COMPARISON OF MEAN YIELD COMPONENTS AND FIBER QUALITY PARAMETERS OF ADVANCED BULK GENERATIONS IN F₂, F₃ AND F₄ INTERSPECIFIC AND INTRASPECIFIC COTTON POPULATIONS

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ABSTRACT

The performance of interspecific and intraspecific cotton hybrid populations were compared to investigate the correlation among the F₂, F₃ and F₄ bulk generations in terms of yield, lint percentage, and fiber quality from 2009 to 2011. In addition, the effect of combining abilities on hybrid performance were investigated at further generations. For this purpose, nine interspecific and six intraspecific hybrids with eight parents were evaluated under the west part of Turkey (Aegean region) environmental conditions. With the generation progresses, the highest drops in fiber length and fiber strength were detected in interspecific due to the inbreeding depression and genetic breakdown in advanced populations. Based on 15 tested hybrids, the observed mean yield and fiber quality in the F₂ do not adequately predict the performance of hybrids in the F₄ generation. Thus, selection of individual plants should be delayed until the F₄ generation especially for interspecific hybrids, but individual plants would be selected at early generation in intraspecific hybrid populations. In the study it was found that a higher general combining ability (GCA) does not necessarily confer a higher specific combining ability (SCA) and that the GCA and SCA were independent of one another, and that in F₄ high yielded hybrid population was obtained from cross which at least one parent of hybrid has maximum positive GCA effects. These results indicated that instead of using only one criteria, the F₂ performance for intraspecific hybrids and the F₃ performance for interspecific hybrids, low heterosis and inbreeding depression, combining ability of parents could be used together to determine the most promising hybrid populations to be used as a source for further selection.

Key words: Bulk generations, cotton, fiber quality, line x tester method

INTRODUCTION

To meet the demand of new spinning and weaving technologies in the textile industry, the major aim of cotton breeders is to develop high yield cultivars of upland cotton with improved fiber quality, especially fiber strength, fiber length, fiber length and uniformity without sacrificing yield potential. However, previous studies report that the negative association resulting from the linkage connections and pleiotropic effects between lint yield and fiber quality has hampered the simultaneous improvement of these two important characteristics in cotton (Worley et al., 1976; Green and Culp, 1990; Basal and Smith, 1997; Smith and Coyle, 1997).

The success of breeding programs depends on magnitude of genetic variation in the segregating population. The accepted general opinion is the narrowed

genetic base in commercial cotton cultivars of *G. hirsutum*. The narrowed genetic base in Upland cotton cultivars is believed to be the cause for the limited success in breakup of the negative associations between lint yield and fiber quality (Zeng, 2009). May et al. (1995) point out that a narrow gene base may result in a decline in long-term genetic gains in lint yield and fiber quality. In order to increase the genetic base and to improve fiber properties of upland cotton, breeders have been trying to bring different approaches including interspecific crossing and backcrossing between Upland and Pima cotton (Zhang et al., 2016), using Acala cotton as a parent (Zhang et al., 2005), the development of a backcross inbred line (BIL) population and its use in quantitative trait locus (QTL) mapping (Yu et al., 2013), and the chromosome substitution lines (Saha et al., 2011). Introgression of useful alleles for fiber quality from *G.*

barbadense to *G. hirsutum* has been used by plant breeders to enhance fiber length and strength in *G. hirsutum* cultivars by using conventional breeding (Ashokkumar et al., 2014). Yet, previous studies have investigated that negative correlation between yield components and fiber quality parameters, genetic breakdown in advanced populations, infertility, cytological abnormalities, distorted segregation, instability, selective elimination of desirable genes during selfing and high level of epistasis are the most important difficulties introgressing desirable alleles from *G. barbadense* into *G. hirsutum*, (Beasley and Brown, 1942; Kohel et al., 1977; Percival et al., 1999; Galanopoulou-Sendouca and Roupakias, 1999; Saha et al., 2004; Paterson et al., 2004; Basbag and Gencer, 2007; Saha et al., 2010; Zhang et al., 2014). Therefore many breeders avoid using interspecific crosses, because they typically result in reduced yield and poor agronomic qualities. Despite all the difficulties, some previous studies reached successful introgression of traits from *G. barbadense* into *G. hirsutum* (Culp, 1979; Culp and Harrell, 1974; Berger et al., 2011).

Most of the previous studies have been focused on the performance of the F_1, or F_2 populations and estimation of general and specific combining ability, and heterosis and inbreeding depression of hybrids in F_1 and F_2 generations. The correlation among the performance of hybrids in F_2, F_3, and F_4 bulk generations has not been studied to establish a consistent relation among three generations. Therefore, the objectives of this study were to investigate the correlation among the mean yield, lint percentage, and fiber quality traits of bulk generations in F_2, F_3, and F_4, and to determine the effect of combining abilities on hybrid performance at further generations.

