

GENETIC CONTROL AND COMBINING ABILITY IN LINE BY TESTER CROSSES OF COTTON

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Abstract

The aim of this study was to evaluate the nature of gene action, combining ability of parents and F₁ hybrids in line × tester cotton crosses. An approach was applied to identify the parents having as high as possible GCA for all studied traits and to select the most reliable F₁ crosses by their ranking based on the total effects using the squared Euclidean distance. Crosses with relatively short Euclidean distances to the “ideal” population in which desirable segregants are expected to occur were identified. The crosses 572 × Chirpan-539, Melani × Chirpan-539 and 641 × Chirpan-539 had the highest positive GCA for the three studied traits and appeared to be the most valuable for breeding programs. Heterosis manifestations were found for the three traits in individual crosses, the heterobeltiosis for productivity per plant ranged from 103.7% to 141.9%, for lint percentage was from 101.3% to 107.2% and for fiber length - from 102.2% to 106.8%. Good general combiners were identified and high GCA of some was mainly due to additive genes, making them very suitable for the synthetic selection.

Key words: cotton, *G. hirsutum*, genetic variance, heterosis, Euclidean distance.

INTRODUCTION

In our country, in cotton breeding, through intra- and interspecific hybridization and experimental mutagenesis, a number of new varieties and selection lines have been created. Their usage as starting material in breeding programs is of great importance for increasing the genetic potential for yield and fiber quality of new cotton varieties.

The main components of genetic variance - additive and non-additive, genetic parameters and indicators such as degree of dominance and type of inheritance, number of effective factors, heritability in broad and narrow sense, heterosis, etc., and the combining ability of parents for hybridization are of importance for clarifying the selection strategy.

Based on the estimates of genetic variance additive or non-additive recommendations are made for effective selection in the earlier or later hybrid generations. In the inheritance of traits, both additive and non-additive variance may be relevant. In the presence of additivity the prediction for selection in the early segregating generations can be good.

Many authors have reported that additive and non-additive gene effects are important for

inheritance of traits in cotton. Some researchers have pointed greater importance of additive (Ekinci & Basbag, 2018; Vasconcelos et al., 2018; Carvalho et al., 2018; Bourgou et al., 2023), others of non-additive gene effects (Ali et al., 2018; Munir et al., 2018; Ullah et al., 2022).

According to Sivia et al. (2017), Nimbal et al. (2019) analysis of combining ability plays an important role in the selection of parents to produce more desirable segregants. General combining ability (GCA) is due to additive gene action, which is very important for faster selection, while specific combining ability (SCA) is caused by non-additive gene action - dominance and epistasis.

Barut et al. (2000) used an approach to select parents having general combining ability as high as possible for all traits. The total GCA effects of parents, for each trait and for each cross combination, were pooled and ranked, and the highest value for each trait was taken as “ideal”. The “ideal” values for each trait were considered to characterize the “ideal” population and the Euclidean distances between the GCA effects of any two parents and the “ideal” population values for each F₁ cross were calculated. Crosses with the shortest

Euclidean distance, i.e. closest to the “ideal” population, were considered to be most valuable.

The aim of this study was: i) to determine the type of gene action controlling the investigated traits in line $\times$ tester cotton crosses in relation the choice of selection strategy and work with the hybrid generations; ii) to evaluate the general and specific combining abilities of parents and by applying the approach mentioned above to identify the parents having general combining ability as high as possible for all studied traits and to select the most reliable F_1 crosses.

MATERIALS AND METHODS

Fifty six cotton hybrid populations derived from two line $\times$ tester crosses design mating systems by applying the experimental method I (without reciprocals) of Savchenko (1984) were the objective of this study. In the first crossing scheme (7×3) four advanced lines 449, 489, 572, 578 and three varieties Anabel, Tiara and Selena (Bulgarian selection) used as females were crossed with Sirius variety and the cultivars Chirpan-539 (Bulgarian) and FR-H-1002 (Spanish) used as males to produced 21 hybrid combinations. In the second crossing scheme (7×5) other five promising lines 639, 641, 643, 681, 682 and Aida and Melani varieties (Bulgarian) used as females were crossed with Sirius variety and the cultivars Chirpan-539, Helius (Bulgarian), FR-H-1002 (Spanish) and Nazili 954 (Turkish) used as males to produced other 35 hybrid combinations.

