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General and specific combining ability effects and variances for fruit yield and its contributing traits in Okra (*Abelmoschus esculentus* (L.) Moench)

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Abstract
The Okra (*Abelmoschus esculentus* (L.) Moench) cultivars were sown at Horticulture Nursery in university campus, SKRAU, Bikaner during *Kharif* 2014. All the recommended general package of practices was followed for raising the good crop. Nine parents (6 lines and 3 testers) and their 18 F_{1S} were grown in a randomized block design (RBD) with three replications. One check variety, Komal 10 was also used as standard check. Crosses among the nine genotypes were made in line x tester mating design at Horticulture Nursery in university campus, SKRAU, Bikaner during *Zaid* 2014. The estimates of SCA variance were high than GCA variance for all characters except number of fruits per plant. The proportion of variance due to σ^2GCA/σ^2SCA was found to be less than unity for all the characters except number of fruits per plant showing thereby preponderance of non-additive effects. The line Kashi Kranti was identified as the best general combiner for most of the characters viz., days to 50% flowering, days to maturity, plant height, number of branches per plant, number of fruits per plant, fruit length and fruit weight. Another line Kashi Pragati also emerged as good combiner for six characters viz., plant height, number of fruits per plant, fruit length, fruit weight, biological yield and fruit yield per plant. The testers which emerged as good general combiner for yield and its contributing metric characters was Arka Anamika. The cross No. 315 x Hisar Unnat was identified as best specific combiner for most of the characters viz., plant height, number of branches per plant, fruit length, fruit weight, biological yield and fruit yield per plant.

Keywords: GCA, SCA, okra and line x tester

Introduction
Okra (*Abelmoschus esculentus* (L.) Moench) most commonly known as *bhindi* (vernacular name in Hindi*)*, is grown in tropical and subtropical parts of the world. South Asia, Ethiopia and West Africa are considered the regions of origin of this crop. Though, okra is native of tropical Africa, yet it is most commonly used vegetable of India. It is an important vegetable grown for its tender pods. It is one of the potential export earner crop among vegetable crops. Okra has good nutritional value, particularly the high content of vitamin C (13 mg/100g), calcium (66 mg/100g) and iron (0.35 mg/100g) in the edible fruits (Gopalan *et al*., 2007) [4]. Green fruits are also rich source of protein, vitamin A and vitamin B. The fruit is rich in glucosides (7-8% of dry matter) mainly in the form of pulp. It is somewhat poor in fiber but rich in protein (1.8% of dry matter). A small amount of calcium (66 mg/100 g), phosphorus (56 mg/100 g), magnesium (53 mg/100 g) and traces of potassium are also present. Dry seeds of okra contain 18-20 percent oil and 20-30 percent crude protein. Okra leaves may be cooked in a similar manner as the greens of beets or dandelions. The leaves are also eaten raw as salads. Okra oil is pressed seed oil, extracted from the seeds of the okra. The greenish yellow edible oil has a pleasant taste and odour, and is high in unsaturated fats such as oleic acid and linoleic acid. The oil content of the seed is quite high (18-20 percent) and the oil yield from okra crop is 794 kg/ha (Mays *et al*. 1990) [10]. Unspecified parts of the plant reportedly possess diuretic properties. Okra seed oil also contains male contraceptive gossypol.
Okra belongs to family Malvaceae with chromosome number 2n=8x=130 and amphidiploid in nature. It has been reported by Joshi and Hardas (1974) [5] that there are 30 species under the genus *Abelmoschus* in the world and four in the new world. Being an often-cross pollinated crop, okra is heterozygous in nature in spite of its adoption for self-pollination. Out crossing ranges from 11.80 – 60.00 percent, which renders a considerable amount of genetic diversity (Martin, 1979) [9].

Major problems of okra are low productivity, lack of location specific varieties, susceptibility to disease like yellow vein mosaic virus, shoot and fruit borer *etc*. Considering the production constraints of this crop an important challenge would be to develop a variety/hybrid which response well to resources and resistant to YVMV disease. The favourable characters of hybrids like production stability, suitability to high input agriculture, uniform growth and maturity shifted the focus towards heterosis breeding, leading to the release of the new potential hybrids.

