DIALLEL MEDIATED HYBRID SCREENING BY ANALYSIS OF YIELD ATTRIBUTES, SEED YIELD AND FIBER QUALITY IN COTTON GENOTYPES

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Abstract. Globally, cotton yield and lint quality improvement especially through selection of promising genotypes continue to remain a pressing task for the sustainability of lint supplies to the textile industry. To achieve these goals, the use of diallel analysis is of prime pertinence in plant breeding to identify and screen out the elite genetic combinations and stable fidelity in subsequent generations. An experiment was carried out to study combining ability of the parental genotypes and their half-diallel hybrids for yield component, seed yield and fiber quality traits. The results showed highly significant differences among tested genotypes, indicating remarkably high genetic variability for all the studied traits. The ratio of δ^2GCA/δ^2SCA > 1 for all traits under study exhibited the preponderance of additive gene action for inheritance of all traits under investigation. The results indicated that selection could be significantly responsive and performed in early segregating generation. Additionally, parents, Coker 139, Aleppo 90 and NIAB 414 were superior general combiner for yield and fiber quality traits. Likewise, hybrids especially Millinium × Aleppo 124, Aleppo 124 × NIAB Kiran and Aleppo 118 × NIAB Kiran showed unmatched response variables. Thus based on these recorded findings, these hybrids can be exploited in future’s breeding programs for boosting cotton yield and fiber quality through development of new promising varieties of cotton.
Keywords: *Gossypium hirsutum, general combining ability, specific combining ability, fiber traits*

Introduction

Upland cotton (*Gossypium hirsutum* L.) belonging to the family of *Malvaceae*, accounts for about 95% of the global cotton production (Bourgou et al., 2022). Cotton has been the most important cash and oil seed crop, along with the most important natural resource of most

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popular fiber, since the dawn of civilization (Bilal et al., 2022; Saleem et al., 2022; Singh et al., 2023). It is the world's leading fiber crop, and a raw material of the worlds' largest textile industries having a yearly economic impact of at least $600 billion (Ashraf et al., 2018; Tarazi et al., 2020). Additionally, cotton seeds are used to produce protein rich animal feed and edible oil for human consumption. In Syria, cotton plays a significant role in rural economy because it is an essential raw material for textile, vegetable oil, and animal feed. Historically in 2011, Syria produced over a million tons of cotton, but the production has declined significantly, reaching less than 20,000 tons in 2021, exhibiting a decline of more than 90% (Anonymous, 2022). In contrast to Syria, Pakistan is 5th and 7th largest producers of cotton and garments manufacturer in the world, respectively. In recent years, Pakistan has been importing raw cotton because cotton yield per hectare has gradually decreased to 730 kg with 10.67 million bales production owing to cultivation of low yielding cultivars (Arshad et al., 2022; Bilal et al., 2022; Khuwaja et al., 2022). This situation necessitates conducting studies for screening superior genotypes having potential to yield higher lint quantities with improved qualitative traits under stressful environments (Majid et al., 2020; El Sabagh et al., 2021).

Diallel cross is a crucial method for identifying the proper parents and their hybrids by estimating the combining ability (Bilal et al., 2022; Khuwaja et al., 2022; Sen et al., 2022). The general combining ability (GCA) is the average performance of parents in a series of crosses that is measured by additive gene action, whereas the specific combining ability (SCA) is the performance of parents in specific crosses measured by non-additive gene action (Çetin and Çopur, 2022). Previously, Griffing (1956) described four methods and two models to estimate thecombining ability in terms of inheritance variation and gene action in the studied characteristics. The useful information regarding parents was produced by GCA in terms of selection of suitable parents for hybridization and their genetic value as pointed out by Chinchane (2018). On similar trends, previous studies utilized diallel analysis to estimate the combining ability (GCA and SCA) for identification of better parents and crosses (Dirbas, 2018; Taha et al., 2018; Sagar et al., 2019; Salem et al., 2020). Likewise, Chaudhari et al. (2023) described the application of graphical and numerical approaches for deep analysis of bread wheat genotypes obtained by half-diallel approach. High yielding genotypes were selected from 10 genotypes by graphical and numerical approaches with significant interaction with the environment. Gene action effect was unraveled to be governed by additive and dominant genes across the environments. Interestingly in rice, diallel analysis of crosses indicated that early embryo size vigor is due to additive genes, and is highly inheritable (Pandey et al., 1994). Similarly, 60 genotypes of rice were evaluated for their GCA, SCA and heterosis and 15 genotypes were screened for their yield out performance and molecular markers showed average genetic distance of 0.5882 (Huang et al., 2015). In cotton, half diallel crosses were developed between Burkina Faso and Texa A & M Agrilife Research and Agronomic analyses were carried out to improve elite varieties from Burkina Faso (Bourgou et al., 2022), however significant research gaps exist pertaining to research works for screening out the superior cotton genotypes in Syria and Pakistan.Thus keeping in view the previous published work, this research was aimed to explorel the genetic variance and combining abilities for cotton yield, yield related components and fiber traits using half diallel mating for selection of cotton cultivars.

Materials and methods

The experiment was conducted at Hama Center for Scientific Agricultural Research, Syria (5° 8' 27.1968" N 36° 45' 18.7164" E having an altitude of 287 m) during

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summer months of 2019 and 2020. Twelve adversely parents of cotton (*G. hirsutum*) namely Fantom, Millinium, Lider, Cherpan 432, Coker 139, Aleppo 90, Aleppo 124, Aqqa 5, Aleppo 118, NIAB Kiran, NIAB 414 and Deir ELzour 22 were sown along with their 65 hybrids using half-diallel method (*Table 1*). These set of parents and their hybrids were evaluated during two consecutive years. Randomized Complete Block Design (RCBD) was used to execute the trial with three replications as three rows for each genotype with P×P distance of 25 cm and R×R spacing of 75 cm. Seeds were sown by hand on 15th April 2019 and 2020 by maintaining the intensity 10 plants m^{-2}. Urea (400 kg ha^{-1}) and di-ammonium phosphate (100 kg ha^{-1}) fertilizers were applied uniformly in all experimental units. All P_2O_5 was applied at sowing time while urea was applied in four splits including 100 kg ha^{-1} at sowing time, 200 kg ha^{-1} at 40 days after sowing, 100 kg ha^{-1} at square and 100 kg ha^{-1} at flowering. However, bio control was applied for plant protection especially against boll worms. Ten furrow irrigations were applied, amounting to 10000 m^3 ha^{-1} water. The lint was harvested twice by hand for yield estimation on 15th August and 15th September. From each replication, 10 middle plants were randomly selected for recording data. The plant height (PH) from ground to tip of plant was measured using scale (cm) at the time of maturity. The monopodial branches/plant (MB), vegetative or non-fruiting branches arises from base of main stem and resemble like main stem were counted on selected plants of parents and their F_1 hybrids in three replicates, and averaged for analysis. The sympodial branches/plant (SB), the fruiting branches were counted on selected plants in three replicates and averaged for analysis. The bolls number/plant (BN), total number of bolls per plant were collected in three repeats from selected plants. The boll weight (g) (BW), the boll weight of plants was obtained by weight of seed cotton yield per plant divided by number of bolls per plant. The seed cotton yield/plant (g) (SCY), the seed cotton at maturity of all selected plants was picked separately and weighed with an electronic balance. The average seed cotton yield of each genotype in each replication was calculated for analysis of lint percentage (LP %). All the lint samples collected during both years were analyzed at 21°C ± 1°C temperature and 65% ± 2% relative humidity at Fiber Testing Laboratory, Department of Plant Breeding, Cotton Research Administration, Syria. The fiber length at 2.5% (FL, mm) was estimated along with the fiber strength (FS) and fiber elongation (FE) by using a stelometer (g/tex). Micronaire reading was used to express fiber fineness (FF).

