Received: 18 Apr 2020 | Revised: 15 Apr 2021 | Accepted: 18 Apr 2021

Electronic Journal of Plant Breeding

Research Article

Gene action, combining ability and standard heterosis for seed cotton yield and fibre quality components in upland cotton

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Abstract

Twelve parental genotypes and twenty F_1 hybrids developed in a Line x Tester fashion were used in the present study to estimate gene action, combining ability and standard heterosis for eleven quantitative and five quality traits in cotton. All the traits studied exhibited greater SCA variance than GCA except days to fifty per cent flowering suggesting that these traits are controlled by dominant gene action. Among the parents used, SVPR 2 and TSH 325 were detected with higher general combining ability for seed cotton yield and should be given importance while developing hybrids or recombinants. The hybrids namely SVPR 2 x TSH 325, SVPR 2 x Suraj and GJHV 370 x PBH 116 were identified as the best hybrids for seed cotton yield and SVPR 2 x TCH 1828 for fibre properties and recommended for heterosis breeding. Besides, the hybrid between GJHV 370 x CPD 1702 was suggested for recombination breeding for earliness and ginning percentage as it fulfilled the criteria of non-significant *sca* effects for hybrid and significant *gca* effects for respective parents.

Key words

Cotton, line x tester, combining ability, heterosis, fibre properties, yield

INTRODUCTION

Cotton is well known as the "white gold" and cultivated by about 80 countries in the world. The requirement of cotton is rising at a rapid pace than the population growth rate and hence increase in the yield per unit area is the need of the hour. To make the productivity of Indian cotton comparable to other leading countries like USA and China, there is a need to give more importance on the degree of heterosis, the mean performance and potency of genotypes. The concept of combining ability helps in the identification of good parents and development of elite lines or hybrids. Utilization of hybrid vigour has become prospective tool for the improvement of this crop. The selection of appropriate parents for the improvement of elite hybrid depends on the selection of parents based on combining ability. Combining ability investigation provides the information for choice of the desirable parents and cross combinations for its exploitation (Sprague and Tatum, 1942). Application of appropriate biometrical techniques namely line x tester analysis has appeared to be the best and useful breeding tool, which gives comprehensive picture of genetics of the characters under study. Study of gene action involved is very crucial for choosing of desirable parents and crosses for cotton yield improvement and has been reported by several scientists *viz.,* Babu *et al.* (2017) and Kumbhalkar *et. al.* (2018). Present investigation was carried out with the objectives to study gene action, combining ability and standard heterosis for seed cotton yield, yield components and fibre quality traits in cotton.

MATERIALS AND METHODS

The investigation was undertaken during the winter 2019 in the research farm of Cotton Research Station, Srivilliputtur, Tamil Nadu, India under irrigated condition.

Twelve parents, among which two lines *viz.,* SVPR 2 and GJHV 370 and ten testers *viz.,* PBH 116, CSH 3419, CPD 1702, TCH 1828, RAH 0603, RS 2913, F 2596, BGDS 0607, TSH 325 and Suraj were used for hybridization. Individual female lines were crossed with all the ten male parents separately in a line x tester mating design (Kempthorne, 1957) to generate twenty hybrids during the winter, 2018. Thus the twenty intra-*hirsutum* hybrids were developed by hand emasculation and pollination method developed by Doak (1934).

Twenty hybrids along with twelve parents and two standard checks (RCH 659 BG II and Mallika NBt.) were raised during the winter 2019 in three replications in a randomized block design (RBD). Each genotype was raised in a row of 4.5 m length and spacing adopted was 100 x 45 cm. Recommended agronomic practices and need based plant protection measures were adopted.

Five plants from each parents, F_1s and check hybrids were selected randomly per replication and tagged with labels for recording observations for sixteen characters *viz*., days to first flowering ,days to fifty per cent flowering, plant height (cm), the number of monopodia per plant, the number of sympodia per plant, the number of bolls per plant, boll weight (g), seed index, lint index, ginning percentage, seed cotton yield (kg/ha), upper half mean length (mm), bundle strength (g/tex), fibre fineness (µ), uniformity index (%) and fibre elongation (%). The average values obtained from the observations was denoted as the mean of that genotype per replication. The data on five fibre quality properties *viz.,* upper half mean length (mm), bundle strength (g/tex), fibre fineness (µ), uniformity index(%) and fibre elongation (%) for each replication were recorded with High Volume Instrument (HVI) under HVI mode. The recorded mean values were subjected to statistical analysis using TNAU Stat package for getting gene action, combining ability and standard heterosis. The estimation of heterosis was done by calculating the superiority of the F_1 over standard check (Mallika NBt.).

Table 1. Analysis of variance for various yield components and fibre quality traits

Source of Variation	DF	DFF	DFPF	PH	NMP	NSyP	NB	BW	SI	LI	GP	SCY	UHML	BS	FF	UI	FE
Replication	2	2.70	3.17	23.30	0.01	0.72	8.14	0.29	2.04	0.69	0.36	15280.64	0.20	0.01	0.07	0.12	0.16
Genotypes	34	9.36*	9.74*	92.35*	0.32*	1.4*	45.96*	0.37*	1.47*	0.87*	18.68*	539855.18*	1.95*	1.53*	0.32*	0.55*	0.02*
Crosses	19	6.38*	7.15*	90.96*	0.46*	1.39*	54.62*	0.18*	1.63*	0.83*	20.16*	534654.68*	1.43*	1.37*	0.17*	0.68*	0.01*
Parents	11	12.99*	12.45*	97.58*	0.09*	1.53*	34.50*	0.33*	1.25ns	0.55*	12.48*	357207.54*	2.82*	1.93*	0.51*	0.34*	0.02*
Error	64	1.25	1.64	20.18	0.02	0.73	3.36	0.08	0.79	0.26	3.01	25879.45	0.004	0.01	0.004	0.01	0.01

*Significant at 5 % level

Table 2. Analysis of variance for combining ability for various yield components and fibre quality traits

