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Research Article

Study of heterosis for agronomic, yield and fiber quality traits in cotton under the irrigated condition of Middle Awash, Ethiopia

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ABSTRACT

The present investigation was undertaken to study the extent of heterosis in respect of seed cotton and lint yield, fiber quality traits and other agronomic performances. Six cotton genotypes were crossed in all possible combinations including reciprocals. The resulting filial generation (F_1 hybrids) seed of 30 crosses and 6 parents were planted in a simple lattice design with a perfect square of 6x6 replicated twice. Mean square due to genotypic differences were found significant for all the traits under study except for boll number per plant indicating the availability of substantial genetic diversity for different traits in the experimental materials. Among the hybrids intra specific *G. hirsutum* L. hybrid, HS-46 x Stonoville 453 19-8 X Stam 59A x Cucurova 1518 30-2 (B-1) exhibited considerable heterotic values for seed cotton and lint yield, and fiber length possibly suitable for local cottage and textile industries. The obtained results indicated the possibility of improving yield and fiber quality traits simultaneously using interspecific hybrids. Moreover, research on cotton breeding needs to address all possibilities including the exploitation of hybrid vigour to increase yield and fiber qualities of cotton production in Ethiopia.
Keywords: Intra and interspecific hybrid, Hybrid vigour, *Gossypium hirsutum* L., *Gossypium barbadense* L., Lint yield, Micronaire, Fiber length, Fiber strength

INTRODUCTION

Cotton (*Gossypium* spp.) is the earliest domesticated fiber crop independently in both the Old and New Worlds. Among the four domesticated *Gossypium* species, *G. hirsutum* L. is the most important natural textile fiber source globally and provides about 90% of world production having, high yield potential and broader environmental adaptability. *G. barbadense* L. constitutes about 5% of world cotton due to, lower yield potential and longer growing period. Nevertheless, it possesses superior fiber quality (Chen et al., 2007; Yu & Gervers, 2019; Teodoro et al., 2019; Sanamyan et al., 2022). The cotton plant is a crop of tropical and subtropical climates. However, it is grown on every continent except in Antarctica and thrives well in the warmer temperate regions where the frost-free period is less than 180 days (Shakeel *et al*., 2011; Abdellatif *et al*., 2012).

In Ethiopia, the use and cultivation of cotton started in ancient times (Nicholson, 1960; Gervers, 1990; 2008). It is believed that one of the Old-World species of cotton was also domesticated in Ethiopia (Nicholson, 1960). Berger (1969) stated that the most primitive cultivated form of the species of *G. herbaceum*, race *acerifolium* is found occasionally in fields and gardens in Ethiopia. Currently, introduced cotton *Gossypium hirsutum* L. is one of the most important cash crops for the growers besides its role as an export item in the national economy of the country. It is grown extensively in lowlands on large-scale farms under irrigation and rain-fed conditions. It plays an important role in the economic development of the country and offers considerable employment opportunities on farms, in ginneries, textile and garment factories. Cotton lint is used as a raw material by textile mills and cottage industries, and it is also used as an export item. Cotton seed is used for the production of edible vegetable oil. After the extraction of oil, oil-cake residue is used as a feed for livestock (Gurmessa, 2019; Gudeta et al., 2022; Gurmessa et al., 2022a).

The objective of any cotton breeding programme is mostly to develop varieties with high yield and superior fiber qualities, resistance to insect pests and diseases, and tolerance to environmental stress. The yield plateau in cotton productivity can be broken by identifying suitable high yielding hybrids exhibiting high heterosis. Heterosis is the phenomenon in which the F1 derived from two genetically different inbred varieties or stocks of a species or crosses between species exhibit superiority for various characteristics including growth, size, yield, or general vigour (Shull, 1908; Shull, 1952; Birchler et al., 2003). The genetic causes of heterosis are not completely understood, but possible explanations have been explained with the gene action hypothesis of dominance (Davenport, 1908; Bruce, 1910; Jones, 1917; Xiao et al., 1995), over-dominance (East, 1908; Shull, 1908), and epistasis (Williams, 1959; Yu et al., 1997).

The dominance hypothesis assumes that cross-pollinated species consist of a large number of genetically different individuals, many of which carry deleterious recessive genes concealed in heterozygote. At each locus the dominant allele has a favorable effect, while the recessive allele has unfavorable effect and, in heterozygous state, the deleterious effects of the recessive alleles are masked by their dominant alleles. Under this hypothesis, the intercrossing of inbred lines should lead to the formation of hybrids in which deleterious recessive alleles contributed by one parent are again hidden, as in the original open-pollinated population. Since the dominant loci rather than heterozygosity cause heterosis, it is assumed that the homozygous dominant is as superior as the heterozygous individual. In general, this hypothesis explains the causes of heterosis based on the accumulation of favourable dominant alleles in the F_1, some of which are contributed by each parent. Detrimental effects caused by homozygous recessive alleles would be masked. If this is the case, then inbred lines containing all homozygous dominant alleles in their genotypes should be possible through breeding and selection, and heterosis would be permanently fixed as a true breeding condition. While this has not yet been achieved, inbred lines are continually being improved genetically. In addition, the linkage may make the accumulation of all dominants a very difficult task since correct recombination must take place between every dominant and recessive allelic combination. Considering the number of loci, the probability of this happening with the subsequent selection of correct gametes may be extremely low.

According to the over-dominance hypothesis, heterozygotes at some of the loci are superior to both the homozygotes. This hypothesis supposes that the heterozygous combination a1a2 of the alleles at a single locus is superior to either of the homozygous combinations a1a1 or a2a2. The implication is that a1 and a2 perform different functions and that the total of their different products is superior to the single product produced by either allele in the homozygote state. Under this hypothesis, it would, therefore, be impossible to isolate inbred lines as vigorous as F1 hybrids.

The epistasis hypothesis explains heterosis from nonallelic interactions. Classically, epistasis is defined as the interaction between genes in at least two loci that affect the phenotypic expression of the trait. C.J. Goodnight (1999) analyzed the role of epistasis in the manifestation of heterosis and showed that under additive-dominant and dominant-dominant epistasis the manifestation of heterosis in a separate locus change, that is, intraloci heterosis is a function of the genetic background. Consequently, the genetic background and interactions there can influence the effects of individual loci, including the formation of a heterotic response (Khotyleva et al., 2017).