With the increase in demand of quality vegetables, there is a need to develop new okra hybrids suited to different agro-climatic zones of India with high marketable fruit yield. Therefore, it is essential to understand the genetic architecture of okra, which provides useful guidelines to determine the source population, from which it is possible to derive appropriate genotypes with desired characters. But it is difficult to have a common kind of plant architecture to suit all the requirements of different localities and their preferences. Therefore, the most advisable way is to improve the yielding potentiality within the locally preferred and adopted varieties.

However, the exploitation of hybrid vigour in okra has been recognized as a practical tool in providing the breeders a means of increasing fruit yield and other economic characters. In heterosis breeding programme large number of hybrid combinations are produced and evaluated to exploit hybrid vigour, which usually require more resources and manpower. It is possible to select parents/inbreds based on morphological diversity with good combining ability for economic traits and producing superior hybrids. Sprague and Tatum (1942) proposed concept of general combining ability (GCA) and Specific combining ability (SCA). The analysis of general combining ability (GCA) and specific combining ability (SCA) helps to identify potential parents and hybrids for the production of superior hybrids for fruit yield and its attributing traits. Furthermore, combining ability analysis also provides useful information about nature and magnitude of various types of gene effects involved in the expression of different quantitative traits. General and specific combining abilities accounts for additive and non-additive gene actions of parents and particular cross, respectively. The knowledge related to nature and magnitude of gene effects controlling inheritance of characters related to crop productivity will be helpful in formulating an effective and efficient breeding programme, since such a knowledge not merely gives an idea about the relative importance of different types of gene effects for controlling the characters but also elucidates information about the cause(s) of heterosis and inbreeding depression. Several biometrical procedures have been utilized having their utility and limitations, to provide unbiased variation. Line x tester analysis as per the procedure of Kempthorne (1957) [6] provides information about general and specific combining ability of parents and crosses, respectively and at the same time it is helpful in estimating various types of gene effects.

Materials and Methods

The present investigation was undertaken during *Zaid* 2014 at Horticulture Nursery situated in University Campus, SKRAU, Bikaner. The experimental material consisted of nine diverse okra [*Abelmoschus esculentus* (L.) Moench] varieties/strains selected on the basis of morphological and genetic diversity as well as geographical origin using six genotypes as lines and three as testers. Hisar Naveen, Varsha Uphar, Pusa A-4, Kashi Kranti, No. 315 and Kashi Pragati as lines, Hisar Unnat, Pusa Makhmali and Arka Anamika as testers. Nine parents and their 18 F_{1S} were grown in a randomized block design (RBD) with three replications. Crosses among the nine genotypes were made in line x tester mating design (Kempthorne, 1957) [6] at Horticulture Nursery in university campus, SKRAU, Bikaner during *Zaid* 2014. One check variety, Komal 10 was also used. All the recommended general package of practices was followed for raising the good crop.

Observations were made on ten characters viz., days to 50% flowering, days to maturity, plant height, number of branches per plant, number of fruits per plant, fruit length, fruit weight, biological yield, harvest index and fruit yield per plant. the traits were recorded on five plants selected randomly, after avoiding end plants from both sides of a single row plot to avoid the border effect, for each genotype in each replication except for days to 50 percent flowering, days to maturity which were recorded on whole plot basis.

The mean computed for the hybrids and parents in all the three replications for ten characters were subjected to statistical analysis and variance due to different sources was worked out as per the method outlined by Kempthorne (1957) [6]. The variation among the hybrids was further partitioned into genetic components attributed to general combining ability (gca) and specific combining (sca) following the method suggested by Kempthorne (1957) [6].