Analysis of variance was carried out by GenStat 12 program. The GCA variance effects of the parents and the SCA variance effects of the hybrids were estimated using the half diallel analysis method as described by Griffing (1956) based on method 4 (direct crosses), and model 1 (fixed). Moreover, significant combining ability was calculated using SE method (Steel and Torrie, 1980).

Results

Analysis of variance (Mean squares) showed highly significant differences ($p < 0.01$) among the genotypes (crosses) for all response variables (*Table 2*) which assisted in estimating the combining ability for identifying the potential parents and appropriate hybrids. The mean squares for GCA (*Table 2*) were highly significant ($p < 0.01$) for all the traits, also, the mean squares for SCA were significant for all the traits except for the monopodial branches/plant. The ratio of δ^2GCA/δ^2SCA were more than unity for all traits under study.

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***Table 1.** A list of the investigated hybrids*

Serial number	Hybrids	Serial number	Hybrids	Serial number	Hybrids
1	Fantum × Millinium	23	Lider × Coker 139	45	Coker 139 × Deir ELzour 22
2	Fantum × Lider	24	Lider × Aleppo 90	46	Aleppo 90 × Aleppo 124
3	Fantum × Cherpan 432	25	Lider × Aleppo 124	47	Aleppo 90 × Raqqa 5
4	Fantum × Coker 139	26	Lider × Raqqa 5	48	Aleppo 90 × Aleppo 118
5	Fantum × Aleppo 90	27	Lider × Aleppo 118	49	Aleppo 90 × NIAB Kiran
6	Fantum × Aleppo 124	28	Lider × NIAB Kiran	50	Aleppo 90 × NIAB 414
7	Fantum × Raqqa 5	29	Lider × NIAB 414	51	Aleppo 90 × Deir ELzour 22
8	Fantum × Aleppo 118	30	Lider × Deir ELzour 22	52	Aleppo 124 × Raqqa 5
9	Fantum × NIAB Kiran	30	Cherpan 432 × Coker 139	53	Aleppo 124 × NIAB Kiran
10	Fantum × NIAB 414	32	Cherpan 432 × Aleppo 90	54	Aleppo 124 × NIAB 414
11	Fantum × Deir ELzour 22	33	Cherpan 432 × Aleppo 124	55	Aleppo 124 × Deir ELzour 22
12	Millinium × Lider	34	Cherpan 432 × Raqqa 5	56	Raqqa 5× Aleppo 118
13	Millinium × Cherpan 432	35	Cherpan 432 × Aleppo 118	57	Raqqa 5 × NIAB Kiran
14	Millinium × Coker 139	36	Cherpan 432 × NIAB Kiran	58	Raqqa 5× NIAB 414
15	Millinium × Aleppo 90	37	Cherpan 432 × NIAB 414	59	Raqqa 5× Deir ELzour 22
16	Millinium × Aleppo 124	38	Cherpan 432 × Deir ELzour 22	60	Aleppo 118 × NIAB Kiran
17	Millinium × Raqqa 5	39	Coker 139 × Aleppo 90	61	Aleppo 118 × NIAB 414
18	Millinium × Aleppo 118	40	Coker 139 × Aleppo 124	62	Aleppo 118 × Deir ELzour 22
19	Millinium × NIAB Kiran	41	Coker 139 × Raqqa 5	63	NIAB Kiran × NIAB 414
20	Millinium × NIAB 414	42	Coker 139 × Aleppo 118	64	NIAB Kiran× Deir ELzour 22
21	Millinium × Deir ELzour 22	43	Coker 139 × NIAB Kiran	65	NIAB 414 × Deir ELzour 22
22	Lider × Cherpan 432	44	Coker 139 × NIAB 414		

***Table 2.** Analysis of variance of yield, yield contributing and fiber quality traits for diallel analysis of cotton genotypes*

Sources of variance	DF	PH	MB	SB	BN	BW	SCY	LP%	FL	FS	FE	FF
Genotypes	64	216.33**	0.60**	2.205**	129.04**	1.37**	4115.6**	4.93**	2723**	3.38**	3.06**	0.25**
GCA	11	8112.09**	6.30**	114.76**	812.75**	42.55**	30186.07**	1792.86**	1554234**	629.67**	71.48**	25.51**
SCA	64	135.3**	0.10	1.56*	43.93**	0.56*	1218.05**	21.68**	17612.6**	7.77**	1.58**	0.30**
δ^2GCA/δ^2SCA		59.96	64.12	73.37	18.50	77.93	24.78	82.69	88.25	80.99	45.40	86.45
Error	128	13.06	0.19	0.33	4.93	0.21	169.9	0.59	373	0.21	0.15	0.04

δ^2GCA: variance of general combining ability, δ^2SCA: variance of specific combining ability, *and **Significant at the $P \leq 0.05$ and $P \leq 0.01$ probability levels, respectively, DF: Degrees of freedom, PH: Plant height (cm), MB: Monopodial branches/plant, SB: Sympodial branches/plant, BN: Bolls number/plat, BW: Boll weight (g), SCY: Seed cotton yield/plant (g), LP %: Lint percentage (%), FL: Fiber length (mm), FS: Fiber strength (g/tex), FE: Fiber Elongation FF: Fiber fineness (micronaire)

General combining ability effects

General combining ability effects were estimated and have been presented in *Table 3*. Out of 12 parents, four of them *viz*., Coker139 (7.37), Millinium (3.77), NIAB 414 (2.99) and Fantum (2.78) displayed positive and significant or highly significant (desirable) GCA effects for the plant height, so declared as the best general combiners, whereas Aleppo 118 (-6.97) showed the maximum negative and high significant GCA effects which revealed poor general combining ability for the traits under study.

For the monopodial branches/plant, the parents Aleppo 124 (-0.39) and Deir ELzour 22 (-0.27) showed the maximum GCA effects, and proved their superiority as the best

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general combiners, while the Cherpan 432 (0.22) showed the maximum positive and significant GCA effect.

Only parent, the Coker139 (0.77) had the maximum positive and high significant (desirable) GCA effects, and declared as the best general combiner for the number of sympodial branches/plants, whereas the Aleppo 124 (-0.57) had the maximum negative and high significant GCA effects which revealed its poor general combining potential for this trait. The positive and significant or highly significant GCA effects for the boll number were predicted for the Aleppo 90 (1.92) and Raqqa 5 (1.49), which may be declared as the best general combiners, whereas the negative and highly significant GCA effects were predicted for the Deir ELzour 22 (-4.67) indicating its poor general combining potential.

