

Original Research Article

Genetic Analysis of Yield, Protein, and Oil Traits in Soybean Diallel Crosses for Enhanced Crop Quality and Productivity

ABSTRACT

The study was conducted at Sakha Research Station, ARC, Egypt, during three successive seasons from 2021 to 2023. A half diallel cross of fifteen F_1 and F_2 generations in addition to the six soybean parental genotypes namely, Japanese 13, Giza 111, Crawford, $H_{18L_{54}}$, Nc92-2231 and Linford were evaluated to determine the genetic behavior of yield and its component traits in both F_1 and F_2 generations, as well as seed protein and oil contents in F_1 . Results indicated that mean squares of General Combining Ability (GCA) and Specific Combining Ability (SCA) were significant and highly significant for all the studied characters of soybean genotypes in F_1 's and F_2 's, except SCA for 100-seed weight in F_2 's only. The GCA/SCA ratios were less than unity in all traits, indicating that, the non-additive gene effects seemed to be responsible for the inheritance of these traits. The parental genotypes; $H_{18L_{54}}$, Nc 92-2231 and Linford seemed to be excellent combiners for days to flowering and maturity; however, Giza 111 and Japanese 13 were good combiners for seed yield. Meanwhile, Giza 111 was a good combiner for protein and oil content; also, $H_{18L_{54}}$ and Nc 92-2231 were good combiners for protein content. The crosses C7, C9, C10, C11 and C13 were earlier for maturity date, and also showed the most negative significant desirable \hat{S}_{ij} effects. The best (\hat{S}_{ij}) values in F_2 were shown in the C1, C5, C8 and C15 crosses for seed yield/plant, these crosses also had the highest seed yield values in F_2 . The crosses; C5 and C8 showed significant to highly significant positive heterotic effects relative to the better parent for protein% and seed yield per plant. In addition three crosses; C13, C14, and C15 had highly significant positive heterotic effects relative to the better parent for oil% and seed yield per plant.

Key words: Soybean, combining ability, heterosis, earliness, yield, protein, oil.

INTRODUCTION

Soybean (*Glycine max*) is a versatile crop that is valuable not only for its oil and protein content but also for its nutritional benefits. The total production was over 394.71 million tons in 2023 harvested from 134 million hectares worldwide. In Egypt the total harvested area in 2023 was 30000 hectares with a total production of 85000 tons, 2.83 yield average per hectare [1]. Soybean is a major player in the global edible oil and high protein meal markets, making significant contributions to human and animal nutrition. The high protein meal derived from soybean is widely used in poultry and human food production due to its rich nutrient profile. With its high oil content and essential nutrients, soybean is a valuable commodity that plays a crucial role in the food industry worldwide.

Soybean cultivation in Egypt faces challenges such as water scarcity, pests and diseases, as well as fluctuating market prices. However, efforts are being made to increase soybean production through research and extension programs to improve cultivation practices and develop new varieties that are better adapted to local conditions. Additionally,

government support and incentives for soybean farmers are being provided to promote the crop's cultivation and increase its contribution to the agricultural sector in Egypt.

Soybean breeders aim to enhance soybean productivity by understanding the inheritance of key agronomic traits such as earliness and yield. This knowledge is crucial for developing improved soybean varieties that can meet the growing demand for this important crop. The objectives of this study could be defined as the production of high-yield genotypes and improving seed quality characters.

MATERIALS AND METHODS

The experiment was conducted at Sakha Agricultural Research Station, ARC, Egypt, during the three successive seasons from 2021 to 2023. Six soybean parental genotypes, namely Giza 111, Crawford, Japanese 13, H18L54, Nc92-2231 and Linford were used, as shown in Table 1. The choice of these parents was based on genetic diversity, differences in growth habits, and variations in yielding ability.

In the 2021 season, the parents were sown on three sowing dates to ensure synchronization of flowering periods for parental genotypes. Once flowering began, the crosses were made manually. All possible parental combinations (half diallel) excluding reciprocals were made among the six genotypes to produce fifteen F_1 crosses.

Table 1: Names, pedigree, origin, maturity group and growth habit of the parental soybean genotypes used in this investigation.

Parents	Pedigree	Original	Maturity group	Growth habit
P1 (Japanese 13)	Introduced from Japan	Japan	II	Determinate
P2 (Giza 111)	Crawford x Celest	Egypt	III	Indeterminate
P3 (Crawford)	Williams x Columbus	USA	IV	Indeterminate
P4 (H18L54)	Crawford x Dekabig	Egypt	IV	Indeterminate
P5 (Nc 92-2231)	Introduced from USA	USA	IV	Indeterminate
P6 (Linford)	Williams82 x Fayette	USA	III	Indeterminate

During the 2022 season, the six parental genotypes were rehybridized to produce F_1 seeds and the F_1 plants were sown to produce F_2 seeds. In the 2023 season, seeds of the six parents and their F_1 's and F_2 's were sown in three replications. The experimental plot consisted of one ridge for each parent, five ridges for F_1 and ten ridges for F_2 generations, in addition to two border rows. The wet sowing method called Herati was used. Cultural practices were applied as usually recommended for ordinary soybean production.

The data were recorded on 30 plants for both parental genotypes and their F_1 and 300 F_2 guarded individual plants, which were labeled for different genotypes on the following characters: days to flowering, days to maturity, plant height, number of branches per plant, number of pods per plant, 100-seed weight (g) and seed yield per plant (g).