Results and discussion

Analysis of variance (Table 1) indicated highly significant differences among the genotypes for all the characters. The variance due to replication were non-significant for all the characters except for fruit length. The parents, crosses, lines, testers and line x tester had significant differences for all the characters

The estimates of SCA variance were high than GCA variance for all characters except number of fruits per plant. The proportion of variance due to σ^2GCA/σ^2SCA was found to be less than unity for all the characters except number of fruits per plant showing thereby preponderance of non-additive effects. The contributions of lines as compared to testers was more for, days to 50 percent flowering, days to maturity, plant height and number of branches per plant while Contibution of testers was more for number of fruits per plant, fruit length, fruit weight, biological yield, harvest index and fruit yield per plant (Table 2). The line x testers interaction was higher than either of their parents for characters like days to 50% flowering, days to maturity, plant height, fruit weight, biological yield and harvest index.

Table 1: Analysis of variance for fruit yield and its components in okra

Source of variation	d.f.	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of branches/ plant	No. of fruits/ plant	Fruit length (cm)	Fruit weight (g)	Biological yield (g)	Harvest index (%)	Fruit yield/ plant (g)
Replications	2	0.90	4.98	26.32	0.07	0.11	0.76*	0.22	10.36	0.08	14.94
Genotypes	26	48.99**	81.96**	2148.28**	1.57**	39.16**	4.51**	5.28**	9176.45**	38.47**	4696.07**
Parents	8	41.18**	90.42**	1174.59**	1.46**	24.90**	2.97**	5.20**	5117.09**	44.51**	2405.82**
Parents vs Crosses	1	99.56**	426.97**	704.58**	12.84**	85.80**	0.49	0.45*	26242.13**	16.96**	15452.04**
Crosses	17	49.70**	57.69**	2691.40**	0.95**	43.12**	5.47**	5.60**	10082.87**	36.90**	5141.13**
Lines	5	32.59**	98.86**	697.20**	1.78**	25.25**	1.34**	3.63**	2810.77**	56.11**	1585.14**
Testers	2	16.33**	12.44*	731.28**	0.40**	33.61**	7.43**	10.69**	12980.57**	12.75**	4669.13**
Line x tester	10	51.10**	72.40**	2630.07**	0.46**	13.36**	3.34**	4.46**	8912.75**	33.99**	4057.84**
Error	52	2.21	2.62	11.10	0.04	0.41	0.20	0.08	79.71	0.70	68.66

* and ** indicate significant at 5 and 1 percent levels, respectively.

Table 2: General and specific combining ability variances and percent contribution of lines, testers and their interaction for fruit yield and yield component traits in okra

		Variances (Random effect)			Percent contribution		
S. No.	Characters	σ^2 gca	σ^2 sca	σ^2 gca / σ^2 sca	Lines	Testers	Line x tester
1.	Days to 50% flowering	-0.81	16.30	-0.05	34.21	5.30	60.49
2.	Days to maturity	-3.10	23.26	-0.13	22.87	3.31	73.82
3.	Plant height (cm)	50.05	872.99	0.06	22.69	19.82	57.48
4.	No. of branches per plant	0.07	0.14	0.50	63.10	8.73	28.16
5.	No. of fruits per plant	8.61	4.32	1.99	18.43	63.34	18.23
6.	Fruit length (cm)	0.57	1.05	0.54	27.60	36.40	35.99
7.	Fruit weight (g)	0.37	1.46	0.25	22.77	30.40	46.83
8.	Biological yield	785.75	2944.34	0.27	4.08	43.92	52.00
9.	Harvest index (%)	1.30	11.10	0.12	21.56	24.26	54.18
10.	Fruit yield per plant (g)	504.65	1329.73	0.38	6.37	47.21	46.43

* and ** indicate significant at 5 and 1 percent levels, respectively.

Table 3: General combining ability effects of lines and testers for yield and yield component traits in okra