Cotton improvement programmes that concentrate on the development of hybrids through the utilization of heterosis have contributed to the improvement of cotton productivity in India and China (Xing et al., 2007; Bilwal et al., 2018). To develop potential hybrids in cotton, it is necessary to exploit heterosis using genetic divergence and good combing ability of parents, which can lead to higher production and productivity. Hybrid cotton is a good approach for significant improvement in genetic potential for morpho-yield and fiber quality traits and has attracted the attention of cotton breeders for commercial growing of hybrid generations (Baloch et al., 1993a; Baloch et al., 1993b; Meredith & Brown, 1998; Khan et al., 2000; Khan et al., 2009). Moreover, heterosis studies can provide basis for the exploitation of valuable hybrid combinations in future breeding programs. In Ethiopia, the introduced hybrid cotton which came into the picture very lately in 2011 has possessed high fibre quality characteristics with a reasonably good seed cotton and lint yield as reported by Gudeta et al., 2019; Gurmessa et al., 2022b,c; Balcha et al., 2022. However, the introduced hybrid cotton`s apart from registration for use are not yet entered into the production system. The objective of the present study was to study the extent of heterosis and per se performance of intra and inter-specific hybrids in respect of yield, yield components and fiber quality traits using Ethiopian cotton genotypes.

MATERIALS AND METHODS

Description of study area

The study was conducted under irrigated conditions at the Werer Agricultural Research Center of the Ethiopian Institute of Agricultural Research. Werer Agricultural Research Center is located at 9°20’31" N latitude and 40°10’11" E longitude in the Middle Awash rift valley of Afar National Regional State at an elevation of 740m above sea level. The average rainfall of Werer is about 571mm annually with the minimum and maximum average temperatures of 19^0C and 34^0C respectively. The soil type of the area is predominantly vertisol.

Plant materials and experimental design

In the main cropping season of 2019, six cotton genotypes were crossed in all possible combinations including reciprocals (Table 1). The resulting filial generation (F_1 hybrids) seed of 30 crosses and 6 parents was planted in a simple lattice design with a perfect square of 6x6 replicated twice in 2020. Each plot consisted of four rows of 5m in length spaced 90cm apart with plant-to-plant distance of 20cm within rows. The crop management practices were carried out as per the recommendation for the area. Before the emergence of square five consecutive plants, in total 10 from the two central rows marked with wool threads and used as sample plants for the measure of plant height, boll number per plant, boll weight, ginning out-turn, micronaire, fiber length, and fiber strength. The harvested total bolls from each net plot were weighed and converted to seed cotton yield per hectare. Furthermore, the product of seed cotton yield and ginning out-turn was divided by 100 to calculate lint yield per hectare.

Data analysis

Analysis of variance for all the characters was done using SAS 9.3 statistical software. The mid-parent heterosis (MPH%) and better-parent heterosis (BPH%) were estimated as deviation of F_1 value from the mid-parent and the better-parent values as suggested by Matzinger et al. (1962) and Fonsecca and Patterson (1968), respectively for those traits that showed statistically significant differences among the genotypes. The standard errors of the difference for heterosis and the critical difference were calculated as follows,

$\mathrm{SE}\ (\mathrm{d}) = \sqrt{2\mathrm{MSe}/\mathrm{r}}$, for better parent heterosis

$\mathrm{SE}\ (\mathrm{d}) = \sqrt{3\mathrm{MSe}/2\mathrm{r}}$, for mid-parent heterosis

Where, SE (d) =standard error of the difference, MSe = error mean square, r = number of replication, CD = critical difference

Table 1. List of F_1 hybrids and parental lines used for the study.

S. no	Entries	Designated code	Description
1	Stam 59A x Cucurova 1518 30-2 X Stam 59A x Nazzili-84 28-8	A-1	Intra *G. hirsutum* L.
2	Stam 59A x Nazzili-84 28-8 X Stam 59A x Cucurova 1518 30-2	A-2	Intra *G. hirsutum* L.
3	HS-46 x Stonoville 453 19-8 X Stam 59A x Cucurova 1518 30-2	B-1	Intra *G. hirsutum* L.
4	Stam 59A x Cucurova 1518 30-2 X HS-46 x Stonoville 453 19-8	B-2	Intra *G. hirsutum* L.
5	Stam 59A x Cucurova 1518 30-2 X HTO#052 x LS-90 24-11	C-1	Interspecific
6	HTO#052 x LS-90 24-11XStam 59A x Cucurova 1518 30-2	C-2	Interspecific
7	HTO #052 x Pima S3 22-4 X Stam 59A x Cucurova 1518 30-2	D-1	Interspecific
8	Stam 59A x Cucurova 1518 30-2 x HTO #052 X Pima S3 22-4	D-2	Interspecific
9	G-45 x HTO#052 8-4 X Stam 59A x Cucurova 1518 30-2	E-1	Interspecific
10	Stam 59A x Cucurova 1518 30-2 x G-45 x HTO#052 8-4	E-2	Interspecific
11	HS-46 x Stonoville 453 19-8 X HTO#052 x LS-90 24-11	F-1	Interspecific
12	HTO#052 x LS-90 24-11 X HS-46 x Stonoville 453 19-8	F-2	Interspecific
13	G-45 x HTO#052 8-4 X Stam 59A x Nazzili-84 28-8	G-1	Interspecific
14	Stam 59A x Nazzili-84 28-8 X G-45 x HTO#052 8-4	G-2	Interspecific
15	Stam 59A x Nazzili-84 28-8 X HTO #052 x Pima S3 22-4	H-1	Interspecific
16	HTO #052 x Pima S3 22-4 X Stam 59A x Nazzili-84 28-8	H-2	Interspecific
17	Stam 59A x Nazzili-84 28-8 X HTO#052 x LS-90 24-11	I-1	Interspecific
18	HTO#052 x LS-90 24-11 X Stam 59A x Nazzili-84 28-8	I-2	Interspecific
19	Stam 59A x Nazzili-84 28-8 X HS-46 x Stonoville 453 19-8	J-1	Intra *G. hirsutum* L.
20	HS-46 x Stonoville 453 19-8 X Stam 59A x Nazzili-84 28-8	J-2	Intra *G. hirsutum* L.
21	HTO #052 x Pima S3 22-4 X HS-46 x Stonoville 453 19-8	K-1	Interspecific
22	HS-46 x Stonoville 453 19-8 X HTO #052 x Pima S3 22-4	K-2	Interspecific
23	HS-46 x Stonoville 453 19-8 X G-45 x HTO#052 8-4	L-1	Interspecific
24	G-45 x HTO#052 8-4XHS-46 x Stonoville 453 19-8	L-2	Interspecific
25	HTO #052 x Pima S3 22-4 X HTO#052 x LS-90 24-11	M-1	Intra *G. barbadense* L
26	HTO#052 x LS-90 24-11 X HTO #052 x Pima S3 22-4	M-2	Intra *G. barbadense* L.
27	HTO#052 x LS-90 24-11 X G-45 x HTO#052 8-4	N-1	Intra *G. barbadense* L.
28	G-45 x HTO#052 8-4 X HTO#052 x LS-90 24-11	N-2	Intra *G. barbadense* L.
29	G-45 x HTO#052 8-4 X HTO #052 x Pima S3 22-4	O-1	Intra G. barbadense L.
30	HTO #052 x Pima S3 22-4 X G-45 x HTO#052 8-4	O-2	Intra *G. barbadense* L.
Parental lines			
31	G-45 x HTO#052 8-4	P-1	*G. barbadense* L.
32	HTO #052 X Pima S3 22-4	P-2	*G. barbadense* L.
33	HTO#052 X LS-90 24-11	P-3	*G. barbadense* L.
34	HS-46 X Stonoville 453 19-8	P-4	*G. hirsutum* L.
35	Stam 59A X Nazzili-84 28-8	P-5	*G. hirsutum* L.
36	Stam 59A X Cucurova 1518 30-2	P-6	*G. hirsutum* L.

