



Combining ability analysis for earliness and yield related characters in pea (*Pisum sativum*)

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ABSTRACT

A study was conducted on the combining ability analysis in a 11 × 11 half-diallel cross of garden pea (*Pisum sativum* L.). F₁ hybrids (55) along with 11 parental lines were grown in randomized block design with three replications. The mean square due to GCA and SCA were highly significant for all the characters indicating the importance of additive and non-additive genetic components for the characters under study. Further, σ^2_s was more than σ^2_g for all the characters suggested the importance of non-additive variance for the improvement of these characters. The parents P₂ (GP-17), P₅ (GP-473) and P₇ (VRP-7) were observed to be good combiners for most characters under study including yield per plant. The crosses P₆ × P₁₀, P₂ × P₈ and P₈ × P₁₀ were most promising combinations for total yield per plant. The results indicated the importance of recombinant breeding for effective utilization of non-additive genetic variance in garden pea.

Key words: Combining ability, Diallel, Pea, *Pisum sativum*, Yield

Garden pea (*Pisum sativum* L.) is a highly nutritive containing high percentage of digestible protein along with carbohydrates and vitamins. In India, it is grown as winter vegetable in the plains of north India and as summer vegetable in the hills. The crop is normally grown in the field during mid October to December in northern plains of the country. Green pea is considered as vegetable crop as it needs smaller area of land and can also be grown without any competition with cereal crops. There is a shortage of off-season vegetable in our country. Large proportion of peas are processed (canned, frozen or dehydrated) for consumption in the off season. Under frozen condition we can make the vegetable available round the year. Compared to other grain crops no attempt has been made to develop improved cultivars of vegetable pea in this country. So stress should be given to develop high yielding vegetable pea having vegetable quality through hybridization. For the development of elite strains, the identification of genetically superior parents is an important prerequisite. The combining ability analysis is the most important and efficient tool in choosing the desirable parents for

hybridization programmes. The GCA is defined as the average performance of lines/strains in a set of cross combinations and the SCA as those instances in which certain cross combinations do relatively better or worse than would be expected on the basis of average performance of the parental lines involved cross combination. It is also expressed that GCA is mainly the result of additive gene effects and additive × additive interactions, while SCA is consequences of dominance, epistatic deviation and genotype × environmental interactions.

MATERIALS AND METHODS

Eleven inbred parents viz. Arkel (P₁), GP-17 (P₂), Arka Ajit (P₃), Pusa Pragati (P₄), GP-473 (P₅), VP-233 (P₆), VRP-7 (P₇), VRP-6 (P₈), AP-3 (P₉), IP-3 (P₁₀) and GP-6 (P₁₁) were crossed in diallel fashion without reciprocals. The seeds of 11 inbred parents and their 55 F₁'s were sown in the experimental field, Division of Vegetable Science, IARI, New Delhi. The experiment was laid out in a randomized complete block design (RCBD) with three replications during winter season of 2014-2015. The plot size was kept as two rows of 4 m length for each genotype keeping plant spacing 45 × 10 cm apart. The recommended fertilizer (40:60:40 as NPK) doses and cultural practices were followed to raise a good crop. The observations were recorded for nine pod yield traits based on 10 sample plant and the average were computed for the characters such as plant height (cm), node bearing first flower, pod length (cm), days to 50% flowering, number of pods/plant, number of

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seeds/pod, average pod weight, shelling percentage and pod yield per plant. Data were subjected to analysis according to Method 2 Model I of Griffing (1956).