The trials were carried out in 2020 at the Field Crops Institute in Chirpan, in randomized complete block design with three replications. Each plot with parents and hybrids consisted of two rows 2.4 m long with a distance of 0.60 m between rows and 0.20 m within row. Traditional practices for cotton growing in our country were applied during the growing season. The traits under study were productivity per plant, lint percentage and mean fiber length. For each genotype ten plants from each replication were observed.

General combining ability (GCA) and specific combining ability (SCA) were evaluated by applying the methodology of Savchenko (1984). The main effects of females and males

are equivalent to GCA, and the female $\times$ male interaction represents SCA (Hallauer & Miranda, 1981). To rank the parents on GCA for the three studied traits total effects of females and males ($f_i + m_j$) were calculated for each trait. The highest ($f_i + m_j$) values were taken as “ideals” (Barut et al., 2000) and the Squared Euclidean Distances (Manly, 1995) were calculated between those “ideals” and total effects of any two parents for each F_1 hybrid combination. The shorter the Euclidean Distances to the “ideal” population, the more desirable the crosses are. Euclidean distances were determined by the formula:

$$\text{Squared Euclidean Distance} = \sum (x_i - x_j)^2$$

where: x_i - “ideal” value;

x_j - total GCA effects of any two parents.

The studied traits were measured in different units and data were pre-standardized.

RESULTS AND DISCUSSIONS

Analysis of combining ability variance (Table 1) reveals that effects of crosses, GCA effects of females and males, and SCA effects of crosses are significant for all three traits in both crossing schemes, which means that females and males differed in general and specific combining ability. Only GCA effects of females for fiber length in the first crossing scheme (Trial I) were insignificant.

The participation of σ^2_{GCA} and σ^2_{SCA} in the genetic variance of productivity per plant reveals that non-additive gene effects were essential for the inheritance of this trait in both crossing schemes. The results obtained are consistent with those reported by Çoban & Ünay (2017), Munir et al. (2018), Roy et al. (2018), Ali et al. (2018), Ullah et al. (2022), Vadodariya et al. (2022) that non-additive gene action predominated in inheritance of productivity per plant and seed cotton yield in intra- and interspecific (*G. hirsutum* $\times$ *G. barbadense*) crosses. Regarding inheritance of lint percentage additive gene effects predominated $\sigma^2_{GCA} > \sigma^2_{SCA}$ in the first group of crosses, while non-additive gene effects have had predominance $\sigma^2_{GCA} < \sigma^2_{SCA}$ in the second

group of crosses. Preponderance of additive gene action in inheritance of this trait was reported by Vasconcelos et al. (2018), Vadodariya (2022) in *G. hirsutum* diallel and *G. hirsutum* × *G. barbadense* cotton crosses. In contrast, other researchers Ali et al. (2018) and Munir et al. (2018), Ullah et al. (2022) in intra- and interspecific cotton crosses reported non-additive gene action in the inheritance of lint percentage. As for fiber length, in the first group of crosses, the values of variance components σ^2_{GCA} and σ^2_{SCA} are close and reveal that additive and non additive gene effects were of importance in inheritance of this trait. In the second group of crosses, non-additive gene effects prevailed over additive gene effects $\sigma^2_{GCA} < \sigma^2_{SCA}$, which is consistent with that found by Khan et al. (2017) (in *G. hirsutum* crosses), Munir et al. (2018) (in intra- and interspecific crosses), Ali et al. (2018) (in line × tester crosses), Roy et al. (2018), Vadodariya et al. (2022) (in *G. hirsutum* × *G. barbadense* crosses), that non-additive gene

effects were more important in fiber length inheritance. Superiority of additive gene effects for fiber length was reported by Ekinci & Basbag (2018) in interspecific *G. hirsutum* × *G. barbadense* crosses, Carvalho et al. (2018), Bourgou et al. (2023) in *G. hirsutum* diallel crosses. Crosses from the first group demonstrated more additive gene action for lint percentage and fiber length, which from a selection point of view is important for rapid improvement of this trait. These results confirm that the choice of parents can increase additivity. In the second group of crosses the studied traits were influenced by non-additive gene action and quick selection regarding these traits cannot be expected. The three traits were strongly influenced by year conditions. Vozhehova et al. (2022) found that year conditions affected the adaptive capacity of cotton samples. Muhova & Stefanova-Dobrevva (2022) studied the effect of mineral fertilization as well as the influence of year conditions on the seed cotton yield.

