2 model I. (fixed model). Hayman's simple additive/dominance model (1954 a and b) was used to estimate genetic components of variance (D, H1, H2, F, and h2) and genetic proportions. Plotting each array's variance (Vr) against its covariance yielded information on gene function (Wr). Mather and Jinks (1982) computed broad- and narrow-sense heritability (Hb and Hn, respectively).

## 3. Results

### 3.1. Mean performance, mean square, PCV and GCV

Underwater shortage stress, analysis of variance (Table 2) indicated substantial differences among genotypes for all the examined characteristics, indicating their genetic diversity. PCV was slightly higher than GCV; these results demonstrate the low

**Table 1**  
Pedigrees of the 6 cotton parents used in this study.

No.	Genotype	Pedigree*	Category
1	Giza 86	Giza 75 × Giza 81	LS
2	Giza 87	Giza 77 × Giza 45-A	ELS
3	Giza 89	Giza 75 × Russian-6022	LS
4	Giza 94	Giza 86 × 10229	LS
5	Menoufi (Giza 36)	Wafeer × Sakha 3	ELS
6	Suvin	Indian variety (Sujata × Vincent)	LS

influence of environmental factors on the studied traits under water shortage stress.

Table 3 shows the average performance of all the examined attributes for the six parents and their 15 crosses. The data indicated that all studied traits had a wide range of variability, reflected in the variation among parents and their crosses. Data in Table 3 shows that the parental genotypes G.94 and Menoufi gave the highest mean values for LA, LDW, PH, and LCY/P. The crosses G.87xG.94 and G.94 × Menoufi exhibited the highest LCY/P and exceeded the better parent, which recommends these two crosses for further improvement of LCY/P.

### 3.2. Phenotypic, genotypic correlations and path analysis

The phenotypic and genotypic correlation coefficients among different character combinations are presented in Table 4. The results revealed that LCY/P was significantly positively correlated with LA, LDW, and 2.5% SL; the highest phenotypic and genotypic correlations were with PH (0.853 and 0.915, respectively), followed by LDW and LA. Also, plant height showed positively significant phenotypic and genotypic with LA and LDW. Furthermore, LA and LDW were positively correlated; this means genetic factors affecting LA and LDW could affect LCY/P and PH; selection for these two leaf traits could increase LCY. Although 2.5% SL did not reveal a significant correlation with any of the studied traits, the trend was a negative genetic association.

The genetic correlation coefficients between LCY/P and LA, LDW, PH, and % SL under deficiency water stress were divided into direct and indirect impacts. The path coefficient analysis (Table 5) demonstrated that features have a positive and negative immediate effect on LCY/P. The highest direct impact on lint cotton yield was exhibited by leaf area (3.905), and the highest indirect impacts of all traits were through leaf area except for 2.5% SL was through LDW. These results confirm the importance of leaf traits (LA and LDW) and reveal that selection to improve lint yield under water shortage stress could be more effective through natural selection for leaf traits.

### 3.3. Genetic divergence among parental genotypes

Genetic divergence studies in the parental genotypes have been based on the traits that revealed some exciting features of differentiation and adaptability. Table 6 showed dissimilarity matrices based on the studied traits among the six parental cotton genotypes, the results indicated that the highest dissimilarity (Euclidean Distance) was between G.87 and G.94 (34.65), followed by G.87 and Menoufi (28.75). However, the lowest dissimilarity was between G.89 and Suvin (6.242), followed by G.86 and G.89 (8.670). The results of the dissimilarity matrix conclude that G.94 was the farthest parental genotypes regarding the other genotypes except to Menoufi, was the closest one; however, G.89 was the most identical genotypes to G.86, G.87, and Suvin. These results

recommend G.94 as a suitable adaptation. Genotype and the combination G.87 × G.94 and G.87 × Menoufi may surpass their parents. Cluster analysis was used to group the parental genotypes and to construct a dendrogram (Fig. 1). The 6 genotypes were grouped into three major clusters.

**First cluster:** Included G.94 and Menoufi, which characterized by the highest LDW, PH, and LCY/P.

**Second cluster:** included G.87, which revealed the highest 2.5% SL and the lowest other traits.

**Third cluster:** included G.86, G.89, and Suvin; these genotypes manifested intermediate behavior for all traits.

### 3.4. Heterosis

Heterosis is expressed in Table 7 as the percentage deviation of F1 mean values from their respective mid-parent and better parent estimates for the traits under consideration. Regardless of significance, significant positive heterotic effect values for LA and LDW, G.87 × Menoufi, G.89 × G.94, and G.89 × Suvin would be of interest.