Table 3. *General combining ability effects (GCA) of parents for studied traits.*

Parents	PH	MB	SB	B.N	BW	SCY	LP%	FL	FS	FE	FF
Fantum	2.78*	0.08	0.16	0.50	-0.10	-7.55	1.38**	18.37**	0.81**	0.19	0.10
Millinium	3.77**	0.19	0.20	-0.16	0.23	5.6	0.63**	22.77**	0.34*	-0.07	0.23**
Lider	-3.65**	0.17	0.09	0.65	0.29*	5.1	0.95**	1.37	-0.48**	0.43**	0.06
Cherpan 432	0.75	0.22*	-0.05	0.91	0.28*	13.35**	0.22	15.57*	0.45**	-0.46**	0.13*
Coker 139	7.37**	0.20	0.77**	-0.05	0.26	12.43**	0.53*	31.87**	-0.28*	0.07	0.08
Aleppo 90	1.99	0.05	0.20	1.92**	0.59**	11.49**	0.32	35.87**	0.70**	-0.16	0.15*
Aleppo 124	-6.92**	-0.39**	-0.57**	0.37	-0.75**	-11.62**	-3.17**	-92.13**	-1.91**	-0.55**	-0.54**
Raqqa 5	-1.84	-0.03	0.27	1.49*	0.05	8.08*	0.20	33.37**	1.01**	0.49**	0.06
Aleppo 118	-6.97**	-0.17	-1.10**	-0.29	-0.67**	-8.33*	-2.53**	-99.03**	-1.73**	-0.49**	-0.38**
NIAB Kiran	-0.85	-0.08	0.18	-1.39*	-0.20	-11.51**	0.70**	14.37*	0.36*	-0.01	0.00
NIAB 414	2.99**	0.04	-0.13	0.70	0.11	17.31**	0.14	19.47**	0.47**	0.56**	0.12*
Deir ELzour 22	0.59	-0.27*	-0.01	-4.67**	-0.10	-34.33**	0.63**	-1.83	0.26	0.02	0.00
SE gij	1.09	0.10	0.17	0.67	0.12	3.95	0.23	5.85	0.14	0.12	0.06

SE gij: standard error, *and **Significant at the P ≤ 0.05 and P ≤ 0.01 probability levels, respectively, PH: Plant height (cm), MB: Monopodial branches/plant, SB: Sympodial branches/plant, BN: Bolls number/plat, BW: Boll weight (g), SCY: Seed cotton yield/plant (g), LP %: Lint percentage (%), FL: Fiber length (mm), FS: Fiber strength (g/tex), FE: Fiber Elongation FF: Fiber fineness (micronaire)

Among parents, the Aleppo 90 (0.59) followed by Lider (0.29) and Cherpan 432 (0.28) showed the maximum positive and significant or highly significant (desirable) GCA effects, and declared as best general combiner for boll weight, while the Aleppo 124 (-0.75) showed the maximum negative and significant GCA effects. For the seed cotton yield/plant, five parents like the NIAB 414 (17.31), Cherpan 432 (13.35), Coker139 (12.43), Aleppo 90 (11.49) and Raqqa 5 (8.08) showed the positive and significant or highly significant (desirable) GCA effects, which revealed that these parents were the superior general combiners. However, the negative and high significant GCA effects for the seed cotton yield were predicted for the Deir ELzour 22 (-34.33). The positive and significant or highly significant (desirable) GCA effects for lint percentage were predicted for the Fantum (1.38), Lider (0.95), NIAB Kiran (0.70), Deir EL-zour 22 (0.63), Millinium (0.63) and Coker139 (0.53) so reported them as the best general combiners, whereas the negative and high significant GCA effects were predicted for the Aleppo 124 (-3.17). Out of 12 parents, eight of them namely the Aleppo 90 (35.87), Raqqa 5 (33.37), Coker139 (31.87), Millinium (22.77), NIAB 414

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(19.47), Fantum (18.37), Cherpan432 (15.57) and NIAB Kiran (14.37) displayed the maximum positive and significant or highly significant (desirable) GCA effects for the fiber length, whereas the Aleppo 118 (-99.03) displayed the significantly negative GCA effects. For fiber strength, the Raqqa 5 (1.01) showed the maximum positive and significant or highly significant (desirable) GCA effects followed by the Fantum (0.81), Aleppo 90 (0.70), NIAB 414 (0.47), Cherpan 432 (0.45), NIAB Kiran (0.36), and Millinium (0.34), and might be declared as the best general combiners, whereas the Aleppo 124 (-1.91) showed the maximum negative and high significant GCA effects. The positive and highly significant GCA effects for fiber elongation were predicted for the NIAB 414 (0.56), Raqqa 5 (0.49) and Lider (0.43), whereas the negative and high significant GCA effects were predicted for the Aleppo 124 (-0.49). The parents, Aleppo 124 (-0.54) and Aleppo 118 (-0.38) showed the maximum negative and high significant (desirable) GCA effects, which revealed that these parents were the best general combiners for fiber fineness, while the Millinium (0.23) showed the maximum positive and high significant GCA effects which designated as the poor general combining ability effects.

Specific combining ability effects

The SCA effects were calculated and ordered in *Table 4*. Out of 65 cross combinations, 17 crosses recorded positive and significant or highly significant SCA effects for the plant height (*Table 4*). The parents Millinium × Aleppo 118 (18.77), Cherpan 432 × Aleppo 124 (17.69) and Raqqa 5 × Aleppo 118 (14.60) showed the maximum positive and high significant SCA effects, and reported as the best specific combiners, while the Raqqa 5 × Deir EL-zour 22 (-23.37) showed the maximum negative and high significant SCA effects, and reported as the poor specific combiner for the plant height. For the monopodial branches/plant, the crosses NIAB 414 × Deir EL-zour 22 (-1.07) and Fantum × Aleppo 90 (-0.75) showed the maximum negative and significant SCA effects which revealed that these new combinations were the best combiners, whereas the Aleppo 124 × Raqqa 5 (1.20) showed the maximum positive and high significant SCA effects. Among 65 hybrids, 12 crosses were recorded positive and significant or highly significant SCA effects for the sympodial branches/plant. The crosses, Coker139 × NIAB 414 (2.09) seemed to be the best specific combiner with the maximum positive and high significant SCA effects followed by the Aleppo 118 × NIAB Kiran (1.85) and Millinium × Aleppo 118 (1.74), while Lider × Coker139 (-1.80) showed the maximum negative and high significant SCA effects, and reported as the poor specific combiner for the sympodial branches/plant. On the other hand, 17 crosses displayed the positive and significant or highly significant SCA effects for the bolls number out of 65 cross combinations. However, the crosses especially Aleppo 90 × Deir ELzour 22 (18.89) was found to be the best specific combiner with the maximum positive and high significant SCA effects followed by the crosses of Aleppo 118 × NIAB Kiran (14.56) and Cherpan 432 × Aleppo 90 (13.93), while Raqqa 5 × NIAB Kiran (-9.14) was found to be the poor specific combiner with the maximum negative SCA effects for the number of bolls.