Table 1. Analysis of combining ability variance for productivity per plant, lint percentage and fiber length in 7 × 3 (Trial I) and 7 × 5 (Trial II) F₁ line × tester crosses

Sources on variation	Degrees of freedom	Mean squares		
		Productivity per plant	Lint percentage	Fiber length
Trial I				
Crosses	20	120.303 F_{exp} 18.143***	3.450 F_{exp} 24.126***	1.258 F_{exp} 4.642***
Errors	60	6.631	0.143	0.271
GCA-females	6	33.544 F_{exp} 15.178**	0.395 F_{exp} 8.229**	0.163 F_{exp} 1.811 ns
GCA-males	2	93.424 F_{exp} 42.273**	0.226 F_{exp} 4.708*	1.410 F_{exp} 15.667**
SCA-females × males	12	34.489 F_{exp} 15.606**	1.681 F_{exp} 35.021**	0.382 F_{exp} 4.244**
Errors	60	2.210	0.048	0.090
Components of variance		σ^2_{GCA} =0.146; σ^2_{SCA} =10.760	σ^2_{GCA} =1.328; σ^2_{SCA} =0.544;	σ^2_{GCA} =0.093; σ^2_{SCA} =0.097;
Trial II				
Crosses	34	165.446 F_{exp} 72.279***	19.048 F_{exp} 84.283***	3.197 F_{exp} 24.977***
Errors	92	2.289	0.226	0.128
GCA-females	6	124.620 F_{exp} 163.329**	28.514 F_{exp} 380.187**	2.315 F_{exp} 53.837**
GCA-males	4	72.012 F_{exp} 94.380**	5.016 F_{exp} 66.880**	0.593 F_{exp} 13.791**
SCA-females × males	24	34.970 F_{exp} 45.832**	1.030 F_{exp} 13.733**	0.832 F_{exp} 19.349**
Errors	92	0.763	0.075	0.043
Components of variance		σ^2_{GCA} =0.394; σ^2_{SCA} =23.750	σ^2_{GCA} =0.109; σ^2_{SCA} =0.318;	σ^2_{GCA} =0.005; σ^2_{SCA} =0.263;

*, ** and *** at P 0.5%, 0.1% and 0.01%

Evaluations of GCA effects are presented in Table 2. Of the females included in the first crossing scheme (Trial I), Tiara variety having the lowest productivity per plant showed the highest GCA followed by Anabel variety and line 449, the last one having the highest productivity per plant. Among the males, the cultivar Chirpan-539 showed the highest productivity per plant had the highest GCA. This cultivar and line 449 could be used as good general combiners in breeding programs to enhance productivity of new cotton varieties. Of the females included in the second crossing scheme (Trial II) high GCA was found for Melani variety and lines 639 and 641 having low to medium high productivity per plant. Lines having high productivity per plant exhibited low GCA. Of the males, the Turkish cultivar Nazili 954 had the highest GCA. The cultivar Helius and Sirius variety having high

productivity per plant had lower GCA. Sirius variety having the highest productivity among the males in the first group of crosses showed negative GCA. The Spanish cultivar FR-H-1002 also had inconsistent GCA. It is necessary the GCA of both varieties to be evaluated in different crosses and in different environments. The cultivars Nazili 954 and Helius could be used as good general combiners for productivity in breeding programs with cotton. Of the females in the Trial I, line 572 having the lowest lint percentage had the highest GCA for this trait. Selena variety also having low lint percentage had negative but insignificant GCA. Other lines having the same lint percentage had different combining abilities. Of the males, the cultivar Chirpan-539 showed the highest lint percentage had negative but insignificant GCA, the Spanish cultivar FR-H-1002 had positive GCA but lower lint percentage.

Table 2. Estimates of general combining ability (GCA) effects of parents for productivity per plant, lint percentage and fiber length