RESULTS AND DISCUSSION

The results of the analysis of variance of parents and their hybrids for various traits are given in Table 2. Mean squares due to genotypic differences were found significant for all the traits under study except for boll number per plant. This indicated the availability of substantial genetic diversity for different traits in the experimental material under study. The crosses were also sufficiently different from each other and selection is possible to identify the most desirable crosses. In line with this finding, different authors reported significant differences among crosses in yield, yield-related and fiber quality traits in different Ethiopian cotton genotypes (Zerihun et al., 2004; Merdasa et al., 2019).

Table 2. Analysis of variance for different characters in cotton

Traits	Source of variation				R^2 (%)	CV (%)	Mean
	Group (df=1)	Block(Group) (df=10)	Treatment (df = 35)	Error (df=25)			
Plant height (cm)	80.88	199.37*	1290.71**	53.56	98	4.69	156.15
Boll number per plant	0.01	16.69	25.81	17.83	73	11.99	35.23
Boll weight (g)	0.00	0.26	1.60**	0.17	95	10.30	3.95
Seed cotton yield (ton/ha)	2.05	0.46	1.74**	0.35	90	11.93	4.98
Ginning out-turn (%)	0.07	5.26	22.93**	1.49	96	3.56	34.32
Lint yield (ton/ha)	0.29	0.04	0.40**	0.05	93	13.47	1.73
Micronaire	0.41	1.14	0.70*	0.22	85	13.44	3.49
Fiber length (mm)	5.22	3.27	18.07*	7.60	81	7.83	35.18
Fiber strength (g/tex)	5.39	7.22	39.94**	11.27	87	9.30	36.10

Note: * = significant at $p \leq 0.05$, ** = significant at $p \leq 0.01$

Estimates of Heterosis for Plant height and Boll weight.

The mean performance for plant height, yield and yield components were given in Supplementary Table 1. Interspecific hybrids exhibited tallness with 177.61cm mean plant height followed by intra *G. barbadense* L. (159.17cm) and intra *G. hirsutum* L. (117.01cm) hybrids. The mean plant height of *G. barbadense* L. and *G. hirsutum* L. parental lines were 145cm and 110.72cm, respectively. The range of observed plant height was 162.50cm to 201.67cm, 149.50cm to 171.17cm and 107.33cm to 126.83cm in interspecific, intra *G. barbadense* L. and *G. hirsutum* L. hybrids, respectively. In *G. barbadense* L. parental lines the range of plant height was 137.33cm to 155.67cm, while 101.17cm to 126.83cm was observed in *G. hirsutum* L. parental lines. The estimates of heterosis measured as percent increase or decrease over mid parent and better parent of the hybrids for plant height and boll weight are depicted in Table 3. Among intra *G. hirsutum* L. hybrids, the mid parent heterosis ranged from -1.30% to 10.22% and the better parent heterosis range was from -10.12% to 8.64% for plant height. A comparable range of heterosis over mid parent and better parent were reported for plant height in intra *G. hirsutum* L. hybrids by other authors (Baloch et al., 2014; Solongi et al., 2019). In intra *G. barbadense* L. hybrids the mid-parent heterosis was within range of 6.38% to 16.84% and the better parent heterosis was between 1.71% to 9.95% range. Interspecific hybrids showed a higher magnitude of heterosis over mid parent (28.26% to 52.69%) and better-parent (8.88% to 46.85%) compared to intraspecific hybrids. This result is more or less consistent with a previous study in interspecific cotton hybrids (*Gossypium hirsutum* L. x *Gossypium barbadense* L.) as reported by Malathi et al. (2019). In general, twenty (66.67%) of F_1 hybrids exhibited significant ($p \leq 0.001$) and positive mid-parent heterosis. In contrast only thirteen (43.33%) of F_1 hybrids exhibited significant heterosis over better parents in a positive direction. The hybrids viz., F-1 (52.69%), C-1 (49.27%), I-1(47.96%) and F-2 (47.79%) recorded maximum heterosis over mid-parent, whilst, the maximum values of 46.85%, 42.14%, 30.10%, 29.61%, 27.70% and 25.35% heterosis over better parent belongs to F-1, F-2, I-1, C-1, L-2 and L-1 hybrids, respectively. In the cotton farming sector of Ethiopia, cotton varieties of below 60cm plant height are too short and not preferable, especially by large-scale commercial cotton producers. This is associated with the difficulty for labourers to pick opened bolls at harvesting time and the inefficiency of suppressing weed growth during the cotton growing period. In contrast, cotton with 150cm height is not suitable to spray chemical for insect pest control and may also exposed/susceptible to either breakage of stem or lodging which can cause yield loss. Hence in one way or the other the increase in heterosis for plant height may not be desirable and cautious consideration should be taken depending on a given agro ecologies.