For the seed cotton yield/plant, 10 hybrids recorded the positive and significant or highly significant SCA effects. The hybrids such as Aleppo 118 × Deir EL-zour 22 (1.49), Lider × Aleppo 118 (1.48) and Cherpan 432 × Deir EL-zour 22 (1.12) exhibited the maximum positive and highly significant SCA effects which revealed that these new combinations were the best combiners, whereas Lider × Cherpan 432 cross showed the

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maximum negative and highly significant SCA effects (-1.19), which exhibited its poor specific combining ability for seed cotton yield/plant. Among 65 hybrids, 17 crosses recorded the positive and significant or highly significant SCA effects for boll weight. The hybrid, Coker139 × Raqqa 5 (85.14) seemed to be the best specific combiner with the maximum positive and high significant SCA effects followed by the Fantum × Deir EL-zour 22 (71.83) and Aleppo 118 × NIAB Kiran (62.19), while the NIAB 414 × Deir EL-zour 22 (-60.13) showed the maximum significantly negative SCA effects. Out of 65 cross combinations, 22 crosses displayed highly significant SCA effects for the lint percentage. The crosses, Aleppo 124 × NIAB Kiran (6.05), Millinium × Aleppo 118 (5.94) and Lider × Aleppo 124 (4.16) showed the maximum positive and high significant SCA effects, which revealed that these new combinations were the best combiners. In contrary, Raqqa 5 × NIAB 414 (-3.04) showed the maximum negative and high significant SCA effects, which showed it as the poor specific combiner for the lint percentage.

Table 4. *Specific combining ability effects (SCA) of crosses for studied traits*

Crosses	PH	MB	SB	B.N	BW	SCY	LP%	FL	FS	FE	FF
Fantum × Millinium	-2.76	-0.07	-0.02	-5.35**	-27.20*	-0.84*	0.61	-58.16**	0.13	0.80*	-0.06
Fantum × Lider	2.89	0.79*	-0.24	9.90**	53.00**	-0.55	-0.08	-62.76**	-0.18	-0.37	0.09
Fantum × Cherpan 432	0.04	-0.38	-0.15	2.25	-14.85	-1.13**	1.58*	-15.96	0.07	0.02	-0.26
Fantum × Coker 139	-6.47*	-0.02	0.80	-1.07	-28.53*	-0.54	-1.59*	39.74*	1.08*	0.69	-0.15
Fantum × Aleppo 90	-2.31	-0.75*	-0.84	-1.32	-5.89	0.15	-1.31	-22.26	-1.03*	0.27	0.42*
Fantum × Aleppo 124	6.81*	0.01	1.26*	-1.66	2.52	0.58	1.31	121.74**	2.78**	0.31	-0.07
Fantum × Raqqa 5	-7.04*	-0.46	-1.30*	-0.67	-18.18	-0.44	-1.03	-36.76*	-0.40	-1.13**	-0.12
Fantum × Aleppo 118	13.32**	0.24	1.34*	1.67	1.53	0.84*	3.89**	80.64**	0.55	1.32**	0.53**
Fantum × NIAB Kiran	-6.81*	-0.24	-1.04*	-6.79**	-7.99	1.10**	-1.06	-10.76	-0.01	-1.03**	-0.01
Fantum × NIAB 414	-0.31	0.36	0.38	-5.88**	-26.21*	0.37	-0.40	-43.86*	-1.89**	-0.17	-0.04
Fantum × Deir ELzour 22	2.65	0.51	-0.19	8.94**	71.83**	0.46	-1.92**	8.44	-1.11**	-0.72*	-0.33
Millinium × Lider	0.34	0.23	0.22	-7.83**	-19.85	0.54	-1.31	9.84	0.53	0.06	-0.43*
Millinium × Cherpan 432	-2.39	-0.49	-0.64	-8.76**	-40.40**	-0.51	-1.39*	10.64	-0.98*	-0.78*	-0.01
Millinium × Coker 139	-10.69**	-0.02	-0.91	-2.08	-9.08	0.71	-1.19	4.34	0.48	0.25	0.01
Millinium × Aleppo 90	-9.30**	0.47	-1.33*	-1.21	-2.54	-0.49	-1.95**	-21.66	-1.24**	-1.15**	-0.23
Millinium × Aleppo 124	13.16**	-0.04	0.88	8.45**	30.97**	0.61	2.57**	106.34**	1.77**	1.41**	0.64**
Millinium × Raqqa 5	9.20**	-0.12	0.15	2.77	40.57**	0.30	-0.21	-31.16	-1.39	-1.57**	0.25
Millinium × Aleppo 118	18.77**	-0.26	1.74**	8.77**	14.18	0.82*	5.94**	109.24**	2.77**	2.41**	0.25
Millinium × NIAB Kiran	-17.55**	-0.07	-0.87	-3.57	-30.94**	-0.38	-1.09	-62.16**	-0.88*	-1.07**	-0.22
Millinium × NIAB 414	2.03	-0.20	0.44	5.90**	-9.16	-0.58	-0.35	-44.26*	-0.85*	0.62	-0.26
Millinium × Deir ELzour 22	-0.79	0.56	0.32	2.93	53.48**	-0.17	-1.62*	-22.96	-0.34	-0.99**	0.06
Lider × Cherpan 432	-1.72	-0.13	0.19	-3.40	13.40	-1.19**	-0.51	-28.96	-0.99*	-0.61	-0.23
Lider × Coker139	-7.15*	-0.55	-1.80**	-0.72	1.92	0.62	-1.85**	-44.26*	-0.25	-1.91**	0.41*
Lider × Aleppo 90	-1.77	-0.51	1.11*	-6.80**	-50.24**	-0.07	-0.19	-45.26*	-0.93*	2.02**	-0.02
Lider × Aleppo 124	6.02	0.03	0.99	4.53*	5.17	0.60	4.16**	87.74**	0.84*	0.78*	0.44*
Lider × Raqqa 5	4.84	-0.05	0.93	5.74**	5.07	-0.54	-1.54*	2.24	-0.20	0.64	-0.08
Lider × Aleppo 118	13.08**	-0.13	0.52	2.63	50.38**	1.48**	3.19**	147.64**	0.25	1.12**	0.04
Lider × NIAB Kiran	0.84	0.51	0.47	4.84*	1.56	-0.86*	0.30	-8.76	0.85*	-0.50	-0.52**
Lider × NIAB 414	-10.77**	-0.29	-1.67**	-3.58	-35.26**	0.25	-1.19	-20.86	0.84*	-0.51	0.12
Lider × Deir ELzour 22	-6.59*	0.08	-0.74	-5.32**	-25.12*	-0.27	-0.98	-36.56*	-0.76	-0.72*	0.17
Cherpan 432 × Coker139	-9.89**	0.28	-0.21	-0.31	-13.63	-0.43	-0.18	-55.46**	-0.07	1.91**	-0.28
Cherpan 432 × Aleppo 90	-7.06*	0.10	0.25	13.93**	46.81**	-0.47	-0.27	-79.46**	-1.08*	-0.66	-0.09
Cherpan 432 × Aleppo 124	17.69**	-0.13	1.47**	3.04	14.52	0.55	2.86**	90.54**	3.28**	1.73**	0.15
Cherpan 432 × Raqqa 5	0.11	0.23	0.57	-1.20	-28.28*	1.11**	0.30	-49.96**	-0.15	-0.57	0.02
Cherpan 432 × Aleppo 118	9.46**	-0.02	0.22	-1.53	11.63	0.03	3.06**	132.44**	1.69**	1.61**	0.22
Cherpan432 × NIAB Kiran	-5.23	0.28	-1.17*	0.80	1.71	0.05	-2.26**	-1.96	-1.30**	-0.47	0.21