The standard germination test was carried out according to the international testing rules [2]. The germination percentage was determined on four replicates of 50 seeds for each seed sample placed in petri dishes containing filter paper soaked with distilled water. The petri dishes were then placed in an incubator at $25 \pm 1^\circ\text{C}$ for 8 days, and normal seedlings were counted. The Electrical Conductivity (EC) of leaches from four replicates of 50 seeds weighed (g) and soaked in 250 ml of distilled water for 24 hours, was measured. The mean values of EC were expressed in $\mu\text{m g}^{-1}$ using conductivity meter, following the international rules [2]. Seed protein (%) and oil contents (%) were determined according to the procedures outlined by AOAC [3].

The data were analyzed on a plot mean basis. An ordinary analysis of variance was firstly performed for parents and their hybrids F₁ and F₂ diallel according to **Snedecor and Cochran [4]**.

Heterosis as proposed by **Mather and Jinks [5]** was determined as the deviation of the F₁ means from better parent (BP). The average heterosis value for each trait was computed for parents vs. F₁ and F₂ hybrids. In the procedure, genotypes were sub-divided into their components (parents, crosses and parents vs. crosses). General and Specific Combining Ability estimates were obtained using **Griffing's [6]** diallel cross analysis designated as method 2 model 1. GCA/SCA ratio was calculated as follows:

$$\text{GCA/SCA ratio} = \frac{M_{S_{gca}} - (M_{S_{error}}/p)}{M_{S_{sca}} - M_{S_{error}}}$$

Where: M_{S_{gca}} is the mean square of GCA

M_{S_{sca}} is the mean square of SCA

M_{S_{error}} is the mean square of error and P is the number of parents

RESULTS AND DISCUSSION

Test of significance of F₁ as well as F₂ studied traits (Tables 2, 3 and 4) indicated that the mean squares of entries were highly significant for all studied traits. As the entries are partitioned into; parents, crosses and their interaction, the results pointed out that mean squares of parents as well as crosses were highly significant for all traits, except for 100-seed weight where it was not significant. The mean squares of parents vs. crosses as an indication to average heterosis overall crosses seems to be significant for all traits, except for days to flowering in both generations, plant height, number of branches/plant and 100-seed weight in both generations and number of pods/plant in F₂ generation where the differences did not reach the level of significance.

However, it appeared that, the magnitudes of the mean squares of entries or any of its components were several times larger than their corresponding mean square of error. The sizable magnitudes of entries mean square indicated the presence of considerable differences between their entries, and therefore, it became statistically valid for the required diversity for the success of the planned crosses.

It could be concluded from the results listed in Tables 2,3, and 4 that the ratio of GCA/SCA mean squares exceeded unity for all traits, except for number of branches/plant and number of pods/plant in the F₁ and seed yield per plant in both generations. These could be indicated that, the studied traits were controlled in their inheritance by additive genes, while for the excepted traits, the non-additive genes were responsible to the inheritance of the traits in view. Also, it could be indicated that both additive and non-additive genes were involved in the inheritance of all traits in different proportions where GCA and SCA mean squares were highly significance. Similar result for GCA and SCA variances were reported by **El-Hosary et al [7]**, **Yassien and Abd El-Mohsen [8]**, **Mansour [9]**, **Mansour et al [10]**, **Fayiz [11]**, **Waly [12]**, **Waly and Ibrahim [13]**, and **El-Seidy et al [14]**.

Table 2: Mean squares for ordinary and combining ability analysis for days to flowering, days to maturity, plant height and number of branches per plant characters associated with F₁ and F₂ soybean diallel crosses.

SOV	df	Days to flowering		Days to maturity		Plant height		Number of branches per plant	
		F ₁	F ₂	F ₁	F ₂	F ₁	F ₂	F ₁	F ₂
Reps	2	9.87**	1.76	26.56**	0.73	58.26	5.6	1.8	0.43
Entry	20	188.75**	141.05**	343.56**	733.54**	1024.82**	760.77**	14.96**	10.85**

Parents (P)	5	132.06**	149.17**	534.41**	792.99**	1982.48**	2458.06**	28.71*	29.16**
Crosses (C)	14	222.22**	141.6**	291.2**	526.61**	651.62**	208.84**	9.37**	4.62**
P vs C	1	3.69	92.82	122.36*	3333.26**	1461.31	1.41	24.42	6.59
Error	40	1.7	1.35	2.25	1.88	27.08	33.66	1.77	1.09
GCA	5	71.82**	70.06**	259.44**	590.49**	488.63**	462.71**	2.76**	5.95**
SCA	15	59.95**	39.34**	66.22**	129.19**	292.6**	183.89**	5.73**	2.84**
Error	40	0.57	0.45	0.75	0.63	9.03	11.22	0.09	0.36
GCA/SCA		1.21	1.80	3.96	2.26	2.08	2.67	0.52	2.73

* and **refer to significance at 0.05 and 0.01 levels of probability, respectively.

Table 3: Mean squares for ordinary and combining ability analysis for number of pods per plant, 100-seed weight and seed yield per plant characters associated with F₁ and F₂ soybean diallel crosses.

