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Genetic variation and heterotic effects for seed oil, seed protein and yield attributing traits in upland cotton (*Gossypium hirsutum* L.)

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An investigation was carried out to assess the expression of *per se* performance and heterotic effect for seed oil, seed protein besides various yield attributing characters studied from 28 hybrids involving four adapted varieties as lines and the seven testers in line x tester analysis. A wide range of variability was observed for seed oil content in the parents and their 28 hybrids. The seed oil content in parents ranged from 17.0 to 22.1%, and hybrids varied from 17.7 to 22.9%.The hybrid, MCU 12 x SOCC 11 exhibited significant positive heterotic effect and *per se* performance for boll weight. The hybrid MCU 5 x SOCC 17 had high *per se* performance and positive significant heterotic effect for seed protein with seed cotton yield. Two hybrids showed high heterotic effect and *per se* performance for seed protein content. The hybrid MCU 12 x SOCC 17 exhibited higher *per se* performance and heterotic effect for seed cotton yield along with seed oil content and MCU 5 x SOCC 17 recorded more seed protein combined with seed cotton yield. Four hybrids revealed greater *per se* performance and positive heterosis for seed oil content. Of these, Surabhi x TCH 1646 exhibiting highest *per se* performance, heterotic effect was found to be best for directional selection.

Key words: Cotton, heterosis, seed oil, seed protein, yield.

INTRODUCTION

Cotton crop is mainly cultivated for fibre. The cotton seed, a by-product, is an important source of edible oil. Cotton seed is the second largest source of vegetable oil in the world. In India, secondary source of edible oil production is 19.90 lakh tons. Cotton seed oil is generally considered as healthy vegetable oil. It is cholesterol free and hence termed as "*Heart oil*". After extraction of oil, the cotton seed meal is a protein rich by product and assumes great importance in feed and fermentation industries. Therefore, cotton seed has an important contribution in helping to feed the world in the future.

The genetic improvement of a new variety with high yield and seed quality parameters is the unique target of all cotton breeders. Industrial demand of cotton with superior fibre trait is also source of guide line for cotton breeders. The success of transgressive segregation depends on the identification of genotypes with the ability to transmit high production potential into specific genotypic combinations. Heterosis is a performance of F_1/F_2 genotypic combinations and is useful in determining the most appropriate parents for specific traits (Khan et al., 2010). Development of hybrids as a commercial variety is getting importance. Heterosis has substantially remained as one of the significant developments in cotton breeding programs (Baloch et al., 2003; Ansari et al., 2004; Ansari et al., 2005; Memon et al., 2005; Ansari et al., 2006).

The yield increase through intra- and inter-specific heterosis over the better parent or best commercial cultivar

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Table 1. List of parental genotypes used for genetic studies in upland cotton.

S/N	Parent	Source
Lines		
1	MCU 5	Department of Cotton, TNAU, Coimbatore-3, India.
2	MCU 12	Department of Cotton, TNAU, Coimbatore-3, India.
3	SURABHI	CICR, Regional station, Coimbatore-3, India.
4	SVPR 2	Department of Cotton, TNAU, Coimbatore-3, India.
Testers		
1	F 776	CICR, Regional station, Coimbatore-3, India
2	F 1861	CICR, Regional station, Coimbatore-3, India
3	SOCC 11	CICR, Regional station, Coimbatore-3, India
4	SOCC 17	CICR, Regional station, Coimbatore-3, India
5	TCH 1641	Department of Cotton, TNAU, Coimbatore-3, India.
6	TCH 1644	Department of Cotton, TNAU, Coimbatore-3, India.
7	TCH 1646	Department of Cotton, TNAU, Coimbatore-3, India.

CICR, Central Institute for Cotton Research, TNAU, Tamil Nadu Agricultural University.

(useful heterosis) has been documented (Galanopoulou and Roupakias, 1999; Wei et al., 2002; Yuan et al., 2002; Zhang et al., 2002; Khan et al. 2007a). The oil content increase through intra-*hirsutum* hybrids over mid parent and better parent were documented (Kowsalya et al., 1999; Ganapathy and Nadarajan, 2008).

