Heterosis and Combining Ability Studies for Oil and Protein Content in Soybean [*Glycine max* (L.) Merrill]

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Soybean [*Glycine max* (L.) Merrill] is energy rich oil seed crop in India. Heterosis and combining ability studies were carried out in F_1, F_2, and F_3 generations of 45 crosses derived from crossing of 15 soybean lines with 3 testers. Based on various estimates viz., mean performance, heterosis and combining ability the best soybean parents and crosses for quality traits were identified. For both seed oil and protein content, high heterosis and positive Specific Combining Ability (SCA) effects were recorded in crosses Pusa 40 x NRC 12, JS 79-81 x MACS 58, JS 80-21 x MACS 58 and PK 564 x PK 472 and could be further exploited. These crosses involved geographically diverse parents and at least on parent of high General Combining Ability (GCA) effects in combination of high x high, high x average and high x low. Therefore, these crosses could throw transgressive segregants in still advance generations. Future, the results of present study suggested that heterosis coupled with high SCA effects might be considered as a criteria for selecting crosses for further improvement with respect to quality traits.

Key Words: Heterosis, Combining Ability, *Glycine max* (L.) Merrill, Line x Tester

Introduction

Soybean regarded as "Wonder crop" is the richest, cheapest and easiest source of best quality proteins and fats. It contains 40-44 per cent protein with high biological value and 20-22 per cent oil and shares about 10-11 per cent of the domestic edible oil need of the country. The protein component is rich in essential amino acid lysine and used to supplement other cereals foods. It can play a vital role in meeting the acute problem of malnutrition in developing countries. Natural soybean oil is highly unsaturated and contains 7 per cent of omega 3 (alfa linolenic) fatty acid which is beneficial in the diet for the cardio-vascular health of human beings.

To develop elite and better nutritional quality varieties such cultivars a systematic approach has to be adopted. Protein and oil are polygenic characters and their improvement is basically based upon identification and selection of superior parents or lines, which can be effectively used for developing superior quality genotypes for breeding programme. Combining ability studies are regarded useful in assessing the relative nicking ability of parents, which on crossing would produce more desirable segregants and elucidate the nature and magnitude of gene action involved. The study becomes much more reliable if a good degree of correspondence is observed between various genetic estimates over filial generations.

Further, extent of heterosis will have direct effect on breeding methodology in varietal improvement programmes. Therefore, keeping aforesaid considerations in view, present study was undertaken in soybean to evaluate, identification and selection of better nutritional quality genotypes.

Materials and Methods

Experimental material consisted of F_1, F_2, and F_3 generations of 45 crosses derived from crossing of 15 soybean lines with 3 testers. The parents were selected on the basis of diverse pedigree, growth habit, geographical origin and adaptation. The experimental material including parents, F_{1S}, F_{2S} and F_{3S} were planted in randomized block design with 3 replications under rainfed conditions at the Instructional Farm, Rajasthan College of Agriculture, Udaipur during *Kharif*, 2001. One row of 3 m of parents and F_{1S} while 3 rows each of F_2 and F_3 generations were planted. Seeds were dibbled at the spacing of 45 cm x 10 cm row to row and plant to plant. Bulk seed of 10 randomly selected competitive plants of parents and F_{1S}, where as 20 plants in F_2 and F_3 generations in each replication was used for analysis of seed oil and protein content. Oil content was estimated by Soxhlet extraction while Nitrogen content in seed sample was analysed by micro–Kjeldhal's method. The average N per cent value was multiplied by the protein conversion factor 5.71 for soybean to give the per cent crude protein for each entry. Different types of heterosis viz., heterosis over mid parent, heterobeltiosis over better parent, economic heterosis over standard check (JS-335) as well as inbreeding depression in F_2 and F_3 generations were estimated using mean values. Analysis of line x tester data for combining ability was done according to Kempthorne (1957) and Arunachalam (1974).