SOV	df	Number of pods per plant		100-seed weight		Seed yield per plant	
		F ₁	F ₂	F ₁	F ₂	F ₁	F ₂
Reps	2	1392.68	170.56	1.59	6.26	165.73	111.72
Entry	20	28018.16**	10999.87**	16.23**	16.15**	10393.2**	1605.67**
Parents (P)	5	20036.4**	20293.61**	10.83*	15.09**	2493.43**	1386.4**
Crosses (C)	14	12591.73**	7940.48**	18.5**	17.53	9972.34**	1588.95**
P vs C	1	283897.05**	7362.69	11.31	2.18	55784**	2936.07*
Error	40	1256.84	832.34	1.61	6.27	356.78	118.48
GCA	5	2492.22**	7110.02**	10.75**	12.25**	455.72**	405.45**
SCA	15	11621.78**	2518.83**	3.63**	3.09	4467.29**	578.48**
Error	40	418.95	277.45	0.54	0.09	118.93	39.49
GCA/SCA		0.216	3.15	3.22	4.08	0.10	0.57

* and **refer to significance at 0.05 and 0.01 levels of probability, respectively.

Table 4: Mean squares for ordinary and combining ability analysis for Germination%, EC, Protein % and Oil % characters associated with F₁ soybean diallel crosses.

SOV	df	Germination %	EC	Protein %	Oil %
Reps	2	1.25	0.05	4.76	0.3
Entry	20	118.83**	7.76**	183.21**	13.33**
Parents (P)	5	72.99**	3.61**	277.85**	8.14**
Crosses (C)	14	141.37**	9.5**	138.17**	16.03**
P vs C	1	32.46*	4.09**	340.52*	1.53*
Error	40	0.9	0.02	7.1	0.27
GCA	5	59.65**	4.51**	84.94**	0.67**
SCA	15	32.93**	1.94**	53.11**	5.7**
Error	40	0.3	2.33	2.37	0.09
GCA/SCA		1.99	0.82	1.66	0.12

* and **refer to significance at 0.05 and 0.01 levels of probability, respectively.

The Mean performance of the sixsoybean genotypes and their F₁ and F₂ for days to flowering, days to maturity, plant height and number of branches per plant are presented in Table 5.

The parental genotypes Linford was the earliest parent for days to flowering and maturity dates in both generations. Also, C13 (H₁₈L₅₄ x Nc 92-2231) in F₁ and F₂ generations was the earliest cross among all crosses in flowering and maturity dates, followed by C9 (Giza 111 x Linford). On the other hand, P₁ (Japanese 13) was the latest parent, also C1 (Japanese 13 x Giza 111), C2 (Japanese 13 x Crawford), C3 (Japanese 13 x H₁₈L₅₄) and C4 (Japanese 13 x Nc 92-2231) showed the latest crosses in F₁'s for flowering and for C4 and C2 for maturity date since recorded 125.95 and 131.20 days, respectively.

Table 5: Mean performance of the sixsoybean genotypes, F₁ crosses and their F₂ generations for days to flowering, days to maturity, plant height and number of branches per plant characters.

Genotypes	Days to flowering	Days to maturity	Plant height (cm)	Number of branches per plant
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	F ₁	F ₂	F ₁	F ₂	F ₁	F ₂	F ₁	F ₂
P1 (Japanese 13)	51.30	53.81	133.15	149.39	62.50	58.33	4.76	6.00
P2 (Giza 111)	46.17	43.39	126.00	132.00	130.04	136.67	11.07	11.00
P3 (Crawford)	42.01	43.22	117.29	128.39	111.67	110.00	4.67	4.33
P4 (H ₁₈ L ₅₄)	38.46	36.83	102.33	114.51	105.00	108.33	2.00	3.67
P5 (Nc 92-2231)	37.46	36.61	114.57	117.75	135.00	136.67	7.67	10.67
P6 (Linford)	32.75	34.80	98.42	102.45	108.33	108.33	6.33	7.00
Hybrids								
C1 (Japanese 13 x Giza 111)	41.38	38.15	122.25	130.65	91.94	110.28	8.36	6.45
C2 (Japanese 13 x Crawford)	38.11	39.17	121.42	131.20	115.00	118.30	6.32	5.84
C3 (Japanese 13 x H ₁₈ L ₅₄)	42.46	37.68	122.21	108.45	138.01	116.10	5.99	6.27
C4 (Japanese 13 x Nc 92-2231)	37.70	48.75	125.92	124.84	118.00	94.01	6.58	3.89
C5 (Japanese 13 x Linford)	37.07	29.39	111.33	106.44	126.29	111.39	8.52	5.42
C6 (Giza 111 x Crawford)	56.01	51.00	102.50	116.64	134.08	116.38	5.88	6.53
C7 (Giza 111 x H ₁₈ L ₅₄)	36.33	46.34	98.29	93.97	122.07	115.28	7.00	6.31
C8 (Giza 111 x Nc 92-2231)	55.47	48.93	123.48	113.76	141.85	123.83	6.29	8.37
C9 (Giza 111 x Linford)	28.99	30.85	101.96	95.09	114.33	107.84	5.43	4.76
C10 (Crawford x H ₁₈ L ₅₄)	53.67	33.61	102.54	95.27	125.22	96.92	10.35	7.23
C11 (Crawford x Nc 92-2231)	36.47	34.30	114.04	95.57	112.76	105.30	8.29	6.90
C12 (Crawford x Linford)	43.34	36.36	116.53	112.49	87.47	108.68	6.04	6.12
C13 (H ₁₈ L ₅₄ x Nc92-2231)	26.91	32.35	98.57	94.88	123.88	99.01	6.21	5.72
C14 (H ₁₈ L ₅₄ x Linford)	41.26	36.81	116.54	97.16	119.76	104.72	10.78	7.58
C15 (Nc 92-2231 x Linford)	37.15	37.67	105.57	103.29	120.61	112.83	9.85	8.52
LSD0.05	2.15	1.92	2.24	4.09	13.65	8.74	4.14	3.35
LSD0.01	2.88	2.56	3.18	5.81	19.42	12.43	5.89	4.76