Several studies have been reported on seeds traits, but little work has been reported on the genetics and heterosis of cottonseed oil percentage in cotton breeding. A few reports in the literature (Kohel, 1980; Dani and Kohel, 1989; Dani, 1991; Khan et al., 2007b; Ganapathy and Nadarajan, 2008; Sharma et al., 2009; Khan et al., 2010) have determined that cotton genotypes differ in oil percentage. The estimates of *per se* performance and heterosis provided useful information with regard to the possibilities and extent of improvement in the characters of breeding material through selection. Any breeding programme has to consider the improvement in quality, especially in crop like cotton. Seed quality generally increases with high level of seed oil but declines with the increase of seed cotton yield. For a simultaneous selection of both quality and yield, knowledge of inter relationship between the components of quality and those of yield is a pre-requisite. In cotton, heterosis studies for seed cotton yield and other fiber properties are many. But to know the nature and extent of heterosis for oil content with seed cotton yield and other traits are limited.

Therefore, the present study objective was to estimate genetic variation for mean performance of parents and their hybrids and to estimate the effects of heterosis in F_1 cross combinations, to obtain information heterotic potential as to develop hybrid with improved yield along with high seed oil content through line x tester (L x T) analysis.

MATERIALS AND METHODS

Genetic material

A field experiment was conducted to evaluate the growth, yield and fibre quality traits performance of four commercially cultivated varieties of cotton (*Gossypium hirsutum* L.) as *viz.,* MCU 5, MCU 12, Surabhi and SVPR 2 and seven *G. hirsutum* genetic accessions as *viz.,* F 776, F 1861, SOCC 11, SOCC 17, TCH 1641, TCH 1644 and TCH 1646 (Table 1). The commercial cultivars were cultivated in southern states of India and genetic accessions were collected from the Central Institute of Cotton Research, Coimbatore, Tamil Nadu, India.

Experimental design and field procedures

The cotton cultivars and accessions were evaluated in randomized block design (RBD) with three replications at Cotton Breeding Station, Tamil Nadu Agricultural University, Coimbatore, and Tamil Nadu in India. Each genotype was grown in a 4.5 m length row adopting a spacing of 75 cm between rows and 30 cm between the plants, so as to have 15 plants per row.

Sampling, traits measurements and methods

Data were recorded on five randomly selected plants per replication for all the 11 characters *viz.,* Plant height (cm), number of sympodia per plant, number of bolls per plant, boll weight per plant (g), number of seeds per boll, seed cotton yield per plant (g), ginning outturn (%), lint index (g), seed index (g), seed oil content (%) and seed protein content (%). The line x tester analysis of heterosis was performed as suggested by Kempthorne, (1957). Heterosis was calculated in terms of percent increase (+) or decrease (-) of the F_1 hybrids against its mid parent, and better parent value as suggested by Fehr (1987).

Biochemical analysis

The seed oil content of parents and their F_1 hybrids was estimated

Table 2. Analysis of variance for seed oil, seed protein and yield traits from L X T analysis.

Source of variation	df	Plant height (cm)	Number of sympodia/ plant	Number of bolls	Boll weight (g)	Number of seeds/bolls	Ginning outturn (%)	Lint index (g)	Seed index (g)	Seed cotton yield (g/plant)	Seed oil (%)	Seed protein (%)
		Mean square										
Replication	2	1.04	1.71	1.18	0.93	0.55	0.07	1.38	1.28	2.41	1.64	8.42
Parents	10	2.73**	3.91**	2.95**	2.38*	4.13**	3.40**	5.28**	2.41*	12.22**	15.61**	25.47**
Hybrids	27	16.69**	1.73*	4.92**	1.72*	2.54**	5.98**	2.38**	2.61**	23.53**	24.54**	102.49**
Parents vs hybrids	1	222.76**	6.61*	20.39**	17.71**	33.20**	35.15**	2.36	2.88	523.99**	1.70	48.48**
Error	76	6.46	2.90	3.57	0.07	1.82	1.87	0.30	1.13	8.9	0.28	0.86
Replication	2	0.82	2.26	1.67	0.66	0.35	0.01	1.79	1.26	3.35	1.98	13.84
Lines	3	3.41*	4.29**	6.17**	1.40	0.59	0.82	0.56	2.24	12.47**	1.12	14.19**
Tester	6	0.41	0.55	0.91	1.88	1.39	1.91	1.73	1.40	3.23**	0.26	1.19
line x tester	18	12.91**	2.08*	4.35**	2.01*	3.06**	4.23*	2.25*	1.92*	10.15**	30.37**	75.20**
Error	54	7.42	3.39	2.59	0.08	1.45	2.23	0.28	1.39	9.4	0.27	0.46

*, Significant at 5% level; **, significant at 1%level.

by nuclear magnetic resonance analyses (NMR) (Oxford 4000 NMR auto Analyser) using 10 g delinted seed for each sample. Before NMR analysis, the delinted seeds were dried at 38°C for 24 h. Seed protein content was estimated through total nitrogen content using Microkjeldhal method (Humphries, 1956), and seed protein content was calculated by multiplying the nitrogen content with a factor 6.25 and the result was expressed as percentage.