MATERIALS AND METHODS

The genetic population was developed by crossing five cotton varieties (female/lines), including 'Askabat 100', 'Aydin 110', 'Sealand 542', 'GW Teks', and 'TAM94L-25', with three cotton varieties (male/tester), including 'Carmen', 'Sahin-2000', and 'SG-125', in a line× tester mating design. Askabat 100 is a *Gossypium barbadense* L. variety with extra long stable and finest fiber characteristics. Sealand 542 and Aydin-110 were developed through interspecific hybridization (*Gossypium hirsutum* L. × *Gossypium barbadense* L.) and have long stable and finest fiber characteristics. GW Teks (*G. hirsutum* L.) has fiber superior strength. TAM 94L-25 (*G.hirsutum* L.) is an early-fruiting upland cotton line that has superior fiber length and strength even under dryland conditions (Smith, 2003). Carmen, Sahin-2000, GW Teks, and SG-125 (*G. hirsutum* L.) have acceptable fiber properties with high yield potential and are well-adapted current commercial cotton varieties.

Five female (lines) and three male (testers) cotton varieties were hand crossed using the line × tester method in 2006. The parents and their intraspecific and interspecific F_1 cotton populations were grown in 2007 in the experimental fields of Adnan Menderes University (ADU) Agriculture Faculty. Single lock descendant method was used to establish F_2, F_3, and F_4 generations, which were subsequently planted at ADU in 2009, 2010, and 2011, respectively. In 2009 (F_2), and 2010 (F_3), the 15 F_4 progenies together with the eight parents were planted in a single 6 m long row in a randomized complete block design (RCBD) with four replications. In 2011, F_4 generation the same test using the same experimental design with three replications was grown in the same location. During the experiment, seeds were sown directly to the field in May, and crop management followed the local recommendations. The distances between and within the rows were 0.70 m and 0.20 m, respectively. At crop maturity, 25 well developed open bolls were hand harvested randomly from each row of parents and F_2's, F_3's, and F_4's. The bulked bolls from each genotype were ginned on a laboratory roller gin. Lint percentage (LP) was obtained from each boll sample. A high volume instrument (HVI) was used to measure upper half mean fiber length (UHML), fiber strength (FS), and micronaire (Mic.). Individual plots were then hand harvested for determination of the seed cotton weight which was converted to seed cotton yield (SCY).

All the recorded data were subjected to analysis of variance (ANOVA) techniques using MSTATC computer software separately for all the traits to evaluate statistical differences among F_2, F_3, F_4 and their parental lines. The genotypes means for each parameter were further separated and compared by using the least significant difference (LSD) test at 5% level of F_2, F_3, and F_4 hybrids, respectively. The general combining ability (GCA) of parents and specific combining ability (SCA) of hybrids were estimated using line × tester analyses method described by Kempthorne (1957).

RESULTS AND DISCUSSION

Analyses of variance for the F_2 and F_3 generations are shown in Table 1 for seed cotton yield, lint percentage, and fiber quality parameters. Significant variations were detected among parents and hybrids for all investigated traits at the both generations. These data indicate that the parents or crosses do not follow the same pattern for investigated traits. Therefore, further analyses were performed to estimate combining abilities of parents and crosses for investigated traits in this study. In F_2 generation the GCA variances were higher than SCA for UHML, STR and micronaire, and in F_3 generation, the GCA variances were also greater than SCA for all the characters, indicating predominance of additive gene action in the inheritance of investigated traits.

Table 1. Analysis of variance for yield, lint percentage, and fiber quality parameters of eight parents and 15 hybrids in F_2 and F_3 Generations

Source of variation	DF[1]	UHML[1]	FS	Mic	LP	SCY
				F_2		
Replication	3	3,29*	0,22	0,23*	1,47	2744,6
Genotypes	22	8,48**	25,16**	0,53**	28,74**	32976,1**
Parents	7	10,03**	30,99**	0,76**	57,33**	14620,2**
Parents vs. Hybrids	1	30,06	7,39*	1,40**	35,53**	21512,6**
Hybrids	14	6,16**	23,51**	0,34**	13,95**	42972,8**
Lines	4	18,36**	41,28**	0,63**	40,58**	92928,0**
Testers	2	0,36	58,63**	0,08	2,23	14365,8**
Lines × Testers	8	1,52	5,84**	0,27**	3,57**	25146,9**
Error	66	1,11	1,21	0,07	1,10	1685,5**
σ^2 GCA		0.201	1,74	0.05	0,47	1.096
σ^2 SCA		0.103	1,16	0.01	0,62	5.865
σ^2 GCA/ σ^2 SCA		1.95	1.47	0.05	0.76	0.19
				F_3		
Replication	3	0,16	2,47	0,06	1,20	1815,1*
Genotypes	22	6,16**	19,41**	0,23**	20,00**	14898,5**
Parents	7	8,99**	29,18**	0,41**	42,35**	24641,8**
Parents vs. Hybrids	1	3,60*	29,32**	0,48*	6,37	14282,6**
Hybrids	14	4,93**	13,81**	0,12	9,79**	10070,9**
Lines	4	15,09**	19,28**	0,19	27,54**	30009,2**
Testers	2	0,95	45,07**	0,12	3,79	8359,7**
Lines × Testers	8	0,84	3,270	0,08	2,42	529,56
Error	66	0,64	1,40	0,09	3,74	393,44
σ^2 GCA[2]		0,18	1,21	0,001	0,37	5.24
σ^2 SCA		0,05	0,47	-0,002	-0,33	3.4
σ^2 GCA/ σ^2 SCA		3.6	2.57	-0.5	-1.12	1.54