RESULTS AND DISCUSSION

Analysis of variance

The mean sum of squares due to general combining ability (GCA) and specific combining ability (SCA) were highly significant for all the characters indicating that both the additive and non-additive gene actions were predominant, for the expression of these characters (Table 1). Similarly, Singh *et al.* (2005), Thakur and Khosla (2008) and Sharma *et al.* (2015) reported significant GCA and SCA variances for yield and yield contributing characters in garden pea. GCA was observed to be of higher magnitude for the characters like plant height, days to 50% flowering, number of pods/plant and yield/plant indicating the importance of additive gene action. The SCA variance was higher than those of GCA variance for all the characters indicating the preponderance of non-additive variance of gene action. Karmakar and Singh (1990) observed non-additive gene action ($\sigma^2_g / \sigma^2_s < 1$) was predominant for the characters like seed yield/plant, pods/plant, seeds/plant, plant height and days to flowering. Similar kinds of results were also reported by Singh *et al.* (2005), Sharma *et al.* (2007), Sharma and Bora (2013) in garden pea. The GCA and SCA ratio (Table 1) were more than one for all the characters except node bearing first flower, pod width and shelling percentage indicating that these characters were predominantly under additive genetic control. Similarly, Singh *et al.* (2005) reported higher GCA values for yield related traits in garden pea. The non-additive components of variance were also involved in the inheritance of node bearing first flower, pod width and shelling percentage. The GCA and SCA effects of parent and their F_1 's are presented in Tables 2 and 3, respectively. The detailed results of combining ability analysis are discussed character wise in succeeding paragraphs.

Eight parental lines showed significant GCA effect for

plant height except P_6 , P_8 and P_9 but parents, P_7 , P_{10} , P_{11} and P_3 showed desirable significant positive GCA effect, i.e. -6.67, 3.41, 2.13 and 1.34 respectively. Out of 55 F_1 crosses, 27 crosses exhibited positive desirable SCA effects but only 10 crosses showed significant SCA effects. The crosses $P_6 \times P_8$ (VP 233 \times AP-3) and $P_2 \times P_{10}$ (GP-17 \times IP-3) observed the maximum positive SCA effect (15.15) and (11.17) respectively.

Five parents exhibited desirable negative GCA effect for node bearing first flower, but only parent, P_{11} showed significant negative GCA effects, i.e. -0.56. Among 55 F_1 crosses studied, 10 crosses showed significant negative SCA effects. The cross $P_6 \times P_9$ (VP 233 \times AP-3) was showing the maximum significant negative SCA effect (-2.36) followed by $P_2 \times P_6$ (GP-17 \times VP 233) (-1.57).

All eleven parental lines showed significant GCA effect for days to 50% flowering. Out of these, six parents (P_1 , P_2 , P_3 , P_4 , P_8 and P_9) showed significant negative GCA effects (-1.92, -2.40, -0.99, -4.12, -2.48, and -3.30) respectively. Among 55 F_1 crosses, 18 crosses exhibited significant negative SCA effects. The cross $P_8 \times P_{11}$ (VRP-6 \times GP-6) recorded maximum significant negative SCA effect (-10.21) followed by $P_3 \times P_{10}$ (Arka Ajit \times IP-3) (-10.03).

Among eleven parental lines, six lines showed significant GCA effect for number of pods per plant. Of these, only three parental lines (P_6 , P_7 and P_{10}) showed significant positive GCA effect (2.31, 1.08 and 2.54) respectively. Among 55 F_1 crosses, 14 crosses exhibited significant positive SCA effects. The cross $P_2 \times P_7$ (GP-17 \times VRP-7) observed maximum significant positive SCA effect (8.51) followed by $P_6 \times P_{11}$ (VP 233 \times GP-6) (6.68).

Seven parents showed significant GCA effect for number of pods per plant. Of these, four parents (P_3 , P_4 , P_6 and P_8) showed significant positive GCA effects (0.30, 0.37, 0.85 and 0.38) respectively. Ten F_1 crosses out of 55 crosses exhibited significant positive SCA effects. The maximum significant positive SCA effect (2.88) was exhibited by cross $P_3 \times P_{10}$ (Arka Ajit \times IP-3) followed by $P_2 \times P_6$ (GP-17 \times VP 233) (2.30).