With respect to plant height, the results in Table 5 show that P₅ (Nc 92-2231) had the significantly highest mean values among the six parents in both generations with mean values of 135 and 136.67 cm in first and second generations, respectively. On the other hand, the parental variety P₁ (Japanese 13) was the shortest parent among all parents since it recorded 62.50 and 58.33 cm in the first and second generations, respectively. Regarding the crosses, C8 (Giza 111 x Nc 92-2231) was the tallest, with mean values of 141.85 and 123.83 cm in F₁ and F₂ generations, respectively. While C12 (Crawford x Linford) and C4 (Japanese 13 x Nc 92-2231) were the shortest crosses in F₁ and F₂, respectively.

Regarding the number of branches per plant, the results revealed that Giza 111 (11.07 and 11) had the significantly highest mean values in the first and second generations, respectively. Meanwhile, the lowest mean values were estimated for H₁₈L₅₄ (2 and 3.67) in the first and second generations, respectively. With regard to the highest F₁'s crosses mean values were 10.78 for C14 (H₁₈L₅₄ x Linford) followed by 10.35 for C10 (Crawford x H₁₈L₅₄). While the lowest mean value (5.43 and 4.76) were obtained in C9 (Giza 111 x Linford) in the F₁ and F₂, respectively. For F₂'s crosses, the highest values were obtained from C15 (Nc 92-2231 x Linford) and C8 (Giza 111 x Nc 92-2231). While the lowest mean values were obtained from C4 (Japanese 13 x Nc 92-2231). Concerning the number of pods per plant, the parental variety P₅ (Nc 92-2231) showed the highest mean values of 318.52 and 336.67 followed by P₃ (Crawford) 313.33 and 303.67 in the first and second generations, respectively. While P₄ (H₁₈L₅₄) had the lowest mean pods with mean values of 98.25 and 104.92 in the first and second generations, respectively (Table 6). The highest F₁'s mean values were 471.84, 462.92 and 462.70 which estimated for C3, C5 and C13, respectively. For F₂'s crosses, the highest mean value were 328.97 and 399.50 obtained from C5 and C8, respectively.

Regarding the 100-seed weight per gram, the parental variety P₆ (Linford) exhibited the highest mean values of 20.01 and 21.16 g in the first and second generations, respectively. The highest mean values were 22.45 and 21.07 for C5 (Japanese 13 x Linford) in F₁ and F₂ generations, respectively.

The results also indicated that the mean values for seed yield per plant character, P₃ (Crawford) had the highest mean values (119.64 and 111.73 g in the first and second generations, respectively), among the six parents used. However, the highest F₁'s mean values were 261.44 g and 221.10 g for C1 and C13, respectively. For F₂'s crosses, the significantly highest values were obtained from C15 (Nc 92-2231 x Linford) (131.10 g) followed by C5 (Japanese 13 x Linford) (124.54 g).

Table 6: Mean performance of the sixsoybean genotypes and F₁ crosses and their F₂ generations for number of pods per plant, 100-seed weight and seed yield per plant characters.

Parents	Number of pods per plant		100-seed weight (g)		Seed yield per plant(g)	
	F ₁	F ₂	F ₁	F ₂	F ₁	F ₂
P1 (Japanese 13)	210.62	250.00	19.97	21.16	71.09	76.22
P2 (Giza 111)	253.89	201.67	15.78	15.45	107.91	72.47
P3 (Crawford)	313.33	303.67	18.65	17.87	119.64	111.73
P4 (H₁₈L₅₄)	98.25	104.92	17.13	17.13	41.20	46.39
P5 (Nc 92-2231)	318.52	336.67	17.95	19.02	91.50	80.41
P6 (Linford)	209.78	212.33	21.01	21.01	67.81	64.67
Hybrids						
C1 (Japanese 13 x Giza 111)	383.47	266.89	18.10	18.79	261.44	110.79
C2 (Japanese 13 x Crawford)	368.35	289.16	13.10	16.98	74.56	90.43
C3 (Japanese 13 x H H₁₈L₅₄)	462.92	263.19	18.04	19.42	146.88	100.16
C4 (Japanese 13 x Nc 92-2231)	331.85	267.11	16.95	18.32	98.34	87.18
C5 (Japanese 13 x Linford)	471.84	328.97	22.45	21.07	174.54	124.54
C6 (Giza 111 x Crawford)	367.08	225.76	15.52	15.23	219.59	61.43
C7 (Giza 111 x H H₁₈L₅₄)	280.06	240.81	13.43	15.88	94.76	86.14
C8 (Giza 111 x Nc 92-2231)	417.05	399.50	18.38	16.33	148.32	118.11
C9 (Giza 111 x Linford)	263.33	202.77	20.17	18.36	84.66	82.32
C10 (Crawford x H₁₈L₅₄)	438.33	253.33	16.94	18.05	170.75	95.14
C11 (Crawford x Nc 92-2231)	362.65	251.20	17.86	18.45	94.14	70.00
C12 (Crawford x Linford)	336.69	226.66	17.24	17.22	96.42	77.76
C13 (H₁₈L₅₄ x Nc92-2231)	462.70	234.60	15.67	15.07	221.10	58.13
C14 (H₁₈L₅₄ x Linford)	435.33	190.12	17.77	24.59	186.29	63.18
C15 (Nc 92-2231 x Linford)	358.27	242.01	20.54	19.12	164.11	131.10
LSD0.05	70.19	66.30	2.91	1.89	8.53	25.40
LSD0.01	99.84	94.30	4.14	2.69	12.13	36.13