[1] DF: degrees of freedom; UHM: Upper half mean fiber length; FS: Fiber bundle strength; Mic.: Micronaire; LP: Lint percent; SCY: Seed cotton yield.

*, ** Significant at 0.05 and 0.01% levels, respectively. 2 σ^2 GCA: general combining ability variance; σ^2 SCA: specific combining ability variance

General and specific combining ability

Askabat 100 (*G. barbadense* L.) had the highest and positive GCA effects for fiber length and fiber strength, and desirable the lowest and negative GCA effects for micronaire, however same genotype had the lowest and negative GCA effects for lint percentage and yield in the two generations. It was found interesting that Aydin 110 and, Sealand 542 (*G. barbadense* L. x *G. hirsutum* L.) showed the negative GCA effects for fiber quality traits, but had the positive GCA effects for seed cotton yield in both generations. Among *G. hirsitum* L. varieties, GW Teks and Sahin 2000 had negative GCA effects for fiber length and fiber strength respectively, while Carmen had higher and positive GCA effects for fiber strength. TAM94L 25 and SG 125 had the highest and positive GCA effect for yield in F_2 and F_3 generations. None of the genotypes had consistent and higher GCA for both yield and fiber quality traits (Table 2). The results indicate that GCA of parents is largely determined by genotype performance.

For fiber length, Askabat 100 x Sahin 2000 as an interspecific hybrid had positive SCA effects in F_2 and F_3.

In terms of intraspecific hybrid, TAM94L 25 x Carmen and GW Teks x Carmen were found as best specific combiners by having maximum SCA effects in F_2 and F_3, respectively. Askabat 100 x Sahin 2000 and Sealand 542 x Carmen in F_2 generation, and Aydin 110 x SG 125 hybrid in F_3 generation revealed positive and significant SCA effects for fiber strength. Askabat 100 x SG 125 and GW Teks x Carmen had desirable negative SCA effects for micronaire in F_2 generation. For fiber percentage, the highest SCA effect owned by Sealand 542 x Sahin 2000 in F_2, and by GW Teks x Sahin 2000 in F_3. Majority of interspecific hybrids in both generations exhibited negative SCA effects for yield, while Askabat 100 x Carmen, Aydin 110 x Sahin 2000, and Sealand 542 x SG 125 hybrids showed positive and significant SCA effects for yield in F_2 generation (Table 3). In F_2 generation, GW Teks x SG 125 and TAM94L 25 x Carmen revealed positive and significant SCA effects for seed cotton yield. None of the inter and intraspecific hybrids had positive and significant SCA effects for seed cotton yield in F_3 generation (Table 3).

Table 2. General combining ability effects of lines and testers for yield, lint percentage, and fiber quality parameters in F_2 and F_3 generations.

	F_2 generation				
	UHML[1]	FS	Mic	LP	SCY
Lines					
Askabat 100	2,16**	2,98**	-0,411**	-1,47**	-150,5**
Aydin 110	-0,44	0,05	0,152	0,67*	30,3*
Sealand 542	-0,34	-2,05**	0,063	-1,35**	79,6**
GW Teks	-0,99**	-0,21	0,087	2,92**	9,3
TAM94L 25	-0,39	-0,77*	0,112	-0,77**	31,3*
S.E. Lines	0,304	0,318	0,075	0,302	9,18
Tester					
Carmen	0,16	1,86**	-0,013	0,13	-23,5
Sahin 2000	-0,08	-1,52**	-0,061	-0,38	-5,6
SG 125	-0,07	-0,34	0,072	0,25	29,2**
S.E. Testers	0,235	0,246	0,058	0,234	11,85
	F_3 generation				
	UHML[1]	FS	Mic	LP	SCY
Lines					
Askabat 100	1,75**	1,74**	-0,132	-0,87	-85,1**
Aydin 110	-0,72**	-0,58	0,134	0,40	14,5*
Sealand 542	-0,44	-1,69**	0,043	-1,95**	18,3**
GW Teks	-1,03**	0,06	0,091	2,09**	5,4
TAM94L 25	0,44	0,47	-0,130	0,33	46,9**
S.E. Lines	0,23	0,34	0,09	0,56	5,73
Tester					
Carmen	0,24	1,57**	0,022	-0,38	-2,9
Sahin 2000	-0,16	-1,42**	-0,091	-0,09	-18,9**
SG 125	-0,08	-0,16	0,073	0,47	21,7**
S.E. Testers	0,18	0,26	0,07	0,43	4,43

1 UHM: Upper half mean fiber length; FS: Fiber bundle strength; Mic.: Micronaire; LP: Lint percent; SCY: Seed cotton yield.