Results and Discussion

Analysis of variance was carried out for tester, lines and their crosses in 3 generations and that revealed highly significant differences for all the lines and crosses indicating sufficient variation in the material for both oil and protein content. However, mean squares due to testers were significant for only protein content. The study for mean and range revealed that among parents there was great variability in the lines than testers for both the characters. Among generations F_{1S} showed superiority than their parents, F_2 and F_3 generations as F_{1S} exhibited higher mean values and wide range of variation for both the characters. It was reflected that the hybrids superior in F_1 involved both or at least one parent of high *per se* performance. Almost these hybrids showed consistent performance in their subsequent generations for all the characters studied. However, a considerable decrease from F_1 to F_2 and F_2 to F_3 generations for both oil and protein content was noticed.

Among the parents JS 71-05 for both oil and protein, RAUS 97-1 for oil and MACS 58 for protein content appeared promising. Crosses JS 79-81 x MACS 58, JS 80-21 x MACS 58, PK 564 x PK 472 and JS 71-05 x PK 472 turned out to be superior for both oil and protein content over the generations. These crosses also involved one of the parents as high performer.

In heterosis studies for oil content no cross combination showed significant positive heterosis and heterobeltiosis (Table 1). However, 5 and 2 crosses were positive but insignificant for heterosis and heterobeltiosis, respectively. On the other hand, undesirable negative significant heterosis also found in 5 crosses. These findings suggested the importance of additive gene effects. Moreover, desirable economic heterosis over standard check JS 335 was reported in 13 crosses and ranged in between 4.43 to 23.33 per cent. Maximum economic heterosis was recorded for RAUS 97-1 x NRC-12 followed by JS 79-81 x MACS 58, JS 71-05 x MACS 58, JS 71-05 x PK 472 and JS 71-05 x MACS 58. Considerable inbreeding depression was expressed by 23 crosses in F_2 and 3 crosses in F_3 generation. Similar to the present study Nelson and Bernard (1984) and Chen (1987) also reported insignificant heterosis while Sabbouh *et al.* (1998) recorded significant heterobeltiosis for seed oil content.

Incase of seed protein content 4 crosses viz., JS 79-81 x MACS 58, RAUS 97-1 x PK 472, PK 564 x PK 472 and JS 80-21 x MACS 58 showed significant positive heterosis and heterosis ranged from – 5.20 to 5.62 pre cent (Table 1). Among these crosses JS 80-21 x MACS 58 also exhibited significant economic heterosis. Gadag and Upadhyaya (1995) and Sabbouh *et al*. (1998) also observed significant positive heterosis for protein content. However, 13 crosses showed desirable positive but insignificant heterobeltiosis. Significant positive inbreeding depression was recorded in 22 crosses in F_2 and 3 crosses in F_3 generations.

Based on heterosis study, crosses JS 79-81 x MACS 58 and PK 564 x PK 472 appeared superior for both oil and protein content (Table 1). While RAUS 97-1 x NRC 12 for oil and JS 80-21 x MACS 58 and RAUS 97-1 x PK 472 superior for protein content.

In autogamous crops like soybean, combining ability provides required information about the nature and magnitude of genetic variation along with nicking ability of genotypes. Over and above, the study become much more precise and reliable if the relative combining ability is analyzed in F_1, F_2, and F_3 generations so as to obtained a good degree of correspondence between these estimates which will help in identifying superior parents and crosses that could be effectively utilized in breeding progamme. Such study may also reflect the possibility of obtaining rare favourable combinations of characters in segregating generations.

Analysis of variance for combining ability for both the quality traits indicated that variance due to crosses, lines and line x tester interaction were significant for seed oil and protein content in all the 3 generations. While variance due to testers was significant for oil content in F_3 and protein content in F_1 and F_2 generations. Significance of lines and testers indicated higher contribution towards general combining ability, while for lines x tester interaction towards specific combining ability for both the characters. Predominance of estimated component of Specific Combining Ability (SCA) variance over General Combining Ability (GCA) indicated importance of non-additive genetic effects for seed protein and oil content. Contribution of lines was higher for oil content in F_1 and F_3 and for protein content in F_1 generation. Whereas higher contribution due to interaction between line and tester was for oil content in F_2 and for protein content in F_2 and F_3 generations.