S. No.	Parents	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of branches/ plant	No. of fruits/ plant	Fruit length(cm)	Fruit weight (g)	Biological yield (g)	Harvest index (%)	Fruit yield/ plant (g)
Lines											
1.	Hisar Naveen	2.50**	2.20**	13.33**	-0.11	-0.52*	-0.47**	-0.30**	-6.59*	-1.02**	-9.40**
2.	Varsha Uphar	-4.06**	-2.80**	-2.88*	0.34**	0.14	0.16	-0.49**	-3.62	1.01**	1.04
3.	Pusa A-4	0.94	0.54	-9.90**	-0.89**	-1.30**	-0.49**	-0.11	-17.73**	-0.23	-12.11**
4.	Kashi Kranti	-2.06**	-2.46**	14.32**	0.42**	1.43**	1.04**	1.02**	2.86	-1.75**	-5.26
5.	No. 315	0.72	0.09	-24.08**	0.15*	-2.21**	-0.91**	-0.78**	6.03	2.98**	16.32**
6.	Kashi Pragati	1.94**	2.43**	9.22**	0.10	2.46**	0.66**	0.65**	19.04**	-0.99**	9.40**
	S.Ed.	0.50	0.54	1.11	0.07	0.21	0.15	0.10	2.98	0.28	2.76
	C.D. at 5%	1.01	1.10	2.26	0.14	0.43	0.30	0.20	6.05	0.57	5.61
	C.D. at 1%	1.35	1.47	3.03	0.18	0.58	0.40	0.26	8.12	0.76	7.54
Testers											
7.	Hisar Unnat	-1.17**	-0.63	-18.05**	-0.22**	-2.24**	-0.79**	-0.73**	-31.71**	1.48**	-16.28**
8.	Pusa Makhmali	1.06**	1.09**	6.25**	0.16**	-1.90**	-0.29**	-0.28**	-20.71**	-2.35**	-22.63**
9.	Arka Anamika	0.11	-0.46	11.80**	0.06	4.14**	1.08**	1.00**	52.42**	0.87**	38.92**
	S.Ed.	0.35	0.38	0.79	0.05	0.15	0.10	0.07	2.10	0.20	1.95
	C.D. at 5%	0.71	0.77	1.60	0.10	0.31	0.21	0.14	4.28	0.40	3.97
	C.D. at 1%	0.96	1.04	2.14	0.13	0.41	0.28	0.19	5.74	0.54	5.33

* and ** indicate significant at 5 and 1 percent levels, respectively.

Table 4: SCA effects of hybrids for different yield and yield component traits in okra

S. No.	Crosses	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of branches/ plant	No. of fruits/ plant	Fruit length (cm)	Fruit weight (g)	Biological yield (g)	Harvest index (%)	Fruit yield/ plant (g)
1.	Hisar Naveen x Hisar Unnat	-1.17	-1.04	-38.13**	-0.07	3.40**	-1.85**	-2.27**	-24.05**	5.48**	2.02
2.	Hisar Naveen x Pusa Makhmali	-0.06	-0.76	12.20**	-0.15	-2.81**	1.31**	1.38**	-6.84	-2.95**	-12.50*
3.	Hisar Naveen x Arka Anamika	1.22	1.80	25.93**	0.22	-0.59	0.54*	0.90**	30.89**	-2.53**	10.48*
4.	Varsha Uphar x Hisar Unnat	-0.61	1.30	-14.82**	0.11	-2.54**	0.05	0.41*	-48.91**	-0.09	-34.82**
5.	Varsha Uphar x Pusa Makhmali	3.83**	1.24	34.08**	-0.21	2.12**	-0.12	-0.50**	51.07**	-1.97**	26.50**
6.	Varsha Uphar x Arka Anamika	-3.22**	-2.54*	-19.26**	0.1	0.41	0.07	0.09	-2.15	2.06**	8.31
7.	Pusa A-4 x Hisar Unnat	-2.94**	-5.37**	-2.66	-0.39**	-0.76*	0.77**	0.77**	-22.22**	-0.41	-17.54**
8.	Pusa A-4 x Pusa Makhmali	1.50	3.57**	15.44**	0.73**	0.57	-0.20	-0.61**	13.06*	-2.24**	0.81
9.	Pusa A-4 x Arka Anamika	1.44	1.80	-12.77**	-0.34**	0.19	-0.57*	-0.16	9.16	2.65**	16.73**
10.	Kashi Kranti x Hisar Unnat	-0.28	-1.04	30.25**	0.03	-1.56**	0.64*	0.57**	31.47**	-2.53**	12.88*
11.	Kashi KrantixPusa Makhmali	3.50**	4.24**	-31.18**	0.11	1.37**	-1.06**	-0.41*	-21.66**	5.28**	5.16
12.	Kashi Kranti x Arka Anamika	-3.22**	-3.20**	0.94	-0.15	0.19	0.43	-0.16	-9.81	-2.75**	-18.04**
13.	No. 315 x Hisar Unnat	5.28**	7.07**	36.06**	0.43**	-0.65	1.12**	1.50**	107.96**	-0.68	73.11**
14.	No. 315 x Pusa Makhmali	-8.28**	-9.65**	-26.19**	-0.19	-0.39	-0.18	-0.48**	-65.70**	0.42	-44.94**
15.	No. 315 x Arka Anamika	3.00**	2.57**	-9.87**	-0.25*	1.04**	-0.95**	-1.02**	-42.27**	0.26	-28.16**
16.	Kashi Pragati x Hisar Unnat	-0.28	-0.93	-10.69**	-0.11	2.11**	-0.72**	-0.99**	-44.24**	-1.77**	-35.65**
17.	Kashi Pragatix Pusa Makhmali	-0.50	1.35	-4.35*	-0.30*	-0.86*	0.25	0.63**	30.07**	1.46**	24.97**
18.	Kashi Pragati x Arka Anamika	0.78	-0.43	15.04**	0.41**	-1.24**	0.47	0.35*	14.17**	0.31	10.68*
	S.Ed.	0.86	0.93	1.92	0.12	0.37	0.26	0.17	5.15	0.48	4.78
	C.D. at 5%	1.74	1.90	3.91	0.24	0.75	0.52	0.34	10.48	0.98	9.72
	C.D. at 1%	2.34	2.55	5.25	0.32	1.01	0.70	0.46	14.06	1.32	13.05