LDW irrespective of significance, G.87 × Menoufi, G.89 × G.94, and G.89 × Suvin revealed the highest heterosis values over mid-parents and better parents, which recommend these crosses for genetic improvement for leaf traits under water shortage. Regarding plant height, G.87 × Suvin and G.89 × Suvin showed the highest heterosis regarding mid parents and better parent, and G.87 × G.94 and G.87 × G.89 over the mid parent. In respect to 2.5% SL, G.86 × G.87, G.86 × Suvin, G.89 × Suvin and G.94 × Menoufi represented the highest heterosis over mid parents and better parents, which recommend these crosses for breeding to improve 2.5% SL under watershortage stress. In terms of LCY/P, G.87 × G.94, G.87 × Suvin, and G.94 × Menoufi had the highest heterosis values when compared to mid and better parents. These results recommend these crosses for further lint cotton yield improvement under shortage water stress.

### 3.5. Analysis of combining ability

The mean square of GCA and SCA effects are presented in Table 3. The results revealed significant differences between parental GCA effects and F1 crosses SCA effects, which indicate the possibility of detecting the most suitable combiner genotype.

### 3.6. General combining ability (GCA) effect

Table 8 shows estimates of general combining ability effects of individual parental lines for the variables investigated. For all the variables studied, parental genotype G.94 had the highest significant and positive GCA effects, except for 2.5 % SL, where G.87 had the highest significant and positive GCA. These findings support the importance of these two genotypes in water shortage stress genetic breeding.

**Table 2**  
Mean squares for the five studied traits.

S.O.V.	d.f	LA	LDW (mg)	PH	2.5% SL	LCY/P(mg)
Replication	3	116.23	0.043**	58.52	0.82	27.29**
Genotype	20	240.75**	0.075**	456.25**	4.07**	30.68**
GCA	5	399.04**	0.203**	693.46**	9.29**	54.93**
SCA	15	188.70**	0.032**	377.30**	2.29**	22.36**
Error	60	77.16	0.0099	78.28	0.59	4.23
$\sigma^2$ GCA		10.04	0.0061	19.24	0.275	1.60
$\sigma^2$ SCA		27.75	0.0055	74.68	0.427	4.55
PCV %		14.34	16.15	6.25	2.95	15.16
GCV %		11.82	15.04	5.69	2.73	14.08

\* and \*\* significant at 0.05 and 0.01 levels of probability, respectively.

**Table 3**  
Mean performance of parents and their crosses for the five studied traits.

Genotype	LA (cm)	LDW (mg)	PH (cm)	2.5% SL(mm)	LCY/P (mg)
G.86	60.4	9	164.0	34.0	156
G.87	47.0	6.9	155.0	35.0	133
G.89	53.1	8.1	167.3	34.3	189
G.94	65.4	11.58	183.3	33.2	209
Menoufi	56.1	9.3	181.0	31.4	207
Suvin	48.1	6.9	171.0	33.8	188
G.86 × G.87	41.1	6.68	158.3	36.0	160
G.86 × G.89	42.1	0.763	158.7	34.0	152
G.86 × G.94	64.3	10.1	180.7	34.6	20.7
G.86 × Menoufi	49.5	7.43	151.7	33.2	142
G.86 × Suvin	55.5	8.1	165.7	34.8	158
G.87 × G.89	45.4	7.13	172.3	35.5	190
G.87 × G.94	61.5	10.18	184.8	34.8	218
G.87 × Menoufi	57.5	9.33	163.0	33.6	180
G.87 × Suvin	43.2	6.4	183.7	34.5	206
G.89 × G.94	65.9	9.53	172.3	34.9	188
G.89 × Menoufi	61.8	9.8	166.7	34.2	182
G.89 × Suvin	60.4	8.6	188.7	35.2	190
G.94 × Menoufi	51.9	9.2	181.2	34.2	246
G.94 × Suvin	52.2	7.88	165.0	32.9	163
Menoufi × Suvin	54.1	7.93	174.7	34.0	174
LSD (0.05)	8.69	1.09	15.45	6.91	5.05
LSD (0.01)	12.43	1.55	22.09	9.88	7.22

**Table 4**  
Phenotypic (upper) and genotypic (lower) correlation between all pairs of studied traits.

Traits	LA	LDW (mg)	PH	2.5% SL
LDW	0.887**			
PH	1.027**	0.442*		
2.5% SL	0.615**	4.66*	5.48*	
LCY/P	-0.179	-2.84	-0.036	
	-0.260	-3.31	-0.068	
	0.350*	5.08*	0.853**	-0.093
	0.375*	5.65*	0.915**	-0.136

\* and \*\* significant at 0.05 and 0.01 level of probability, respectively.