Source of Variation	df	DFF	DFPF	PH	NMP	NsyP	NBP	BW	SI	LI	GP	SCY	UHML	BS	FF	UI	FE
Replication	2	5.45	7.27	27.99	0.01	0.31	7.73	0.32	3.57	1.09	0.44	3857.82	0.11	0.05	0.05	0.11	0.15
Crosses	19	6.38*	7.15*	90.96*	0.46*	1.39*	54.62*	0.18*	1.63*	0.83*	20.16*	534654.68*	1.43*	1.37*	0.17*	0.68*	0.01*
Lines	1	72.60*	86.40*	122.12*	0.11*	0.42ns	40.67*	0.003	2.73	7.35*	221.57*	1168452.15*	1.84*	0.22*	0.22*	0.12*	0.01
Testers	9	3.77*	5.03*	104.49*	0.33*	2.56*	60.95*	0.21*	2.25*	0.70*	8.33*	669713.20*	1.76*	1.06*	0.21*	0.67*	0.02*
Line × Tester	9	1.64	0.47	73.97*	0.64*	0.32	49.85*	0.17*	0.90	0.23	9.60*	329174.22*	1.06*	1.81*	0.12*	0.75*	0.01*
Error	38	1.01	0.67	22.46	0.02	0.78	4.30	0.08	0.69	0.22	2.98	26437.06	0.005	0.01	0.004	0.005	0.003
GCA		0.11	0.15	0.38	-0.002	0.02	0.11	0.0002	0.02	0.01	0.24	4647.77	0.01	-0.01	0.001	-0.002	0.0001
SCA		0.21	-0.07	17.17	0.21	-0.15	15.18	0.03	0.07	0.004	2.21	100912.39	0.35	0.60	0.04	0.25	0.001
GCA/SCA		0.51	-2.31	0.02	-0.02	-0.16	0.01	0.01	0.24	3.05	0.11	0.05	0.02	-0.02	0.03	-0.01	0.09

*Significant at 5 % level

Days to first flowering (DFF) ,days to fifty per cent flowering (DFPF), plant height (PH) (cm), number of monopodia per plant (NMP), number of sympodia per plant (NSyP), number of bolls per plant (NB), boll weight (g) (BW), seed index (SI), lint index (LI), ginning percentage (GP), seed cotton yield (SCY) (kg/ha), upper half mean length (UHML) (mm), bundle strength (BS)(g/tex), fibre fineness (FF) (µ), uniformity index (UI)(%) and fibre elongation (FE) (%).

RESULTS AND DISCUSSION

The significant differences among parents and hybrids showed the presence of sufficient genetic diversity for all the characters studied (**Table 1**). The considerable differences between the traits were observed among the parents and hybrids studied except seed index in parents. The estimation of the mean sum of squares of the combining ability studies (**Table 2**) disclosed significant differences in the female parents for all the traits studied except the number of sympodia per plant, boll weight, seed index and fibre elongation. Likewise male parents exhibited significant differences for seed cotton yield, yield contributing traits and fibre property traits while the interaction between female and male parents have significant variation for the most of the characters under examined which was in agreement with the earlier reports made by Sivia *et al.* (2017), Monicashree *et al.* (2017), Kumbhalkar *et al.* (2018), Gnanasekaran *et al.* (2019), Thiyagu *et al.* (2019) and Gnanasekaran *et al.* (2020). The dominance variance is higher than the additive variance for all the biometric traits and fibre properties except days to fifty per cent flowering indicating the preponderance of dominance gene action. The proportion between additive (δ^2 GCA) and dominance (δ^2 SCA) variance is less than one for sixteen traits studied except days to fifty per cent flowering indicating predominance of non-additive gene action which is an imperative in exploitation of heterosis by heterosis breeding. This result was similar to findings of Usharani *et al.* (2016), Vekariya *et al.* (2017)**,** Monicashree *et al.* (2017), Khokhar *et al.* (2018), Gnanasekaran *et al.* (2019), Thiyagu *et al.* (2019) and Gnanasekaran *et al.* (2020). The traits *viz.*, the number of monopodia per plant, the number of sympodia per plant, the number of bolls per plant, boll weight and seed cotton yield per plant,

Table 3. Proportional contribution of lines, testers and their interactions for various yield components and fibre quality traits (Per cent)

Particulars	DFF	DFPF	PH	NMP	NsyP	NBP	BW	SI	LI	GP	SCY	UHML	BS	FF	UI	FE
Lines	59.87	63.56	7.07	1.29	1.58	3.92	0.08	8.8	46.83	57.85	11.5	6.76	0.83	6.82	0.94	2.94
Testers	27.98	33.3	54.41	33.4	87.39	52.85	54.98	65.17	39.86	19.58	59.33	58.25	36.61	59.48	46.76	70.59
Line × Tester	12.15	3.14	38.52	65.31	11.03	43.23	44.94	26.04	13.32	22.57	29.16	35.00	62.56	33.7	52.3	26.47

Table 4. Mean performance of parents for yield components and fibre quality traits