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Crosses	PH	MB	SB	B.N	BW	SCY	LP%	FL	FS	FE	FF
Cherpan 432 × NIAB 414	-2.11	-0.01	-0.31	-4.90*	-17.91	0.87*	-1.08	7.94	0.18	-0.78*	-0.23
Cherpan432 × Deir ELzour 22	1.12	0.25	-0.21	0.08	27.03*	1.12**	-2.10**	-9.76	-0.65	-1.40**	0.49**
Coker 139 × Aleppo 90	-1.07	0.46	-1.13*	-2.21	2.13	-0.01	-0.96	-6.76	-0.81	-0.21	-0.09
Coker 139 × Aleppo 124	14.33**	-0.10	1.31*	1.56	11.24	1.04*	2.19**	83.24**	0.10	-2.07**	0.63**
Coker 139 × Raqqa 5	3.81	-0.13	-0.31	6.44**	85.14**	0.19	-1.28	-27.26	-1.14**	0.49	-0.39*
Coker 139 × Aleppo 118	7.84*	0.29	0.06	-3.89	-27.85*	-0.13	3.80**	57.14**	1.46**	0.27	0.47*
Coker 139 × NIAB Kiran	-5.07	0.37	-0.66	5.32**	-0.27	-0.40	-0.91	-48.26**	0.71	0.12	-0.13
Coker 139 × NIAB 414	13.77**	-0.31	2.09**	-3.98*	-20.39*	-0.49	1.54*	-28.36	-0.99**	0.08	-0.15
Coker 139 × Deir ELzour 22	0.60	-0.28	0.75	0.93	-0.65	-0.56	0.43	25.94	-0.56	0.36	-0.34
Aleppo 90 × Aleppo 124	2.16	0.71*	0.55	-1.97	28.38*	1.09*	3.68**	84.24**	2.49**	0.63	0.40*
Aleppo 90 × Raqqa 5	1.09	-0.42	0.49	-5.87**	-33.12**	-0.89*	0.43	16.74	-1.14**	0.49	-0.35
Aleppo 90 × Aleppo 118	2.55	0.50	1.47**	-0.32	-4.91	0.16	1.57*	100.14**	2.21**	-0.50	0.13
Aleppo 90 × NIAB Kiran	6.88*	-0.20	-0.19	-7.21**	-22.43*	0.04	-1.74*	2.74	0.34	-0.01	-0.43*
Aleppo 90 × NIAB 414	3.81	-0.22	0.34	-5.91**	-8.25	0.11	-1.04	-27.36	1.23**	-0.46	0.02
Aleppo 90 × Deir ELzour 22	5.03	-0.13	-0.73	18.89**	50.09**	0.37	1.78*	-1.06	-0.04	-0.41	0.23
Aleppo 124 × Raqqa 5	7.10*	1.20**	1.15*	0.52	8.89	0.62	2.94**	86.74**	4.03**	0.07	0.13
Aleppo 124 × NIAB Kiran	2.89	-0.49	1.41**	6.23**	40.88**	0.78	6.05**	132.74**	1.94**	2.16**	0.39*
Aleppo 124 × NIAB 414	-0.29	-0.03	-0.23	11.98**	28.96*	-0.36	4.13**	94.64**	1.37**	0.39	0.27
Aleppo 124 × Deir ELzour 22	-1.22	0.58	-0.65	-6.49**	-32.60**	-0.94*	3.24**	63.94**	0.77	1.29**	0.72**
Raqqa 5× Aleppo 118	14.60**	0.01	-0.10	-1.00	-20.7*	-0.13	2.47**	65.64**	3.27**	0.11	0.34
Raqqa 5 × NIAB Kiran	-5.42	-0.57	0.62	-9.14**	-48.02**	0.50	1.16	5.24	-2.06**	0.92**	-0.03
Raqqa 5× NIAB 414	-4.91	0.69*	-1.47**	9.02**	51.86**	0.18	-3.04**	-4.86	-0.61	-0.40	0.36*
Raqqa 5× Deir ELzour 22	-23.37**	-0.39	-0.74	-6.61**	-43.20**	-0.91*	-0.20	-26.56	-0.22	0.95**	-0.13
Aleppo 118 × NIAB Kiran	9.27**	0.29	1.85**	14.56**	62.19**	0.03	3.88**	85.64**	1.27**	0.85*	0.75**
Aleppo 118 × NIAB 414	-17.56**	0.66*	-0.15	6.80**	60.17**	-0.03	3.23**	120.54**	1.54**	-0.52	0.40*
Aleppo 118 × Deir ELzour 22	-2.66	0.15	1.18*	-1.49	-7.69	1.49**	2.10**	52.84**	4.37**	0.03	0.55**
NIAB Kiran × NIAB 414	5.64	0.41	-0.42	-1.32	36.35**	-0.30	-2.71**	-46.86**	-0.11	-0.44	0.45*
NIAB Kiran× Deir ELzour 22	14.54**	-0.28	0.01	-3.73	-33.01**	-0.57	-1.63*	-47.56**	-0.75	-0.55	-0.47**
NIAB 414 × Deir ELzour 22	10.71**	-1.07**	0.99	-8.14**	-60.13**	-0.02	0.91	-6.66	-0.71	2.17**	-0.95**
SE sij	3.27	0.31	0.52	2.01	11.79	0.41	0.7	5.85	0.42	0.35	0.18

SE sij: standard error, *and **Significant at the $P \leq 0.05$ and $P \leq 0.01$ probability levels, respectively, PH: Plant height (cm), MB: Monopodial branches/plant, SB: Sympodial branches/plant, BN: Bolls number/plat, BW: Boll weight (g), SCY: Seed cotton yield/plant (g), LP%: Lint percentage (%), FL: Fiber length (mm), FS: Fiber strength (g/tex), FE: Fiber Elongation FF: Fiber fineness (micronaire)

For the fiber length, 21 hybrids showed the positive and significant or highly significant SCA effects. Nonetheless, the hybrids, Lider × Aleppo 118 (147.64), Aleppo 124 × NIAB Kiran (132.74) and Cherpan 432 × Aleppo 118 (132.44) showed the maximum positive and high significant SCA effects which revealed that these combinations were best combiners whereas, Cherpan 432 × Aleppo 90 (-79.46) showed maximum negative SCA effects.