3.7. Specific combining ability (SCA) effect

Table 9 shows estimates of specific combining ability impacts for the 15 F1 crosses. Regarding LA and LDW, G.87 × G.94, G.87 × Menoufi, G.89 × Menoufi and G.89 × Suvin revealed the highest significant and positive SCA for these traits. These results agree with heterosis and confirm the possibility of using these crosses

**Table 5**  
Direct (diagonal) and indirect effects for leaf area (LA), leaf dry weight (LDW), plant height (PH), and fiber length (2.5% SL) on lint cotton yield/plant (LCY/P).

Trait	LA	LDW(mg)	PH	2.5% SL	r <sub>g</sub> (LCY/P) (mg)
LA	<b>3.905</b>	-40.08	0.387	0.091	<b>3.75</b>
LDW	4.010	<b>-39.02</b>	0.345	0.112	<b>5.65</b>
PH	2.402	-21.38	<b>0.629</b>	0.023	<b>9.15</b>
2.5% SL	-1.047	12.92	-0.043	<b>-0.338</b>	<b>-1.36</b>

**Table 6**  
Dissimilarity matrices based on the studied traits among the six parental cotton genotypes.

Case	Euclidean Distance					
	G.86	G.87	G.89	G.94	Menoufi	Suvin
G.86	0.000	16.337	8.670	20.647	18.446	14.513
G.87	16.337	0.000	14.845	34.651	28.750	16.997
G.89	8.670	14.845	0.000	20.313	14.434	6.242
G.94	20.647	34.651	20.313	0.000	9.753	21.344
Menoufi	18.446	28.750	14.434	9.753	0.000	13.169
Suvin	14.513	16.997	6.242	21.344	13.169	0.000

to improve leaf traits under water shortage stress. Regarding PH and LCY/P, G.86 × G.94, G.87 × G.94, and G.87 × Suvin manifested the highest significant and positive SCA. These results are associated with those of heterosis and confirm the results of genetic diversity.

4. Discussion

Water shortage cause drought stress in cotton that adversely affect yield quantity and quality. Natural compounds such as chitosan, amino acids (Fouda et al., 2021), peptides (El-Saadony et al., 2021a,b; Saad et al., 2021b), polyphenolic extracts and essential oils (El-Tarabily et al., 2021; Saad et al., 2021, 2021a), biological nanoparticles (El-Saadony et al., 2021) and microorganisms (Alagawany et al., 2021; Desoky et al., 2020) improve yield quantity and quality through enhancing the genetic expression in plants to tolerate with water shortage. In this study, the parental genotypes G.87, G.86 and G.89 as well as the crosses G.86 × G.87, and G.87 × G.89 manifested the highest 2.5% SL among the genotypes, confirm the importance of G.87 to improve 2.5% SL under shortage water stress. Also, the parental genotype G.94 was involved on

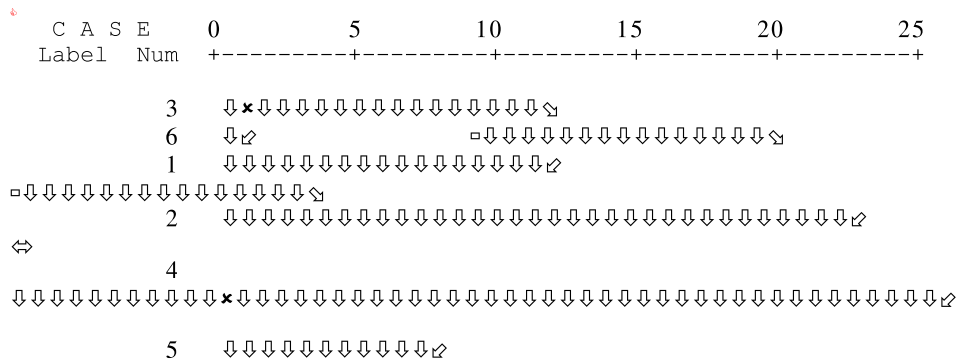


Fig. 1. Results of hierarchical cluster analysis based on dissimilarity coefficients between the six parental cotton genotypes.