RESULTS AND DISCUSSION

Evaluation of mean performance and heterotic effect is essential to know whether new cross combinations are suitable for direct exploitation or can be used to isolate useful and transgressive segregants from subsequent generation to develop a variety. The utilization of hybrids directly for commercial production mainly depends upon the nature and extent of heterosis. Increasing F_1 hybrid value over the better parent value is more relevant for exploitation of heterosis for commercial purpose (Williams and Gilbert, 1960). The expression of heterosis was worked out for all the characters over mid parent, and better parent was estimated in the entire cross combinations under this study.

Analysis of variance

The analysis of variance showed that line was significant for the characters *viz.,* plant height, number of sympodia, number of bolls, seed cotton yield, and seed protein. The testers varied significantly for the seed cotton yield. In case of the line x tester component, significant variation was observed for all the characters (Table 2). Between the parents and hybrids, significant variation was observed for all the characters. In addition, the parents versus hybrids showed significant variation for all the characters except lint index, seed index, and seed oil.

Genetic variability in F_1 hybrids and their parents

Significant variation was found for each trait in all the genotypes. The mean expression of the 11 characters was recorded on the 11 genotypes. All the 11 cotton genotypes (four lines and seven testers) differ significantly for plant height. The maximum plant height (122.5 cm) was observed in TCH 1646, and the lowest (112.6 cm) was observed in SOCC 17. Among the 28 hybrids, the weakest value of 120.1 cm and highest value of 143.1 cm were recorded in MCU 5 x F 776 and MCU 5 x TCH 1641, respectively. Differences observed for plant height among cotton cultivars can be attributed to variation in genetic makeup of

Table 3. Ranges for mean expression of parents in different characters.

Character	Minimum value	Maximum value	Mean	Parent recording	
				Lowest	Highest
Plant height (cm)	113.6	122.5	120.71	SOCC 17	TCH 1641
No. of sympodia/plant	20.00	29.00	22.32	TCH 1641	F 776
Number of bolls/plant	20.10	26.47	23.60	F 776	Surabhi
Boll weight/boll (g)	3.36	4.19	3.92	TCH 1644	MCU 5
Number of seeds / boll	26.70	32.00	29.70	TCH 1644	TCH 1641
Seed cotton yield (g/plant)	59.40	95.33	83.43	TCH 1644	MCU 12
Ginning outturn (%)	31.68	36.24	34.0	SOCC 17	Surabhi
Lint index (g)	3.96	6.12	5.01	SOCC 11	SVPR 2
Seed index (g)	8.05	11.11	9.25	F 1861	F 776
Seed oil (%)	17.74	22.07	19.94	F 1861	TCH1644
Seed protein (%)	19.39	27.69	23.67	Surabhi	MCU 5

crop plants. These results are supported by the findings of Anwar et al. (2002) and Copur (2006) who also noted significant differences among cultivars for plant height. In parents, highest number of sympodia per plant and lowest number of sympodia per plant were produced by TCH 1614 and F776, respectively (Table 3). In hybrids, the weakest value of 21.7 (SVPR 2 x TCH 1641) and the greatest value of 27.2 (Surabhi x F 776) were recorded with a mean value of 25.0. The difference to the number of sympodial branches per plant can be attributed to differences in genetic makeup of the cultivars.

There was significant difference between the parents in case of the number of bolls per plant. Significant and maximum number of bolls per plant was observed in cultivar SURABHI (26.5). The minimum number of bolls per plant was found in accession F776 (20.1). The hybrids displayed a variation from 21.40 bolls in SVPR 2 x SOCC 11 to 32.4 bolls in MCU 12 x F 1861 for the number of bolls per plant with a mean value of 25.4 bolls. The result indicating the importance of hybrid MCU 12 x F 1861 offering the scope of selection and can be utilized for the improvement of number of bolls per plant which will directly influence the seed cotton yield. In addition, the present results have been further supported by Soomro (2000), Baloch (2002), Chandio et al. (2002), Basbag and Gencer (2004) and Soomro et al., (2008).