Parents/Traits	DFF	DFPF	PH	NMP	NsyP	NBP	BW	SI	LI	GP	SCY	UHML	BS	FF	UI	FE
Lines																
SVPR 2	56.00	60.00	110.67*	0.87*	14.53*	26.87*	4.77*	9.47	4.90	33.90	1842.00*	26.50	26.80	4.77	82.70	5.60
GJHV 370	51.00*	54.67*	91.13	0.73	12.13	19.40	4.10	8.67*	5.60	39.37*	1407.33	27.60*	27.50*	4.53*	83.00*	5.60
Mean	**53.50**	**57.33**	**100.90**	**0.80**	**13.33**	**23.13**	**4.43**	**9.07**	**5.25**	**36.63**	**1624.67**	**27.05**	**27.15**	**4.65**	**82.85**	**5.60**
Testers																
PBH 116	50.00*	54.00	92.0	0.20	13.13	28.73*	4.57*	9.53	5.07	34.87	2360.33*	26.00	27.30	4.87	82.70	5.70
CSH 3419	51.00	55.00	98.87	0.47	14.60	23.87*	4.00	8.57*	5.13	37.4	1585.33	26.80	27.50	4.10*	83.30	5.60
CPD 1702	49.33*	52.00*	89.87	0.67	13.53	20.80	4.57*	9.33	5.70	37.77	1152.67	28.50*	27.30	4.43*	83.60*	5.60
TCH 1828	51.00	54.33	96.53	0.67	14.40	21.20	4.77*	10.57	5.30	33.40	1305.33	28.50*	28.80*	4.50*	83.70*	5.70
RAH 0603	53.33	57.00	95.73	0.60	13.87	19.2	3.90	8.93	4.93	35.40	1714.67*	26.30	26.70	4.03*	82.90	5.50
RS 2913	52.00	55.67	98.53	0.60	14.20	20.80	4.17	9.33	5.23	35.93	1298.00	27.70*	28.50*	4.57*	83.50*	5.70
F 2596	49.67*	54.00	101.67*	0.80	14.20	20.80	3.83	9.33	5.33	36.43	1506.00	25.60	27.30	4.70	83.10	5.60
BGDS 0607	50.33	53.33*	95.67	0.60	14.20	19.73	4.03	8.57*	5.50	39.00*	1103.00	27.00	29.20*	4.60	83.50*	5.70
TSH 325	54.67	55.67	93.67	0.73*	14.40	27.13*	4.47	10.4	6.43*	38.27*	1727.70*	26.20	27.60	5.63	83.10	5.60
Suraj	53.00	56.33	92.20	0.73*	14.27	19.87	4.37	9.03	5.73	38.90*	1473.33	27.80*	28.50*	4.90	83.30	5.80*
Mean	**51.43**	**54.73**	**95.47**	**0.61**	**14.08**	**22.21**	**4.27**	**9.36**	**5.44**	**36.74**	**1522.63**	**27.04**	**27.87**	**4.63**	**83.27**	**5.65**
Grand Mean	**51.78**	**55.17**	**96.38**	**0.64**	**13.96**	**22.37**	**4.29**	**9.31**	**5.41**	**36.72**	**1539.64**	**27.04**	**27.75**	**4.64**	**83.20**	**5.64**
SEd	**0.91**	**1.05**	**3.67**	**0.11**	**0.70**	**1.50**	**0.24**	**0.73**	**0.41**	**1.42**	**131.35**	**0.05**	**0.08**	**0.05**	**0.07**	**0.06**

*Significant at 5 % level

Days to first flowering (DFF) ,days to fifty per cent flowering (DFPF), plant height (PH) (cm), number of monopodia per plant (NMP), number of sympodia per plant (NSyP), number of bolls per plant (NB), boll weight (g) (BW), seed index (SI), lint index (LI), ginning percentage (GP), seed cotton yield (SCY) (kg/ha), upper half mean length (UHML) (mm), bundle strength (BS)(g/tex), fibre fineness (FF) (µ), uniformity index (UI)(%) and fibre elongation (FE) (%).

non-additive gene action was appeared to be dominant and this was confirmed with the findings of Sivia *et al.* (2017), Monicashree *et al.* (2017) and Khokhar *et al.* (2018) while Ali and Khan (2007) reported the dominance of additive type of gene action for the number of monopodia per plant and the number of sympodia per plant. Natera e*t al.* (2012) showed additive genetic effects for the number of bolls per plant and boll weight and Yanal *et al.* (2013) for seed cotton yield. Non-additive genetic effect was observed for days to first flowering, upper half mean length and fibre strength and these were confirmed with earlier finding of Monicashree *et al.* (2017) whereas both additive and non-additive type of gene action was observed by Rauf *et al.* (2006). Thus the results obtained from the present investigation will be very helpful to cotton breeder in handling the breeding materials. Low heritability reported by crop researcher for non-additive gene action suggesting to postpone the selection for a specific traits in early generations (Falconer and Macky, 1996).

The relative contribution of the female, male parents and their interactions are presented in T**able 3**. The proportional contribution of lines was more for days to first flowering, days to fifty percent flowering, lint index, ginning percentage whereas line x tester interaction was higher for the number of monopodia per plant, bundle strength and uniformity index. The male parents showed the highest proportional contribution for remaining traits. Similar results that is proportional contribution by lines, testes and line x tester interaction was reported for some of the traits under study by Monicashree *et al.* (2017) and Gnanasekaran *et al.* (2020). Contrary to the findings of present study, Thiyagu *et al.* (2019) reported that the proportional contribution by interactions is more for all traits under study.

Selection of parents for enhancement of yield and fibre quality characters is a critical step in cotton breeding programme. Parents are selected based on their mean performance and also their general combining ability effects. Parents with high mean performance and parents with positively significant *gca* effects were generally preferred for all the traits except days to first flowering , days to fifty present flowering, seed index and fibre fineness. The mean performance and general combining ability effects of the parents are given in **Table 4 and 5**. Taking into consideration of *per se* performance and *gca* effects (**Table 6**) for seed cotton yield and fibre properties, the line GJHV 370 registered significant *per se* and *gca* effect for five characters *viz.*, days to first flowering (51.0, -1.10), days to fifty per cent flowering (54.7, -1.20), ginning percentage (39.37, 1.92), bundle strength (27.5, 0.06), uniformity index (4.53, 0.05) and SVPR 2 was the good combiner for the number of bolls per plant (26.87, 0.82) and seed cotton yield (1842.0, 139.55). Among male parents, CPD 1702 was recorded a significant mean and

Table 5. General combining ability effects of parents for yield components and fibre quality traits