Table 1 Analysis of variance for combining ability of 10 quantitative characters

Character	Source of variation of GCA			Source of variation of SCA			Error		σ^2_g	σ^2_s
	D F	M S S	F	D F	M S S	F	D F	MSS		
Plant height	10	153.92**	36.462	55	35.25**	8.351	130	4.22	0.295	3.626
Node bearing first flower	10	0.79**	2.790	55	1.16**	4.076	130	0.28	0.019	0.245
Days to 50% flowering	10	167.14**	76.667	55	32.24**	14.792	130	2.18	0.152	1.872
Number of pods/plant	10	34.48**	23.378	55	10.73**	7.275	130	1.47	0.103	1.267
Pod length	10	2.34**	12.264	55	1.41**	7.381	130	0.19	0.013	0.164
Pod width	10	0.09**	6.709	55	0.11**	8.641	130	0.01	0.001	0.011
Number of seeds/pod	10	0.74**	3.835	55	0.39*	2.006	130	0.19	0.014	0.166
Pod weight	10	0.83**	14.166	55	0.48**	8.113	130	0.06	0.004	0.050
Shelling percentage	10	33.65**	5.23	55	19.62**	3.048	130	6.43	0.450	5.532
Yield/plant	10	478.92**	17.24	55	163.84**	5.899	130	27.77	1.943	23.860

* and ** Significant at P=0.05 and P=0.01, respectively.

Table 2 Estimates of general combining ability (GCA) effects of parents for 10 quantitative traits

Parents	Plant height	Node bearing first flower	Days to 50% flowering	Number of pods / plant	Pod length	Pod width	Number of seeds/ pod	Pod weight	Shelling percentage	Yield/ plant
P1	-3.66**	0.19	-1.92**	-0.40	-0.16	-0.03	0.28*	-0.12	-0.83	-7.62**
P2	-4.60**	0.28	-2.40**	0.59	-0.23	-0.09*	-0.10	0.14	-0.34	3.82*
P3	1.34*	0.02	-0.99*	-2.86**	0.30*	0.07	0.15	0.27**	-1.39	-7.36**
P4	-4.07**	-0.02	-4.12**	-1.73**	0.37**	-0.09*	0.08	0.08	-0.73	-2.11
P5	-1.95**	-0.06	1.03*	-0.66	-0.19	-0.12**	0.08	0.44**	2.13*	8.46**
P6	-0.55	0.06	2.42**	2.31**	0.85**	0.04	0.34*	-0.30**	3.69**	1.94
P7	6.67**	0.24	1.21**	1.08**	0.00	0.13**	-0.33*	-0.02	0.11	9.67**
P8	0.54	-0.18	-2.48**	0.59	0.38**	0.04	0.20	-0.06	-0.02	1.22
P9	0.72	-0.20	-3.30**	-0.55	-0.38**	0.05	-0.13	-0.20**	0.04	-7.78**
P10	3.41**	0.22	2.11**	2.54**	-0.52**	-0.06	-0.21	-0.41**	-1.99*	1.65
P11	2.13**	-0.56**	8.44**	-0.90**	-0.43**	0.07	-0.36*	0.18*	-0.68	-1.88
SE (gi)	0.54	0.14	0.39	0.32	0.12	0.03	0.12	0.06	0.67	1.39
SE (gi-gj)	0.810	0.210	0.579	0.476	0.171	0.044	0.172	0.095	0.995	2.067
CD (P=0.05)	1.16	0.31	0.84	0.71	0.26	0.07	0.26	0.14	1.49	3.09

* & ** Significant at P=0.05 and P=0.01, respectively.

Table 3 Estimates of specific combining ability (SCA) effects of F₁ crosses for 10 quantitative traits