Table 7  
Estimates of heterosis % over mid parent (MP) and better parent (BP) for the five studied traits.

Crosses	LA		LDW(mg)		PH		2.5% SL		LCY/P(mg)	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
G.86 × G.87	-23.46*	-31.88**	-159.7*	-258.3**	-0.75	-3.46	4.35**	2.74	107.3	24.8
G.86 × G.89	-25.81**	-30.30**	-107.6	-152.8	-4.20	-5.18	-0.44	-0.93	-118.8	-197.1*
G.86 × G.94	2.23	-1.65	-18.5	-127.4**	4.06	-1.45	2.98*	1.74	134.3*	-12.2
G.86 × Menoufi	-15.02	-17.97	-188**	-201.6**	-12.06**	-16.21**	1.53	-2.38	-217.6**	-317.6**
G.86 × Suvin	2.30	-8.15	18.9	-100	-1.07	-3.12	2.66*	2.25	-81.4	-160.9*
G.87 × G.89	-9.29	-14.49	-49.3	-120.4	6.92*	2.99	2.45*	1.26	181*	4.5
G.87 × G.94	9.43	-5.88	101.7	-121.0*	9.25**	0.81	2.05	-0.52	274.9**	40.8
G.87 × Menoufi	11.54	2.55	151.9*	27	-2.98	-9.94**	1.21	-4.15**	58.8	-132.7
G.87 × Suvin	-9.15	-10.20	-72.5	-72.5	12.70**	7.41*	0.29	-1.48	283.5**	93.9
G.89 × G.94	11.22	0.71	-31.15	-177.1**	-1.71	-6.00	3.41**	1.52	-55.3	-102.6
G.89 × Menoufi	13.19	10.18	126.4*	53.8	-4.28	-7.92*	4.11**	-0.26	-80.8	-122.8
G.89 × Suvin	19.37*	13.70	146.7*	61.7	11.56**	10.33**	3.38**	2.59	8	6
G.94 × Menoufi	-14.57	-20.68*	-118.8*	-205.2**	-0.52	-1.18	5.88**	3.15	182.7**	175.1*
G.94 × Suvin	-8.02	-20.13*	-147.2*	-319.7**	-6.86*	-10.00**	-1.79	-2.72	-178.8**	-220.7**
Menoufi × Suvin	3.84	-3.52	-21	-147.8	-0.74	-3.50	4.29**	0.52	-119.0*	-163.5*

\* and \*\* significant at 0.05 and 0.01 levels of probability, respectively.

Table 8  
GCA effect for the five studied traits.

Parent	LA	LDW(mg)	PH	2.5% SL	LCY/P(mg)
G.86	-0.69	-0.16	-6.66**	0.154	-18.5**
G.87	-4.52**	-0.71**	-3.03*	0.629**	7.4*
G.89	0.37	-0.04	-0.38	0.379**	10
G.94	5.97**	0.135**	6.78**	-0.196	20.1**
Menoufi	1.02	0.38*	0.37	-0.921**	7.3*
Suvin	-2.15	-0.82**	2.93*	-0.046	-1.5
SD(Gi)	1.41	0.016	1.43	0.124	0.33
SD(Gi - Gj)	2.20	0.025	2.21	0.192	0.51
R	0.87*	0.98**	0.74*	0.99**	0.80*

r. correlation coefficient between parental means and their corresponding GCA.

\* and \*\* significant at 0.05 and 0.01 levels of probability, respectively.

most superior crosses for the other traits, which recommend this genotype to improve productivity under shortage water stress. These findings demonstrate the role of leaf characteristics (LA and LDW) in enhancing lint productivity under water deficiency stress. Leaf area is a determinant factor in radiation interception, photosynthesis, biomass buildup, transpiration, and energy transfer by crop canopies, and it plays a vital physiological role in cotton's water shortage tolerance (Chaturvedi et al., 2012).

The parental genotypes were classified using dissimilarity matrices and cluster analysis based on the combination of their features. Crossing of distantly related parents is likely to outperform crossing of closely related parents in most characters. It should result in more considerable variation for most characters in the next generation.