Parents/ Traits	DFF	DFPF	PH	NMP	NsyP	NBP	BW	SI	LI	GP	SCY	UHML	BS	FF	UI	FE
Lines																
SVPR 2	1.10 **	1.20 **	1.43	0.04	0.08	0.82 *	0.01	0.21	-0.35 **	-1.92 **	139.55 **	0.17 **	-0.06 **	-0.06 **	-0.05 **	-0.01
GJHV 370	-1.10 **	-1.20 **	-1.43	-0.04	-0.08	-0.82 *	-0.01	-0.21	0.35 **	1.92 **	-139.55 **	-0.17 **	0.06 **	0.06 **	0.05 **	0.01
SEd	**0.26**	**0.21**	**1.22**	**0.04**	**0.23**	**0.54**	**0.07**	**0.21**	**0.12**	**0.45**	**41.98**	**0.02**	**0.02**	**0.02**	**0.02**	**0.01**
Testers																
PBH 116	-0.70	-1.53 **	-2.29	-0.33 **	-0.83 *	0.43	0.17	1.12 **	0.38	-1.14	412.15 **	-0.23 **	-0.70 **	0.19 **	0.00	-0.06 **
CSH 3419	-0.20s	-0.70 *	-0.66	-0.03	0.04	-1.90 *	0.02	-0.18	-0.57 **	-2.02 **	-292.18 **	0.16 **	-0.25 **	-0.19 **	-0.29 **	-0.06 **
CPD 1702	-1.37 **	-0.70 *	-4.06 *	0.14 *	0.17	-2.84 **	-0.00	-0.06	0.31	1.48 *	-404.35 **	0.26 **	-0.30 **	-0.06 *	0.50 **	-0.06 **
TCH 1828	0.97 *	1.13 **	1.31	0.24 **	0.57	-0.74	-0.32 **	-0.73 *	-0.19	1.19	-174.52 *	1.21 **	0.90 **	-0.26 **	0.55 **	-0.06 **
RAH 0603	1.47 **	1.47 **	-6.09 **	0.04	-0.43	-2.84 **	-0.08	0.04	-0.17	-0.74	-331.02 **	-0.33 **	-0.00	-0.24 **	-0.14 **	0.04
RS 2913	-0.03	0.80 *	4.47 *	-0.36 **	0.37	3.30 **	-0.15	-0.58	-0.44 *	-0.29	70.15	-0.78 **	-0.15 **	0.08 **	-0.10 **	0.04
F 2596	-0.20	-0.03	1.31	0.17 **	-0.53	0.83	-0.03	-0.21	-0.02	0.30	-60.52	-0.19 **	-0.05	0.01	-0.54 **	0.04
BGDS 0607	-0.20	-0.37	-0.43	0.34 **	-0.20	-3.37 **	-0.00	-0.06	0.21	0.90	-10.02	0.32 **	0.15 **	0.08 **	-0.04	0.04
TSH 325	-0.03	-0.03	8.37 **	-0.16 **	1.37 **	6.93 **	0.40 **	1.02 **	0.41 *	-0.82	644.98 **	-0.38 **	0.15 **	0.31 **	-0.09 **	0.04
Suraj	0.30 ns	-0.03	-1.93	-0.03	-0.53	0.20	0.00	-0.35	0.06	1.14	145.32 *	-0.04	0.25 **	0.08 **	0.15 **	0.04
SEd	**0.58**	**0.47**	**2.74**	**0.08**	**0.51**	**1.20**	**0.16**	**0.48**	**0.27**	**1.00**	**93.9**	**0.04**	**0.05**	**0.03**	**0.04**	**0.03**

*Significant at 5 % level, ** Significant at 1 % level

Days to first flowering (DFF) ,days to fifty per cent flowering (DFPF), plant height (PH) (cm), number of monopodia per plant (NMP), number of sympodia per plant (NSyP), number of bolls per plant (NB), boll weight (g) (BW), seed index (SI), lint index (LI), ginning percentage (GP), seed cotton yield (SCY) (kg/ha), upper half mean length (UHML) (mm), bundle strength (BS)(g/tex), fibre fineness (FF) (µ), uniformity index (UI)(%) and fibre elongation (FE) (%).

https://doi.org/10.37992/2021.1202.048

Table 6. Parents chosen based on mean and general combining ability effects

Traits	Line	Tester
DFF	GJHV 370 (51.0*, -1.10**)	CPD 1702 (49.33*, -1.37**)
DFPF	GJHV 370 (54.7*, -1.20**)	CPD 1702 (52.0*, -0.70*)
NBP	SVPR 2 (26.87*, 0.82*)	TSH 325 (27.13*, 0.40**)
LI	-	TSH 325 (6.43*, 0.41*)
GP	GJHV 370 (39.37*, 1.92**)	-
UHML	-	CPD 1702 (28.5*,0.26**), TCH 1828 (28.5*, 1.21**)
BS	GJHV 370 (27.5*, 0.06**)	TCH 1828 (28.8*, 0.90**), BGDS 0607 (29.2*, 0.15**), Suraj (28.5*, 0.15**)
FF	-	CSH 3419 (4.1*, -0.19**), CPD 1702 (4.43*, -0.06**), TCH 1828 (4.5*, -0.26**), RAH 0603 (4.03*, -0.24**)
UI	GJHV 370 (4.53*, 0.05**)	CPD 1702 (83.6*, 0.50**), TCH 1828 (83.7*, 0.55**)
SCY	SVPR 2 (1842.0*, 139.55**)	PBH 116 (2360.33*, 412.15**), TSH 325 (1727.7*, 644.98**)

*Significant at 5 % level, ** Significant at 1 % level
Days to first flowering (DFF) ,days to fifty per cent flowering (DFPF), plant height (PH) (cm), number of monopodia per plant (NMP), number of sympodia per plant (NSyP), number of bolls per plant (NB), boll weight (g) (BW), seed index (SI), lint index (LI), ginning percentage (GP), seed cotton yield (SCY) (kg/ha), upper half mean length (UHML) (mm), bundle strength (BS)(g/tex), fibre fineness (FF) (μ), uniformity index (UI)(%) and fibre elongation (FE) (%).

gca effects for five traits *viz*., days to first flowering (49.33, -1.37), days to fifty per cent flowering (52.0, -0.70), upper half mean length (28.5, 0.26), fibre fineness (4.43, -0.06) and uniformity index (83.6, 0.50) followed by TCH 1828 for four traits namely upper half mean length (28.5, 1.21), bundle strength (28.8, 0.90), fibre fineness (4.5, -0.26) and uniformity index (83.7, 0.55). The tester TSH 325 was the good combiner for the number of bolls per plant (27.13, 0.40), lint index (6.43, 0.41) and seed cotton yield (1727.7, 644.98). The remaining male parents were the good general combiner for one traits each ie., PBH 116 (2360.33, 412.15) for seed cotton yield**;** BGDS 0607 (29.2, 0.15) and Suraj (28.5, 0.15) for bundle strength**;** CSH 3419 (4.1, -0.19) and RAH 0603 (4.03, -0.24) for fibre fineness **.** The parents having positive and significant value for both *per se* and *gca* effects may have more number of additive genes and could help to accumulate favourable genes in a particular genotypes. Non association between *per se* and the *gca* effects of parents, either high mean with low *gca* effect or *vice versa* signify that the particular trait is probably under the control of non-additive gene action. Based on the present study, an attempt can be made for picking enviable hybrids through multiple crosses for yield and fibre quality traits in the segregating generations, as none of the parent was found to be a good combiner for all the traits under the study as reported in their earlier study by Sivia *et al.* (2017), Monicashree *et al.* (2017), Khokhar *et al.* (2018), Kumbhalkar *et al.*(2018), Gnanasekaran *et al.* (2019), Thiyagu *et al.* (2019) and Gnanasekaran *et al.* (2020).