Among 65 hybrids, 20 crosses recorded the positive and significant or highly significant SCA effects for fiber strength. The cross, Aleppo 118 × Deir ELzour 22 (4.37) was found to be the best specific combiner showing the maximum positive and high significant SCA effects followed by the Aleppo 124 × Raqqa 5 (4.03) and Cherpan 432 × Aleppo 124 (3.28), while the Raqqa 5 × NIAB Kiran (-2.06) was found to be the poor specific combiner with maximum negative SCA effects for fiber strength.

Out of 65 cross combinations, 16 crosses displayed positive and significant or highly significant SCA effects for fiber elongation. Nevertheless, the Millinium × Aleppo 118 (2.41), NIAB 414 × Deir EL-zour 22 (2.17) and Aleppo 124 × NIAB Kiran (2.16) crosses showed the highest positive and highly significant SCA effects indicating their

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outstanding combining ability, whereas the Coker139 × Aleppo 124 (-2.07) cross showed the maximum negative and high significant SCA effects which showed the poor specific combiner for fiber elongation.

For fiber fineness, six crosses showed the maximum negative and significant or highly significant SCA effects. The crosses NIAB 414 × Deir EL-zour 22 (-0.95), Lider × NIAB Kiran (-0.52) and NIAB Kiran × Deir EL-zour 22 (-0.47) showed the maximum negative and highly significant SCA effects which revealed that these crosses were the best combiners, conversely the Aleppo 118 × NIAB Kiran (0.75) showed the maximum positive and high significant SCA effects, which showed that it is poor specific combiner for this trait.

Discussion

Cotton is being grown as strategic crop in developing countries such as Pakistan, India, Syria etc. due to its vital role in capital generation for farmers and economic stability through exports of garments and other textile products. But it is facing serious challenges of limited resilience under changing climate, soil degradation and many abiotic constraints especially drought, heat, salinity etc. Moreover, pressure from urbanization and intensive cropping is demanding that resilience of modern cotton cultivars must be improved from available germplasm by dissecting genetic mechanisms with trustable inheritance (Tadele, 2017). A reasonable breeding progress has been achieved in sexually propagated crops by diallel analysis of crosses leading to development of high yielding cultivars of many foods, feed and cash crops (Bourgou et al., 2022). However, considerable genetic variation in plant materials may be exploited for enhancement of different plant agronomic characteristics. In this study, the recorded findings revealed that all the characteristics under investigation exhibited significant variation among the genotypes under study. Hence, later combining ability analysis was achieved. According to Kempthorne (1957), the genetic variability for each trait is partitioned to general and specific combining. Several studies indicated that presence genetic variability among the genotypes and practiced to GCA and SCA variances (AL-Hibbiny et al., 2020; Gnanasekaran and Thiyagu, 2021).

Combining ability effects partially provide pertinent information about the genetic control of different traits, as well as to enables cotton breeder for selecting the excellent genotypes (parents and crosses). The GCA to SCA ratio indicated the controlling of additive gene action for all studied characteristics. Present findings are in accordance with Giri et al. (2021) and Bourgou et al. (2022) for the plant height, sympodial and monopodial branches. For the number of bolls/plant and boll weight, seed cotton yield, lint percentage and additive genetics effects were appeared by Khan et al. (2015), Zhang et al. (2017) and Soomro et al. (2021). Akiscan and Gencer (2014), Sawarkar et al. (2015) and Giri et al. (2020) noted the predominance of additive type of gene action for the fiber length, strength and fineness. However, contrary to the findings of present study, non-additive genetics effects were observed by Vasconcelos et al. (2018) for plant height, while Monicashree et al. (2017) and Kocher et al. (2018) reported the similar findings for sympodial and monopodial branches per plant. Additionally, Bilwal et al. (2018) recorded non-additive genetics effects for the boll numbers and boll weight, seed cotton yield and lint percentage, while Chakholoma et al. (2022) reported the same trend for the fibre strength, upper half mean length and fiber fineness. Moreover, it has been inferred that selection in early populations of segregating material

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can be achieved for improving all tested traits of cotton in terms of higher yield and fiber quality (Falconer and Macky, 1996).

The combining ability analysis (GCA and SCA) is considered as a useful tool for distinguishing superior parents and crosses to develop new genotypes. Generally, one or both parents should be a good general combiner to obtain a hybrid with high SCA effects. For the plant height, the Coker139 and NIAB 414 were good combiners, and produced good hybrids i.e., Coker139 × NIAB 414 and NIAB 414 × Deir EL-zour 22. NIAB 414 proved to be a good general combiner for the number of monopodia and produced good hybrid NIAB 414 × Deir EL-zour 22. The parent, Coker139 reported as a superior general combiner for sympodial branches/plant and contributed to best hybrids i.e., Aleppo 124 × NIAB 414, and Coker139 × NIAB 414. For the number of bolls, the parents, Aleppo 90 and Raqqa 5 were proved to be good general combiners where superior hybrids i.e., Aleppo 90 × Deir EL-zour 22 and Raqqa 5 × NIAB 414. Parents, Cherpan 432, Coker139, Aleppo 90, Raqqa 5 and NIAB 414 were superior general combiners for the seed cotton yield, and produced good hybrids i.e., Cherpan 432 × Aleppo 90, Coker139 × Raqqa 5, Raqqa 5 × NIAB 414. Fantum and Millinium were reported as best general combiners for lint percentage, fiber length and fiber strength and contributed to most performing hybrids i.e., Fantum × Cherpan432, Fantum × Coker139 and Millinium × Aleppo 124. On the other hand, some hybrids were found good specific combiners, nonetheless, their parents were poor general combiners i.e., Aleppo 124 × Deir ELzour 22 for the seed cotton yield, Lider × Aleppo 118 for the fiber strength, and Cherpan 432 × Aleppo 124 and Cherpan 432 × Aleppo 118 for the fiber elongation. Similar results were also observed by Sajjad et al. (2016), Naeem et al. (2017), Vekariya et al. (2017), Solongi et al. (2019) and Abro et al. (2021). Half diallel approach was also used in cotton (*Gossypiu hirsutum* L.) for producing F1 hybrids between Burkina Faso and Texa A & M Agrilife. The Agrilife parent i.e, 15-03-416 reduced flowering days (50%), and the plant height in F1 hybrids while other parent 16-02-216FQ improved fiber percentage (+2.68%) (Bourgou et al., 2022). The diallel approach highlights the scope for cotton breeders in identification and selection of better combiners for particular objectives that will expedite the pace of cotton improvement in breeding programs (Grifing et al., 1956; Khan et al., 1991; Rauf et al., 2005; Karademir and Gencer, 2010).