Parent and Hybrid Performance

The results for parents and hybrids performance tested in three years are shown in Table 4 and 5. The eight parents used in this study varied significantly for each of the evaluated yield components and fiber quality parameters. Based on three years mean, as expected the longest fibers were produced by Askabat 100 (32,9 mm) (*G. barbadense* L.), followed by Aydin-110 (32,2 mm) and Sealand 542 (31,0 mm) which were developed through interspecific hybridization. Among the upland cotton parents, fiber length varied from 29.0 mm (Carmen) to 30.1 mm (TAM94L 25). Askabat 100 had the strongest fiber (35.7 cN tex^{-1}) followed by Aydin 110 (35.5 cN tex^{-1}), TAM94L 25 (34.0 cN tex^{-1}), GW Teks (33.9 cN tex^{-1}), and Carmen (33.7 cN tex^{-1}), and Sahin-2000 had the weakest fiber strength (28.7 cN tex^{-1}). The lowest micronaire was detected in Askabat 100 (3.9 Mic.), and the investigated trait was ranged from 4.9 Mic. (Carmen) to 4.3 Mic. (Aydin 110) among the rest of the cotton genotypes (Table 4). In terms of mean lint percentage, SG 125 and Sealand 542 had maximum (42.0 %) and minimum (34.0 %) lint percentages, respectively (Table 5). The highest mean seed cotton yield of 3857 kg h^{-1} was obtained in TAM94L 25 and was followed by Sahin 2000 (3844 kg h^{-1}), SG 125 (3799 kg h^{-1}) and Carmen (3726 kg h^{-1}). The lowest mean seed cotton yield was recorded in Askabat 100 (2386 kg h^{-1}) (Table 5).

In F_2, F_3, and F_4 generations, interspecific hybrids had distinguished fiber quality parameters including fiber length, fiber strength, and fiber fineness (Table 4). The highest fiber length was recorded for Askabat 100 x Sahin 2000 hybrid at F_2, F_3, and F_4 generations. In F_2 and F_3, Askabat 100 x Sahin 2000 was followed by Askabat 100 x Carmen and Askabat 100 x SG 125 hybrids. Among hybrids in F4, the longest fiber length was produced by Askabat 100 x Sahin 2000 (32.1 mm) and TAM94L 25 x Sahin 2000 (31.8 mm) hybrids and difference in fiber length between interspecific and intraspecific hybrids was not significant.

Table 3. Specific combining ability effects of lines x testers crosses for yield, lint percentage, and fiber quality parameters in F_2 and F_3 generations.

	F_2 generation				
Interspecific hybrids	**UHML[1]**	**FS**	**Mic**	**LP**	**SCY**
Askabat 100 x Carmen	-0,90	-0,67	0,10	0,84	59,1**
Askabat 100 x Sahin 2000	0,99	1,11*	0,24	0,00	-13,2
Askabat 100 x SG 125	-0,09	-0,44	-0,34*	-0,83	-45,9*
Aydin 110 x Carmen	-0,15	-1,23*	0,08	-0,02	19,6
Aydin 110 x Sahin 2000	-0,15	0,15	-0,03	-0,41	90,2**
Aydin 110 x SG 125	0,30	1,08	-0,06	0,43	-109,6**
Sealand 542 x Carmen	0,29	1,53**	0,15	-0,68	-72,2**
Sealand 542 x Sahin 2000	-0,05	-1,50**	-0,07	1,20*	-11,1
Sealand 542 x SG 125	-0,24	-0,03	-0,07	-0,53	83,3**
Intraspecific hybrids					
GW Teks x Carmen	0,04	0,87	-0,38*	-0,97	-50,4*
GW Teks x Sahin 2000	-0,30	0,24	0,05	0,16	-2,6
GW Teks x SG 125	0,26	-1,11*	0,33*	0,81	53,0*
TAM94L 25x Carmen	0,72	-0,50	0,05	0,82	44,0*
TAM94L 25x Sahin 2000	-0,48	0,00	-0,19	-0,95	-63,4**
TAM94L 25x SG 125	-0,24	0,50	0,14	0,12	19,4
S.E.	0,53	0,55	0,13	0,52	20,53
	F_3 generation				
Interspecific hybrids	**UHML[1]**	**FS**	**Mic**	**LP**	**SCY**
Askabat 100 x Carmen	-0,05	-0,25	0,11	0,56	-7,42
Askabat 100 x Sahin 2000	0,53	0,17	-0,17	-0,30	-3,63
Askabat 100 x SG 125	-0,47	0,08	0,06	-0,27	11,04
Aydin 110 x Carmen	0,02	-0,51	0,08	0,69	-1,00
Aydin 110 x Sahin 2000	-0,55	-0,77	0,11	0,00	-3,55
Aydin 110 x SG 125	0,52	1,27*	-0,18	-0,69	4,55
Sealand 542 x Carmen	-0,30	-0,80	0,06	-0,26	9,04
Sealand 542 x Sahin 2000	0,28	0,79	-0,10	-0,35	5,18
Sealand 542 x SG 125	0,01	0,01	0,04	0,61	-14,22
Intraspecific hybrids					
GW Teks x Carmen	0,35	1,04	-0,12	-0,20	2,78
GW Teks x Sahin 2000	-0,46	-0,52	0,07	0,84	-11,64
GW Teks x SG 125	0,11	-0,51	0,05	-0,65	8,86
TAM94L 25 x Carmen	-0,03	0,52	-0,13	-0,80	-3,40
TAM94L 25 x Sahin 2000	0,21	0,33	0,09	-0,21	13,63
TAM94L 25 x SG 125	-0,18	-0,85	0,04	1,00	-10,23
S.E.	0,40	0,59	0,15	0,97	9,92