The foremost objective of hybridization is to assemble the enviable genes present in two or more diverse parents into a single genetic background and also to create new variation. The hybrids developed are critically analyzed for their *per se* performance, specific combining ability effects and heterosis over a standard check (Mallika NBt.) in order to recommend the hybrids to follow heterosis breeding or to fallow recombination breeding procedures. *Per se*, *sca* effects and standard heterosis of hybrids for yield components and fibre quality traits are presented in **Table 7a, 7b and 7c**. The utilization of hybrids in anyone of the two ways will depend upon the genetic constitution of the parents as well as the hybrids. To exploit the hybrid vigour, the parameters like *per se* performance; *sca* effects and standard heterosis of hybrids have to be taken into account. Low *per se*, negative *sca* effects and standard heterosis were taken into consideration for days to first flowering, days to fifty per cent flowering, seed index and fibre fineness.

Hybrids for heterosis breeding were chosen based on the criterion *viz*., significant *per se*, *sca* effects and standard heterosis for important traits. Seed cotton yield and fibre properties like upper half mean length and fibre strength are the important economic traits in cotton and with this perspective, the hybrids SVPR 2 x TSH 325 (2861.33, 194.12, 32.71), SVPR 2 x Suraj (2428.67, 261.12, 12.65) and GJHV 370 x PBH 116 (2688.33, 533.05, 24.69) for seed cotton yield and SVPR 2 x TCH 1828 for fibre properties were selected as the best hybrids for the exploitation through heterosis breeding for traits as pointed out (**Table 8**). Similar results for yield and fibre quality traits have also been reported by Monicashree *et al.* (2017), Khokhar *et al.* (2018); Kumbhalkar *et al.* (2018), Gnanasekaran *et al.* (2019), Thiyagu *et al.*(2019) and Gnanasekaran *et al.* (2020).

Recombination breeding permits further accumulation of alleles in segregating generations, so that we could acquire genotypes with desirable combination of alleles for the traits of interest under improvement. Selection

https://doi.org/10.37992/2021.1202.048

Table 7a. Mean performance of crosses for yield and fibre quality traits

CROSS	DFF	DFPF	PH	NMP	NsyP	NBP	BW	SI	LI	GP	SCY	UHML	BS	FF	UI	FE
SVPR 2 x PBH 116	50.33	53.33	93.67	0.20	13.20	17.73	5.00*	10.40	5.93	36.37	1901.33	26.40	27.30	4.63	83.60*	5.50
SVPR 2 x CSH 3419	51.67	54.67	99.07	0.87*	13.80	19.00	4.60	9.20	5.33	36.63	1707.67	26.90*	27.10	4.03	82.70	5.50
SVPR 2 x CPD 1702	51.00	54.67	98.27	1.27*	14.33	21.33	4.77	9.87	5.87	37.43	1519.00	28.00*	28.00*	4.20	84.10*	5.50
SVPR 2 x TCH 1828	52.67	56.33	100.47	1.13*	14.60*	22.73	4.57	9.53	5.23	35.50	1686.00	28.50*	28.70*	4.10	84.20*	5.50
SVPR 2 x RAH 0603	53.00	56.67	96.20	0.53	13.67	22.20	4.67	9.63	5.53	36.63	1658.33	26.60	27.40	3.97*	83.00	5.60
SVPR 2 x RS 2913	52.00	56.00	97.33	0.33	14.27	27.47*	4.70	9.63	5.23	35.23	2259.33*	26.20	27.70	4.50	83.20	5.60
SVPR 2 x F 2596	52.00	55.33	100.00	0.53	13.67	26.40*	4.33	9.17	5.53	37.43	2154.67*	26.40	27.50	4.63	82.60	5.60
SVPR 2 x BGDS 0607	50.67	54.33	98.40	0.60	13.93	20.33	4.97*	9.17	5.47	37.37	2046.00*	26.50	26.50	4.43	82.50	5.50
SVPR 2 x TSH 325	52.00	55.33	107.47*	0.20	14.80*	32.33*	5.10*	11.03	5.90	34.93	2861.33*	26.60	27.80*	4.83	82.90	5.60
SVPR 2 x Suraj	52.67	55.67	103.67*	0.07	13.53	28.07*	4.70	9.30	5.33	36.63	2428.67*	27.00*	28.40*	4.30*	83.70*	5.60
GJHV 370 x PBH 116	49.67*	51.67*	97.80	0.20	12.93	29.00*	4.80	10.80	6.60*	38.03	2688.33*	26.60	26.70	4.60	83.00	5.50
GJHV 370 x CSH 3419	49.33*	52.00*	95.67	0.13	14.07	23.07	4.90	9.40	5.30	36.00	1473.33	26.90*	27.80*	4.43	83.30	5.50
GJHV 370 x CPD 1702	47.67*	52.00*	89.67	0.07	13.80	18.87	4.70	8.97	6.53*	42.20*	1437.67	26.00	26.80	4.53	83.50*	5.50
GJHV 370 x TCH 1828	50.67	54.00	98.20	0.40	14.33	21.67	4.27	7.97*	6.17	43.57*	1730.33	27.40*	28.50*	4.23*	83.50*	5.50
GJHV 370 x RAH 0603	51.33	54.33	87.67	0.60	13.27	18.00	4.63	9.40	5.90	38.57	1445.00	26.20	28.00*	4.40	83.30	5.60
GJHV 370 x RS 2913	49.33*	53.67	107.67*	0.00	14.27	25.00*	4.47	8.17*	5.67	40.87*	1646.33	25.70	27.40	4.50	83.20	5.60
GJHV 370 x F 2596	49.00*	52.67*	98.67	0.87*	13.07	21.13	5.07*	9.37	6.20	39.83*	1489.67	26.70	27.80*	4.23*	82.90	5.60
GJHV 370 x BGDS 0607	50.33	53.00	96.80	1.13*	13.47	18.80	4.50	9.67	6.73*	41.10*	1699.33	27.60*	29.20*	4.57	84.00*	5.70*
GJHV 370 x TSH 325	49.33*	52.67*	105.33*	0.53	15.73*	27.40*	5.17*	9.97	6.70*	40.10*	2194.00*	26.10	27.90*	4.63	83.50*	5.60
GJHV 370 x Suraj	49.33*	52.33*	88.53	0.93*	13.20	18.20	4.77	8.97	6.57*	42.33*	1627.33	26.40	27.50	4.70	83.20	5.60
Mean	**50.70**	**54.03**	**98.03**	**0.53**	**13.90**	**22.94**	**4.73**	**9.48**	**5.89**	**38.34**	**1882.68**	**26.74**	**27.70**	**4.42**	**83.29**	**5.56**
SEd	**0.91**	**1.05**	**3.67**	**0.11**	**0.70**	**1.50**	**0.24**	**0.73**	**0.41**	1.42	**131.35**	**0.05**	**0.08**	**0.05**	**0.07**	**0.06**