The mean boll weight for intra *G. hirsutum* L. hybrids (5.72g) was found to be higher than interspecific hybrids (3.55g) and *G. barbadense* L. hybrids (3.10g) as given in Supplementary Table 1. Similarly, the mean boll weight of *G. hirsutum* L. (5.02g) parental lines was higher than *G. barbadense* L. (3.39g) parental lines. In intra *G. hirsutum* L. hybrids a range of 4.90g to 6.44g boll weight observed, whilst 2.87g to 3.41g and 2.85g to 4.30g exhibited among intra *G. barbadense* L. and interspecific hybrids, respectively. In *G. hirsutum* L. and *G. barbadense* L. parental lines a range of 4.86g to 5.26g and 3.25g to 3.53g boll weight was observed, respectively. Among interspecific hybrids heterosis over mid parent varied from -33.86% to -1.12% while heterosis over better parent was within range of -44.74% to -18. 31% for boll weight (Table 3).

Table 3. Estimates of heterosis over mid parent and better parent for Plant height and Boll weight

Hybrids	Plant height (cm)		Boll weight (g)	
	MPH (%)	BPH (%)	MPH (%)	BPH (%)
A-1	4.54	3.04	27.21**	22.37**
A-2	10.22	8.64	15.32**	10.93**
B-1	3.80	-6.70	0.00	-0.81
B-2	7.34	-3.52	10.17**	9.28**
C-1	49.27**	29.61**	-13.95**	-25.72**
C-2	43.68**	24.76**	-17.68**	-28.94**
D-1	39.26**	14.88	-5.26**	-20.95**
D-2	35.23**	11.56	-5.14**	-20.85**
E-1	42.84**	22.30**	-13.68**	-26.65**
E-2	40.37**	20.19*	-26.59**	-37.62**
F-1	52.69**	46.85**	-15.70**	-27.73**
F-2	47.79**	42.14**	-17.28**	-29.08**
G-1	32.02**	14.44	-1.12**	-18.60**
G-2	42.86**	23.83*	-23.98**	-37.42**
H-1	30.46**	8.88	-23.66**	-38.24**
H-2	34.70**	12.42	-14.61**	-30.93**
I-1	47.96**	30.10**	-33.86**	-44.74**
I-2	37.89**	21.24**	-2.24**	-18.31**
J-1	9.81**	0.00	12.91**	9.47**
J-2	-1.30	-10.12	17.29**	13.72**
K-1	31.33**	19.16*	-9.28**	-24.80**
K-2	28.26**	16.38**	-12.41**	-27.40**
L-1	32.43**	25.35**	-12.51**	-26.15**
L-2	34.91**	27.70**	-31.69**	-42.34**
M-1	16.84**	9.95	0.44	-3.54**
M-2	10.69	4.17	-3.34**	-7.18**
N-1	7.04	5.28	-13.23**	-14.83**
N-2	8.12	6.34	-13.23**	-14.83**
O-1	6.38	1.71	-8.27**	-10.29**
O-2	9.41	4.60	-13.83**	-15.74**
Mean	26.56	14.51	-8.31	-17.60
Mse	53.56	53.56	0.17	0.17
SE(d)	6.34	7.32	0.36	0.41
CD (5%)	13.06	15.08	0.74	0.85
CD (1%)	17.66	20.40	1.00	1.15
SE(+)	5.17	5.17	0.29	0.29

The current result is in agreement with those obtained by Solongi et al. (2019) and Malathi et al. (2019) who reported negative heterosis over mid and better parent for boll weight in interspecific hybrids. In intra *G. barbadense* L. hybrids a range of between -13.83% to 0.44% and -15.74% to 3.54% observed for mid parent and better heterosis, respectively. In study by Sultan et al. (2018) the decrease of -27.37% and increase of 29.55% heterosis over better parents reported for boll weight in intra *G. barbadense* L. hybrids. Comparatively, intra *G. hirsutum* L. hybrids showed higher heterosis for boll weight with a range of 0 % to 27.21% mid parent heterosis and -0.81% to 22.37% better parent heterosis. Other studies reported comparable values of an increase in mid parent and better parent heterosis in intra *G. hirsutum* L. hybrids for boll weight (Patel et al., 2012; Baloch et al., 2014; Soomro et al., 2016; Eswari et al., 2018). In a complete panel of the crosses apart from M-1 and B-1, the remaining F_1 hybrids showed significant ($p \leq 0.001$) heterosis over mid parent with the majority (82.14%) of these F_1 hybrids showing towards a negative direction. Similarly, apart from B-1 hybrids, the remaining F_1 hybrids showed significant ($p \leq 0.001$) heterosis over better parents of which 82.75% were towards a negative direction. Higher and positive mid parent heterosis and better parent heterosis values belongs to *G. hirsutum* intraspecific hybrids viz. A-1 (27.21% and 22.37%), J-2 (17.29% and 13.72%), A-2 (15.32% and 10.93%), J-1(12.91% and 9.47%) and B-2 (10.17% and 9.28%). On the other hand, heterosis over mid parent and better parent in *G. barbadense* L. and interspecific hybrids were not in desirable direction for boll weight.

Estimates of heterosis for Seed cotton yield, Ginning out-turn and Lint yield.

In respect of seed cotton yield the range of 5.21 ton/ha to 7.29 ton/ha, 3.96 ton/ha to 6.02 ton/ha and 3.53 ton/ha to 4.82 ton/ha was observed in intra *G. hirsutum* L., interspecific and *G. barbadense* L. hybrids, respectively (Supplementary Table 1). The mean seed cotton yield was 7.29 ton/ha in intra *G. hirsutum* L. hybrids followed by 6.02 ton/ha in interspecific and 4.82 ton/ha in *G. barbadense* L. hybrids. Furthermore the mean performance of *G. hirsutum* L. parental lines was 5.70 ton/ha, while 4.04 ton/ha for *G. barbadense* L. parental lines. The estimates of mid parent heterosis was varied from -2.33% to 26.61%, while the better parent heterosis was within -20.76% to 11.36% range in interspecific hybrids (Table 4). In other studies -54.19% to 43.76% mid parent heterosis and -71.71% to 14.65% better parent heterosis (Patel et al., 2019), -28.59% to 31.64% better parent heterosis (Gohil et al., 2017) and -41.35% to 174.18% mid parent heterosis and 66.43% to 84.80 better parent heterosis (Malathi et al., 2019), were reported. In intra *G. barbadense* L. hybrids a range of -1.97% to 27.03% mid parent and -5.32% to 19.27% better parent heterosis were exhibited. In line with this finding, Sultan et al. (2018) reported an increase of 27% heterosis over better parent in intra *G. barbadense* L.

hybrids. In other study by Yehia and El-Hashash (2019) higher magnitude of 70.54% mid parent heterosis and 60.69% heterosis over better parent was reported. Furthermore, positive and higher magnitude (5.44% to 42.86%) of mid parent heterosis and -2.35% to 32.32% better parent heterosis were observed in intra *G. hirsutum* L. hybrids (Table 4). In line with the present finding, Baloch et al. (2016) and Soomro et al. (2016) reported significant and positive mid parent heterosis and better parent heterosis for seed cotton yield in intra *G. hirsutum* L. hybrids.