Regard to seed quality characteristics in F₁-generation only, P₄ (H₁₈L₅₄) had the highest germination percentage 95% and also it had the lowest EC value of 1.82 (Table 7). The highest germination percentage mean values were 96.67, 91.67 and 97.67, %which estimated by C3, C14 and C15, respectively. With respect to F₁ crosses, the same crosses had the lowest EC values 1.52, 1.94 and 1.25. There is a negative relationship between electrical conductivity and seed germination, which indicated that more cell leaches escaped from deteriorated seed and lowered the germination percentage of seed (Table 7).

The parental variety P₄ (H₁₈L₅₄) had the highest protein content (46.50%) followed by P5 (Nc 92-2231) (41.98%). For F₁ crosses, C4 (Japanese 13 x Nc 92-2231), C8 (Giza 111 x Nc 92-2231) and C13 (H₁₈L₅₄ x Nc 92-2231) had the highest protein content with mean values of 52.25%, 49.00% and 45.50%, respectively. Both P₁ (Japanese 13), P₂ (Giza 111) and P₄ (H₁₈L₅₄) showed the highest oil seed content 26.54, 26.43 and 25.05%, respectively. Meanwhile, C1 (Japanese 13 x Giza 111) and C14 (H₁₈L₅₄ x Linford) F₁ crosses showed the highest oil seed content (27.00 and 27.08%), respectively. The results are in agreement with those reported by **El-Garhy et al [15]**, **Perez et al [16]**, **Waly [12]** and **Waly and Ibrahim [13]** which found highly significant differences in the mean performances of seed yield and oil percentage in different genotypes of soybean.

Table 7: Mean performance of the sixsoybean genotypes and their F₁ crosses for germination %, EC, protein % and oil % characters.

Parents	Germination %	EC(μ m g ⁻¹)	Protein %	Oil %
P1 (Japanese 13)	87.00	3.59	25.67	26.54
P2 (Giza 111)	80.00	5.27	34.42	26.43
P3 (Crawford)	88.00	3.42	31.58	23.16
P4 (H₁₈L₅₄)	95.00	1.82	46.50	25.05
P5 (Nc 92-2231)	84.33	3.74	41.98	23.34
P6 (Linford)	86.00	3.55	21.00	23.00
Hybrids				
C1 (Japanese 13 x Giza 111)	85.00	4.92	34.29	27.00
C2 (Japanese 13 x Crawford)	88.00	3.70	30.95	24.82
C3 (Japanese 13 x H H₁₈L₅₄)	96.67	1.52	33.25	18.85

C4 (Japanese 13 x Nc 92-2231)	87.00	3.60	52.25	24.67
C5 (Japanese 13 x Linford)	90.00	2.50	37.92	20.75
C6 (Giza 111 x Crawford)	77.33	6.27	39.08	23.78
C7 (Giza 111 x H ₁₈ L ₅₄)	78.33	6.27	40.83	24.48
C8 (Giza 111 x Nc 92-2231)	84.00	4.76	49.00	21.68
C9 (Giza 111 x Linford)	85.00	3.65	39.66	25.18
C10 (Crawford x H ₁₈ L ₅₄)	75.00	6.95	28.00	23.19
C11 (Crawford x Nc 92-2231)	78.00	5.33	33.25	25.52
C12 (Crawford x Linford)	83.33	3.95	44.33	25.25
C13 (H ₁₈ L ₅₄ x Nc92-2231)	80.00	5.33	45.50	26.60
C14 (H ₁₈ L ₅₄ x Linford)	91.67	1.94	36.75	27.08
C15 (Nc 92-2231 x Linford)	97.67	1.25	35.00	24.81
LSD0.05	1.31	0.11	5.81	0.98
LSD0.01	1.87	0.16	8.27	1.40

Estimation of General combining ability effects (\hat{g}_i) were found to be significant for most characters in this study. High positive values of GCA (desirable) would be highly appreciated for yield and its component characters. Characters such as flowering date, maturity date and EC with high negative effects would be useful (desirable) from the breeder's point of view.