*Significant at 5 % level

Days to first flowering (DFF) ,days to fifty per cent flowering (DFPF), plant height (PH) (cm), number of monopodia per plant (NMP), number of sympodia per plant (NSyP), number of bolls per plant (NB), boll weight (g) (BW), seed index (SI), lint index (LI), ginning percentage (GP), seed cotton yield (SCY) (kg/ha), upper half mean length (UHML) (mm), bundle strength (BS)(g/tex), fibre fineness (FF) (µ), uniformity index (UI)(%) and fibre elongation (FE) (%).

Table 7b. Specific combining ability effects of crosses for yield and fibre quality traits

CROSS	DFF	DFPF	PH	NMP	NsyP	NBP	BW	SI	LI	GP	SCY	UHML	BS	FF	UI	FE
SVPR 2 x PBH 116	-0.77	-0.37	-3.49	-0.04 ns	0.05	-6.46 **	0.09	-0.41	0.02	1.09	-533.05 **	-0.28 **	0.36 **	0.08 *	0.34 **	0.01
SVPR 2 x CSH 3419	0.07	0.13	0.27	0.32 **	-0.22	-2.86 *	-0.16	-0.31	0.37	2.24 *	-22.38	-0.17 **	-0.29 **	-0.14 **	-0.26 **	0.01
SVPR 2 x CPD 1702	0.57	0.13	2.87	0.56 **	0.18	0.41	0.03	0.24	0.02	-0.46	-98.88	0.83 **	0.66 **	-0.11 **	0.34 **	0.01
SVPR 2 x TCH 1828	-0.10	-0.03	-0.29	0.32 **	0.05	-0.29	0.14	0.57	-0.12	-2.11 *	-161.72	0.38 **	0.16 **	-0.01	0.40 **	0.01
SVPR 2 x RAH 0603	-0.27	-0.03	2.84	-0.08	0.12	1.28	0.01	-0.10	0.17	0.95	-32.88	0.03	-0.24 **	-0.16 **	-0.10 *	0.01
SVPR 2 x RS 2913	0.23	-0.03	-6.59 *	0.12	-0.08	0.41	0.11	0.52	0.13	-0.90	166.95	0.08	0.21 **	0.06	0.05	0.01
SVPR 2 x F 2596	0.40	0.13	-0.76	-0.21 *	0.22	1.81	-0.37 *	-0.31	0.02	0.72	192.95 *	-0.33 **	-0.09	0.26 **	-0.11 *	0.01
SVPR 2 x BGDS 0607	-0.93	-0.53	-0.63	-0.31 **	0.15	-0.06	0.23	-0.46	-0.28	0.05	33.78	-0.73 **	-1.29 **	-0.01	-0.70 **	-0.09 **
SVPR 2 x TSH 325	0.23	0.13	-0.36	-0.21 *	-0.55	1.64	-0.04	0.32	-0.05	-0.66	194.12 *	0.08	0.01	0.16 **	-0.25 **	0.01
SVPR 2 x Suraj	0.57	0.47	6.14 *	-0.48 *	0.08	4.11 *	-0.04	-0.05	-0.27	-0.93	261.12 *	0.13 *	0.51 *	-0.14 *	0.30 *	0.01
GJHV 370 x PBH 116	0.77	0.37	3.49	0.04	-0.05	6.46 **	-0.09	0.41	-0.02	-1.09	533.05 **	0.28 **	-0.36 **	-0.08 *	-0.34 **	-0.01
GJHV 370 x CSH 3419	-0.07	-0.13	-0.27	-0.32 **	0.22	2.86 *	0.16	0.31	-0.37	-2.24 *	22.38	0.17 **	0.29 **	0.14 **	0.26 **	-0.01
GJHV 370 x CPD 1702	-0.57	-0.13	-2.87	-0.56 **	-0.18	-0.41	-0.03	-0.24	-0.02	0.46	98.88	-0.83 **	-0.66 **	0.11 **	-0.34 **	-0.01
GJHV 370 x TCH 1828	0.10	0.03	0.29	-0.32 **	-0.05	0.29	-0.14	-0.57	0.12	2.11 *	161.72	-0.38 **	-0.16 **	0.01	-0.40 **	-0.01
GJHV 370 x RAH 0603	0.27	0.03	-2.84	0.08	-0.12	-1.28	-0.01	0.10	-0.17	-0.95	32.88	-0.03	0.24 **	0.16 **	0.10 *	-0.01
GJHV 370 x RS 2913	-0.23	0.03	6.59 *	-0.12	0.08	-0.41	-0.11	-0.52	-0.13	0.90	-166.95	-0.08	-0.21 **	-0.06	-0.05	-0.01
GJHV 370 x F 2596	-0.40	-0.13	0.76	0.21 *	-0.22	-1.81	0.37 *	0.31	-0.02	-0.72	-192.95 *	0.33 **	0.09	-0.26 **	0.11 *	-0.01
GJHV 370 x BGDS 0607	0.93	0.53	0.63	0.31 **	-0.15	0.06	-0.23	0.46	0.28	-0.05	-33.78	0.73 **	1.29 **	0.01	0.70 **	0.09 **
GJHV 370 x TSH 325	-0.23	-0.13	0.36	0.21 *	0.55	-1.64	0.04	-0.32	0.05	0.66	-194.12 *	-0.08	-0.01	-0.16 **	0.25 **	-0.01
GJHV 370 x Suraj	-0.57	-0.47	-6.14 *	0.48 *	-0.08	-4.11 *	0.04	0.05	0.27	0.93	-261.12 *	-0.13 *	-0.51 *	0.14 *	-0.30 *	-0.01
SEd	**0.82**	**0.67**	**3.87**	**0.11**	**0.72**	**1.69**	**0.23**	**0.68**	**0.38**	**1.41**	**132.76**	**0.06**	**0.07**	**0.05**	**0.06**	**0.04**