Among the parents lines JS 71-05, PK 564 and JS 79-81 recorded positive significant GCA effects in all

Table 1. Estimation of heterosis (MP), heterobeltiosis (BP), economic heterosis (EP) and inbreeding depression for seed oil and protein content in soybean

S.No.	Cross	Seed oil content (%)					Seed protein content (%)				
		MP	BP	EP	IDF_2	IDF_3	MP	BP	EP	IDF_2	IDF_3
1.	Bragg x PK 472	–1.50	–	4.96	9.29	0.62	–2.03	–	–	2.98	2.14
2.	JS 79–81 x PK 472	0.74	0.00	18.02	–0.65	0.05	2.41	–	–	3.68	1.33
3.	RAUS 97–1 x PK 472	–3.37	–	17.84*	5.41	1.48	4.36*	2.58	1.31	10.43**	–0.72
4.	Pusa 24 x PK 472	–1.69	–	12.92	9.14	0.98	0.55	0.46	–	3.58*	0.92
5.	PK 416 x PK 472	–2.14	–	16.07	6.36	–0.24	0.29	0.23	–	2.85	–0.73
6.	PK 564 x PK 472	6.26	2.35	20.79*	3.62	–2.13	3.48*	2.56	3.13	2.27*	0.05
7.	JS 71–05 x PK 472	1.35	–	22.33*	5.84	–2.46	2.77	1.47	2.82	2.48**	–0.63
8.	Pusa 20 x PK 472	–1.15	–	11.87	11.83	1.14	0.96	–	–	1.58	3.54
9.	MACS 57 x PK 472	–7.84	–	7.21	–1.60	18.98*	0.38	–	–	2.28	–0.29
10.	Monetta x PK 472	–3.85	–	8.45	9.69	–1.33	1.34	0.61	–	1.95	0.10
11.	JS 80–21 x PK 472	–3.89	–	8.09	15.57*	–19.09	0.43	–	0.23	2.52*	0.21
12.	Pusa 40 x PK 472	–12.44*	–	6.20	9.51	5.29	3.72	0.33	–	3.05	1.81
13.	PK 471 x PK 472	5.19	–	13.70	12.00*	–2.07	2.22	1.43	1.74	–0.32	1.63
14.	Pusa 16 x PK 472	0.13	–	16.95*	6.52	15.45*	1.70	0.08	–	3.65	–0.87
15.	NRC 2 x PK 472	–4.69	–	14.71	10.92*	0.75	–3.97**	–	–	2.66*	–0.06
16.	Bragg x MACS 58	4.09	–	10.45	12.03	2.25	1.00	–	1.84	–0.05	1.98
17.	JS 79–81 x MACS 58	5.27	4.89	22.86*	7.21**	–2.23	5.62**	1.41	3.33	2.83**	0.70
18.	RAUS 97–1 MACS 58	–3.21	–	17.60*	5.98	13.84	–0.66	–	–	5.69*	–1.72
19.	Pusa 24 MACS 58	–2.79	–	11.22	10.62**	–0.06	0.21	–	0.45	2.53*	6.58**
20.	PK 416 x MACS 58	–7.82*	–	8.92	8.35*	0.71	0.21	–	0.61	1.53*	–0.46
21.	PK 564 x MACS 58	3.03	–	16.66*	2.73*	1.98	–0.41	–	0.81	2.15	–0.69
22.	JS 71–05 x MACS 58	0.88	–	21.32*	8.47**	–3.09*	–1.03	–	0.56	1.26	0.03
23.	Pusa 20 x MACS 58	1.55	–	14.47	11.76*	–2.63	0.12	–	–	–0.98	0.03
24.	MACS 57 x MACS 58	0.31	–	16.24	17.78**	–14.22*	–0.10	–	0.63	1.65	6.24**
25.	Monetta x MACS 58	3.10	–	15.83	21.98**	1.31	0.73	–	0.35	8.87**	–2.34
26.	JS 80–21 x MACS 58	–2.45	–	9.27	–6.11	0.31	2.49*	1.95	3.88*	2.52	6.62*
27.	Pusa 40 x MACS 58	–11.00**	–	7.56	14.83*	–1.48	–5.12*	–	–	2.22	0.70
28.	PK 471 x MACS 58	–2.33	–	5.14	–0.45	–0.56	0.04	–	1.13	11.84**	–12.70*
29.	Pusa 16 x MACS 58	–2.54	–	13.41	9.43*	2.53	0.22	–	–	3.13	–0.42
30.	NRC 2 x MACS 58	–12.91**	–	4.43	7.69	0.86	2.14	–	–	2.13	–0.41
31.	Bragg x NRC 12	4.67	–	10.87	12.68	–13.97	1.24	0.18	–	1.51	–0.51
32.	JS 79–81 x NRC 12	–0.44	–	16.01	7.84**	0.17	–3.33	–	–	5.94**	–4.84**
33.	RAUS 97–1 x NRC 12	1.66	–	23.33*	21.41**	1.28	–0.20	–	–	5.31*	–7.85*
34.	Pusa 24 x NRC 12	–5.11*	–	8.39	10.03	–16.23	0.13	–	–	3.23**	–0.48
35.	PK 416 x NRC 12	–0.47	–	17.42*	3.67	1.98	0.64	0.03	–	4.05**	1.75
36.	PK 564 x NRC 12	2.15	–	15.48	9.00**	–3.43	0.28	–	–	1.88*	–0.80
37.	JS 71–05 x NRC 12	–2.94	–	16.54*	1.57	–3.96*	0.16	–	–	2.61*	–0.26
38.	Pusa 20 x NRC 12	1.82	–	14.59	11.13**	–3.48	–0.18	–	–	4.60*	1.97
39.	MACS 57 x NRC 12	–0.09	–	15.59	10.22**	–3.45	0.55	–	–	2.75	2.30
40.	Monetta x NRC 12	2.85	–	15.36	9.47**	–1.41	–1.10	–	–	3.84	–6.88**
41.	JS 80–21 x NRC 12	1.62	–	13.64	11.69**	–1.41	0.72	–	–	11.37**	–1.99
42.	Pusa 40 x NRC 12	–1.61	–	18.72*	4.98	14.82**	0.33	–	–	–4.79*	–0.76
43.	PK 471 x NRC 12	4.32	–	12.11	9.54*	–2.80	0.31	–	–	3.76	0.69
44.	Pusa 16 x NRC 12	–0.40	–	15.71	9.90**	–1.36	0.44	–	–	–1.09	–0.98
45.	NRC 2 x NRC 12	–1.72	–	17.66*	4.67*	–1.19	0.48	–	–	9.68**	–5.40**
	Range	–12.44 – 12.91	2.35 – 4.89	4.43 – 23.33	–611 – 21.98	–19.09 – 18.98	–5.12 – 5.62	0.03 – 2.58	0.23 – 3.88	–4.79 – 11.84	–12.70 – 6.62
	Check JS 335	–	–	16.93	–	–	–	–	39.67	–	–