* and ** indicate significant at 5 and 1 percent levels, respectively

The combining ability results of different characters are presented in Table 3 and Table 4 described separately for each character. For Days to 50 percent flowering the general combining ability (gca) effects of lines Varsha Uphar and Kashi Kranti were negative and significant while that of Hisar Naveen and Kashi Pragati werer positive and significant. Among testers, Hisar Unnat showed negatively significant effect and Pusa Makhmali appeared with positive and significant effect. Four crosses viz., Varsha Uphar x Arka Anamika, Pusa A-4 x Hisar Unnat, Kashi Kranti x Arka Anamika and No. 315 x Pusa Makhmali showed negative and significant specific combining ability (sca) effects and four crosses viz., Varsha Uphar x Pusa Makhmali, Kashi Kranti x Pusa Makhmali, No. 315 x Hisar Unnat and No. 315 x Arka Anamika exhibited positive and significant sca effects.

For Days to maturity the general combining ability (gca) effects of lines, Varsha Uphar and Kashi Kranti were negative and significant while that of Hisar Naveen and Kashi Pragati werer positive and significant. Among testers, only Pusa Makhmali appeared with positive and significant effect.

Among 18 crosses, four crosses viz., Varsha Uphar x Arka Anamika, Pusa A-4 x Hisar Unnat, Kashi Kranti x Arka Anamika and No. 315 x Pusa Makhmali showed negative and significant specific combining ability (sca) effects and four crosses viz., Pusa A-4 x Pusa Makhmali, Kashi Kranti x Pusa Makhmali, No. 315 x Hisar Unnat and No 315 x Arka Anamika exhibited positive and significant sca effects.

For the character plant height (cm) general combining ability (gca) effects of lines, Hisar Naveen, Kashi Kranti and Kashi Pragati were positive and significant while that of Varsha Uphar, Pusa A-4 and No. 315 were negative and significant. Among testers, Pusa Makhmali and Arka Anamika appeared with positive and significant effect while Hisar Unnat appeared with negative and significant effect. Seven crosses viz., Hisar Naveen x Pusa Makhmali, Hisar Naveen x Arka Anamika, Varsha Uphar x Pusa Makhmali, Pusa A-4 x Pusa Makhmali, Kashi Kranti x Hisar Unnat, No. 315 x Hisar Unnat and Kashi Pragati x Arka Anamika showed positive and significant specific combining ability (sca) effects and nine crosses viz., Hisar Naveen x Hisar Unnat, Varsha Uphar x Hisar Unnat, Varsha Uphar x Arka Anamika, Pusa A-4 x Arka Anamika, Kashi Kranti x Pusa Makhmali, No. 315 x Pusa Makhmali, No. 315 x Arka Anamika, Kashi Pragati x Hisar Unnat and Kashi Pragati x Pusa Makhmali exhibited negative and significant sca effects. For number of branches per plant the general combining ability (gca) effects of lines, Varsha Uphar, Kashi Kranti and No. 315 were positive and significant while that of Pusa A-4 was negative and