Parents		Characters					
		Productivity per plant		Lint percentage		Fiber length	
		g	GCA	%	GCA	mm	GCA
Trial I							
Females	449	59.4	1.616	36.9	-0.368	26.5	-0.060
	489	54.8	-5.017	36.5	0.365	25.2	0.162
	Anabel	49.5	1.794	36.6	0.054	25.2	0.040
	Tiara	39.8	5.149	36.5	-0.079	25.9	-0.249
	572	40.9	-0.784	35.5	0.554	25.4	0.095
	578	42.3	-2.984	36.2	-0.446	25.5	0.340
	Selena	41.7	0.226	35.9	-0.079	25.5	-0.327
	Standard error		1.487		0.218		0.301
Males	Chirpan-539	44.9	3.221	38.1	-0.194	25.6	0.508
	Sirius	43.1	-3.970	35.5	0.030	25.0	-0.344
	FR-H-1002	39.9	0.749	36.2	0.163	26.0	-0.163
	Standard error		0.973		0.143		0.197
Trial II							
Females	Aida	50.9	-1.025	37.3	0.973	26.3	-0.584
	Melani	37.9	4.652	37.1	0.849	26.7	-0.150
	639	43.0	6.16	40.5	2.663	25.4	-0.610
	641	34.0	4.388	35.2	1.535	26.1	-0.210
	643	37.4	-5.825	35.1	0.702	28.5	-0.337
	681	56.3	-4.832	33.6	-3.447	28.7	1.163
	682	56.6	-3.518	32.2	-3.275	26.2	0.729
	Standard error		0.675		0.213		0.159
Males	Chirpan-539	46.3	-3.085	38.0	0.879	28.1	0.434
	Helius	49.3	0.865	37.6	-0.560	25.2	-0.318
	Sirius	54.3	0.961	36.8	-0.086	25.6	-0.156
	Nazili 954	46.6	4.448	36.4	-1.051	27.2	0.129
	FR-H-1002	46.1	-3.190	36.9	0.818	28.1	-0.089
	Standard error		0.573		0.180		0.135

Of the females in the Trial II, line 639 had the highest lint percentage and the highest GCA. This line could be used in breeding programs for improving of this trait. Four other lines exhibited positive GCA, but their lint percentage was very low. Among the males, the cultivar Chirpan-539 had the highest lint percentage and the highest GCA.

Regarding fiber length, in the first group of crosses, line 578 from the females and the cultivar Chirpan-539 from the males showed the best general combining abilities. Insignificant positive GCA was observed for Anabel variety and lines 489 and 572. In the second group of crosses, these were line 681 from the females and the cultivar Chirpan-539 from the males exhibited the highest general combining abilities and the longest fibers. Among the males, the cultivars Chirpan-539 and FR-H-1002 having equal and the longest fibers demonstrated positive and negative GCAs, respectively. The cultivar Chirpan-539 showed the highest positive and significant GCA was followed by the Turkish cultivar Nazili 954, while the Spanish cultivar FR-H-1002 had insignificant negative GCA. The

cultivar Helius and Sirius variety formed the shortest fibers and had negative GCAs.

Analysis of results reveals that the parents having the same mean values for the studied traits exhibited different GCAs. Genotypes with high mean values did not always develop high GCA. According to Batool et al. (2010), Makhdoom et al. (2010) many commercial cultivars regardless of how they perform economically, better or worse, when combined in crosses can perform differently better or worse.

In Trial I nine crosses demonstrated positive and significant SCA effects for productivity per plant, highest in Anabel $\times$ FR-H-1002, Tiara $\times$ Chirpan-539 and 572 $\times$ Chirpan-539 (Table 3).

Of these ones, eight crosses showed heterosis relative to average of the two parents (mid parent heterosis) from 106.8% to 150.4%, seven crosses relative to the better parent (heterobeltiosis) from 105.8% to 141.9%. The crosses Anabel $\times$ FR-H-1002 and Tiara $\times$ Chirpan-539 had the highest productivity per plant and the highest mid parent heterosis of 143.2% and 150.4%, and heterobeltiosis of 129.3% and 141.9%. Tiara variety and line 449

Table 3. Mean values, effects of specific combining ability (SCA) (below line) and variances (σ^2S_i ; σ^2S_j) for the first group of crosses included in the Trial I