The variance of GCA and SCA (Table 3) manifested the predominance of non-additive; As a result, selection processes based on the accumulation of beneficial alleles may fail to improve these characteristics. The correlation coefficient between parental means and their corresponding GCA showed a significant and positive relationship, indicating that these qualities may be selected based on their mean values under water shortage stress (Kumar et al., 1985; Murthy, 1999; Sultan et al., 1999). Whereas the majority of the parental genotypes included in this cross had a high genetic distance between them, particularly between G.87 and G.94 (Euclidean distance 34.651), The cross formed by these two genotypes (G.87 x G.94) revealed stable positive and significant SCA for all of the traits studied, recommending this cross for further genetic improvement of these traits under water shortage stress. Referring



**Table 9**  
SCA effect for the five studied traits.

Crosses	LA	LDW (mg)	PH	2.5% SL	LCY/P (mg)
G.86 × G.87	-7.81**	-0.91**	-2.92	1.021**	3.2
G.86 × G.89	-11.70**	-0.63*	-5.17	-0.729**	-12.3
G.86 × G.94	4.90	0.45	9.67**	0.446	22.70**
G.86 × Menoufi	-4.95	-1.25**	-12.92**	-0.229	-29.55**
G.86 × Suvin	4.23	0.62*	-1.48	0.496**	-4.68
G.87 × G.89	-4.57	-0.58	4.81	0.296	14.57*
G.87 × G.94	5.93*	0.108**	10.14**	0.171	22.57**
G.87 × Menoufi	6.88**	1.2**	-5.24	-0.304	-0.2.68
G.87 × Suvin	-4.25	-0.53	12.89**	-0.279	32.20**
G.89 × G.94	5.44*	-0.24	-5.01	0.521*	-1493*
G.89 × Menoufi	6.29*	100	-4.19	0.546*	-8.18
G.89 × Suvin	8.06**	1**	15.24**	0.671**	8.7
G.94 × Menoufi	-9.21**	-1**	3.14	1.121**	35.82**
G.94 × Suvin	-5.74*	-1.12**	-15.62**	-1.054**	-38.30**
Menoufi × Suvin	1.11	-0.1	0.49	0.771**	-14.55*
SD(S <sub>ij</sub> )	3.89	0.044	3.92	0.34	0.91
SD(S <sub>ij</sub> - S <sub>ik</sub> )	5.81	0.066	5.85	0.51	1.36
SD(S <sub>ij</sub> - S <sub>kl</sub> )	5.38	0.061	5.41	0.47	1.26

\* and \*\* significant at 0.05 and 0.01 levels of probability, respectively.

to 2.5% SL, G.86 x G.87 and G.94 x Menoufi revealed the highest significant and positive SCA (Johnson et al., 1955; Mahmood et al., 2020; Saeed et al., 2021). conventional breeding between parents have genes tolerate with drought and others have high yield produce water shortage tolerat inbred with valuable yield (Hassanin et al., 2020).

**5. Conclusion**

The cross-G.94 x Menoufi demonstrated the highest LCY/P (24.6 g.) and outperformed the better parent; its high SCA for 2.5 percent SL could be exploited in segregate generations, recommending this cross for use in future breeding programmes to improve both lint yield and fibre length under water shortage stress.

**Declaration of Competing Interest**

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

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**References**

Areej, J. A. V. A. I. D., Azhar, F. M., Khan, I. A., Amir, S. H. A. K. E. E. L., & Azhar, M. T., 2021. Drought Stress Modified Genetic Components and Combining Ability of Cotton Genotypes. 10.21203/rs.3.rs-389629/v1.

Alagawany, M., Madkour, M., El-Saadony, M.T., Reda, F.M., 2021. *Paenibacillus polymyxa* (LM31) as a new feed additive: Antioxidant and antimicrobial activity and its effects on growth, blood biochemistry, and intestinal bacterial populations of growing Japanese quail. Anim. Feed Sci. Technol. 276, 114920.

Azeem, I.K., Azhar, S.F.M., 2006. Estimates of heritability and pattern of association among different characters of *Gossypium hirsutum* L. Pak. J. Agr. Sa. 37, 1–2.

Burton, G.W., 1952. Quantitative inheritance in grasses. Proceedings of the 6<sup>th</sup> International Grassland Congress 1, 277 – 283.