Conclusions

The changing climate scenario has necessitated selection of the most resilient genotypes of cotton for boosting lint yield and fiber quality otherwise cotton growers and textile industry could sustain irreparable losses especially in developing countries like Pakistan and Syria. The varietal improvement is vital to meet modern challenges of cotton cultivation, harvesting along with efficient management of crop variables. In this study, diallel analyses of cotton genotypes remained effective in generating valuable information revealing the genetic base of plant agronomic traits. From this study, it has been inferred that a wide range of genetic variation existed among the parents for all studied characteristics which was imparted in their hybrids as well. Moreover, the parents, Coker 139, Aleppo 90 and NIAB 414 were good general combiner for yield and fiber quality under study. Hybrids, Millinium × Aleppo 124, Aleppo 124 × NIAB Kiran and Aleppo 118 × NIAB Kiran performed superiorly for most of the yield attributes, lint yield and quality attributes of cotton staple. Thus, based on recorded findings, it might be

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inferred that these genotypes may serve as potent candidates for utilization in further breeding programs to develop new varieties which might contribute in the uplift of socio-economic conditions of Syria and Pakistan through increased cotton production per unit of land area under changing climate.

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REFERENCES

[1] Abro, S., Deho, Z. A., Rizwan, M., Sial, M. A., Abro, S. A. (2021): Combining ability estimates for seed cotton yield and its related traits using line × tester mating design in upland cotton. – International Journal of Biology and Biotechnology 18(2): 315-319.

[2] Akiscan, Y., Gencer, O. (2014): Diallel analysis for fiber quality properties of cotton (*Gossypium hirsutum* L.). – Genetics and Plant Physiology. Conference on the Plant Physiology and Genetics- Achievements and Challenges, 24-26 September 2014, Sofia, Bulgaria, Special Issue (Part 2) 4(3-4): 209-215.

[3] Al-Hibbiny, Y. I. M., Ramadan, B. M., Mariz, S. (2020): Heterosis and combining ability for yield and fiber quality in cotton (*Gossypium barbadense* L.) using half diallel mating system Max. – Menoufia J. Plant Prod. 5: 233-248.

[4] Anonymous (2022): Syrian Cotton: From 1 Million Tons to Below 20,000 tons. – The Syrian Observer (syrianobserver.com), Thursday January 13th, 2022 by SYRIA STEPS (Pro-government website). https://syrianobserver.com/features/72634/syrian-cotton-from-1-million-tons-to-below-20000-tons.html. Accessed 19 August 2022.

[5] Arshad, M. U., Zhao, Y., Hanif, O., Fatima, F. (2022): Evolution of overall cotton production and its determinants: implications for developing countries using Pakistan case. – Sustainability 14: 840. https://doi.org/10.3390/su14020840.

[6] Ashraf, J., Zuo, D., Wang, Q., Malik, W., Zhang, Y., Abid, M. A., Song, G. (2018): Recent insights into cotton functional genomics: progress and future perspectives. – Plant Biotechnol. 16(3): 699-713. https://doi.org/10.1111/pbi.12856.

[7] Bilal, H., Shakee. L. A., Chattha, W. S., Azhar, M. T., Abro, S., Rizwan, M. (2022): Genetic variability studies of seed cotton yield and fibre quality in upland cotton (*Gossypium hirsutum* L.) grown under salinity stress. – Pakistan Journal of Botany 54: 1995-1999.

[8] Bilwal, B. B., Vadodariya, K. V., Rajkumar, B. K., Lahane, G. R., Shihare, N. D. (2018): Combining ability analysis for seed cotton yield and its component traits in cotton (*Gossypium hirsutum* L.). – International Journal of Current Microbiology and Applied Sciences 7(7): 3005-3010. https://doi.org/10.20546/ijcmas.2018.707.351.

[9] Bourgou, L., Dever, J. K., Sheehan, M., Kelly, C. M., Diané, S. K., Sawadogo, M. (2022): Diallel crosses of cotton (*Gossypium hirsutum* L.) from Burkina Faso and Texas A & M AgriLife Research—1-analysis of agronomic traits to improve elite varieties from Burkina Faso. – Agronomy 12(4): 939.

[10] Çetin, B., Çopur, O., (2022): Combining ability and heterosis for fiber color and quality in cotton (*Gossypium hirsutum* L.). – Notulae Botanicae Horti Agrobotanici Cluj-Napoca 50(2): 12782-12782.

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DOI: http://dx.doi.org/10.15666/aeer/2105_47214734
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[11] Chakholoma, M., Nimbal, S., Jain, A., Kumar, M. (2022): Combining ability analysis for yield and fibre quality traits in American cotton (*Gossypium hirsutum* L.) genotypes. – Ekin Journal of Crop Breeding and Genetics 8(1): 61-69.

[12] Chaudhary, C., Sharma, N., Khurana, P. (2023): Genome-wide identification of Aux/IAA and ARF gene families in bread wheat (*Triticum aestivum* L.). – Protoplasma 260: 257-270.

[13] Chinchane, V. N., Duomai, K., Kalpande, H. V. (2018): Combining ability studies for yield and its components in desi cotton (*Gossypium arboreum* L.). – Journal of Pharmacognosy and Phytochemistry 7(5): 3406-3408.

[14] Dirbas, J. (2018): Combining ability and heritability of some productivity characters in some hybrids of cotton (*Gossypium hirsutum* L.). – Syrian Journal of Scientific Agricultural Research 5(3): 113-124.

[15] El Sabagh, A., Islam, M. S., Iqbal, M. A., Hossain, A., Mubeen, M., Jabeen, T., et al. (2021): Salinity Stress in Cotton: Adverse Effects, Survival Mechanisms and Management Strategies. – In: Engineering Tolerance in Crop Plants against Abiotic Stress. CRC Press, Boca Raton, pp. 59-80.

[16] Falconer, D. S., Mackay, T. F. C. (1996): Introduction to Quantitative Genetics. 3rd Ed. – Longman, London.

[17] Giri, R. K., Verma, S. K., Yadav, J. P. (2020): Generation mean analysis for yield and its component traits in a diallel population of cotton (*Gossypium hirsutum* L.). – Indian Journal of Agricultural Research A-5639: 1-6. DOI: 10.18805/IJARe.A-5639.

[18] Giri, R. K., Verma, S. K., Yadav, J. P. (2021): Study of heterosis, combining ability and parental diversity for seed cotton yield and contributing traits using diallel data in cotton (*G. hirsutum* L.). – Indian Journal of Agricultural Research A-5680: 1-7. DOI: 10.18805/IJARe.A-5680.

[19] Gnanasekaran, M., Thiyagu, K. (2021): Gene action, combining ability and standard heterosis for seed cotton yield and fibre quality components in upland cotton. – Electronic Journal of Plant Breeding 12(2): 325-334.

[20] Griffing, B. (1956): Concept of general and specific combining ability in relation to diallel crossing system. – Australian Journal of Biological Sciences 9: 463-493.

[21] Huang, M., Chen, L. Y., Chen, Z. Q. (2015): Diallel analysis of combining ability and heterosis for yield and yield components in rice by using positive loci. – Euphytica 205: 37-50.

[22] Karademir, E., Gencer, O. (2010): Combining ability and heterosis for yield and fiber quality properties in cotton (G. hirsutum L.) obtained by half diallel mating design. – Not. Bot. Hort. Agrobot. Cluj. 38(1): 222-227.

[23] Kempthorne, O. (1957): An Introduction to Genetic Statistics. – John Wiley and Sons Inc., New York; Chapman and Hall, London.