Females	Productivity per plant, g				Lint percentage, %				Fiber length, mm			
	Males											
	Chirpan-539	Sirius	FR-H-1002	σ^2S_i	Chirpan-539	Sirius	FR-H-1002	σ^2S_i	Chirpan-539	Sirius	FR-H-1002	σ^2S_i
449	57.5	47.0	50.6		37.1	36.0	38.0		26.5	24.4	24.3	
	2.579	-0.730	-1.849	5.092	0.249	-1.075	0.825	0.944	0.936	-0.311	-0.625	0.674
489	46.4	44.2	44.6		36.3	38.2	38.7		26.0	24.5	25.3	
	-1.89	3.103	-1.216	7.124	-1.284	0.459	0.825	1.266	0.181	-0.340	0.219	0.112
Anabel	53.2	38.2	64.1		37.2	36.9	38.2		24.7	25.4	25.4	
	-1.79	-9.708	11.51	114.7	-0.04	-0.563	0.603	0.340	-0.963	0.555	0.408	0.693
Tiara	63.7	49.8	52.2		38.8	37.4	35.7		25.5	24.5	24.6	
	5.246	-1.463	-3.783	21.78	1.694	0.037	-1.73	2.927	0.159	-0.055	-0.103	0.011
572	54.3	50.4	43.2		36.8	38.2	38.8		25.4	25.2	25.0	
	1.779	5.070	-6.849	37.68	-0.973	0.237	0.736	0.768	-0.286	0.367	-0.081	0.103
578	45.4	45.6	50.3		35.6	37.5	37.7		26.5	25.0	24.8	
	-4.92	2.470	2.451	17.95	-1.140	0.560	0.560	0.970	0.570	-0.111	-0.459	0.265
Selena	52.5	47.6	50.8		38.6	37.7	35.6		24.7	24.4	25.3	
	-0.99	1.259	-0.260	1.114	1.494	0.337	-1.83	2.842	-0.570	-0.044	0.641	0.376
σ^2S_i	11.35	23.11	33.89		1.505	0.358	1.485		0.429	0.111	0.199	
SE (SCA)	1.863				0.273				0.375			

from the females and the cultivar Chirpan-539 from the males having high GCA effects had low variances of SCA, which means that their high GCA was mainly due to additive gene action and they are very suitable for hybridization and selection programs. Anabel variety (as female component) having high GCA has manifested high variances of SCA, which means that its high GCA was due to additive and non-additive gene actions.

Ten crosses exhibited positive SCA effects for lint percentage, the highest in Tiara $\times$ Chirpan-539 and Selena $\times$ Chirpan-539. All crosses having positive SCA effects manifested mid parent heterosis from 104.0% to 108.1% and heterobeltiosis from 101.3% to 107.2%. The crosses Tiara $\times$ Chirpan-539, 489 $\times$ FR-H-1002 and 572 $\times$ FR-H-1002 had the highest lint percentage of 38.7-38.8% and evaluated heterobeltiosis was 101.8%, 106.0% and 107.2%, respectively. Lines 572 of females, had low variance of SCA and is very suitable for the pedigree selection, while line 489 of females and the cultivar FR-H-1002 of males showed high GCA had high SCA variances and are more suitable for the heterosis selection.

Regarding fiber length, only four crosses showed positive and significant SCA effects. Of these ones, only two crosses manifested very weak mid parent heterosis of 101.2-101.5%. Line 578 of the females and the cultivar Chirpan-539 of the males showed high GCAs for this trait exhibited low and high variances of SCA, respectively. The cross 449 $\times$ Chirpan-539 having the longest fiber manifested very low mid parent heterosis of 101.5%.

In Trial II nine crosses showed positive SCA effects for productivity per plant (Table 4). Heterosis manifestations were registered in six crosses. The values of mid parent heterosis ranged from 107.0% to 144.4%, of heterobeltiosis - from 103.7% to 148.5%. The cross 641 $\times$ Nazili 954 showed the best productivity performance, followed by the cross 641 $\times$ Sirius both exhibited heterobeltiosis of 148.5% and 117.3%, respectively. Melani variety and line 639 from the females and the cultivar Helius from the males having high GCA had low SCA variances. Line 641 from the females possessed high GCA and high SCA variance. The cultivar

Nazili 954 and Sirius variety from the females having high GCA had high and medium-high SCA variances, respectively. At low SCA variances, high GCA is due to additive gene action, while at high and medium-high SCA variances, high GCA is due to additive and non-additive gene action, which should be considered in recommendations for selection of productivity.

Heterosis results for productivity per plant in this study are comparable to those reported by other authors. Positive mid parent heterosis for this trait in the hybridization of the species *G. hirsutum* $\times$ *G. barbadense* was reported by Adsare et al. (2017), Rajeev et al. (2018). Tian et al. (2019) concluded that overdominance is the genetic basis of lint yield heterosis in intra- and interspecific hybrids. Borzan & Güvercin (2021) noted that F_1 hybrids can be more superior from mean of parents (mid parent heterosis) and superior parent (heterobeltiosis) because of the influence of dominant genes. Tian et al. (2019), Li et al. (2022) noted that heterosis is related to overdominance.