*Significant at 5 % level, ** Significant at 1 % level

Days to first flowering (DFF) ,days to fifty per cent flowering (DFPF), plant height (PH) (cm), number of monopodia per plant (NMP), number of sympodia per plant (NSyP), number of bolls per plant (NB), boll weight (g) (BW), seed index (SI), lint index (LI), ginning percentage (GP), seed cotton yield (SCY) (kg/ha), upper half mean length (UHML) (mm), bundle strength (BS)(g/tex), fibre fineness (FF) (μ), uniformity index (UI)(%) and fibre elongation (FE) (%).

Table 7c. Standard heterosis of crosses for yield and fibre quality traits

CROSS	DFF	DFPF	PH	NMP	NsyP	NBP	BW	SI	LI	GP	SCY	UHML	BS	FF	UI	FE
SVPR 2 x PBH 116	2.03	3.23 *	-3.44	83.33 **	-4.35	32.57 **	15.38 **	24.30 **	4.09	10.50 **	11.81	-4.69 **	-2.85 **	2.96 **	0.12	0.00
SVPR 2 x CSH 3419	4.73 **	5.81 **	2.13	27.78 **	-0.00	27.76 **	6.15	9.96	-6.43	-9.84 **	20.79 **	-2.89 **	-3.56 **	10.37 **	-0.96 **	0.00
SVPR 2 x CPD 1702	3.38 *	5.81 **	1.31	5.56	3.86	18.88 **	10.00	17.93 *	2.92	-7.88 *	29.55 **	1.08 **	-0.36	-6.67 **	0.72 **	0.00
SVPR 2 x TCH 1828	6.76 **	9.03 **	3.57	-5.56	5.80	13.56 *	5.38	13.94	-8.19	12.63 **	21.80 **	2.89 **	2.14 **	-8.89 **	0.84 **	0.00
SVPR 2 x RAH 0603	7.43 **	9.68 **	-0.82	55.56 **	-0.97	15.59 *	7.69	15.14	-2.92	-9.84 **	23.08 **	-3.97 **	-2.49 **	11.85 **	-0.60 **	1.82 *
SVPR 2 x RS 2913	5.41 **	8.39 **	0.34	72.22 **	3.38	4.44	8.46	15.14	-8.19	13.29 **	4.79	-5.42 **	-1.42 **	0.00	-0.36 **	1.82 *
SVPR 2 x F 2596	5.41 **	7.10 **	3.09	55.56 **	-0.97	0.38	0.00	9.56	-2.92	-7.88 *	-0.06	-4.69 **	-2.14 **	2.96 **	-1.08 **	1.82 *
SVPR 2 x BGDS 0607	2.70	5.16 **	1.44	50.00 **	0.97	22.69 **	14.62 **	9.56	-4.09	-8.04 *	-5.10	-4.33 **	-5.69 **	-1.48	-1.20 **	0.00
SVPR 2 x TSH 325	5.41 **	7.10 **	10.79 *	83.33 **	7.25	22.94 **	17.69 **	31.87 **	3.51	14.03 **	32.71 **	-3.97 **	-1.07 **	7.41 **	-0.72 **	1.82 *
SVPR 2 x Suraj	6.76 **	7.74 **	6.87	-94.44 **	-1.93	6.72	8.46	11.16	-6.43	-9.84 **	12.65 *	-2.53 **	1.07 **	-4.44 **	0.24 **	1.82 *
GJHV 370 x PBH 116	0.68	0.00	0.82	-83.33 **	-6.28	10.27	10.77 *	29.08 **	15.79 *	-6.40	24.69 **	-3.97 **	-4.98 **	2.22 *	-0.60 **	0.00
GJHV 370 x CSH 3419	0.00	0.65	-1.37	-88.89 **	1.93	-12.29	13.08 *	12.35	-7.02	-11.40 **	-31.66 **	-2.89 **	-1.07 **	-1.48	-0.24 **	0.00
GJHV 370 x CPD 1702	-3.38 *	0.65	-7.56	-94.44 **	0.00	-28.26 **	8.46	7.17	14.62 *	3.86	-33.32 **	-6.14 **	-4.63 **	0.74	0.00	0.00
GJHV 370 x TCH 1828	2.70	4.52 **	1.24	-66.67 **	3.86	-17.62 **	-1.54	-4.78	8.19	7.22 *	-19.74 **	-1.08 **	1.42 **	-5.93 **	0.00	0.00
GJHV 370 x RAH 0603	4.05 *	5.16 **	-9.62 *	-50.00 **	-3.86	-31.56 **	6.92	12.35	3.51	-5.09	-32.98 **	-5.42 **	-0.36	-2.22 *	-0.24 **	1.82 *
GJHV 370 x RS 2913	0.00	3.87 **	11.00 **	100.00 **	3.38	-4.94	3.08	-2.39	-0.58	0.57	-23.64 **	-7.22 **	-2.49 **	0.00	-0.36 **	1.82 *
GJHV 370 x F 2596	-0.68	1.94	1.72	-27.78 **	-5.31	-19.65 **	16.92 **	11.95	8.77	-1.97	-30.91 **	-3.61 **	-1.07 **	-5.93 **	-0.72 **	1.82 *
GJHV 370 x BGDS 0607	2.03	2.58 *	-0.21s	-5.56	-2.42	-28.52 **	3.85	15.54	18.13 *	1.15	-21.18 **	-0.36	3.91 **	1.48	0.60 **	3.64 **
GJHV 370 x TSH 325	0.00	1.94	8.59 *	-55.56 **	14.01 **	4.18	19.23 **	19.12 *	17.54 *	-1.31	1.76	-5.78 **	-0.71 **	2.96 **	0.00	1.82 *
GJHV 370 x Suraj	0.00	1.29	-8.73 *	-22.22 *	-4.35	-30.80 **	10.00	7.17	15.20 *	4.18	-24.52 **	-4.69 **	-2.14 **	4.44 **	-0.36 **	1.82 *
SEd	**0.79**	**0.65**	**3.96**	**0.12**	**0.71**	**1.68**	**0.23**	**0.70**	**0.39**	**1.42**	**134.92**	**0.06**	**0.07**	**0.05**	**0.06**	**0.04**

*Significant at 5 % level, ** Significant at 1 % level

Days to first flowering (DFF) ,days to fifty per cent flowering (DFPF), plant height (PH) (cm), number of monopodia per plant (NMP), number of sympodia per plant (NSyP), number of bolls per plant (NB), boll weight (g) (BW), seed index (SI), lint index (LI), ginning percentage (GP), seed cotton yield (SCY) (kg/ha), upper half mean length (UHML) (mm), bundle strength (BS)(g/tex), fibre fineness (FF) (μ), uniformity index (UI)(%) and fibre elongation (FE) (%).