[24] Khan, A. M., Masord, A., Sadaqat, H. A., Cheema, K. L. (1991): Implication of combining ability its utilization in cotton (*G. hirsutum* L.). – J. Agric. Res. 29: 167-175.

[25] Khan, S. A., Khan, N. U., Gul, R., Bibi, Z., Khan, I. U., Gul, S., Ali, S., Baloch, M. (2015): Combining ability studies for yield and fiber traits in upland cotton. – J. Anim. Plant Sci. 25(3): 698-707.

[26] Khuwaja, S., Bux, H., Abro, S., Rizwan, M., Kaleri, G. M. (2022): Estimate of heterosis and heterobeltiosis for the improvement of yield in upland cotton (Gossypium hirsutum L.). – Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences 38(1): 1-6. https://doi.org/10.47432/2022.38.1.1.

[27] Kocher, E. S., Shakeel, A., Maqbool, M. A., Abuzar, M. K., Zareen, S., Aamir, S. S., Asadullah, M. (2018): Studying combining ability and heterosis in different cotton (*Gossypium hirsutum* L.) genotypes for yield and yield contributing traits. – Pakistan Journal of Agricultural Research 31(1): 55-68.

[28] Majid, M., Ali, M., Shahzad, K., Ahmad, F., Ikram, R. M., Ishtiaq, M., Alaraidh, I. A., Al-hashimi, A., Ali, H. M., Zarei, T. et al. (2020). Mitigation of osmotic stress in cotton

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for the improvement in growth and yield through inoculation of Rhizobacteria and phosphate solubilizing bacteria coated diammonium phosphate. – Sustainability 12: 10456. https://doi.org/10.3390/su122410456.
[29] Monicashree, C., Balu, P. A., Gunasekaran, M. (2017): Combining ability and heterosis studies on yield and fibre quality traits in upland cotton (*Gossypium hirsutum* L.). – International Journal of Current Microbiology and Applied Sciences 6(8): 912-927.
[30] Naeem, M., Javaid, A. (2017): Combining ability analysis for within-boll yield components in metric traits in cotton (*Gossypium hirsutum* L.). – J. Agric. Soc. Sci. (3): 112-116.
[31] Pandey, M. P., Seshu, D. V., Akbar, M. (1994): Genetics of embryo size and its relationship with seed and seedling vigour in rice (*Oryza sativa* L.). – Indian Journal of Genetics and Plant Breeding 54(03): 258-268.
[32] Rauf, S., Kahn, T. M., Nazir, S. (2005): Combining ability and heterosis in *Gossypium hirsutum* L. – Int. J. Agric. Biol. 7: 109-113.
[33] Sagar, S. N., Sangwan, R. S., Kumar, P., Jangid, K., Bankar, A. H. (2019): Combining ability analysis for different morphological traits in diallel crosses of upland cotton (*Gossypium hirsutum* L.). – J. Cotton Res. Dev. 33(2): 208-213.
[34] Sajjad, M., Azhar, M. T., Malook, M. U. (2016): Line × tester analysis for different yield and its attributed traits in upland cotton (*Gossypium hirsutum* L.). – Agric. Biol. Am. 7(4): 163-172.
[35] Saleem, M. F., Ghaffar, A., Rahman, M. H. u., Imran, M., Iqbal, R., Soufan, W., Danish, S., Datta, R., Rajendran, K., EL Sabagh, A. (2022): Effect of short-term zero tillage and legume intercrops on soil quality, agronomic and physiological aspects of cotton under arid climate. – Land 11: 289. https://doi.org/10.3390/land11020289.
[36] Salem, T. S. G., Rabie, H. A., Mowafy, S. A. E., Eissa, A. E. M., Mansour, E. (2020): Combining ability and genetic components of Egyptian cotton for earliness, yield, and fiber quality traits. – SABRAO Journal of Breeding and Genetics 52(4): 369-389.
[37] Sawarkar, M., Solanke, A., Mhasal, G. S., Deshmukh, S. B. (2015): Combining ability and heterosis for seed cotton yield, its components and quality traits in *Gossypium hirsutum* L. – Indian J. Agric. Res. 49(2): 154-159.
[38] Sen, E. Z. F. A., El-Dahan, M. A. A., Badawy, S. A., Katta, Y. S., Aljuaid, B. S., El-Shehawi, A. M., El-Saadony, M. T., El-Tahan, A. M. (2022): Evaluation of genetic behavior of some Egyptian cotton genotypes for tolerance to water stress conditions. – Saudi Journal of Biological Sciences 29: 1611-1617. https://doi.org/10.1016/j.sjbs.2021.11.001.
[39] Singh, K., Singh, P., Singh, M., Mishra, S. K., Iqbal, R., Al-Ashkar, I., Sabagh, A. E. (2023): Sub-surface drip fertigation improves seed cotton yield and monetary returns. – Frontiers in Plant Science 13. https://doi.org/10.3389/fpls.2022.1038163.
[40] Solongi, N., Jatoi, W. A., Baloch, M. J., Siyal, M., Solangi, A. H., Memon, S. (2019): Heterosis and combining ability estimates for assessing potential parents to develop F1 hybrids in upland cotton. – Journal of Animal and Plant Sciences 29(5): 1362-1373.
[41] Soomro, A. B., Shahzad, S., Khan, S. (2021): Diallel analysis in upland cotton over the environments for yield, earliness, fiber quality traits and cotton leaf curl virus. – Int. J. Biol. Biotech. 18(1): 147-155.
[42] Steel, R. G. D., Torrie, J. H. (1980): Principles and Procedures of Statistics. Second Ed. – McGraw Hill Book Company Inc., New York.
[43] Tadele, Z. (2017): Raising crop productivity in Africa through intensification. – Agronomy 7(1): 22.
[44] Taha, E. M., El-Karamity, A. E., Eissa, A. E. M., Asaad, M. R. (2018): Heterosis and - combining ability of some Egyptian cotton genotypes. – Minia J. Agric. Res. & Develop. 38(1): 11-61.
[45] Tarazi, R., Jimenez, J. L., Vaslin, M. F. (2020): Biotechnological solutions for major cotton (*Gossypium hirsutum*) pathogens and pests. – Biotech Res Innov. 3: 19-26.

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[46] Vasconcelos, U. A. A., Cavalcanti, J. J. V., Farias, F. J. C., Vasconcelos, W. S., Santos, R. C. D. (2018): Diallel analysis in cotton (*G. hirsutum* L.) for water stress tolerance. – Crop Breed. Appl. Biotechnol. 18(1): 24-30.
[47] Vekariya, R. D., Nimbal, S., Batheja, A., Sangwan, R. S., Mandhania, S. (2017): Combining ability and gene action studies on seed cotton yield and its related traits in diploid cotton (*Gossypium arboreum* L.). – Electronic Jour. Plant Breed. (8): 1159-1168.
[48] Zhang, J. F., Abdel Raheem, A., Wu, J. X. (2017): Heterosis, combining ability and genetic effect and relationship with genetic distance based on a diallel of hybrids from five diverse *Gossypium barbadense* cotton genotypes. – Euphytica 213: 208.

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