Across all the F_1 hybrids, twenty-six F_1 hybrids manifested significant mid parent heterosis and of this with the range of 3.8% to 42.86%, twenty four hybrids showed increased heterosis over mid parents. Furthermore, twenty-seven F_1 hybrids exhibited significant heterosis over better parent and of these fourteen hybrids surpassed their better parents with a range of 2.8% to 32.32%. The highest heterosis over mid parent was observed in A-2 hybrid followed by B-2 (32.15%), B-1 (31.86%), N-2 (27.03%), D-1 (26.61%) and E-1 (25.62%). The least values of mid parent and better parent heterosis belongs to F-2 hybrid. Moreover, the highest heterosis over better parent recorded for A-2 hybrid, followed by B-2 (27.98%), B-1 (27.69), N-2 (19.27), G-1 (11.36), J-1(10.67) and E-1(10.35).

Table 4. Estimates of heterosis over mid parent and better parent of Seed cotton yield, Ginning out turn and Lint yield.

Hybrids	Seed cotton yield (ton/ha)		Ginning out- turn (%)		Lint yield (ton/ha)	
	MPH (%)	BPH (%)	MPH (%)	BPH (%)	MPH (%)	BPH (%)
A-1	5.44**	-2.35**	-0.68	-6.80**	3.89**	-9.23**
A-2	42.86**	32.32**	-1.64	-7.70**	39.63**	22.00**
B-1	31.86**	27.69**	-1.76	-2.01	29.50**	25.82**
B-2	32.15**	27.98**	-4.75**	-4.99**	25.99**	22.41**
C-1	5.43**	-12.25**	-19.56**	-24.03**	-16.90**	-33.57**
C-2	3.80**	-13.60**	-17.65**	-22.22**	-16.18**	-32.99**
D-1	26.61**	6.68**	-15.02**	-23.40**	5.39**	-18.44**
D-2	7.21**	-9.68**	-15.62**	-23.95**	-11.33**	-31.37**
E-1	25.62**	10.35**	-16.56**	-23.73**	3.16**	-16.09**
E-2	18.72**	4.30**	-16.84**	-23.98**	-2.79**	-20.93**
F-1	12.29**	-8.90**	-15.77**	-20.26**	-7.19**	-27.38**
F-2	-2.33**	-20.76**	-20.31**	-24.56**	-23.67**	-40.27**
G-1	17.95**	11.36**	-11.80**	-14.24**	3.51**	-4.84**
G-2	12.16**	5.88**	-13.39**	-15.79**	-3.11**	-10.93**
H-1	7.60**	-2.96**	-22.63**	-25.90**	-17.38**	-28.41**
H-2	11.09**	0.19	-17.73**	-21.21**	-9.12**	-21.25**
I-1	-2.15**	-12.93**	-14.11**	-14.70**	-16.44**	-24.74**
I-2	4.67**	-6.86**	-15.45**	-16.03**	-12.12**	-20.85**
J-1	23.07**	10.67**	-2.15**	-7.96**	19.19**	1.61**
J-2	17.40**	5.57**	-0.73**	-6.63**	15.46**	-1.57**
K-1	-0.40	-18.24**	-13.04**	-21.45**	-15.31**	-35.77**
K-2	1.02	-17.08**	-15.32**	-23.51**	-16.26**	-36.49**
L-1	16.75**	-0.23	-14.27**	-21.45**	-2.05**	-22.07**
L-2	23.54**	5.57**	-12.60**	-19.93**	6.37**	-15.37**
M-1	4.36**	2.80**	-4.82**	-9.45**	-1.13**	-5.35**
M-2	-1.97	-3.43**	-5.02**	-9.64**	-7.68**	-11.62**
N-1	10.97**	4.20**	0.20	-3.22*	10.57**	8.11**
N-2	27.03**	19.27**	1.28	-2.18	28.12**	25.27**
O-1	-0.60	-5.32**	4.15**	2.54*	3.40**	-3.11**
O-2	5.56**	0.55	3.10**	1.50	8.51**	1.68**
Mean	12.92	1.36	-10.02	-14.56	0.80	-12.19
Mse	0.35	0.35	1.49	1.49	0.05	0.05
SE(d)	0.51	0.59	1.06	1.22	0.19	0.22
CD (5%)	1.06	1.22	2.18	2.51	0.40	0.46
CD (1%)	1.43	1.65	2.95	3.40	0.54	0.62
SE(+)	0.42	0.42	0.86	0.86	0.16	0.16

Heterosis for seed cotton yield is the main objective for cotton breeding. Intraspecific *G. hirsutum* L. hybrids generated maximum of heterosis over their respective mid parent and better parent than did interspecific hybrids and *G. barbadense* L. intraspecific hybrids. In cotton, for development of hybrid cultivars, there should be considerable magnitude of heterosis over the popular hybrid considering the cost of F_1 hybrid seed production to be considered as significant yield advantage. In Ethiopia, there are about seven registered/recommended hybrid varieties introduced from abroad for production. However, they are yet to enter into production and hence better performing hybrids can be used as a base to develop high yielding possessing acceptable fiber quality standard hybrids. The range for ginning out-turn was 38.18% to 40.85%, 33.49% to 36.25% and 27.08% to 33.21% in intra *G. hirsutum* L., intra *G. barbadense* L. and interspecific hybrids, respectively (Supplementary Table 1). In *G. hirsutum* L. parental lines the range of ginning out-turn was 36.55% to 41.69%, while in *G. barbadense* L. parental lines it was 33.46% to 37.06%. The range of mid parent heterosis and better parent heterosis was from -22.63% to 4.15% and -25.90% to 2.54%, respectively. Majority (83.33%) of F_1 hybrids showed significant mid parent heterosis towards negative direction apart from O-1(4.15%), O-2 (3.10%), N-2 (1.28%) and N-1(0.20%) intra *G. barbadense* L. hybrids (Table 4). Similarly, 90% of F_1 hybrids exhibited significant better parent heterosis towards negative direction apart from O-1 hybrids. The maximum values of mid parent and better parent heterosis belongs to O-1(2.54%) hybrid. In contrast, the minimum values of mid parent and better parent heterosis belongs to H-1 (-22.63% and -25.90%) hybrid. Overall, the majority of the hybrids manifested low magnitude of heterosis for ginning out-turn than their parents. Other studies reported negative heterosis over mid parent and better parent in intra *G. hirsutum* L. hybrids (Soomro et al., 2016; Monicashree et al., 2017; Naik et al., 2020). Similarly, Gohil et al. (2017) and Malathi et al. (2019) reported heterosis over mid parent and better parent towards negative direction in interspecific hybrids.