Boll weight is directly related to the seed cotton yield of cotton. An evaluation of data indicated that greatest boll weight was recorded in cultivar MCU12 (4.2 g), and it was on par with cultivar MCU5 (4.14 g) and SVPR 2 (4.12 g) the lowest boll weight was recorded in accession TCH1644 (3.36 g). Significant differences among parents for average boll weight also were reported by Hofs et al. (2006). Boll weight variation among the hybrids ranged from 3.8 g in Surabhi x SOCC 11 to 4.4 g in MCU 12 x SOCC 11, and the mean value was 4.2 g. Boll weight was positively associated with seed cotton yield as reported (Rauf et al., 2004; Gite et al., 2006; Preetha and Raveendran, 2007). There was significant difference among the parents and hybrids in case of the number of seeds per boll. Maximum and minimum number of seeds per boll observed was 32.0 and 26.7, respectively. The average number of seeds per boll for all the genotypes was 29.7 (Table 3). The hybrids displayed a variation from 29.6 in Surabhi x TCH 1641 and SVPR 2 x TCH 1646 to 34.9 in Surabhi x SOCC 11.

All the parents and hybrids had wide variation for seed cotton yield per plant. The cultivar MCU 12 produced significantly higher seed cotton yield (95.3 gm/plant) and lowest seed cotton yield was registered by the accession TCH 1644 (59.5 gm/plant). The mean yield of all the genotypes was 83.4 g/plant. Lowest yield of 87.7 g was recorded by a Surabhi x TCH 1646 and highest yield of 145.4 g was recorded by MCU 12 x F 1861, and the mean value of hybrids was 106.96 g. The maximum seed cotton yield with MCU 12 x F 1861 can be attributed to the maximum number of sympodia per plant, number of bolls, boll weight, ginning outturn, lint index and seed index. Similar findings for seed cotton yield have also been reported by early workers (Baloch, 2004; Soomro et al., 2008). Hence, suggesting the prompt selection of the hybrid MCU 12 x F 1861 for increasing seed cotton yield per plant and suggesting the utilization of this hybrid for evolving new high yielding genotypes of cotton.

The highest value of ginning out turn was obtained in case of cultivar SURABHI (36.2%), but it was on par with cultivars SVPR 2 (35.8%) and MCU12 (35.4%). Among the hybrids, MCU 5 x TCH 1646 recorded minimum (30.0%) ginning outturn while SVPR 2 x SOCC 11 registered maximum ginning outturn of 39.9%. The mean expression for ginning out turn in hybrids was 35.6%. These results were supported by those of Ehsan et al. (2008). There were significant differences in all the hybrids in the case of lint index (g) and seed index (g) (Table 4).

A wide range of variability was observed for seed oil content in the parents and their 28 hybrids. The oil content in parents ranged from 17.7 (%) to 22.1 in F 1861

Table 4. Mean performance and expression of heterosis in hybrids (%) for yield attributing traits.