Positive and significant SCA effects for lint percentage were recorded in 9 crosses. Mid parent heterosis from 3.5% to 4.4% was observed in three crosses, heterobeltiosis from 3.0% to 6.0% was registered in only two crosses, which is consistent with the study of Karademir & Gençer (2010) who reported heterosis level of 5.52% in only one cross among studied diallel crosses. The crosses 639 $\times$ Chirpan-539 and 639 $\times$ FR-H-1002 had the highest lint percentage of 40.0%, respectively with significant and insignificant positive, but not very high SCA effects. In these two crosses, the female component also exhibited high lint percentage of 40.5%. Line 639 from the females having high GCA showed low SCA variance, the cultivar Chirpan-539 from the males, with high GCA had medium high SCA variance. This cultivar is suitable for both pedigree selection and heterosis selection.

As for fiber length, positive SCA effects were found in 9 crosses. Heterosis relative to the mean of both parents from 101.5% to 109.5% was registered in all nine crosses, while heterobeltiosis from 102.2% to 106.8% was reported in only 4 crosses.

Table 4. Mean values, effects of specific combining ability (SCA) (below line) and variances (σ^2S_i ; σ^2S_j) for the second group of crosses included in the Trial II

Females	Males					
	Chirpan-539	Helius	Sirius	Nazili 954	FR-H-1002	σ^2S_i
Productivity per plant, g						
Aida	35.6	52.8	56.3	59.9	43.8	
	-11.008	2.242	5.678	5.792	-2.703	49.740
Melani	52.6	58.8	56.4	61.3	47.6	
	0.315	2.715	0.068	1.482	-4.580	7.575
639	53.3	59.2	56.6	58.9	56.4	
	-0.493	1.456	-1.248	-2.427	2.711	4.204
641	52.0	48.4	63.7	69.2	42.2	
	-0.022	-7.572	7.665	9.645	-9.717	75.795
643	43.5	46.6	39.8	45.7	48.9	
	1.692	0.842	-6.055	-3.675	7.196	26.294
681	48.7	47.6	46.2	42.1	44.8	
	5.932	0.848	-0.648	-8.235	2.103	27.053
682	47.7	47.5	42.7	49.1	49.0	
	3.585	-0.532	-5.461	-2.582	4.990	18.544
σ^2S_i	28.650	12.173	26.491	37.019	35.107	
SE(SCA)	2.654					
Lint percentage, %						
Aida	38.2	35.2	37.5	36.0	37.9	
	0.368	-1.202	0.628	0.135	0.071	0.491
Melani	36.0	37.3	38.2	35.7	37.1	
	-1.687	1.005	1.432	0.013	-0.763	1.614
639	40.0	36.7	38.5	37.8	40.0	
	0.649	-1.295	0.014	0.250	0.381	0.568
641	40.1	37.3	35.8	36.5	37.7	
	1.673	0.428	-1.546	0.057	-0.612	1.428
643	36.8	37.9	35.9	35.2	37.5	
	-0.694	1.811	-0.670	-0.476	0.059	1.112
681	33.4	32.6	32.5	31.1	33.2	
	-0.003	0.589	-0.005	-0.494	-0.088	0.141
682	33.3	30.8	32.7	32.2	34.4	
	-0.305	-1.337	0.177	0.513	0.952	0.732
σ^2S_i	1.121	1.613	0.884	0.128	0.329	
SE(SCA)	0.385					
Fiber length, mm						
Aida	27.6	27.1	26.4	26.2	26.0	
	0.545	0.764	-0.097	-0.616	-0.597	0.402
Melani	30.0	25.3	26.2	27.2	26.7	
	2.479	-1.435	-0.730	0.017	-0.330	2.207
639	25.5	26.4	27.3	26.5	27.4	
	-1.560	0.091	0.863	-0.256	0.863	0.995
641	26.7	26.5	26.8	27.5	27.7	
	-0.794	-0.175	-0.104	0.310	0.763	0.333
643	26.3	27.5	27.3	27.5	25.9	
	-1.068	0.918	0.556	0.470	-0.877	0.816
681	28.5	28.1	28.1	28.6	28.6	
	-0.301	0.051	-0.110	0.103	0.256	0.041
682	29.1	27.4	27.4	28.1	27.8	
	0.699	-0.215	-0.377	-0.029	-0.077	0.166
σ^2S_i	1.867	0.591	0.289	0.124	0.434	
SE(SCA)	0.290					

The cross Melani $\times$ Chirpan-539 exhibited the longest fiber of 30.0 mm and the highest heterobeltiosis, followed by the cross 682 $\times$

Chirpan-539 having fiber length of 29.1 mm and manifested heterobeltiosis of 103.5%. In the other crosses exhibited positive SCA effects

fiber length varied from 27.1 mm to 27.7 mm. had low SCA variances, while the cultivar Chirpan-539 from the males showed high GCA had high variance of SCA.