The range observed for lint yield among intra *G. hirsutum* L. hybrids was 2.02 ton/ha to 2.97 ton/ha, while 1.19 ton/ha to 2 ton/ha in interspecific hybrids and 1.18 ton/ha to1.75 ton/ha in *G. barbadense* L. hybrids (Supplementary Table 1). The parental lines showed 1.67 ton/ha to 2.36 ton/ha in *G. hirsutum* L. and 1.22 ton/ha to 1.40 ton/ha in *G. barbadense* L. The heterosis over mid-parent was within the range of -23.67% to 6.37% and the better parent heterosis was -40.27% to -4.84% in interspecific hybrids (Table 4). The decrease in better parent heterosis of this finding is consistent with the previous finding of Gohil et al. (2017). For intra *G. barbadense* L. hybrids a mid-parent heterosis of 7.68% to 10.57% and a better parent heterosis of -11.62% to 25.27% were observed. The higher range of heterosis increase of up to 41.16% for better parent heteosis reported in intra *G. barbadense* L. hybrids (Abd-El-Haleem et al., 2010). In intra *G. hirsutum* L. hybrids 3.89% to 39.63% mid parent heterosis and -9.23% to 25.82% of better parent heterosis observed. All of F_1 hybrids showed significant ($p \leq 0.001$) mid parent and better parent heterosis. The degree of increased heterosis ranged from 3.16% to 39.63% in mid parent heterosis, while in case of better parent heterosis the increase of 1.61% to 25.82% were observed. The highest mid parent heterosis belongs to A-2, followed by B-1 (29.50%), N-2 (28.12%), B-2 (25.99%), J-1 (19.19%) and J-2 (15.46%) hybrids. In contrast, the highest value of better parent heterosis recorded for B-1 hybrid followed by N-2 (25.27%), B-2 (22.41%), A-2 (22.00%) and N-1 (8.11%) hybrids. In both mid parent and better parent heterosis the least values belong to F-2 hybrid. Cotton lint is the most important natural fiber for which cotton is mainly grown and for this reason one of the most important objectives in Ethiopian cotton improvement program is the improvement of lint yield. In this regard hybrids exhibiting higher heterosis for lint yield towards positive direction is desirable.

Estimates of heterosis for fiber quality traits.

The range observed for micronaire among intra *G. hirsutum* L. hybrids was 3.51 to 4.92 with a mean of 4.42, whereas in intra *G. barbadense* L. hybrids the range was 2.95 to 3.89, having the mean value of 3.31. In interspecific hybrids a range of 2.80 to 3.86 observed with a mean of 3.10, as given in Supplementary Table 2. The range observed for *G. hirsutum* L. parental lines was 4.01 to 4.75 with a mean of 4.42. In *G. barbadense* L. parental lines narrow range of 3.41 to 3.55 with a mean of 3.47 micronaire observed. The range of mid parent heterosis and better parent heterosis was from -30.84 % to 1.98% and -39.58% to -3.87%, respectively in interspecific hybrids.

In intra *G. hirsutum* L. hybrids a range of -17.63% to 12.21% mid parent heterosis and -22.11% to 3.47% better parent heterosis observed (Table 5). The result of this study is with range or relatively similar with the result of Monicashree et al. (2017), who reported a range of -21.90% to 13.95% of heterosis over mid parent and within range of -29.82% to 11.36% heterosis over better parent. Furthermore, -15.86% to 13.41% mid parent heterosis and -17.04% to 12.75% better parent heterosis were observed among intra *G. barbadense* L. hybrids. Similar to this study the decrease of mid parent and better parent heterosis reaching up to -18.32% and -17.33% reported respectively (Yehia and El-Hashash, 2019). Similarly, the increase in mid parent heterosis reaching up to 30% ((Yehia and El-Hashash, 2019), and also the increase in better parent heterosis reaching up to 11.57% reported by Mokadem et al. (2020). The increase or decrease of heterosis for micronaire in cotton may not be desirable. Cotton fiber with below 3.5 and above 5.0 micronaire value considered as immature and coarse fiber respectively and its market value regarded as discount range. The prime micronaire range lies between 3.7 and 4.2 (Anonymous, 2018).

In interspecific hybrids a mean 36.89mm with a range of 32.52mm to 38.83mm fiber length observed. The range observed for fiber length was 28.68mm to 34.27mm with a mean of 30.78mm in intra *G. hirsutum* L. hybrids. In intra *G. barbadense* L. hybrids 34.04mm to 37.58mm observed with a mean of 36.38mm (Supplementary Table 2). The parental lines of *G. hirsutum* L. and *G. barbadense* L. exhibited a mean value of 30.15mm and 36.41mm, respectively (Supplementary Table 2). The observed range of fiber length was 27.54mm to 33.49mm in *G. hirsutum* L. parental lines and 34.80mm to 38.26mm in *G. barbadense* L. parental lines. The mid parent heterosis was within range of -8.54% and 5.91% and the better parent heterosis was between, -11.04% to 3.91% among intra *G. barbadense* L. hybrids (Table 5). This increase in both mid parent and better parent heterosis is in conformity with that of Mokadem et al. (2020). In intra *G. hirsutum* L. hybrids -6.03% to 17.24% mid parent heterosis and -14.38% to 13.52% better parent heterosis was observed. The current results are also in agreement with that obtained by Monicashree et al. (2017) and Mhatre et al. (2000.) Interspecific hybrids exhibited -2.72% to 19.25% mid parent heterosis and -10.08% to 10.01% better parent heterosis. Other study reported -20.64% to 5.45% better parent heterosis in interspecific hybrid cotton (Gohil et al., 2017).