Hybrid	Plant height (cm)			Number of sympodia / plant			Number of bolls/plant			Boll weight/boll (g)		
	mean	di	dii	Mean	di	dii	Mean	di	dii	Mean	di	dii
MCU 5 x F 776	120.07	-1.14	-1.21	4.11	9.75	-1.60	24.90	12.75 *	3.46	4.11	0.24	-1.83
MCU 5 x F 1861	132.17	8.35 **	7.95 **	4.27	9.69	2.80	24.00	-2.24	-4.13	4.27	4.15	8.83
MCU 5 x SOCC 11	131.23	8.23 **	7.98 **	4.05	7.63	4.54	25.03	3.73	3.44	4.05	3.18	-3.34
MCU 5 x SOCC 17	137.67	17.08 **	13.27 **	4.06	12.63 *	1.20	24.13	-1.23	-2.69	4.06	0.04	-3.18
MCU 5 x TCH 1641	143.07	17.93 **	17.72 **	4.06	6.24	-2.27	23.07	-0.07	-4.16	4.06	0.33	-3.18
MCU 5 x TCH 1644	122.13	0.56	0.49	4.03	3.33	1.60	24.63	7.96	2.35	4.03	6.71	-3.82
MCU 5 x TCH 1646	137.14	12.43 **	12.00 **	4.24	7.87	1.60	22.87	-1.29	-4.99	4.24	5.52	7.19
MCU 12 x F 776	129.20	6.87 **	6.45 **	4.35	17.00 **	6.49	24.33	7.51	-3.31	4.35	6.62	5.08
MCU 12 x F 1861	122.07	0.52	-0.30	4.03	0.80	-4.01	32.37	28.95 **	28.61 **	4.03	7.90	6.50
MCU 12 x SOCC 11	123.73	0.86	0.63	4.36	4.06	2.76	29.40	19.11 **	16.82 **	4.36	11.76 *	5.32
MCU 12 x SOCC 17	121.63	3.93 *	1.00	4.10	21.27 **	10.64	32.27	29.15 **	28.21 **	4.10	1.70	-0.97
MCU 12 x TCH 1641	121.20	0.36	0.08	4.15	16.63 **	8.98	24.23	2.54	-3.71	4.15	3.24	0.24
MCU 12 x TCH 1644	122.50	1.32	0.93	4.14	8.01	8.01	26.73	14.41 *	6.23	4.14	10.49 *	0.16
MCU 12 x TCH 1646	122.20	0.62	-0.22	4.31	9.38	4.70	26.13	10.19	3.84	4.31	7.89	4.11
SURABHI x F 776	127.73	5.13 **	5.02 **	4.21	23.88 **	12.69 *	25.47	9.38	-3.78	4.21	5.60	4.81
SURABHI x F 1861	133.07	9.04 **	8.68 **	4.27	14.78 **	9.24	25.13	-2.39	-5.04	4.27	7.29	6.66
SURABHI x SOCC 11	126.03	3.90 **	3.62 *	3.82	2.31	0.97	24.43	-3.55	-7.68	3.82	0.39	-3.37
SURABHI x SOCC 17	135.30	15.02 **	11.24 **	4.15	14.98 **	4.83	25.93	1.17	-2.02	4.15	5.29	4.80
SURABHI x TCH 1641	121.37	6.59 **	6.36 **	3.89	13.29 *	5.79	26.37	8.58	-0.38	3.89	-0.85	-1.60
SURABHI x TCH 1644	125.83	3.57 *	3.45 *	3.97	9.18	9.10	24.90	3.68	-5.92	3.97	8.56	0.42
SURABHI x TCH 1646	132.23	8.34 **	7.97 **	4.34	10.89 *	6.07	25.40	4.24	-4.03	4.34	11.23 *	9.69
SVPR 2 x F 776	134.27	10.86 **	10.63 **	4.20	27.09 **	26.25 **	24.57	11.84	3.08	4.20	3.28	1.94
SVPR 2 x F 1861	127.67	4.95 **	4.27 *	4.17	15.83 **	11.15	25.50	4.37	1.86	4.17	2.71	1.21
SVPR 2 x SOCC 11	128.77	6.49 **	6.45 **	4.20	12.08 *	3.82	21.40	-10.90	-11.57	4.20	7.84	1.78
SVPR 2 x SOCC 17	129.00	10.02 **	6.73 **	4.14	22.60 **	22.09 **	23.97	-1.44	-3.36	4.14	3.03	0.49
SVPR 2 x TCH 1641	121.41	0.37	0.28	4.12	5.61	3.34	24.40	6.24	2.38	4.12	2.74	-0.08
SVPR 2 x TCH 1644	133.00	9.81 **	9.59 **	4.21	1.21	-7.32	24.43	7.64	2.52	4.21	12.47 *	2.10
SVPR 2 x TCH 1646	130.40	7.18 **	6.48 **	4.23	9.18	4.23	23.90	3.69	0.28	4.23	6.15	2.59

*, Significant at 5% level; **, significant at 1% level; di, relative heterosis; dii, heterobeltiosis.

and TCH 1644, respectively. In hybrids, it varied from 17.05 (MCU 12 x TCH 1641) to 22.9% (Surabhi x TCH 1646). The mean was 19.95 for hybrids. Pandey (1977) reported that the variability for oil content in improved strains of *G. hirsutum* ranged from 14.5 to 22.0% with mean of 19.2% (Table 5). The earlier workers, Dani (1989), Dani (1991), Gotmare et al*.* (2004), Khan et al., (2007a) and Sharma et al., (2009) also reported

Table 5. Mean performance and expression of heterosis in hybrids (%) for Seed cotton yield, seed oil and protein content.