It could be concluded from the results drawn in Table 8, P₂ (Giza 111) exhibited highly significant in positive direction (\hat{g}_i) for plant height and number of branches/ plant in F₁ as well as F₂ generations. The parental genotypes P₄ (H₁₈L₅₄) and P₆ (Linford) had highly significant (\hat{g}_i) in negative direction for days to flowering and maturity in both generations, while P₅ (Nc 92-2231) expressed highly significant (\hat{g}_i) in negative direction for days to flowering in F₁ and days to maturity in F₂ and in positive direction for plant height in both generations and number of branches/plant in F₂-generation. However, these parents mentioned above were considered as good combiners for the traits in view in the generation referred. The results of (\hat{g}_i) are in agreement with those reported by Refat [17], Mansour et al [10], El-Shaboury et al [18], Chen [19], Perez et al [16], Waly [9] and El-Seidy et al [14].

Table 8: Estimates of General Combining Ability (GCA) effects for days to flowering, days to maturity, plant height and number of branches per plant characters.

Parents	Days to flowering		Days to maturity		Plant height		Number of branches per plant	
	F ₁	F ₂	F ₁	F ₂	F ₁	F ₂	F ₁	F ₂
P1 (Japanese 13)	1.56**	3.01**	9.73**	14.04**	-12.55**	-12.46**	-0.52	-0.79**
P2 (Giza 111)	2.96**	3.17**	1.11*	3.26**	6.22**	10.07**	0.7*	1.03**
P3 (Crawford)	3.1**	0.53	0.00	2.49**	-2.09	-0.1	-0.4	-0.61*
P4 (H ₁₈ L ₅₄)	-1.16**	-2.03**	-6.1**	-8.66**	3.04*	-2.21	-0.64*	-0.72*
P5 (Nc 92-2231)	-2.28**	-0.18	0.63	-2.53**	9.06**	5.24**	0.39	1.07**
P6 (Linford)	-4.19**	-4.5**	-5.36**	-8.59**	-3.68*	-0.53	0.48	0.03
S.E. \hat{g}_i	0.24	0.22	0.28	0.26	0.97	1.08	0.24815	0.19
LSD0.05 (\hat{g}_i - \hat{g}_j)	0.76	0.68	0.88	0.80	3.04	3.39	0.776967	0.61
LSD0.01 (\hat{g}_i - \hat{g}_j)	1.02	0.91	1.17	1.07	4.06	4.53	1.039682	0.82

* and ** refer to significance at 0.05 and 0.01 levels of probability, respectively.

The data in Table, 9 revealed that, the parental genotype P₁ (Japanese 13) had significant (\hat{g}_i) in positive direction for number of pods/plant and seed yield/plant in F₂ generation, while P₂ (Giza 111) expressed significant (\hat{g}_i) in positive direction for seed yield/plant in F₁ generation. The parental genotype P₅ (Nc 92-2231) exposed significant (\hat{g}_i) in positive direction for number of pods/plant in F₁ as well as F₂-generations and P₆ (Linford) revealed significant (\hat{g}_i) in positive direction for 100-seed weight.

With respect to the data shown in Table, 10, the parental genotype P₁ (Japanese 13) had highly significant (\hat{g}_i) in positive direction for germination percentage and protein percentage and in negative direction for EC. The parental genotype P₄ (H₁₈L₅₄) showed highly significant (\hat{g}_i) in positive direction for germination and protein percentage and negative direction for EC. The parental genotype P₅ (Nc92-2231) had highly significant in positive direction for protein percentage and the parental genotype P₆ (Linford) showed highly significant (\hat{g}_i) in positive direction for germination percentage and in negative direction for EC. However, it could be concluded from the obtained results that, P₂ and P₅ performed as good combiner parents for plant height and number of pods/plant in both generations. P₄ and

P₆ could be considered as good combiners parents for earliness in both generations. The results in general considered as poor results, which expected are became the studied traits controlled by non-additive genes as referred in tables 2, 3 and 4 which in turn the low contribution of additive genes in the inheritance of the traits and subsequent low estimates of general combining ability.

The positive and desirable general combining ability has been demonstrated in soybean growth traits by many authors before such as Mansour et al [9], Agrawal et al [20], El-Shaboury et al [18], Maloo and Sharma [24], Chen [19], El-Garhy et al [15], Gavioli et al [21], Perez et al [16], Nassar [22], Waly [12], Rialch et al[23], Waly and Ibrahim [13] and El-Seidy et al [14].

Table 9: Estimates of General Combining Ability (GCA) effects for Number of pods per plant, 100-seed weight and Seed yield per plant characters.

Parents	Number of pods per plant		100-seed weight		Seed yield per plant	
P1 (Japanese 13)	7.28	18.94*	0.55	1.09	-1.72	7.85*
P2 (Giza 111)	-20.33*	-3.09	-0.88*	-1.58*	14.11*	0.12
P3 (Crawford)	14.79	11.21	-0.78*	-0.81	-2.12	1.93
P4 (H ₁₈ L ₅₄)	-13.2	-46.49**	-1.01**	-0.11	-1.19	-13.4**
P5 (Nc 92-2231)	23.51*	38**	0.14	-0.36	-0.33	2.82
P6 (Linford)	-12.05	-18.57*	2**	1.78*	-8.76	0.68
S.E. gi	6.61	5.38	0.24	0.47	3.52	2.03
LSD0.05 (gi-gj)	20.68	16.83	0.74	1.46	11.02	6.35
LSD0.01 (gi-gj)	27.68	22.52	0.99	1.95	14.75	8.50

* and **refer to significance at 0.05 and 0.01 levels of probability, respectively.