*, ** Significant at 5 % and 1% levels, respectively.

the 3 generations for seed oil content. While for seed protein content PK 564 and JS 71-05 could be considered superior as these exhibited high GCA effects in all the 3 generations (Table 2). The *per se* performance of most of the parent was moderate to high for seed oil content and seed protein content.

Among the hybrids, positive significant SCA effects for seed oil content were exhibited by JS 80-21 x MACS 58 and Pusa 40 x NRC 12 in F_2 and RAUS 97-1 x PK 472 and MACS 57 x MACS 58 in F3 generation. On the other hand for seed protein content many crosses showed significantly high SCA effects. JS 79-81 x MACS 58 showed desirable SCA effects in all the 3 generations. While Pusa 40 x NRC 12 and NRC 2 x MACS 58 depicted high SCA effects in F_2 and F_3 generations (Table 3). Among these hybrids most of them had high *per se* and involving good general combiner parents, hence, could be used effectively in quality improvement of soybean.

Therefore on the basis of combining ability effects, crosses Pusa 40 x NRC 12 and JS 80-21 x MACS 58 appeared promising for both seed oil and protein content. While RAUS 97-1 x PK 472 and JS 79-81 x MACS 58 were good specific combiner for oil and protein content, respectively.

Similar to present findings Mc Kendry *et al*. (1985) and Gadag *et al.* (1999) also reported importance of non-additive gene effects for protein content. On the contrary, Zhu *et al.* (1994) and Sabbouh *et al*. (1998) noted significant GCA and additive effects for protein content in soybean.