Cross	Plant height	Node bearing first flower	Days to 50% flowering	Number of pods/plant	Pod length	Pod width	Number of seeds/pod	Pod weight	Shelling percentage	Yield/ plant
P1×P2	0.69	-0.38	2.41	2.49*	1.47**	0.65**	-0.36	0.16	7.93**	6.36
P1×P3	-0.36	0.24	2.33	5.89**	-0.77	-0.45**	0.15	-1.34**	5.24*	0.42
P1×P4	2.86	-0.74	-0.54	-1.37	-1.16**	0.39**	-0.30	0.31	-1.48	0.68
P1×P5	3.13	-0.33	-5.03**	1.56	-0.30	-0.26*	0.30	0.29	-4.51*	0.32
P1×P6	3.53	1.16*	-2.08	-1.56	-1.09**	0.26*	-1.05*	0.29	-6.50**	-2.31
P1×P7	-3.25	0.69	-7.54**	-2.60*	-0.15	-0.51**	1.47**	0.73**	-3.47	5.15
P1×P8	-5.78**	-0.25	4.82**	-3.43**	-0.21	0.26*	-0.69	-0.06	8.04**	-2.65
P1×P9	-1.64	-1.16*	2.64	-1.02	0.67	0.29*	0.40	0.14	-3.61	-3.27
P1×P10	-2.73	-0.98	-0.77	-0.28	-0.14	-0.18	0.62	0.20	-0.25	10.72*
P1×P11	-0.66	0.86	7.23**	-1.79	-0.14	0.26**	-0.37	-0.35	-0.70	-5.65
P2×P3	-3.52	-1.17**	-4.18**	-0.94	-1.07**	0.10	-0.29	-0.32	-3.58	-9.90
P2×P4	1.61	-0.77	4.62**	1.80	-0.02	0.49**	-0.30	-0.40	-5.27*	-5.55
P2×P5	-0.75	0.53	-1.87	-1.21	-0.40	0.48**	-0.23	0.01	-3.73	0.49
P2×P6	-2.81	-1.57**	-2.26	-0.24	2.30**	-0.22*	0.39	-0.15	4.16	0.81
P2×P7	1.49	-0.72	-1.05	8.51**	-0.23	0.04	-0.04	-1.18**	8.32**	4.50
P2×P8	-5.33**	-1.66**	2.64	-1.94	-0.55	0.16	0.26	1.19**	-1.32	26.95**
P2×P9	-0.65	2.03**	3.46**	-1.57	-0.39	-0.37**	0.59	-0.17	-5.01*	-3.38
P2×P10	11.17**	0.91	0.72	-4.34**	-0.73	-0.12	-0.20	-0.41	-0.97	-19.87**
P2×P11	1.41	1.73**	7.05**	-0.59	-0.96**	-0.25*	0.58	0.60*	-3.83	4.23
P3×P4	5.54**	-0.90	-5.46**	-0.35	0.83*	-0.35**	0.90	-0.46*	8.96**	-6.91
P3×P5	5.18**	-0.86	1.72	1.82	-0.72	0.44**	-0.48	0.26	-1.63	3.34
P3×P6	-3.25	0.34	-4.33**	2.42*	-0.06	0.44**	0.22	-0.63*	-5.33*	1.00
P3×P7	-0.24	1.19*	-5.79**	-1.47	1.99**	0.18	-0.01	0.51	0.39	4.10
P3×P8	0.97	-1.07	1.56	0.86	1.49**	0.17	-0.65	-0.43	5.88**	2.96
P3×P9	-5.53**	1.97**	-3.28**	-2.60*	-0.58	0.07	0.18	0.25	0.37	-0.90

Contd.

Table 4 (Concluded)