Chattha, W.S., Ahmad, H.B., Farooq, M.A., Shafiqat, W., Yaseen, M., Ihsan, M.Z., Alghabari, F., Alzamanan, S.M., 2021. A novel parent selection strategy for the development of drought-tolerant cotton cultivars. Plant Genet. Res. 19 (4), 299–307.

Chaturvedi, G.S., Singh, A., Bahadur, R., 2012. Screening techniques for evaluating crop germplasm for drought tolerance. Plant Arch. 12 (1), 11–18.

Desoky, E.S.M., Saad, A.M., El-Saadony, M.T., Rady, M.M., 2020. Plant growth-promoting rhizobacteria: Potential improvement in antioxidant defense system and suppression of oxidative stress for alleviating salinity stress in *Triticum aestivum* (L.) plants. Biocatal. Agric. Biotechnol. 30, 101878.

El-Saadony, M.T., Abd El-Hack, M.E., Swelum, A.A., Al-Sultan, S.I., El-Ghareeb, W.R., Hussein, E.O., Nader, M.M., 2021b. Enhancing quality and safety of raw buffalo meat using the bioactive peptides of pea and red kidney bean under refrigeration conditions. Ital. J. Anim. Sci. 20, 762–776.

El-Saadony, M.T., Khalil, O.S., Osman, A., Alshilawi, M.S., Taha, A.E., Aboelenin, S.M., Saad, A.M., 2021a. Bioactive peptides supplemented raw buffalo milk: biological activity, shelf life and quality properties during cold preservation. Saudi J. Biol. Sci. 28, 4581–4591.

El-Saadony, M.T., Saad, A.M., Najjar, A.A., Alzahrani, S.O., Alkhatib, F.M., Shafi, M.E., Hassan, M.A., 2021. The use of biological selenium nanoparticles to suppress *Triticum aestivum* L. crown and root rot diseases induced by *Fusarium* species and improve yield under drought and heat stress. Saudi J. Biol. Sci. 28 (8), 4461–4471.

El-Tarabily, K.A., El-Saadony, M.T., Alagawany, M., Arif, M., Batiha, G.E., Khafaga, A.F., Abd El-Hack, M.E., 2021. Using essential oils to overcome bacterial biofilm formation and their antimicrobial resistance. Saudi J. Biol. Sci. 28, 5145–5156.

Ergashovich, K.A., Toshmirovna, N.U., Rakhimovna, A.K., Abdullayevna, F.F., 2020. Effects of microelements on drought resistance of cotton plant. Int. J. Psychosoc. Rehabilitation. 24 (2), 643–648.

Fisher, R.A., Yates, F., 1963. Statistical tables for biological, agricultural and medical research. Oliver and Byod, Edinburgh.

Fouda, S.E., El-Saadony, F.M., Saad, A.M., Sayed, S.M., El-Sharnouby, M., El-Tahan, A. M., El-Saadony, M.T., 2021. Improving growth and productivity of faba bean (*Vicia faba*) using chitosan, tryptophan and potassium silicate anti-transpirants under different irrigation regimes. Saudi J. Biol. Sci. <https://doi.org/10.1016/j.sjbs.2021.10.007>.

Griffing, J.G., 1956. Concept of general and specific combining ability in relation to diallel crossing system. Australian J. of Biol. Sci. 9, 463–493.

Hayman, B.I., 1954a. The theory and analysis of diallel crosses. Genetics 39:789-809.

Hassanin, A.A., Saad, A.M., Bardisi, E.A., Salama, A., Sitohy, M.Z., 2020. Transfer of anthocyanin accumulating delila and rosea1 genes from the transgenic tomato micro-tom cultivar to moneymaker cultivar by conventional breeding. J Agric. Food Chem. 68 (39), 10741–10749.

Hayman, B.I., 1954b. The analysis of variance of diallel tables. Biometrics 10 (2), 235. <https://doi.org/10.2307/3001877>.

Hu, G., Grover, C. E., Yuan, D., Dong, Y., Miller, E., Conover, J. L., & Wendel, J. F., 2021. Evolution and diversity of the cotton genome. In cotton precision breeding (pp. 25-78). Springer, Cham. 25-78.

Hussain, K., Khan, I.A., Sadaqt, H.A., Amjad, M., 2010. Genotypic and phenotypic correlation analysis of yield and fiber quality determining traits in upland cotton (*Gossypim hirsutum* L.). Int. J. Agric. Biol. 12, 348–352.

Jinks, J.L., 1954. The analysis of continuous variation in a diallel cross of *Nicotiana rustica* varieties. Genetics 39 (6), 767–788.