In case of oil content, as per present study Sharma *et al.* (1997) and Sabbouh *et al.* (1998) recorded partial dominance and non-additive gene action and Raut *et al.* (2000) reported dominance gene effects in 2 crosses for seed oil content in soybean. Contrary to this, significant additive gene action was reported by Zhu *et al*. (1994) for oil content.

To conclude, combining ability mean squares estimated over each generation reveled that both the quality traits displayed preponderance of non-additive gene effects. Further, a high degree of correspondence between combining ability (GCA and SCA) from F_1 to F_3 generation for both the characters was noticed, which

Table 2. General Combining Ability (GCA) effects for quality characters in F_1, F_2 and F_3 generations in soybean

S.No.	Genotype	Seed oil content (%)			Seed protein content (%)		
		F_1	F_2	F_3	F_1	F_2	F_3
1.	PK 472	–0.10	0.11	–0.17	0.13	0.22	–0.06
2.	MACS 58	–0.15	–0.21	–0.26	0.42**	0.45**	0.23
3.	NRC 12	0.25	0.10	0.43*	–0.55**	–0.67**	–0.17
4.	Bragg	–0.88**	–1.32**	–0.75*	0.29	1.00**	0.47
5.	JS 79–81	0.85**	1.53**	1.62**	–0.31	–0.62	–0.39
6.	RAUS 97–1	0.96**	0.36	–0.71	–0.16	–1.68**	–0.50
7.	Pusa 24	–0.52	–0.74*	0.06	0.15	0.21	–0.77*
8.	PK 416	0.03	0.51	0.32	0.24	0.42	0.29
9.	PK 564	0.63*	1.26**	1.44**	0.86**	1.30**	1.42**
10.	JS 71–05	1.04**	1.60**	2.17**	0.82**	1.26**	1.31**
11.	Pusa 20	–0.05	–0.63	–0.38	–0.86**	–0.23	–0.98**
12.	MACS 57	–0.16	–0.25	–0.48	0.33	0.74*	–0.40
13.	Monetta	–0.12	–1.12**	–1.07**	–0.09	–0.72*	0.32
14.	JS 80–21	–0.61*	–0.29	0.72	0.96**	0.06	–0.68*
15.	Pusa 40	–0.53	–0.68	–1.87**	–1.36**	–0.14	–0.42
16.	PK 471	–0.61*	–0.31	–0.04	0.71*	–0.04	1.08**
17.	Pusa 16	0.24	0.21	–0.85*	–0.26	0.28	0.51
18.	NRC 2	–0.28	–0.11	–0.16	–1.32**	–1.86**	–1.25**
	Standard Error						
	GCA_{Ti}	0.15	0.19	0.19	0.14	0.16	0.16
	GCA_{Lj}	0.30	0.37	0.38	0.28	0.32	0.31
	GCA_{Ti-j}	0.18	0.23	0.23	0.17	0.20	0.19
	GCA_{Li-j}	0.41	0.51	0.52	0.38	0.44	0.43
	GCA_{Ti-Lj}	0.32	0.39	0.40	0.30	0.34	0.33

*, ** Significant at 5 % and 1% levels, respectively.

Table 3. Specific Combining Ability (SPA) effects for yield characters in F_1, F_2 and F_3 generations in soybean