Hybrid	Seed cotton yield/plant (g)			Seed oil (%)			Seed protein (%)		
	Mean	di	dii	Mean	di	dii	Mean	di	dii
MCU 5 x F 776	99.71	20.40 **	14.70 **	19.17	-0.77	-1.00	28.70	17.00 **	3.65
MCU 5 x F 1861	116.13	32.93 **	32.27 **	20.82	12.51 **	8.04 **	27.29	0.05	-1.43
MCU 5 x SOCC 11	104.63	27.39 **	20.36 **	21.26	10.25 **	10.17 **	27.09	0.18	-2.17
MCU 5 x SOCC 17	110.25	32.06 **	26.82 **	19.26	-4.27 *	-8.15 **	31.71	29.76 **	14.52 **
MCU 5 x TCH 1641	97.73	17.47 **	12.42 **	20.68	-0.67	-7.55 **	29.08	19.89 **	5.03
MCU 5 x TCH 1644	105.90	44.74 **	21.82 **	20.89	5.21 **	2.20	21.67	-16.56 **	-21.75 **
MCU 5 x TCH 1646	103.80	15.01 **	10.94 *	18.89	-3.88 *	-5.72 *	27.44	7.08 **	-0.90
MCU 12 x F 776	112.77	29.59 **	18.29 **	21.66	7.24 **	2.96	27.58	20.81 **	13.54 **
MCU 12 x F 1861	145.41	58.80 **	52.52 **	18.20	-6.14 **	-13.50 **	26.04	1.80	-3.09
MCU 12 x SOCC 11	137.03	58.73 **	43.74 **	20.01	-0.77	-4.88 *	18.90	-25.41 **	-28.38 **
MCU 12 x SOCC 17	141.47	61.34 **	48.39 **	21.52	2.47	2.30	18.45	-18.86 **	-24.04 **
MCU 12 x TCH 1641	101.73	16.40 **	6.71	17.01	-21.63 **	-23.96 **	25.10	11.27 **	3.33
MCU 12 x TCH 1644	114.87	48.47 **	20.49 **	20.51	-1.13	-2.53	25.80	6.32 *	6.22 *
MCU 12 X TCH 1646	115.50	22.29 **	21.15 **	18.17	-11.53 **	-13.64 **	22.54	-5.80 *	-7.20 *
SURABHI x F 776	102.60	23.00 **	16.41 **	21.86	13.15 **	17..93 **	23.27	14.18 **	8.89 *
SURABHI x F 1861	104.70	19.02 **	18.79 **	22.30	20.46 **	15.64 **	25.58	10.59 **	-4.80
SURABHI x SOCC 11	94.40	14.10 **	7.11	18.99	-1.56	-1.59	24.99	9.17 **	-5.31
SURABHI x SOCC 17	107.37	27.69 **	21.82 **	19.02	-5.48 **	-9.28 **	27.47	35.40 **	29.66 **
SURABHI x TCH 1641	102.30	22.08 **	16.07 **	20.30	-2.51	-9.24 **	22.92	13.98 **	10.05 **
SURABHI x TCH 1644	92.79	25.78 **	5.28	18.91	-4.77 *	-7.47 **	19.18	-12.09 **	-20.89 **
SURABHI x TCH 1646	87.70	-3.47	-6.27	22.90	15.46 **	13.29 **	14.18	-33.99 **	-39.84 **
SVPR 2 x F 776	99.63	17.40 **	9.45 *	19.64	1.05	0.67	14.35	-37.52 **	-41.58 **
SVPR 2 x F 1861	108.00	20.78 **	18.64 **	16.63	-10.71 **	-14.76 **	14.33	-44.26 **	-46.66 **
SVPR 2 x SOCC 11	94.47	12.22 **	3.77	20.86	7.51 **	6.92 **	14.85	-41.71 **	-43.73 **
SVPR 2 x SOCC 17	100.29	17.26 **	10.17 *	19.44	-3.95 *	-7.30 **	21.31	-6.84 *	-13.24 **
SVPR 2 x TCH 1641	97.83	14.76 **	7.47	20.13	-3.87 *	-10.01 **	16.59	-26.89 **	-32.45 **
SVPR 2 x TCH 1644	97.10	29.09 **	6.66	17.99	-9.94 **	-11.99 **	14.21	-41.77 **	-42.15 **
SVPR 2 x TCH 1646	98.70	6.93	5.49	18.62	-5.85 **	-7.09 **	14.98	-37.75 **	-39.01 **

*, Significant at 5% level; **, significant at 1% level; di, relative heterosis; dii, heterobeltiosis.

similar findings, and supported our results. Hassan et al. (2005) studies exhibited the performance of Egyptian cotton cultivars for cottonseed oil percentage and found significant mean differences. Soomro et al. (2008) observed cottonseed oil percentage ranged from 27.52 to 30.15% among eight upland cotton cultivars and it was negatively correlated with seed cotton yield.