Jinks, J.L., Hayman, B.I., 1953. The analysis of diallel crosses. Maize Genet. Coop. Newsletter 27, 48–54.

Johnson, H.W., Robinson, H.F., Conmstock, R.E., 1955. Estimates of genetic and environmental variability in soybeans. Agron. J. 47, 314–318.

Johnson, R.A., Wichern, D.W., 1988. Applied Multivariate Statistical Analysis 2<sup>nd</sup> ed. Prentice-Hall. Englewood Cliffs, N.J. USA.

Kale, U.V., Kalpande, H.V., Annapurve, S.N., Gite, V.K., 2007. Yield components analysis in American cotton (*Gossypium hirsutum* L.). Madras. Agric. J. 94 (7–12), 156–161.

- Kiani, G., Nematzadeh, G.A., Kazemitabar, S.K., Alshah, O., 2007. Combining ability in cotton cultivars for agronomic traits. *Int. J. Agric. Biol.* 9 (3), 521–522.
- Kumar, A., Misra, S.C., Singh, V.P., Chaahan, B.P.S., 1985. Variability and correlation studies in triticale. *J. of the Maharashtra Agric. Univ.* 10, 273–275.
- Larik, A.S., Kakar, A.A., Naz, M.A., Shaikh, M.A., 1999. Character correlation and path analysis in seed cotton yield of *Gossypium hirsutum* L. *Sarh. J. Agric.* 15 (4), 269–274.
- Mahmood, T., Khalid, S., Abdullah, M., Ahmed, Z., Shah, M.K.N., Ghafoor, A., Du, X., 2020. Insights into drought stress signaling in plants and the molecular genetic basis of cotton drought tolerance. *Cells* 9 (1), 105.
- Mather, K., Jinks, J.L., 1982. *Biometrical Genetics*, 3<sup>rd</sup>. Chapman and Hall, London, p. 396.
- Mohamed, G.I.A., Abd-El-Halem, S.H.M., Ibrahim, E.M.A., 2009. A Genetic analysis of yield and its components of Egyptian Cotton (*Gossypium barbadense* L.) under divergent environments. *American-Eurasian J. Agric. Environ. Sci.* 5 (1), 05–13.
- Murthy, J.S.V.S., 1999. Character association and component analysis in upland cotton. *Mad. Agric. J.* 86 (1–3), 39–42.
- Rakavi, B., Jeyakumar, P., Chandrasekhar, C.N., Vijayalakshmi, D., Kumar, M., Arul, L., Manikanda Boopathi, N., Babu, C., 2021. Growth, phenology and yield response of cotton varieties under drought stress. *Int. J. Ecol. Environ. Sci.*, 518–523.
- Saeed, N. A., Ahmad, M., Mukhtar, Z., 2021. GM Cotton for Stress Environments. In *Cotton Precision Breeding* (pp. 257–280). Springer, Cham.
- Saad, A.M., El-Saadony, M.T., El-Tahan, A.M., Sayed, S., Moustafa, M.A., Taha, A.E., Ramadan, M.M., 2021. Polyphenolic extracts from pomegranate and watermelon wastes as substrate to fabricate sustainable silver nanoparticles with larvicidal effect against *Spodoptera littoralis*. *Saudi J. Biol. Sci.* 28 (10), 5674–5683.
- Saad, A.M., Mohamed, A.S., El-Saadony, M.T., Sitohy, M.Z., 2021a. Palatable functional cucumber juices supplemented with polyphenols-rich herbal extracts. *LWT - Food Sci. Technol.* 148 148, 111668.
- Saad, A.M., Sitohy, M.Z., Ahmed, A.I., Rabie, N.A., Amin, S.A., Aboelenin, S.M., El-Saadony, M.T., 2021b. Biochemical and functional characterization of kidney bean protein alcalase-hydrolysates and their preservative action on stored chicken meat. *Molecules* 26, 4690. <https://doi.org/10.3390/molecules26154690>.
- Steel, R.G.D., Torri, J.H., 1997. *Principles and procedures of statistics: A Biometrics Approach*. McGraw-Hill, New York.
- Sultan, M.K., Mitra, B.N., Choudhry, R., 1999. Correlation and path analysis in upland cotton (*Gossypium hirsutum* L.). *Bangal J. Sci. and Indus. Res.* 34 (1), 55–58.