S.No.	Cross	Seed oil content (%)			Seed protein content (%)		
		F_1	F_2	F_3	F_1	F_2	F_3
1.	Bragg x PK 472	-0.54	-0.31	-0.73	-1.10	-1.76**	-1.81**
2.	JS 79-81 x PK 472	-0.06	0.83	0.97	0.04	0.10	-0.41
3.	RAUS 97-1 x PK 472	-0.20	0.76	1.79*	0.96	-0.51	-1.21
4.	Pusa 24 x PK 472	0.45	0.36	-0.37	-0.17	-0.44	0.40
5.	PK 416 x PK 472	0.43	0.14	0.62	-0.30	-0.41	0.22
6.	PK 564 x PK 472	0.63	0.70	1.18	0.67	0.49	0.57
7.	JS 71-05 x PK 472	0.48	0.15	0.30	0.58	0.33	0.75
8.	Pusa 20 x PK 472	-0.20	-0.42	-0.62	-0.02	-0.06	-0.43
9.	MACS 57 x PK 472	-0.88	0.94	-2.09**	-0.23	-0.34	1.13
10.	Monetta x PK 472	-0.71	-0.05	0.36	0.12	1.19	0.32
11.	JS 80-21 x PK 472	-0.28	-2.01**	0.17	-0.58	0.51	1.39*
12.	Pusa 40 x PK 472	-0.68	-0.80	-0.22	1.29*	0.06	-0.13
13.	PK 471 x PK 472	0.67	-0.50	-0.18	0.27	2.34**	0.78
14.	Pusa 16 x PK 472	0.37	0.55	-1.01	0.08	-0.69	-0.37
15.	NRC 2 x PK 472	0.51	-0.34	-0.18	-1.61**	-0.84	-1.21
16.	Bragg x MACS 58	0.44	0.34	-0.59	0.44	1.00	0.89
17.	JS 79-81 x MACS 58	0.81	0.34	0.69	1.64**	2.04**	1.68**
18.	RAUS 97-1 MACS 58	-0.18	0.93	-0.58	-0.64	-0.07	-0.47
19.	Pusa 24 MACS 58	0.22	0.14	-0.64	0.04	0.22	-1.20
20.	PK 416 x MACS 58	-0.73	-1.04	-0.96	0.00	0.47	0.93
21.	PK 564 x MACS 58	-0.01	0.52	-0.03	-0.54	-0.59	-0.28
22.	JS 71-05 x MACS 58	0.37	-0.23	-0.21	-0.60	-0.29	-0.19
23.	Pusa 20 x MACS 58	0.29	0.30	0.51	0.00	1.00	1.90**
24.	MACS 57 x MACS 58	0.70	-1.01	1.54*	-0.08	0.11	-1.05
25.	Monetta x MACS 58	0.60	-1.01	-1.25	0.23	-1.41*	-1.45*
26.	JS 80-21 x MACS 58	-0.03	2.48**	1.43	0.58	1.69**	-0.07
27.	Pusa 40 x MACS 58	-0.40	-1.24	0.19	-1.76**	-2.53**	-2.35**
28.	PK 471 x MACS 58	-0.72	0.76	0.60	-0.25	-3.00**	0.52
29.	Pusa 16 x MACS 58	-0.18	-0.25	0.38	-0.15	-0.67	-0.58
30.	NRC 2 x MACS 58	-1.17	-1.01	-1.08	1.06	2.01**	1.72**
31.	Bragg x NRC 12	0.10	-0.03	1.32	0.66	0.75	0.92
32.	JS 79-81 x NRC 12	-0.75	-1.17	-1.66*	-1.68**	-2.14**	-1.27*
33.	RAUS 97-1 x NRC 12	0.38	-1.69*	-1.21	-0.32	0.58	1.67**
34.	Pusa 24 x NRC 12	-0.67	-0.49	1.01	0.13	0.22	0.81
35.	PK 416 x NRC 12	0.30	0.90	0.34	0.30	-0.06	-1.16
36.	PK 564 x NRC 12	-0.62	-1.21	-1.15	-0.13	0.09	-0.28
37.	JS 71-05 x NRC 12	-0.85	0.08	-0.09	0.01	-0.05	-0.56
38.	Pusa 20 x NRC 12	-0.09	0.13	0.11	0.02	-0.95	-1.47*
39.	MACS 57 x NRC 12	0.18	0.07	0.55	0.31	0.23	-0.08
40.	Monetta x NRC 12	0.11	1.06	0.89	-0.35	0.22	1.14
41.	JS 80-21 x NRC 12	0.31	-0.47	-1.60*	-0.00	-2.21**	-1.33*
42.	Pusa 40 x NRC 12	1.08	2.04**	0.03	0.47	2.47**	2.48**
43.	PK 471 x NRC 12	0.05	-0.26	-0.42	-0.02	0.66	-1.29*
44.	Pusa 16 x NRC 12	-0.19	-0.30	0.63	0.07	1.35*	0.94
45.	NRC 2 x NRC 12	0.66	1.35	1.26	0.55	-1.18	-0.50
	Standard Error:						
	SCA_{ij}	0.60	0.74	0.76	0.56	0.64	0.62
	SCA_{Ti-Tj}	0.74	0.91	0.93	0.69	0.78	0.76
	SCA_{iL-jL}	0.82	1.02	1.04	0.77	0.87	0.85
	SCA_{ij-kl}	0.84	1.04	1.07	0.79	0.90	0.87

*,**Significantat5%and1%levels,respectively

reflected the reliability and consistency of results obtained with respect to nature of inheritance.