1 UHM: Upper half mean fiber length; FS: Fiber bundle strength; Mic.: Micronaire; LP: Lint percent; SCY: Seed cotton yield.

Comparison of performance of F_4 with F_2 and F_3 generations showed that the hybrids in which Askabat 100 was used as a female parent revealed considerable reduction in fiber length. Declining trend in fiber length was higher at interspecific hybrids than that of intraspecific hybrids. In another research, genetic breakdown has been reported to be prevalent in later generations of interspecific hybrids (Percival et al. 1999) (Table 4). While there were no significant differences in fiber length between Askabat 100 x Carmen and Askabat 100 x Sahin 2000 in F_1 (Basal et al. 2009), fiber length of former hybrid was lower than that of later hybrid due to the high inbreeding depression (-9.43 %) in F_2 generation. Therefore, Askabat 100 x Carmen exhibited a trend of fiber length decrease from generation to generation, while Askabat 100 x Sahin 2000 reached stability in terms of fiber length in F_3 generation. These results indicate that

relatively small inbreeding depression in F_2 would be used a good indicator to determine the most appropriate hybrid population to be used as a source population for further selection which is consistent with previous studies (Meredith, 1990; Yuan et al., 2002, Khan et al., 2007, Galanopoulou and Roupakias, 1999; Khan et al., 2010).

Among the crosses having longest fiber length in F_4, Askabat 100 x Sahin 2000 (32.1 mm) showed positive, Askabat 100 x SG 125 (31.1 mm) exhibited negative SCA effects in F_2 and F_3 generations. In F_4 intraspecific hybrids, maximum fiber length was obtained in the cross combination TAM94L-25 x Sahin 2000 (31.8 mm). TAM94L-25 x Sahin 2000 had negative SCA effects in F_2 and positive SCA effects for fiber length in F_3 generation (Table 3). Among parents involving these hybrids, only Askabat 100 had high and positive GCA effect for fiber length (Table 2). Therefore, high x low and low x low

general combiners revealed promising SCA for fiber length. The present study confirms that good combination for improved fiber quality may not always obtained from parents with positive GCA effects, sometimes parents with low GCA could produce high fiber length. The results indicated that a higher GCA does not necessarily confer a higher SCA and that the GCA and SCA were independent of one another a finding similar to the results of Khan et al. (2007), Basal et al. (2009), and Baloch et al. (2016). On the other hand, Coyle and Smith (1997), Hassan et al. (2000) and Khan et al. (2009) reported that parents with high GCA were found to produce high yielding hybrids.

Table 4. Mean fiber length, fiber strength, and micronaire of crosses and parents at F_2, F_3, and F_4 generations.