significant. Among testers, Pusa Makhmali showed positive and significant effect and Hisar Unnat appeared with negative and significant effect.

Among 18 crosses, three crosses viz., Pusa A-4 x Pusa Makhmali, No. 315 x Hisar Unnat and Kashi Pragati x Arka Anamika showed positive and significant specific combining ability (sca) effects and four crosses viz., Pusa A-4 x Hisar Unnat, Pusa A-4 x Arka Anamika, No. 315 x Arka Anamika and Kashi Pragati x Pusa Makhmali exhibited negative and significant sca effects.

For number of fruits per plant general combining ability (gca) effects of lines, Kashi Kranti and Kashi Pragati were positive and significant while that of Hisar Naveen, Pusa A-4 and No. 315 were negative and significant. Among testers, Arka Anamika showed positive and significant effect whereas Hisar Unnat and Pusa Makhmali appeared with negative and significant effect. Five crosses viz., Hisar Naveen x Hisar Unnat, Varsha Uphar x Pusa Makhmali, Kashi Kranti x Pusa Makhmali, No. 315 x Arka Anamika and Kashi Pragati x Hisar Unnat showed positive and significant specific combining ability (sca) effects and six crosses viz., Hisar Naveen x Pusa Makhmali, Varsha Uphar x Hisar Unnat, Pusa A-4 x Hisar Unnat, Kashi Kranti x Hisar Unnat, Kashi Pragati x Pusa Makhmali and Kashi Pragati x Arka Anamika exhibited negative and significant sca effects.

For fruit length (cm) The general combining ability (gca) effects of lines, Kashi Kranti and Kashi Pragati were positive and significant while that of Hisar Naveen, Pusa A-4 and No. 315 were negative and significant. Among testers, Arka Anamika showed positive and significant effect whereas Hisar Unnat and Pusa Makhmali appeared with negative and significant effect.

Among 18 crosses, five crosses viz., Hisar Naveen x Pusa Makhmali, Hisar Naveen x Arka Anamika, Pusa A-4 x Hisar Unnat, Kashi Kranti x Hisar Unnat and No. 315 x Hisar Unnat showed positive and significant specific combining ability (sca) effects and five crosses viz., Hisar Naveen x Hisar Unnat, Pusa A-4 x Arka Anamika, Kashi Kranti x Pusa Makhmali, No. 315 x Arka Anamika, Kashi Pragati x Hisar Unnat exhibited negative and significant sca effects.

For fruit weight (g) general combining ability (gca) effects of lines, Kashi Kranti and Kashi Pragati were positive and significant while that of Hisar Naveen, Varsha Uphar and No. 315 were negative and significant. Among testers, Arka Anamika showed positive and significant effect whereas Hisar Unnat and Pusa Makhmali appeared with negative and significant effect and eight crosses viz., Hisar Naveen x Pusa Makhmali, Hisar Naveen x Arka Anamika, Varsha Uphar x Hisar Unnat, Pusa A-4 x Hisar Unnat, Kashi Kranti x Hisar Unnat, No. 315 x Hisar Unnat, Kashi Pragati x Pusa Makhmali and Kashi Pragati x Arka Anamika showed positive and significant specific combining ability (sca) effects and seven crosses viz., Hisar Naveen x Hisar Unnat, Varsha Uphar x Pusa Makhmali, Pusa A-4 x Pusa Makhmali, Kashi Kranti x Pusa Makhmali, No. 315 x Pusa Makhmali, No. 315 x Arka Anamika and Kashi Pragati x Hisar Unnat exhibited negative and significant sca effects.