Table 5. Estimates of heterosis over mid parent and better parent for Micronaire, Fiber length and Fiber strength.

Hybrids	Micronaire		Fiber length (mm)		Fiber strength (g/tex)	
	MPH (%)	BPH (%)	MPH (%)	BPH (%)	MPH (%)	BPH (%)
A-1	12.21**	3.47**	-6.03*	-14.38**	-5.50	-16.84**
A-2	10.39**	1.79**	-3.87	-12.41**	-4.83	-16.24
B-1	-8.76**	-11.16**	17.24**	13.52**	-1.55	-7.86*
B-2	-4.22**	-6.74**	3.16	-0.12	-2.83	-9.06*
C-1	-26.14**	-35.47**	17.95**	5.65	11.88**	-7.76*
C-2	-30.84**	-39.58**	15.72**	3.65	11.42**	-8.14*
D-1	-19.63**	-30.63**	14.48**	-1.56	16.45**	-7.41*
D-2	-20.61**	-31.47**	16.11**	-0.16	6.70*	-15.16**
E-1	-21.81**	-32.84**	17.15**	3.18	10.06**	-9.98**
E-2	-25.74**	-36.21**	17.01**	3.06	13.57**	-7.11*
F-1	-25.22**	-33.11**	19.25**	10.01**	7.80*	-5.98
F-2	-28.32**	-35.89**	17.88**	8.75**	9.56**	-4.45
G-1	-19.27**	-25.31**	6.70**	2.75	0.07	-8.10*
G-2	-23.18**	-28.93**	7.66**	3.68**	6.31*	-2.37
H-1	-24.13**	-29.43**	6.22*	-0.41	6.97*	-4.98
H-2	-25.07**	-30.30**	5.14*	-1.41	-1.37	-12.38**
I-1	-23.02**	-27.43**	-2.05	-3.89	1.17	-6.23
I-2	1.98**	-3.87**	-2.72	-4.55	-6.93*	-13.74**
J-1	-17.63**	-22.11**	8.95**	2.31	5.89	-0.89
J-2	8.70**	2.78**	-5.69*	-11.44**	-8.60**	-14.46**
K-1	-23.90**	-32.78**	14.75**	1.48	7.66*	-9.72**
K-2	-25.79**	-34.44**	12.71**	-0.33	3.24	-13.43**
L-1	-4.05**	-15.67**	-0.82	-10.08	-2.81	-15.96**
L-2	-20.10**	-29.78**	15.88**	5.06	6.42*	-7.98*
M-1	-15.29**	-16.48**	-1.46	-5.92	0.00	-4.51
M-2	-15.86**	-17.04**	1.19	-3.38	1.70	-2.89
N-1	-3.74**	-5.63**	5.91**	3.91	13.85**	12.72*
N-2	-4.31**	-6.20**	2.50	0.57	4.41	3.37
O-1	13.41**	12.75**	-8.54**	-11.04**	-16.09**	-19.10*
O-2	-1.46**	-2.03**	0.25	-2.50	2.88	-0.81
Mean	-13.71	-19.99	7.09	-0.53	3.25	-7.92
Mse	0.22	0.22	7.60	7.60	11.27	11.27
SE(d)	0.41	0.47	2.39	2.76	2.91	3.36
CD (5%)	0.84	0.97	4.92	5.68	5.99	6.92
CD (1%)	1.13	1.31	6.65	7.68	8.10	9.36
SE(+)	0.33	0.33	1.95	1.95	2.37	2.37

Supplementary **Table 1.** Agronomic, seed cotton and lint yield performance of hybrids and parental lines at Werer during 2020.

Crosses and Parental lines	PH (cm)	BNP	BW (gm)	SCY (ton/ha)	GOT (%)	LY (ton/ha)
A-1	107.33	25.94	6.44	5.21	38.85	2.02
A-2	113.17	34.31	5.84	7.07	38.48	2.72
B-1	118.33	37.63	4.90	7.28	40.85	2.97
B-2	122.37	36.38	5.40	7.29	39.61	2.89
C-1	178.00	38.81	3.61	4.69	31.67	1.48
C-2	171.33	40.56	3.45	4.61	32.43	1.49
D-1	178.83	38.00	3.84	5.70	31.93	1.82
D-2	173.67	35.81	3.85	4.82	31.71	1.53
E-1	173.67	29.31	3.57	5.89	31.80	1.87
E-2	170.67	34.94	3.03	5.57	31.69	1.76
F-1	201.67	39.63	3.57	5.19	33.08	1.72
F-2	195.20	38.81	3.50	4.52	31.29	1.41
G-1	162.50	35.94	4.28	5.07	31.35	1.59
G-2	175.83	33.19	3.29	4.82	30.78	1.48
H-1	169.50	36.56	3.25	4.42	27.08	1.19
H-2	175.00	36.13	3.63	4.56	28.80	1.31
I-1	178.67	40.38	2.91	3.96	31.61	1.25
I-2	166.50	34.38	4.30	4.24	31.12	1.32
J-1	126.83	29.19	5.76	6.31	38.18	2.40
J-2	114.00	27.44	5.98	6.02	38.73	2.33
K-1	185.50	35.38	3.72	4.66	32.58	1.52
K-2	181.17	38.44	3.59	4.73	31.73	1.50
L-1	178.00	40.44	3.65	5.69	32.58	1.84
L-2	181.33	39.19	2.85	6.02	33.21	2.00
M-1	171.17	37.63	3.41	3.76	33.56	1.26
M-2	162.17	36.88	3.28	3.53	33.49	1.18
N-1	149.50	37.13	3.01	4.21	35.87	1.51
N-2	151.00	36.06	3.01	4.82	36.25	1.75
O-1	158.33	35.00	3.05	3.83	35.41	1.35
O-2	162.83	36.31	2.87	4.06	35.05	1.42
P-1	142.00	36.69	3.40	4.04	34.53	1.40
P-2	155.67	32.44	3.25	3.66	33.46	1.22
P-3	137.33	31.44	3.53	3.55	37.06	1.34
P-4	126.83	33.13	4.94	5.70	41.48	2.36
P-5	104.17	27.94	5.26	4.55	36.55	1.67
P-6	101.17	30.75	4.86	5.34	41.69	2.23
LSD (5%)	15.07	8.70	0.84	1.22	2.52	0.48

Note: LSD = Least significance difference, PH = Plant height, BNP = Boll number per plant, BW = Boll weight, SCY = Seed cotton yield, GOT = Ginning out-turn, LY = Lint yield.