The protein content in parents ranged from 19.4% in Surabhi to 27.7% in MCU 5. In hybrids, it varied between 14.18% (Surabhi x TCH 1646) and 31.71% (MCU 5 x SOCC17), and mean was 22.34% for hybrids. A mean protein content of 32.7% was noticed among the 300 accessions analysed by Liu et al*.* (1994) in *Gossypium barbadense* which support the present study.

Expression of heterosis for yield attributing traits

The relative heterosis for plant height ranged from 3.6 in Surabhi x TCH 1644 to 17.9 in MCU 5 x TCH 1641 over mid parental value in positive direction (Table 4). Out of 27 hybrids, significant positive heterobeltiosis was observed in 19 hybrids, the range being 3.5 (Surabhi x TCH 1644) to 17.7 (MCU 5 x TCH 1641). These results find support from those of Sayal et al*.* (1999), Hassan et al*.* (1999) and Rauf et al., (2005) who observed considerable amount of heterosis for plant height. For number of sympodia, significant relative heterosis percent manifested the hybrids varied from, 10.89 in Surabhi x TCH 1646 to 27.09 in SVPR 2 x F 776 over mid parental value in positive direction. The heterobeltiosis effect was significant in positive direction in SVPR 2 x F 776 (26.25 per cent), SVPR 2 x SOCC 17 (22.09 per cent) and Surabhi x F 776 (12.69 per cent). Heterosis values were significantly positive in 16 cross combinations for relative heterosis and 15 hybrids were recorded significantly positive values over better parent. This is similar with earlier finding of Koodalingam et al*.* (1991) and Ganapathy and Nadarajan (2008). The hybrid MCU 12 x SOCC 17 recorded highest relative heterosis (29.15%) and heterobeltiosis (28.21%) whereas, the lowest relative heterosis (12.75%)

and heterobeltiosis (16.82%) were observed in the hybrid MCU 5 x F 776, and MCU 12 x SOCC 11, respectively. Ganapahty and Nadarajan, (2008), reported for number of bolls per plant, the highest relative heterosis (62.24%) and heterobeltiosis (53.19%) in the same hybrid CWROK 165 x MCU 7. This report also confirmed our results. Among 28 hybrids, four hybrids expressed significantly positive relative heterosis and three hybrids showed significantly positive heterosis values over better parent for number of bolls per plant (Table 4). Heterosis for boll weight significantly ranged from MCU 12 x TCH 1644 (10.29%) to SVPR 2 x TCH 1644(12.47 %), and four hybrids were significantly positive for relative heterosis. None of the hybrids had shown significant heterobeltiosis in the positive direction. Heterosis for number of seeds per boll ranged from -8.55 to 14.81% for relative heterosis and 11 hybrids for positive heterobeltiosis were observed (Ganapathy and Nadarajan, 2008). In this study, nineteen hybrids recorded significant relative heterosis ranging from 7.31% in MCU 5 x TCH 1644 to 22.95% in SVPR 2 x SOCC 11 and five hybrids registered significant positive heterobeltiosis for number of seeds per boll.

The heterotic expression of relative heterosis for ginning outturn was significant and positive in nine hybrids. Heterobeltiotic effect was positive in three hybrids. The highest positive relative heterosis (18.29%) and heterobeltiosis (11.48%) were observed in same hybrid SVPR 2 x SOCC 17. Earlier researcher (Rauf et al., 2005) reported two F_1 hybrids that had 12.64 and 22.95% for ginning outturn relative heterosis and heterobeltiosis. Also, these results are in accordance with those of Zhang et al*.* (1994) and Soomro (2000). Relative heterosis effect for lint index was positive in two hybrids , and none of the hybrids were found to be significant over the parent (Table 4). For seed index, relative heterosis values was positive and significant in MCU 5 x TCH 1646 (27.17%) and SVPR 2 x TCH 1646 (21.20%). Significant positive heterobeltiosis values were registered by two hybrids MCU 5 x TCH 1646 and SVPR 2 x TCH 1646 recorded 19.33 and 21.00%, respectively. Virk and Kalsy (1982), Khan (1986), and Rahman et al. (1993) also reported positive heterosis as well as heterobeltiosis for seed index.