For biological yield (g), the general combining ability (gca) effects of line, Kashi Pragati was positive and significant while that of Hisar Naveen and Pusa A-4 were negative and significant. Among testers, Arka Anamika showed positive and significant effect whereas Hisar Unnat and Pusa Makhmali appeared with negative and significant effect. For seven crosses viz., Hisar Naveen x Arka Anamika, Varsha Uphar x Pusa Makhmali, Pusa A-4 x Pusa Makhmali, Kashi Kranti x Hisar Unnat, No 315 x Hisar Unnat, Kashi Pragati x Pusa Makhmali and Kashi Pragati x Arka Anamika showed positive and significant specific combining ability (sca) effects and seven crosses viz., Hisar Naveen x Hisar Unnat, Varsha Uphar x Hisar Unnat, Pusa A-4 x Hisar Unnat, Kashi Kranti x Pusa Makhmali, No. 315 x Pusa Makhmali, No. 315 x Arka Anamika and Kashi Pragati x Hisar Unnat exhibited negative and significant sca effects.

For harvest index (%), the general combining ability (gca) effects of lines, Varsha Uphar and No. 315 were positive and significant while that of Hisar Naveen, Kashi Kranti and Kashi Pragati were negative and significant. Among testers, Hisar Unnat and Arka Anamika showed positive and significant effect whereas Pusa Makhmali appeared with negative and significant effect.

Among 18 crosses, five crosses viz., Hisar Naveen x Hisar Unnat, Varsha Uphar x Arka Anamika, Pusa A-4 x Arka Anamika, Kashi Kranti x Pusa Makhmali and Kashi Pragati x Pusa Makhmali, showed positive and significant specific combining ability (sca) effects and seven crosses viz., Hisar Naveen x Pusa Makhmali, Hisar Naveen x Arka Anamika, Varsha Uphar x Pusa Makhmali, Pusa A-4 x Pusa Makhmali, Kashi Kranti x Hisar Unnat, Kashi Kranti x Arka Anamika and Kashi Pragati x Hisar Unnat exhibited negative and significant sca effects.

For Fruit yield per plant (g), the general combining ability (gca) effects of lines, No. 315 and Kashi Pragati were positive and significant whereas Hisar Naveen and Pusa A-4 were negative and significant. Among testers, Arka Anamika showed positive and significant effect whereas Hisar Unnat and Pusa Makhmali appeared with negative and significant effect.

Among 18 crosses, seven crosses viz., Hisar Naveen x Arka Anamika, Varsha Uphar x Pusa Makhmali, Pusa A-4 x Arka Anamika, Kashi Kranti x Hisar Unnat, No. 315 x Hisar Unnat, Kashi Pragati x Pusa Makhmali and Kashi Pragati x Arka Anamika showed positive and significant specific combining ability (sca) effects and seven crosses viz., Hisar Naveen x Pusa Makhmali, Varsha Uphar x Hisar Unnat, Pusa A-4 x Hisar Unnat, Kashi Kranti x Arka Anamika, No. 315 x Pusa Makhmali, No. 315 x Arka Anamika and Kashi Pragati x Hisar Unnat exhibited negative and significant sca effects.

The expression of gca effects of the parents are presented in the Table 4. The parents were identified as good, average and poor general combiners on the basis of their gca effects for different quantitative characters. The line Kashi Kranti proved to be the best general combiner for seven quantitative characters, viz., days to 50% flowering, days to maturity, plant height, number of branches per plant, number of fruits per plant, fruit length and fruit weight and also had average general combining ability for biological yield and fruit yield per plant. However, this line proved to be poor combiner for harvest index only. Another line Kashi Pragati emerged as good general combiner for six important characters viz., plant height, number of fruits per plant, fruit length, fruit weight, biological yield and fruit yield per plant while, average combiner for character number of branches per plant but poor combiner for days to 50% flowering, days to maturity and for harvest index. The line Varsha Uphar was identified as good general combiner for four characters viz., days to 50% flowering, days to maturity, number of branches per plant and harvest index, while average general combiner for number of fruits per plant, fruit length, biological yield and fruit yield per plant and poor combiner for plant height and fruit weight. The line No. 315 was a good combiner for three characters

namely, number of branches per plant, harvest index and fruit yield per plant. These two lines namely Varsha Uphar and No. 315 may be considered as average general combiner. Other lines like Hisar Naveen and Pusa A-4 may be regarded as poor combiners and therefore, might have specific use in a breeding programme.