Often the unfavorable association between protein and yield generally met with are due to tight linkages, which could be broken by raising a large population. In the present study JS 79-81 x MACS 58 revealed superiority for yield as well as protein content might be considered a new favorable combination resulted due to breaking of tight linkages. Simultaneous improvement of protein content and grain yield has been achieved in wheat (Sears *et al*., 1991) and rice (Loffier *et al*., 1993). Through the use of recurrent selection suggested that such negative relationship may be caused by linkage and improvements can be made for such traits by enforcing simultaneous selection in large segregation population.

Based on various estimates viz., mean performance, heterosis and combining ability the best soybean parents and crosses for quality traits were identified (Table 4). For both seed oil content and protein content, high heterosis and positive SCA effects were recorded in crosses Pusa 40 x NRC 12, JS 79-81 x MACS 58, JS 80-21 x MACS 58 and PK 564 x PK 472 and could be further exploited. These crosses involved geographically diverse parents and at least on parent of high GCA effects in combination of high x high, high x average and high x low.

Majority of soybean breeding work is based on pedigree method, which exploits the fixable additive type of gene effects. However, this alone may be inadequate in view of the large non-additive component for both quality traits. Further, high heterosis for oil and protein

Table 4. Best parents and crosses selected on the basis of their per se performance, GCA effects, SCA effects and heterotic response for seed oil and protein content in soybean

Characters		Seed oil content	Seed protein content
Best parents *per se*		RAUS 97-1, Pusa 40, JS 71-05, NRC 2, PK 416	MACS 58, JS 71-05, JS 80-21, PK 564, PK 471
Best crosses *per se*	F_1	RAUS 97-1 x NRC 12, JS 79-81 x MACS 58, JS 71-05 x PK 472, JS 71-05 x MACS 58, PK 564 x PK 472	JS 80-21 x MACS 58, JS 79-81 x MACS 58, PK 564 x PK 472, JS 71-05 x PK 472, Bragg x MACS 58
	F_2	JS 79-81 x PK 472, PK 564 x PK 472, JS 80-21 x MACS 58, JS 71-05 x PK 472, JS 79-81 x MACS 58	PK 471 x PK 472, Bragg x MACS 58, JS 80-21 x MACS 58, PK 564 x PK 472, JS 79-81 x MACS 58
	F_3	JS 71-05 x NRC 12, PK 564 x PK 472, JS 79-81 x PK 472, JS 71-05 x PK 472, JS 79-81 x MACS 58	JS 71-05 x PK 472, PK 564 x PK 472, Pusa 40 x NRC 12, PK 471 x MACS 58, PK 471 x PK 472
Best heterotic Crosses		RAUS 97-1 x NRC 12, JS 79-81 x MACS 58, JS 71-05 x PK 472, JS 71-05 x MACS 58, PK 564 x PK 472	JS 80-21 x MACS 58, JS 79-81 x MACS 58, RAUS 97-1 x PK 472, PK 564 x PK 472, JS 71-05 x PK 472
Best GCA parents ($F_1/F_2/F_3$)		JS 71-05, PK 564, JS 79-81, RAUS 97-1, NRC 12	PK 564, JS 71-05, PK 471, MACS 58, JS 80-21
	F_1	Pusa 40 x NRC 12, JS 79-81 x MACS 58, MACS 57 x MACS 58, PK 471 x PK 472,	JS 79-81 x MACS 58, Pusa 40 x PK 472,
Best SCA Crosses		NRC 2 x NRC 12	RAUS 97-1 x PK 472, PK 564 x PK 472, Bragg x NRC 12
	F_2	JS 80-21 x MACS 58, Pusa 40 x NRC 12, NRC 2 x NRC 12, Monetta x NRC 12, MACS 57 x PK 472	Pusa 40 x NRC 12, PK 471 x PK 472, JS 79-81 x MACS 58, NRC 2 x MACS 58, JS 80-21 x MACS 58
	F_3	RAUS 97-1 x PK 472, MACS 57 x MACS 58, JS 80-21 x MACS 58, Bragg x NRC 12, NRC 2 x NRC 12	Pusa 40 x NRC 12, Pusa 20 x MACS 58, NRC 2 x MACS 58, JS 79-81 x MACS 58, RAUS 97-1 x NRC 12
Common crosses in SCA and heterosis with high cross *per se*	F_1	JS 79-81 x MACS 58	JS 79-81 x MACS 58, PK 564 x PK 472
	F_2	--	JS 80-21 x MACS 58 JS 79-81 x MACS 58
	F_3	---	---