Table 8. Hybrids chosen for heterosis breeding based on significant mean, specific combining ability effects and standard heterosis

PH	GJHV 370 x RS 2913 (107.67*,6.59*, 11.00 **)
NMP	SVPR 2 x CSH 3419 (0.87*, 0.32 **, 27.78 **)
BW	GJHV 370 x F 2596 (5.07*, 0.37*, 16.92 **)
GP	GJHV 370 x TCH 1828 (43.57*, 2.11*, 7.22 *)
SCY	SVPR 2 x TSH 325 (2861.33*, 194.12*, 32.71 **), SVPR 2 x Suraj (2428.67*, 261.12*, 12.65*) and GJHV 370 x PBH 116 (2688.33*, 533.05**, 24.69**)
UHML	SVPR 2 x CPD 1702 (28.00*, 0.83**, 1.08**) and SVPR 2 x TCH 1828 (28.50*, 0.38**, 2.89**)
BS	SVPR 2 x TCH 1828 (28.70*, 0.16**, 2.14 **) and SVPR 2 x Suraj (28.40*, 0.51*, 1.07**) and GJHV 370 x BGDS 0607 (29.20*, 1.29**3.91**)
FF	SVPR 2 x Suraj (4.30*, -0.14 *, -4.44 **) and GJHV 370 x F 2596 (4.23*, -0.26**, -5.93**)
UI	SVPR 2 x CPD 1702 (84.10*, 0.34**, 0.72**), SVPR 2 x TCH 1828 (84.20*, 0.40**, 0.84**), SVPR 2 x Suraj (83.70*, 0.30*, 0.24**) and GJHV 370 x BGDS 0607 (84.00*, 0.70**, 0.60**)
FE	GJHV 370 x BGDS 0607 (5.70*, 0.09**, 3.64**)

*Significant at 5 % level, ** Significant at 1 % level

of such genotypes will not delude if such traits and genotypes are under the control of additive genetic effects. So that, the hybrids appropriate for recombination breeding method were chosen based on the presence of additive genetic effects *i.e.* significant *gca* effects of the parents and non-significant *sca* effects of the related hybrids. Thus the hybrid GJHV 370 x CPD 1702 could be suggested for recombination breeding for earliness and ginning percentage as they satisfied criteria for the above said traits. The cross combinations SVPR 2 x RS 2913, SVPR 2 x TSH 325 for the number of bolls per plant and the hybrid involving GJHV 370 x TSH 325 for lint index could also recommended for recombination breeding. In the present study none of the hybrid combination was identified for seed cotton yield to exploit through recombination breeding (**Table 9**). By exploiting the above said hybrids, the best transgressive segregants for yield attributing traits and fibre quality characters can be selected in further generations. High *per se* performance, significant standard heterosis and highly significant *gca* effects for one of the parents for seed cotton yield but non-significant *sca* effect for seed cotton yield may be due to the lack of co-adaptation between favourable alleles of the parents involved for this trait. Similar results were also recorded by Monicashree *et al.* (2017), Munir *et al.* (2018), Gnanasekaran *et al.* (2019), Thiyagu *et al.* (2019) and Gnanasekaran *et al.* (2020).

The present findings indicate the importance of non-additive genetic effects for achieving utmost enhancement in quantitative traits. Parents having high *per se* performance and *gca* effects *i.e.,* SVPR 2 and TSH 325 were detected with higher general combining ability for seed cotton yield per plant and should be given more importance in developing elite hybrid or recombinant in the subsequent segregating generations. The hybrids

Table 9. Hybrids chosen for recombination breeding based on significant general combining ability and non-significant specific combining ability effects

Traits	Hybrids	Parents
DFF	GJHV 370 x CPD 1702 (-0.57)	GJHV 370 (-1.10 **), CPD 1702 (-1.37 **)
DFPF	GJHV 370 x CSH 3419 (-0.13), GJHV 370 x CPD 1702 (-0.13)	GJHV 370 (-1.20 **), CSH 3419 (-0.70 *), CPD 1702 (-0.70 *)
NBP	SVPR 2 x RS 2913 (0.41), SVPR 2 x TSH 325 (1.64)	RS 2913 (3.30 **), TSH 325 (6.93 **)
LI	GJHV 370 x TSH 325 (0.05)	GJHV 370 (0.35 **), TSH 325 (0.41 *)
GP	GJHV 370 x CPD 1702 (0.46)	GJHV 370 (1.92 **), CPD 1702 (1.48 *)

*Significant at 5 % level, ** Significant at 1 % level

Days to first flowering (DFF) ,days to fifty per cent flowering (DFPF), plant height (PH) (cm), number of monopodia per plant (NMP), number of sympodia per plant (NSyP), number of bolls per plant (NB), boll weight (g) (BW), seed index (SI), lint index (LI), ginning percentage (GP), seed cotton yield (SCY) (kg/ha), upper half mean length (UHML) (mm), bundle strength (BS)(g/tex), fibre fineness (FF) (μ), uniformity index (UI)(%) and fibre elongation (FE) (%).

https://doi.org/10.37992/2021.1202.048

2 x TSH 325, SVPR 2 x Suraj and GJHV 370 x PBH 116 for seed cotton yield and SVPR 2 x TCH 1828 for fibre properties were identified as the superior hybrids and these would be well suited for heterosis breeding. Besides, the hybrids GJHV 370 x CPD 1702 could be suggested for recombination breeding for earliness and ginning percentage.

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