Çoban et al. (2015), Çoban & Ünay (2017) in *G. hirsutum* × *G. barbadense* crosses reported mid parent heterosis for fiber length in all cross combinations. Heterosis values were positive and ranged between 0.34% to 14.33% and 2.05% to 16.99% (Çoban et al., 2015). Bölek et al. (2014), Roy et al. (2018), Ünay et al. (2018) also reported positive heterosis for fiber length in this hybridization. According to Ekinici & Basbag (2018) among the studied *G. hirsutum* × *G. barbadense* crosses the determined heterosis (Ht) values for fiber length varied from -1.77 to 3.81%, the estimated heterobeltiosis (Hb) values for this trait varied from -7.87% to -0.03%. Chapara & Madugula (2021) reported heterosis for Upper Half Mean Length (UHML) and mean length in intraspecific line × tester crosses and the highest values were 21.34% and 25.37%, heterobeltiosis for UHML ranged between 7.53 to 20.73% which was higher than achieved in this study.

Line 681 from the females having high GCA Total GCA effects (f_i+m_j) of the parents for each trait and the ranked crosses based on the Euclidean distances to the “ideal” population are presented in Tables 5 and 6. According to the calculated Euclidean distances, in Trial I the cross 572 × Chirpan-539 was the closest to the “ideal” population and most valuable for selection programs. The parental components line 572 and the cultivar Chirpan – 539 had positive total (f_i+m_j) GCA effects for the three traits. The crosses Tiara × Chirpan-539, Tiara × FR-H-1002, Anabel × Chirpan-539 and 449 × Chirpan-539 had high total GCA effects for productivity per plant, but showed negative effects for lint percentage or fiber length (at the second cross). In these crosses, with increasing productivity decrease in lint percentage and fiber length could be expected. Crosses 572 × FR-H-1002 and 572 × Sirius having high GCAs for lint percentage showed negative ones for productivity per plant and fiber length. The crosses 578 × Chirpan-539 and 489 × Chirpan-539 having the highest positive effects for fiber length showed negative effects for lint percentage and productivity per plant.

Table 5. Total general combining ability (GCA) effects ($f_i + m_j$) of the parents for each trait and Squared Euclidean Distances to the “ideal” population in the first group of crosses - Trial I

Parents	Total GCA (general combining effects) of the parents ($f_i + m_j$)			Squared Euclidean Distance
	Productivity per plant, g	Lint percentage, %	Fiber length, mm	
572 × Chirpan-539	2.437	0.360	0.602	3.033
Anabel × Chirpan-539	5.015	-0.140	0.547	6.254
489 × Chirpan-539	-1.796	0.171	0.668	7.605
572 × FR-H-1002	-0.035	0.717	-0.068	8.061
Anabel × FR-H-1002	2.543	0.217	-0.123	8.487
Tiara × Chirpan-539	8.370	-0.273	0.258	8.77
Selena × Chirpan-539	3.447	-0.273	0.180	10.536
Tiara × FR-H-1002	5.898	0.084	-0.412	11.521
489 × FR-H-1002	-4.268	0.528	-0.002	12.289
449 × Chirpan-539	4.837	-0.562	0.447	13.068
449 × FR-H-1002	2.365	-0.205	-0.223	13.921
Selena × FR-H-1002	0.975	0.084	-0.49	15.093
578 × FR-H-1002	-2.235	-0.283	0.177	15.244
572 × Sirius	-4.754	0.584	-0.249	15.343
Anabel × Sirius	-2.176	0.084	-0.304	15.563
578 × Chirpan-539	0.237	-0.64	0.847	16.444
Tiara × Sirius	1.179	-0.049	-0.593	17.767
489 × Sirius	-8.987	0.395	-0.183	21.860
449 × Sirius	-2.354	-0.338	-0.404	22.069
Selena × Sirius	-3.744	-0.049	-0.671	23.883
578 × Sirius	-6.954	-0.416	-0.004	25.011

In the Trial II, the crosses Melani × Chirpan-539 and 641 × Chirpan-539 were found to be most reliable, with the shortest Euclidean distances and positive total GCA effects of parents for the three traits. Crosses 639 × Nazili 954 and 641 × Nazili 954 had the highest total GCA effects for productivity per plant, crosses 639 × Chirpan-539 and 639 × FR-H-1002 for lint percentage, but all showed negative GCA effects for fiber length. In the first two crosses with increasing productivity and in the second two with increasing lint percentage shortening

of fiber length could be expected. The crosses 681 × Nazili 954 and 682 × Chirpan-539 exhibited the highest total GCA effects for fiber length and negative effects for productivity per plant and lint percentage. According to Naoumkina et al. (2019) improving fiber length without reduction yield is one of major goals of cotton breeding. In cotton, there are strong negative dependencies between many of the traits (Gospodinova et al., 2020).