Tester Arka Anamika was good combiner for seven characters i.e., plant height, number of fruits per plant, fruit length, fruit weight, biological yield, harvest index and fruit yield per plant but average combiner for days to 50% flowering, days to maturity and number of branches per plant. In addition to this the tester did not prove poor combiner for any of the character used in the study. Other testers i.e. Hisar Unnat and Pusa Makhmali did not prove good general combiners owing to their poor gca effects for several characters. Similarly, Dhankhar and Dhankhar (2001) [3], Rewale *et al.* (2003a) [15], Kumar *et al*. (2009) [7], Solankey and Singh (2010) [19], Singh *et al*. (2012) [16] and Adiger *et al.* (2013) [1] also observed various lines and testers having good combining ability behaviour.

The cross No. 315 x Hisar Unnat was identified as best specific combiner for most of the characters viz., plant height, number of branches per plant, fruit length, fruit weight, biological yield and fruit yield per plant. Other crosses like Hisar Naveen x Arka Anamika, Kashi Kranti x Hisar Unnat and Kashi Pragati x Arka Anamika, also emerged as good specific combiner for five characters.The crosses viz., Hisar Naveen x Pusa Makhmali, Varsha Uphar x Pusa Makhmali, Varsha Uphar x Arka Anamika, Pusa A-4 x Hisar Unnat, Pusa A-4 x Pusa Makhmali and Kashi Pragati x Pusa Makhmali were average combiners but were good combiner for three or four characters.

The combining ability is determined mainly by two types of gene actions viz., additive and non-additive. The additive effects are mainly due to polygenes which act in additive manner producing fixable effects. The non-additive gene action results from dominance, epistasis and various other interaction effects which are non fixable. The combining ability analysis measures these effects in terms of general and specific combining ability. The former indicated capacity of a variety in relation to all other varieties it was crossed with, and the latter in relation to only one particular cross combination. In the present investigation line x tester analysis analysis indicated the preponderance of non-additive gene effects for all the characters except for number of fruits per plant. These results were also supported by Ahmed *et al*. (1997) [2], Dhankhar and Dhankhar (2001) [3], Singh *et al*. (2001) [17], Rani *et al.* (2002) [13], Prakash *et al.* (2002) [12], Kumar *et al*. (2006) [8], Singh *et al.* (2006) [18], Kumar *et al*. (2009) [7] and Reddy *et al*. (2013a) [14] for preponderance of non-additive gene action. However, Sood and Kalia (2001) [20] and Mitra and Das (2003) [11] highlighted preponderance of additive gene action. Although additive gene effects were also observed in the material but their magnitude was very low. Under such conditions conventional method of breeding may not be very efficient in capitalizing the available genetic variability. The most efficient way for utilizing the non-additive genetic variability is either through the exploitation of heterosis or special breeding methods like diallel selective mating.

Conclusion

Taking into account the overall results of combining ability it was concluded that following lines/testers/crosses were identified to be promising for various characters and may be utilized in breeding programme:

a) Kashi Kranti: Line was identified as the best general combiner for most of the characters viz., days to 50% flowering, days to maturity, plant height, number of branches per plant, number of fruits per plant, fruit length and fruit weight.

b) Kashi Pragati: Line emerged as good combiner for six characters viz., plant height, number of fruits per plant, fruit length, fruit weight, biological yield and fruit yield per plant.

c) Arka Anamika: Tester was good combiner for seven characters viz., plant height, number of fruits per plant, fruit length, fruit weight, biological yield, harvest index and fruit yield per plant.

d) The crosses like No. 315 x Hisar Unnat, Hisar Naveen x Arka Anamika, Kashi Kranti x Hisar Unnat and Kashi Pragati x Arka Anamika emerged as good specific combiner for five or more characters.

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