Table 10: Estimates of General Combining Ability (GCA) effects for germination %, EC, protein %and oil %characters in F₁- generation.

Parents	Germination %	EC	Protein %	Oil %
P1 (Japanese 13)	2.69**	-0.55**	-2.55**	-0.15
P2 (Giza 111)	-3.68**	1.08**	1.41*	0.57**
P3 (Crawford)	-2.68**	0.66**	-2.7**	-0.19
P4 (H ₁₈ L ₅₄)	1.57**	-0.27**	2.12**	-0.01
P5 (Nc 92-2231)	-0.47*	0.00	4.82**	-0.05
P6 (Linford)	2.57**	-0.92**	-3.09**	-0.16
S.E. gi	0.18	0.03	0.50	0.10
LSD0.05 (gi-gj)	0.55	0.08	1.56	0.30
LSD0.01 (gi-gj)	0.74	0.11	2.08	0.40

* and **refer to significance at 0.05 and 0.01 levels of probability, respectively.

The data listed in Tables 11, 12 and 13 revealed that, the C1 (Japanese 13 X Giza 111) showed highly significant negative (\hat{S}_{ij}) for flowering date in F₁ as in F₂ generations and in positive direction for number of pods/plant in F₁, seed yield/plant in both generations and oil percentage. The second cross; C2 (Japanese 13 x Crawford) exhibited highly significant (\hat{S}_{ij}) in negative direction for flowering date in both generations, in positive direction for plant height in both generations, germination percentage and oil percentage and in negative direction for EC. The cross; C3 (Japanese 13 x H₁₈L₅₄) had highly significant (\hat{S}_{ij}) in positive direction for number of pods/plant in both generations, seed yield /plant in F₂, germination percentage, oil percentage and in negative direction for EC. The cross; C5 (Japanese 13 x Linford) exposed highly significant (\hat{S}_{ij}) in positive direction for plant height, number of pods/plant and seed yield/plant in F₁ as well as F₂ generations and protein percentage. The cross; C8(Giza 111 x Nc92-2231) expressed highly significant (\hat{S}_{ij}) in positive direction for plant height in F₁, number of pods/plant in both generations, seed yield/plant in F₂-generation, germination percentage and protein percentage and in negative direction for EC. The cross; C9 (Giza 111 x Linford) had highly significant (\hat{S}_{ij}) in negative direction for flowering and maturity dates in both generations. The cross; C10 (Crawford x H₁₈L₅₄) showed significant and/or highly significant (\hat{S}_{ij}) in negative direction for flowering date in F₂, maturity date in both generations and in positive direction for plant height in F₁-generation, number of

branches/plant in both generations, No. of pods/plant in F₁ and seed yield/plant in both generations. The cross; C13 (H₁₈L₅₄ x Nc92-2231) expressed highly significant (\hat{S}_{ij}) in negative direction for flowering and maturity dates in both generations, positive direction for No. of pods/plant and seed yield/plant in F₁ and oil percentage. The cross; C14 (H₁₈L₅₄ x Linford) revealed significant and/or highly significant (\hat{S}_{ij}) in positive direction for No. of branches/plant in both generations, number of pods/plant and seed yield/plant in F₁, 100-seed weight in F₂, germination percentage and oil percentage and the cross; C15 (Nc92-2231 x Linford) had significant (\hat{S}_{ij}) in positive direction for seed yield/plant in both generations, germination percentage, oil percentage and in negative direction for EC. These results are in agreement with those obtained by Yassien and Abd El-Mohsen [8], Mansour et al [10], Agrawal et [20], El-Shaboury et al [18], Maloo and Sharma [24], Chen [19], El-Garhy et al [15], Gavioli et al [21], Perez et al [16], Shiv et al [24], Nassar [13], Waly [12], Rialch et al [23], Bagateli et al [26], AbouSen [27], Waly and Ibrahim [13] and El-Seidy et al [14].

Table 11: Estimates of Specific Combining Ability (SCA) effects for days to flowering, days to maturity, plant height and number of branches per plant characters.