Interspecific hybrids	Upper half mean fiber length (mm)			Fiber strength (cN tex^{-1})			Micronaire (unit)		
	F_2	F_3	F_4	F_2	F_3	F_4	F_2	F_3	F_4
Askabat 100 x Carmen	32,5bc	32,6ab	29.9e-i	37,3a	35,5bc	34.1a-d	4,0gh	4,3a-f	4.8e-l
Askabat 100 x Sahin 2000	34,2a	32,8 ab	32.1a-c	35,7b	32,9d-f	34.2a-d	4,1fg	3,9fg	4.2mn
Askabat 100 x SG 125	33,0ab	31,9bc	31.1a-g	35,3bc	34,1b-d	31.2f-l	3,7i	4,3a-f	4.9b-l
Aydin 110 x Carmen	30,6e-i	30,2d-i	30.1d-i	33,8c-f	32,9d-f	32.4c-k	4,5b-e	4,5ab	4.9a-k
Aydin 110 x Sahin 2000	30,4d-h	29,4ii	30.0d-i	31,8g-i	29,7i	30.9h-l	4,4d-f	4,4a-d	5.1a-f
Aydin 110 x SG 125	30,8d-f	30,4d-h	30.4c-h	33,9c-f	33,0d-f	30.5i-l	4,5c-e	4,5a-c	5.0a-k
Sealand 542 x Carmen	31,1c-f	30,2e-i	29.2hi	34,4b-e	31,f-i	30.0kl	4,5b-e	4,4a-d	5.3a-d
Sealand 542 x Sahin 2000	30,6d-g	30,3d-h	29.8f-i	28,0j	30,1h-i	30.3j-l	4,3e-g	4,1b-g	5.1a-g
Sealand 542 x SG 125	30,4d-h	30,2e-i	30.9a-h	30,7ii	30,6g-i	32.1d-l	4,4d-g	4,4a-d	4.9a-k
Intraspecific hybrids									
GW Teks x Carmen	30,2d-h	30,2d-i	30.3c-h	35,6b	35,1bc	33.7a-e	4,0gh	4,3a-f	4.8d-l
GW Teks x Sahin 2000	29,7f-i	29,0i	30.5c-h	31,6hi	30,5g-i	31.0g-l	4,4d-f	4,3a-e	4.9a-k
GW Teks x SG 125	30,2d-i	29,7g-i	29.8d-i	31,4hi	31,8f-h	32.6c-j	4,8a-c	4,5a-c	5.2a-e
TAM94L 25 x Carmen	31,5c-e	31,3cd	30.0d-i	33,7d-f	35,0bc	32.6c-j	4,5b-e	4,0d-g	4.7e-l
TAM94L 25 x Sahin 2000	30,1d-i	31,1c-e	31.8a-e	30,8i	31,8f-h	31.9d-l	4,2e-g	4,1b-g	4.6g-m
TAM94L 25 x SG 125	30,3d-h	30,8c-f	29.9f-i	32,5f-g	31,9f-h	31.9d-l	4,6b-d	4,2a-f	5.3a-c
Lines									
Askabat 100	32,6bc	33,7a	32.5ab	35,1b-d	37,5a	34.6a-c	3,7hi	3,9e-g	3.9n
Aydin 110	31,6b-d	32,7ab	32.3ab	35,8ab	35,3bc	35.3ab	4,5d-f	3,8g	4.6k-m
Sealand 542	29,8f-i	31,7bc	31.4a-f	30,7i	32,1e-g	31.1f-l	4,5c-e	3,7g	4.8c-l
GW Teks	28,9h-i	30,0f-i	30.2d-h	32,4f-h	33,8c-e	35.6a	4,4d-f	4,1b-g	4.6j-m
TAM94L 25	30,1e-i	30,2e-i	30.1d-h	34,9b-e	34,0b-d	33.2a-h	5,0a	4,5a-c	4.7e-m
Testers									
Carmen	27,9i	30,8c-g	28.2i	33,3e-g	35,8ab	31.9d-l	5,0a	4,3a-e	5.5a
Sahin 2000	28,7i	29,4h-i	29.8f-i	28,6j	29,0i	29.7l	4,9ab	4,1c-g	4.9b-l
SG 125	29,1i	30,1e-i	29.3g-i	29,1ij	31,3f-i	31.1f-l	4,8ab	4,6a	5.3ab
LSD $_{0.05}$	1.53	1.12	1.86	1.59	1.88	2.20	0.35	0.43	0.50

Based on three generation means, the highest fiber strength value was obtained from Askabat 100 x Carmen (35.6 cN tex-1) and GW Teks x Carmen (34.3 cN tex-1) crosses among hybrids, respectively (Table 4). When the mean performance of hybrids in F4 was compared with previous generations, four out of 15 hybrids exhibited decreased fiber strength and the highest reduction in fiber strength was observed in interspecific hybrids especially for Askabat 100 x SG 125. The decrease in fiber strength with the increasing in homozygosity at further generations would be due to the dominant x dominant epistatic gene effect or parents with negative homozygote dominant gene effect for investigated trait. Wu et al. (2010) observed that inbreeding depression in several crosses would be expected in later generations if parents had negative homozygous dominance effects for a trait.

In case of fiber strength, Askabat 100 x Carmen and Askabat 100 x Sahin 2000 interspecific hybrids and GW Teks x Carmen intraspecific hybrid produced the strongest fibers throughout generations. Line Askabat 100 and tester Carmen showed maximum positive GCA effects and excelled other parental cultivars for fiber strength. Tester Sahin 2000 had the highest negative GCA effects (Table 2). The result show that parents with high and positive GCA were able to produce increased fiber strength at further generation as reported by previous Coyle and Smith (1997), Hassan et al. (2000) and Khan et al. (2009). Askabat 100 x Sahin 2000 and Sealand542 x Carmen in F2, and in F3 Aydin 110 x SG 125 exhibited positive SCA effects for investigated fiber trait (Table 3). Based on the performance of these hybrids, high x low, low x high and low x low GCA parents were involved in presentation of highest desirable SCA for fiber strength.