Table 6. Totals general combining ability (GCA) effects ($f_i + m_j$) of the parents for each trait and Squared Euclidean Distances to the “ideal” population in the second group of crosses - Trial II

Parents	Productivity per plant, g	Lint percentage, %	Fiber length, mm	Squared Euclidean Distance
Melani × Chirpan-539	1.568	1.728	0.284	6.871
641 × Chirpan-539	1.304	2.414	0.224	7.008
641 × Nazili 954	8.836	0.484	-0.081	7.653
Melani × Nazili 954	9.1	-0.202	-0.021	8.041
639 × Chirpan-539	3.076	3.542	-0.176	8.435
639 × Nazili 954	10.608	1.612	-0.481	9.692
641 × Sirius	5.349	1.449	-0.366	9.744
Melani × Sirius	5.613	0.763	-0.306	9.765
Melani × FR-H-1002	1.462	1.667	-0.239	10.419
641 × FR-H-1002	1.198	2.353	-0.299	10.675
641 × Helius	5.253	0.975	-0.528	11.556
Melani × Helius	5.517	0.289	-0.468	11.65
639 × Sirius	7.121	2.577	-0.766	12.242
Aida × Nazili 954	3.423	-0.087	-0.455	12.842
639 × FR-H-1002	2.97	3.481	-0.699	12.940
Aida × Chirpan-539	-4.109	1.852	-0.15	13.999
639 × Helius	7.025	2.103	-0.928	14.124
643 × Nazili 954	-1.377	-0.349	-0.208	14.22
682 × Nazili 954	0.93	-4.326	0.858	15.226
681 × Nazili 954	-0.384	-4.498	1.291	15.659
682 × Sirius	-2.557	-3.361	0.573	16.356
682 × Chirpan-539	-6.602	-2.396	1.163	16.387
Aida × Sirius	-0.064	0.887	-0.74	16.414
681 × Sirius	-3.871	-3.533	1.006	16.514
643 × Chirpan-539	-8.909	1.581	0.097	17.891
681 × Chirpan-539	-7.916	-2.568	1.596	17.904
682 × FR-H-1002	-6.708	-2.457	0.64	18.157
681 × Helius	-3.967	-4.007	0.844	18.293
682 × Helius	-2.653	-3.835	0.411	18.392
643 × Sirius	-4.864	0.616	-0.493	18.515
Aida × FR-H-1002	-4.215	1.791	-0.673	18.534
Aida × Helius	-0.16	0.413	-0.902	18.609
681 × FR-H-1002	-8.022	-2.629	1.073	18.739
643 × Helius	-4.96	0.142	-0.655	20.618
643 × FR-H-1002	-9.015	1.52	-0.426	21.925

CONCLUSIONS

Crosses with relatively short Euclidean distances to the “ideal” population in which desirable segregants are expected to occur were identified.

The crosses 572 × Chirpan-539, Melani × Chirpan-539 and 641 × Chirpan-539 had the highest positive GCA for the three studied traits and appeared to be the most valuable for breeding programs.

The approach of identifying parents with the highest possible GCA for all studied traits and ranking the parental means using the squared Euclidean distance emerged as an effective method for selecting the most reliable F₁ crosses.

Some crosses showed high positive SCA effects and heterosis. Heterosis manifestations were better expressed in the second group of crosses where heterobeltiosis for productivity per plant ranged from 103.7% to 148.5%, for lint percentage it was from 103.0% to 106.0% and for fiber length - from 102.2 % to 106.8%.

Line 449 of the females from the first group of crosses was identified as good general combiner for productivity, lines 639 and 681 of the females from the the second group of crosses emerged as good general combiners for lint percentage and fiber length, respectively. These parents have distinguished with high means for the respective traits, high GCAs and low SCA variances, which make them very valuable for hybridization and breeding programs.

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