Cross	Plant height	Node bearing first flower	Days to 50% flowering	Number of pods/plant	Pod length	Pod width	Number of seeds/pod	Pod weight	Shelling percentage	Yield/plant
P3×P10	-9.43**	-0.48	-10.03**	1.23	2.88**	0.24*	-0.42	0.59*	0.26	19.62**
P3×P11	2.21	0.66	3.31**	-1.81	-1.17**	-0.06	0.25	1.06**	6.00**	8.13
P4×P5	0.60	0.98	3.51**	0.57	-1.52**	0.37**	0.50	-0.26	0.83	2.53
P4×P6	-3.59	0.21	-4.87**	-1.99	0.10	-0.06	0.58	0.81**	0.95	14.42**
P4×P7	3.64	-0.61	-3.33**	-2.06	0.06	-0.05	-1.16**	0.33	-2.04	-3.55
P4×P8	3.26	0.13	4.69**	-1.74	1.65**	-0.06	0.17	0.21	1.65	-5.37
P4×P9	0.86	0.80	4.85**	-1.05	-2.44**	-0.07	-0.18	-0.04	-2.76	0.65
P4×P10	-13.27**	-0.27	-0.90	2.60*	-1.41**	0.13	-0.60	-0.97**	-2.04	-13.60**
P4×P11	-0.09	-1.12*	-3.23**	3.34**	1.85**	0.13	0.87*	-0.05	0.47	16.29**
P5×P6	-10.35**	-0.07	-2.03	-2.74*	-1.62**	-0.03	-0.21	-0.91**	2.69	-12.54**
P5×P7	2.07	-1.54**	-4.49**	5.68**	1.18**	-0.11	-0.13	-2.45**	4.74*	5.36
P5×P8	-14.08**	0.49	1.87	-2.68*	-1.53**	0.19	-0.64	0.20	-5.86**	4.69
P5×P9	-1.24	-0.45	3.36**	-2.58*	-0.99**	-0.04	-0.16	0.89**	2.03	-0.95
P5×P10	-0.81	-1.20*	-4.72**	-2.98*	0.90*	0.24*	-0.38	0.76**	-3.78	-0.77
P5×P11	7.54**	0.71	0.28	6.30**	-0.12	-0.17	0.31	-0.94**	5.33*	0.35
P6×P7	0.81	-1.47**	-3.21**	-2.17	-0.71	0.14	0.51	0.14	-5.66*	-3.19
P6×P8	15.15**	0.54	-1.85	0.93	0.54	-0.47**	0.74	-1.21**	3.49	-24.72**
P6×P9	-8.02**	-2.36**	3.64**	3.16**	0.96**	0.22*	-0.03	-0.07	6.21**	-1.97
P6×P10	5.00**	0.18	-6.10**	3.65**	-0.43	-0.39**	0.30	0.69**	3.58	42.09**
P6×P11	0.02	-0.34	-2.10	6.68**	-0.96**	0.20	0.83*	-0.07	4.14	2.46
P7×P8	-1.27	0.70	-2.64	-1.08	0.71	0.38**	1.25**	0.03	-3.09	0.20
P7×P9	-4.05*	-0.27	-1.49	-0.49	-1.22*	0.10	-0.65	-0.13	-3.98	0.46
P7×P10	-7.88**	-0.33	-1.90	3.91**	-0.14	0.51**	0.49	0.22	-0.29	-2.52
P7×P11	7.07**	-0.90	5.44**	-5.09**	0.44	0.35**	0.01	0.51*	-1.22	-5.96
P8×P9	6.32**	0.18	1.87	6.51**	-0.16	0.01	-0.53	-0.20	3.44	5.81
P8×P10	4.06*	-0.61	0.46	2.14	-0.93**	-0.04	-0.14	0.64**	0.80	24.93**
P8×P11	3.94*	-1.45**	-10.21**	5.23**	-0.43	-0.20	-0.07	0.37	-1.25	23.96**
P9×P10	-3.77	-0.25	-9.05**	0.58	0.17	0.09	1.09*	-0.10	4.39*	0.31
P9×P11	-4.11*	0.20	-7.38**	-1.76	0.82*	0.43**	-0.83*	-0.15	3.61	-0.64
P10×P11	2.87	-0.23	5.21**	-1.42	-0.12	-0.28*	0.30	-0.02	1.23	-1.56
SE (sij)	1.91	0.50	1.37	1.13	0.41	0.10	0.41	0.22	2.13	4.89
SE (sij-ik)	2.79	0.73	2.01	1.65	0.59	0.15	0.60	0.33	3.45	7.16
CD (P=0.05)	3.80	0.99	2.72	2.25	0.81	0.21	0.81	0.45	4.35	9.76

* and ** Significant at P=0.05 and P=0.01, respectively.

For pod width, four parents showed significant GCA effect, but one parent showed significant positive GCA effects. The maximum positive GCA effect (0.13) was observed in P₇ (VRP-7). Among 55 F₁ crosses, 18 crosses exhibited significant positive SCA effects. The cross P₁ × P₂ (Arkel × GP-17) showed the maximum significant positive SCA effect (0.65) followed by P₇ × P₁₀ (0.51).

For number of seeds per pod four parents showed significant GCA effect, out of which two showed significant positive GCA effects. The maximum positive effect (0.34) was observed in P₆ (VP 233). Among 55 F₁ crosses, 5 crosses exhibited significant positive SCA effect. The cross

P₁ × P₇ (Arkel × VRP-7) showed the maximum significant positive SCA effect (1.47) followed by P₇ × P₈ (VRP-7 × VRP-6) (1.25).

Among eleven parental lines, six lines showed significant GCA effect but two lines exhibited significant positive GCA effects. Highest positive effect (0.44) was observed in parental line P₅ (GP-473) followed by (0.27) in P₃ (Arka Ajit). Among 55 F₁ crosses, 19 crosses exhibited significant SCA effects. The maximum significant positive SCA effect (1.19) was exhibited by the cross P₂ × P₈ (GP-17 × VRP-6) followed by P₅ × P₉ (GP-473 × AP-3) (0.89).