Fiber fineness (micronaire) values between 3.7 and 4.2 are optimum for yarn spinning; therefore, negative GCA is desirable for fiber fineness, since a coarser fiber (higher

than 4.2 micronaire) negatively affects the spinning process, as well as overall quality. For investigated trait, the lines GCA ranged from -0.411 to 0.152 in F_2, and from -0.132 to 0.134 in F_3, while in testers the GCA ranged from -0.061 to 0.072 in F_2, and from -0.091to 0.073 in F_3 (Table 2). Generally, fiber fineness of all hybrids progressively increased from F_2 to F_4 generation due to the additive gene effect (Table 4). In F4 generation, among 15 hybrids, the most fineness fiber was observed in Askabat 100 x Sahin 2000 hybrid population, and both parents have negative GCA for fineness. These result shows that parents with good GCA would produce appropriate hybrid population for selection.

Generally *G. hirsutum* L. cultivars and intraspecific hybrids had higher lint percentage than developed through interspecific hybridization (*G. hirsutum* L. × *G. barbadense* L.) cultivars and *G. barbadense* L. cultivars, and interspecific hybrids (Table 5). Majority of hybrids exhibited a trend of increased lint percentage from F_2 to F_4 that may be attributable to the involvement of additive genes via increasing homozygosity. In F_4, among interspecific and intraspecific hybrids maximum lint percentage was recorded in Aydin 110 x Sahin 2000 and GW Teks x Carmen, respectively. At least one parent of those hybrids showed maximum positive GCA effects and excelled other parental cultivars (Table 2). Aydin 110 x Sahin 2000 exhibited negative SCA effects in F_2, and GW Teks x Carmen revealed negative SCA effects in F_2 and F_3 generations (Table 3). The result showed that the GCA and SCA were independent of one another a finding similar to the results of Khan et al. (2007) and Basal et al. (2009). On the other hand, the present study confirms that good combination for improved lint percentage would be obtained from parents with positive GCA effects. Also Coyle and Smith (1997) and Lukonge et al. (2008) reported that parents with high GCA were found to produce high yielding hybrids.

The three years mean seed cotton yield performances of parents are presented in Table 5. Among the eight parents, as expected the lowest yield was obtained from Askabat 100 (2386 kg ha^{-1}), and TAM94L 25 reached the highest yield (3857 kg ha^{-1}). In F_4 generation, the seed cotton yield varied from 1960 kg ha^{-1} (Askabat 100 x SG 125) to 3467 kg ha^{-1} (Aydin 110 x SG 125) among the interspecific hybrids, 3114 kg ha^{-1} (GW Teks x Carmen) to 3634 kg ha^{-1} (GW Teks x Sahin 2000) among the intraspecific hybrids. The hybrids did not follow same pattern in terms of responses to progressive generations (in subsequent generations). The low yielded

hybrids in F_2 exhibited a fairly high yield in F_4 or vice versa due to the over dominance and inbreeding depression, and also some of the high yielded hybrids in F_2 generation tended to yield more in the subsequent generations. Our results indicated that the performance of the F_4 hybrids would not be adequately estimated by the performance of the F_2 hybrid (Table 5). Similarly, Meredith and Bridge (1973) found no significant correlation between the F_2 and F_3 mean yields in ten *G. hirsutum* L. hybrids. Also, Galanopoulou-Sendouca and Roupakias, (1999) reported that the yield of the F_1 did not predict the yield of the bulks in the following generations.

In F_4 generation among the inter- and intraspecific hybrids, the highest seed cotton yield was obtained from Aydin 110xSG 125 (3467 kg ha^{-1}) and GW Teks x Sahin 2000 (3634 kg ha^{-1}) crosses, respectively (Table 5) even after segregation and inbreeding depression. Aydin 110 x SG 125 had negative SCA effects in F_2 and positive SCA effects for investigated trait in F_3 generation (Table 3). Both parents of Aydin 110xSG 125 had high and positive GCA effect for yield (Table 2). GW Teks x Sahin 2000 had negative SCA effects in both generations (Table 3). GW Teks exhibited positive; Sahin 2000 had negative GCA for seed cotton yield (Table 2). Therefore, high x high and low x low general combiners revealed promising SCA for seed cotton yield. Singh et al. (2010) reported that most of the hybrids were among the crosses of good × poor, average × poor and poor × poor general combiner parents for seed cotton yield which indicated the involvement of additive, complementary and non- additive gene actions, respectively for such characters. If the hybrid having two poor general combiner parents express higher SCA effects that means dominant genes were involved in the manifestation of SCA effects and when two good general combiners express higher SCA effects that may be attributable to the involvement of additive genes (Ahuja and Dhayal 2007; Singh et al., 2010). The present study confirms that good combination for high seed cotton yield may not always obtained from parents with positive GCA effects, sometimes parents with low and negative GCA could produce high seed cotton yield. The results indicated that a higher GCA does not necessarily confer a higher SCA and that the GCA and SCA were independent of one another a finding similar to the results of Khan et al. (2007), Basal et al. (2009) and Baloch et al. (2016). Present study showed that that parents with high GCA were found to produce high yielding hybrids which is consistent with previous studies (Coyle and Smith 1997; Hassan et al. 2000; Lukonge et al. 2007, and Khan et al. 2009)

Table 5. Mean lint percentage and seed cotton yield of crosses and parents at F_2, F_3, and F_4 generations.