Expression heterosis for seed cotton yield

For seed cotton yield, 26 hybrids displayed significant positive heterosis over mid parental value with a range of 12.22% in SVPR 2 x SOCC 11 to 61.34% in MCU 12 x SOCC 17. Significant positive heterobeltiotic effect over better parent was observed in 20 hybrids for seed cotton yield. Ganapathy and Nadarajan (2008) also reported positive heterobeltiotic effect over better parent 20 hybrids for seed cotton yield. Similar results were already reported by Chaudhari et al. (1992) for seed cotton yield. Among them, hybrid MCU 12 x F 1861(52.52%) registered highest positive heterobeltiosis over better parent value with highest *per se* performance of 145.41 g/plant. This same hybrid also expressed significant positive heterosis for number of bolls per plant, boll weight and lint index. The hybrid MCU 12 x F 1861 is the best combination in the present study, for direct exploitation. The results suggested that high yield does not necessarily depend on high heterotic expression for all the yield components and high heterosis for some or few of component traits, which are ultimately associated with yield, can generate significant yield heterosis (Kapoor et al*.,* 2002).

Expression of heterosis for seed oil and protein content

Eight hybrids exhibited significant positive relative heterosis over mid parent, and among them Surabhi x F 1861 (20.46%) exhibited highest relative heterosis over mid parent. Six hybrids exhibited significant positive heterobeltiosis for seed oil content. Of these, hybrid SVPR 2 x SOCC 11 (15.64%) exhibited the highest hetero-beltiosis (Table 5). Ganapathy and Nadarajan (2008) reported 19 hybrids had positive heterosis over mid parent and 14 hybrids over better parent for seed oil content and these results confirmed our studies. Similar results were also reported by earlier researchers (Dani, 1988; Kapoor et al*.*, 1994; Kowsalya et al*.*, 1999) in cotton. The hybrid Surabhi x TCH 1646 exhibited highest *sca* effects 2.36 with highest mean performance 22.90% of seed oil content. The same hybrid also exhibited positive heterosis over mid parent up to the extent of 15.46% and over better parent with a value of 13.29%. This hybrid is the best combination in the present study for direct seed oil content exploitation. Positive heterosis for cotton seed oil content was already reported by earlier workers (Kashalkar et al*.,* 1989; Kowsalya et al*.,* 1999; Manimaran and Raveendran, 2004; Ganapathy and Nadarajan, 2008).

Twelve (12) hybrids exhibited positive significant relative heterosis over mid parent for seed protein content (Table 5). Among these, hybrid Surabhi X SOCC 17 exhibited highest relative heterosis (35.40%) over mid parent. The same hybrid Surabhi X SOCC 17 also exhibited highest heterobeltiotic effect (29.66%). Kowsalya et al*.* (1999) reported positive heterotic expression over mid and better parent for seed protein content in cotton and it is supported our results.

Conclusion

Cottonseed oil is edible oil extracted from the seeds of cotton plant of several species, primarily *G. hirsutum* and *Gossypium herbaceum*. Cotton seed meal is used principally as a protein concentrate feed for livestock. Presently, human population growth is rapidly increasing throughout the world, and this condition, we need to fulfill the consumer edible oil requirement. Nowadays, cotton crop is primarily cultivated for fibre production in most of the countries worldwide. In addition, cotton seed also had the sufficient amount of oil and protein content. Therefore, the present studies were made to improve seed oil content along with higher seed cotton yield by Line x Tester analysis. The present study results show that F_1 hybrid mean values were higher than for parents for all the 11 traits. In addition, the hybrid MCU 12 x SOCC 17 exhibited higher *per se* performance and heterotic effect for seed cotton yield along with seed oil content, and MCU 5 x SOCC 17 recorded more seed protein combined with seed cotton yield. Surabhi x TCH 1646 exhibiting highest *per se* performance and heterotic effect for seed oil content was found to be best for directional selection. The highest heterosis was observed for seed cotton yield and cottonseed oil followed by other traits. An increase in cottonseed oil, seed protein, seed cotton yield and other traits will be a valuable addition to cotton cultivars.

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