For shelling percentage, out of eleven parents, two

showed positive significant GCA effects. Highest positive effect (3.69) was observed in parental line P_6 (VP 233) followed by P_5 (GP-473). Among 55 F_1 crosses, 11 crosses exhibited significant positive SCA effects. The maximum significant positive SCA effect (8.96) was exhibited by the cross $P_3 \times P_4$ (Arka Ajit \times Pusa Pragati) followed by $P_2 \times P_7$ (GP-17 \times VRP-7) (8.32) and $P_1 \times P_8$ (Arkel \times VRP-6) (8.04).

For yield per plant, six parental lines showed significant GCA effects but, three parents showed significant positive GCA effects. The parental line P_7 (VRP-7) showed the highest positive GCA effect (9.67) followed by P_5 (GP-473) (8.46) and P_2 (GP-17) (3.82). Among 55 F_1 crosses, 31 crosses exhibited positive SCA effects but seven were highly significant and one with significant positive SCA effects. The cross $P_6 \times P_{10}$ (VP 233 \times IP-3) showed the maximum significant positive SCA effect (42.09) followed by the cross $P_2 \times P_8$ (GP-17 \times VRP-6) (26.95) and $P_8 \times P_{10}$ (VRP-6 \times IP-3) (24.93).

Among eleven parental lines, parent P_{11} (GP-6) exhibited maximum favourable GCA effect for node bearing first flower. Six parents (P_1, P_2, P_3, P_4, P_8 and P_9) showed significant negative GCA effects for days to 50% flowering. The parent P_6 exhibited significant GCA effects in desirable direction for characters like pod length, number of seeds per pod and shelling percentage. In order of merit, the three F_1 crosses showing highest significant SCA effect in desired direction for different characters were $P_6 \times P_8, P_2 \times P_{10}$ and $P_5 \times P_{11}$ for plant height, $P_6 \times P_9, P_2 \times P_6$ and $P_5 \times P_7$ for node bearing first flower, $P_8 \times P_{11}, P_3 \times P_{10}$, and $P_9 \times P_{10}$ for days to 50% flowering, $P_2 \times P_7, P_6 \times P_{11}$ and $P_8 \times P_9$ for number of pods per plant, $P_3 \times P_{10}, P_2 \times P_6$ and $P_3 \times P_7$ for pod length, $P_1 \times P_2, P_7 \times P_{10}$ and $P_2 \times P_4$ for pod width, $P_1 \times P_7, P_7 \times P_8$ and $P_9 \times P_{10}$ for number of seeds per pod, $P_2 \times P_8, P_5 \times P_9$ and $P_4 \times P_6$ for pod weight, $P_3 \times P_4, P_2 \times P_7$ and $P_1 \times P_8$ for shelling percentage, $P_6 \times P_{10}, P_2 \times P_8$ and $P_8 \times P_{10}$ for yield per plant. In many of the crosses it was found that per se performance of parents have direct expression of their respective GCA effects *i.e* parental lines showing high GCA effects for a character were also observed to be good performer with respect to that particular trait. The parental lines involved in the crosses which are having high GCA

effects for yield and its component characters, the derived F_1 hybrids showed promising results for these traits. The results are in agreement with the findings of Singh *et al.* (2005), Sharma *et al.* (2007), Thakur and Khosla (2008), Sharma and Bora (2013) and Sharma *et al.* (2015) in garden pea. The most outstanding parental lines involved in all F_1 crosses which showed best SCA effects were $P_1, P_2, P_5, P_6, P_8, P_{10}$ and P_{11} . The crosses $P_1 \times P_2, P_2 \times P_6, P_2 \times P_7, P_2 \times P_8, P_3 \times P_{10}, P_6 \times P_9, P_6 \times P_{10}$ and $P_8 \times P_{11}$ with high SCA effects were superior for most of the characters including yield/plant, and may be utilized in exploitation of hybrid vigour. Above result led to conclude that there is a good prospect for recombinant breeding in pea for vegetable purpose.

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