Interspecific hybrids	Lint percentage (%)			Seed cotton yield (kg ha^{-1})		
	F_2 2009	F_3 2010	F_4 2011	F_2 2009	F_3 2010	F_4 2011
Askabat 100 x Carmen	36,2h-k	37,5c-g	38.9b-g	2312k	2037j	1778j
Askabat 100 x Sahin 2000	34,9i-l	36,9e-g	36.8d-g	1773l	1912j	3039c-h
Askabat 100 x SG 125	34,7j-l	37,5c-g	39.1b-g	1791l	2467hi	1960ij
Aydin 110 x Carmen	37,5e-i	38,9a-e	39.6b-g	3727fg	3096df	3052c-g
Aydin 110 x Sahin 2000	36,6g-j	38,5b-f	40.9a-e	4614bc	2910fg	3252b-e
Aydin 110 x SG 125	38,1e-h	38,4b-g	40.6a-e	2966ij	3397bc	3467a-e
Sealand 542 x Carmen	34,8j-l	35,6gh	38.6b-g	3305hi	3234ce	2660e-j
Sealand 542 x Sahin 2000	36,2h-k	35,8f-h	37.4d-g	4095df	3035ef	2853d-i
Sealand 542 x SG 125	35,1i-l	37,3c-g	36.9d-g	5380a	3247ce	3145b-f
Intraspecific hybrids						
GW Teks x Carmen	38,8c-f	39,7a-d	43.4ab	2811ij	3043ef	3114c-g
GW Teks x Sahin 2000	39,4b-e	41,0ab	40.6a-e	3477gh	2739gh	3634a-d
GW Teks x SG 125	40,7a-c	40,1a-c	40.5a-f	4380b	3350bd	3169b-e
TAM94L 25 x Carmen	36,9f-i	37,3c-g	39.4b-g	3981df	3396bc	3228b-e
TAM94L 25 x Sahin 2000	34,6kl	38,2b-g	35.6e-g	3085i	3406bc	3231b-e
TAM94L 25 x SG 125	36,0i-k	40,0a-c	37.5d-g	4261cd	3574b	3523a-e
Lines						
Askabat 100	37.6e-i	36.2e-h	35.3fg	2601jk	2330i	2227g-j
Aydin 110	33.2lm	33.7hi	35.9e-g	3822fg	2185ij	2836d-i
Sealand 542	31.6n	32.3i	38.2b-g	3859ef	2847fg	3212b-e
GW Teks	42.2a	39.7a-d	43.6a	3176hi	2907fg	2845d-i
TAM94L 25	39.5b-e	39.9a-c	40.3a-f	4304cd	4061a	3206b-e
Testers						
Carmen	40.2a-d	39.0a-e	38.7b-g	4036df	4132a	3011c-h
Sahin 2000	38.5d-g	38.7b-f	41.8a-d	4279cd	3955a	3298b-e
SG 125	41.4ab	41.6a	42.9a-c	4208de	3594b	3595a-d
LSD $_{0.05}$	2.015	2.875	5.28	370.4	280.4	903.4

CONCLUSIONS

With the generation progresses, the highest drop in fiber length and fiber strength was detected in interspecific hybrids in which Askabat 100 was used as a female parent. The abrupt drop for fiber length and fiber strength in further generation was due to the inbreeding depression. Among the interspecific hybrids Askabat 100 x Sahin 2000 had less inbreeding depression in F_2 and also from the F_3 onwards had stabilized fiber length. Therefore, a relatively small inbreeding depression in the F_2 would be used as a selection criterion to determine promising hybrid populations to be used as source for further selection. The observed mean yield and fiber quality in the F_2 does not adequately predict the performance of hybrids in the F_4 generation. Duo to the genetic distance among parents used in interspecific crosses, genetic breakdown in advanced populations, distorted segregation, and high level of epistasis interspecific hybrids had the lowest stability level. Therefore, selection of individual plants should be delayed until the F_4 generation for interspecific hybrids, but individual plants would be selected at early generation in intraspecific hybrid populations. The present study confirms that in F_4 generation high yielded hybrid population had at least one parent having high GCA for investigated traits. These results show that instead of use only one criteria, F_2 performance for intraspecific and F_3 performance for interspecific hybrids, low inbreeding depression, and combining ability of parents could be used together to determine the most promising hybrid populations to be used as source populations for further selection.

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