along with positive SCA effects was observed in these crosses, which might be due to dominance or epistasis. Although heterosis breeding makes maximal use of the non-additive genetic effects appears to be difficult for improving soybean in view of the non availability of mass pollination systems needed for hybrid seed production. Accordingly, the feasible alternative is to consider simultaneous exploitation of both additive and non-additive gene action by adopting recurrent selection procedures. Under similar situation Harer and Deshmukh (1991) recommended biparental mating in soybean followed by recurrent selection. Since crossing is tedious in soybean, genetic male sterility and single seed or single pod descent method could be employed to facilitate recurrent selection schemes (Wilcox, 1998). Therefore, these crosses could throw transgressive segregants in still advance generations. Further, the results of present study suggested that heterosis coupled with high SCA effects might be considered as criteria for selecting cross for further improvement with respect to quality traits.

References

Arunachalam V (1974) The fallacy behind the use of a modified line x tester design. *Indian J. Genet*. **34:** 280-287.

Chen HH (1987) Dallel analysis of the genetic regulation of protein and oil content in soybean. *Sci. Agri. Simi*. **20:** 32-38.

Gadag RN and HD Upadhyaya (1995) Heterosis in soybean [*Glycine max* (L.) Merrill]. *Indian J. Genet*. **55:** 308-314.

Gadag RN, HD Upadhyaya and JV Goud (1999) Genetic analysis of yield, protein, oil and other related traits in soybean. *Indian J. Genet*. **59:** 487-492.

Harer PN and RB Deshmukh (1991) Components of genetic variation in soybean [*Glycine max* (L.) Merrill]. *J. Oilseeds Res*. **8:** 220-225.

Kemptharne (1957) *An Introduction to Genetical Statistics*. Wiley, New York.

Loffier CM, RH Busch and JV Wiersma (1983) Recurrent selection for grain protein percentage in red spring wheat. *Crop Sci.,* **23:** 1097-1101.

McKendry AI, PBE McVetty and HD Voldeng (1985) Inheritance of seed protein and seed oil content in early maturing soybean. *Canadian J. Genet. Cytol*. **27:** 603-607.

Nelson RL and RL Bernard (1984) Production and performance of hybrid soybeans. *Crop Sci*. **24:** 549-553.

Raut VM, SP Taware and GB Halvankar (2000) Gene effects for some quantitative characters in soybean [*Glycine max* (L.) Merrill] crosses. *Indian J. Agric. Sci.* **70:** 334-335.

Sabbouh MV, LH Edurrds and KR Khim (1998) Heterosis and Combining ability for protein and oil concentration in the seed of soybean [*Glycine max* (L.) Merrill]. SABRAO *J. Breed. Genet.* **30:** 7-17.

Sadasivam S and A Manikam (1996) *Biochemical Methods*. 2nd Edn. New Age International, New Delhi, pp. 37.

Sears RG, EG Heyne, TJ Martin, TS Cox, LE Browder, DL Wetzel, MD Shogren, LC Bolte, SP Curran and JR Lowless (1991). Resistance of 'Karl' wheat. *Crop Sci.,* **30:** 1386.

Sharma SR, PS Phul, RK Raheja and KL Ahuja (1997). Nature of gene effects for fatty acid in soybean. *Crop Improv.* **24:** 273-274.

Wilcox JR (1998). Increasing seed protein in soybean with 8 cycles of recurrent selection. *Crop Sci.,* **38:** 1536-1540.

Zhu HD, JZ Yu, KJ Zhou, H Li, and M Yu (1994). Studies on soybean breeding for high content of both oil and protein. *Acta Agronomica Sinica.* **20:** 614-620.