Twenty one of hybrids showed significant mid parent heterosis and only eight of F$_1$ hybrids exhibited significant better parent heterosis. The maximum and significant mid parent heterosis value belongs to F-1 hybrid, followed by C-1 (17.95%), F-2 (17.88%), B-1 (17.24%), E-1 (17.15%), E-2 (17.01%) and D-2 (16.11%) hybrids. In contrast the maximum and significant better parent heterosis value belongs to B-1 followed by F-1 (10.01%) and F-2 (8.75%) hybrids. The least value of mid parent and better parent heterosis belongs to O-1 and A-1hybrids, respectively. Longer fibers can be processed at greater efficiencies and produce finer and stronger yarns by allowing fibers to twist around each other more times, while shorter fibers require increased twisting during spinning, causing low-strength and poor-quality yarns (Chee et al., 2005). Hence crosses exhibiting higher magnitude of heterosis for fiber length towards positive direction are preferable.

Supplementary **Table 2.** Fiber quality performance of F$_1$ hybrids and parental lines at Werer during 2020.

Crosses and Parental lines	Micronaire	Fiber length (mm)	Fiber Strength (g/tex)
A-1	4.92	28.68	27.90
A-2	4.84	29.34	28.10
B-1	4.22	33.39	26.95
B-2	4.43	29.38	26.60
C-1	3.07	36.77	36.25
C-2	2.87	36.07	36.10
D-1	3.30	37.67	40.00
D-2	3.26	38.20	36.65
E-1	3.19	37.32	36.10
E-2	3.03	37.27	37.25
F-1	3.01	38.29	36.95
F-2	2.89	37.85	37.55
G-1	3.00	37.16	36.85
G-2	2.85	37.50	39.15
H-1	2.83	38.11	41.05
H-2	2.80	37.72	37.85
I-1	2.91	33.45	36.85
I-2	3.86	33.22	33.90
J-1	3.51	34.27	33.25
J-2	4.63	29.66	28.70
K-1	3.03	38.83	39.00
K-2	2.95	38.14	37.40
L-1	3.80	32.52	33.70
L-2	3.16	38.00	36.90
M-1	2.97	36.00	41.25
M-2	2.95	36.97	41.95
N-1	3.35	37.58	45.20
N-2	3.33	36.37	41.45
O-1	3.89	34.04	34.95
O-2	3.38	37.31	42.85
P-1	3.41	36.17	40.10
P-2	3.45	38.26	43.20
P-3	3.55	34.80	39.30
P-4	4.50	29.41	29.25
P-5	4.01	33.49	33.55
P-6	4.75	27.54	25.50
LSD (5%)	0.97	5.68	6.90

The *G. hirsutum* L. parental lines exhibited a mean of 29.43g/tex fiber strength with a range of 25.50g/tex to 33.55g/tex, while *G. barbadense* L. parental lines exhibited 39.30g/tex to 43.20g/tex with a mean of 40.87g/tex. Among intra *G. hirsutum* L. hybrids a range of 26.60 g/tex to 33.25 g/tex with a mean of 28.58 g/tex observed, whilst a range of 34.95g/tex to 45.20 g/tex, with a mean of 41.28g/tex exhibited among intra *G. barbadense* L. hybrids. In interspecific hybrids a mean of 37.19g/tex observed with range of 33.70g/tex to 41.05g/tex. The heterosis over mid parent was from -16.09% to 17.86% and the better parent heterosis was -19.10% to 12.72% in intra *G. barbadense* L. hybrids (Table 5). Other authors reported -8.14% to 3.73% mid parent heterosis and -8.75% to 2.45% better parent heterosis in intra *G. barbadense* L. hybrids (Mokadem et al., 2020). In intra *G. hirsutum* L. hybrids a range of, -8.60% to 5.89% mid parent heterosis and -16.84% to -0.89% better parent heterosis observed. Other studies reported -17.31% to 13.32% mid parent heterosis and -17.70% to 10.05% better parent heterosis (Monicashree et al., 2017), -7.37% to 16.02% mid parent heterosis and -12.71% to 8.31% better parent heterosis (Khokhar et al.,

2018) and -4.93% to 8.52% mid parent heterosis and -6.19% to 6.36% better parent heterosis (Baloch et al., 2014). Interspecific hybrids showed -6.93% to 16.45% mid parent heterosis and -15.96% to -2.37% better parent heterosis (Table 5). About sixteen of the hybrids exhibited significant heterosis over mid parent and of which twelve of hybrids were towards positive direction. In contrast nineteen hybrids showed significant heterosis over better parent heterosis with majority towards negative direction apart from N-1 hybrid. The highest mid parent heterosis belongs to D-1 hybrid followed by N-1 (13.85%), E-2 (13.57%), C-1(11.88%), C-2 (11.42%) and E-1(10.06%) hybrid. On the other hand, the minimum heterosis over mid parent and better parent belongs to O-1 hybrid. Cotton with high fiber strength is more likely to withstand breakage during the manufacturing process (Anonymous, 2018). Hence in a similar way to that of fiber length crosses exhibiting higher magnitude of heterosis for fiber strength towards positive direction are preferable.

CONCLUSIONS

All hybrids displayed a different range of mid parent and better parent heterosis for each trait. The intra F_1 *G. hirsutum* L. hybrids manifested more heterosis than do intra F_1 *G. barbadense* L. hybrids and intraspecific hybrids for seed cotton and lint yield. Among the hybrids intra specific *G. hirsutum* L. hybrid, HS-46 x Stonoville 453 19-8 X Stam 59A x Cucurova 1518 30-2 (B-1) exhibited considerable heterotic values for seed cotton and lint yield, and fiber length possibly suitable for local cottage and textile industries. The majority of interspecific hybrids showed better mid parent heterosis for seed cotton yield and fiber quality traits implying their mean performance were better than their *G. hirsutum* L. parents and *G. barbadense* L. parents for yield and fiber quality traits, respectively. Thus, the results obtained indicate the possibility to improve yield and fiber quality traits simultaneously using interspecific hybrids. Moreover, research on cotton breeding needs to address all possibilities including exploitation of hybrid vigour to increase yield and fiber qualities of thereby increasing profit margins of cotton production in Ethiopia.

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CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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