crosses	Days to flowering		Days to maturity		Plant height		Number of branches per plant	
	F ₁	F ₂	F ₁	F ₂	F ₁	F ₂	F ₁	F ₂
C1 (Japanese 13 x Giza 111)	-4.12**	-7.56**	-1.67	0.78	-18.11**	3.18	1.11	-0.39
C2 (Japanese 13 x Crawford)	-7.52**	-3.89**	-1.4	2.1*	13.27**	21.37**	0.18	0.64
C3 (Japanese 13 x H H ₁₈ L ₅₄)	1.09	-2.83**	5.5**	-9.51**	31.14**	21.29**	0.09	1.18
C4 (Japanese 13 x Nc 92-2231)	-2.56*	6.39**	2.47*	0.75	5.11	-8.26*	-0.35	-2.98**
C5 (Japanese 13 x Linford)	-1.28	-8.65**	-6.13**	-11.59**	26.15**	14.89**	1.5	-0.42
C6 (Giza 111 x Crawford)	8.97**	7.78**	-11.7**	-1.68	13.58**	-3.07	-1.48	-0.48
C7 (Giza 111 x H H ₁₈ L ₅₄)	-6.45**	5.67**	-9.8**	-13.2**	-3.56	-2.06	-0.13	-0.6
C8 (Giza 111 x Nc 92-2231)	13.81**	6.42**	8.65**	0.45	10.19*	-0.96	-1.87*	-0.32
C9 (Giza 111 x Linford)	-10.75**	-7.34**	-6.88**	-12.16**	-4.57	-11.18*	-2.82**	-2.89**
C10 (Crawford x H ₁₈ L ₅₄)	10.76**	-4.41**	-4.44**	-11.13**	7.9*	-10.25*	4.33**	1.97*
C11 (Crawford x Nc 92-2231)	-5.33**	-5.57**	0.32	-16.97**	-10.58*	-9.32*	1.24	-0.16
C12 (Crawford x Linford)	3.45**	0.81	8.8**	6.01**	-23.13**	-0.17	-1.1	0.11
C13 (H ₁₈ L ₅₄ x Nc92-2231)	-10.63**	-4.96**	-9.06**	-6.5**	-4.6	-13.5**	-0.6	-1.23
C14 (H ₁₈ L ₅₄ x Linford)	5.64**	3.81**	14.91**	1.83*	4.03	-2.02	3.87**	1.67*
C15 (Nc 92-2231 x Linford)	2.64*	2.82**	-2.79*	1.82*	-1.14	-1.36	1.92*	0.83
S.E (Sij)	0.67	0.59	0.77	0.70	2.66	2.97	0.68	0.53
LSD0.05 (Sij-gik)	2.01	1.79	2.32	2.11	8.03	8.96	2.06	1.61
LSD0.01 (Sij-gik)	2.70	2.40	3.10	2.83	10.75	11.98	2.75	2.16
LSD0.05 (gij-kl)	1.86	1.66	2.15	1.96	7.44	8.29	1.90	1.49
LSD0.01 (gij-kl)	2.50	2.22	2.87	2.62	9.95	11.10	2.55	2.00

* and **refer to significance at 0.05 and 0.01 levels of probability, respectively.

Table 12: Estimates of Specific Combining Ability (SCA) effects for number of pods per plant, 100-seed weight and seed yield per plant characters.

Crosses	Number of pods per plant		100-seed weight		Seed yield per plant	
	F ₁	F ₂	F ₁	F ₂	F ₁	F ₂
C1 (Japanese 13 x Giza 111)	56.32*	-0.93	0.7	0.97	118.81**	16.72*
C2 (Japanese 13 x Crawford)	6.07	7.04	-4.41**	-1.61	-51.85**	-5.46
C3 (Japanese 13 x H H ₁₈ L ₅₄)	128.63**	38.77*	0.77	0.14	19.55	19.61*
C4 (Japanese 13 x Nc 92-2231)	-39.15	-41.79*	-1.48	-0.72	-29.85*	-9.59
C5 (Japanese 13 x Linford)	136.41**	76.63**	2.16*	-0.11	54.77**	29.9**
C6 (Giza 111 x Crawford)	32.42	-34.33	-0.56	-0.68	77.35**	-26.73**
C7 (Giza 111 x H H ₁₈ L ₅₄)	-26.61	38.42*	-2.42*	-0.73	-48.41**	13.32
C8 (Giza 111 x Nc 92-2231)	73.66**	112.62**	1.38	-0.04	4.3	29.06**
C9 (Giza 111 x Linford)	-44.49	-27.54	1.31	-0.14	-50.94**	-4.6
C10 (Crawford x H ₁₈ L ₅₄)	96.54**	36.64	0.99	0.67	43.81**	20.51*
C11 (Crawford x Nc 92-2231)	-15.86	-49.97*	0.76	1.3	-33.65*	-20.87*
C12 (Crawford x Linford)	-6.26	-17.94	-1.72*	-2.05	-22.95	-10.96
C13 (H ₁₈ L ₅₄ x Nc92-2231)	112.18**	-8.88	-1.2	-2.77	92.38**	-17.4*
C14 (H ₁₈ L ₅₄ x Linford)	120.38**	3.21	-0.95	4.62*	65.99**	-10.21
C15 (Nc 92-2231 x Linford)	6.6	-29.38	0.66	-0.61	42.96**	41.48**
S.E (Sij)	18.14	14.76	0.65	1.28	9.67	5.57
LSD0.05 (Sij-gik)	54.72	44.53	1.96	3.86	29.16	16.80

LSD0.01 (Sij-gik)	73.23	59.59	2.62	5.17	39.02	22.48
LSD0.05 (gij-kl)	50.66	41.23	1.81	3.58	26.99	15.56
LSD0.01 (gij-kl)	67.80	55.17	2.43	4.79	36.12	20.82

* and **refer to significance at 0.05 and 0.01 levels of probability, respectively.

Table 13: Estimates of specific combining ability (SCA) effects for germination %, EC, protein % and oil % characters in F₁.

Crosses	Germination %	EC	Protein %	Oil %
C1 (Japanese 13 x Giza 111)	0.4	0.41**	-1.77	2.24**
C2 (Japanese 13 x Crawford)	2.4**	-0.38**	-1	0.82*
C3 (Japanese 13 x H H ₁₈ L ₅₄)	6.82**	-1.64**	-3.51*	-5.33**
C4 (Japanese 13 x Nc 92-2231)	-0.81	0.18	12.78**	0.54
C5 (Japanese 13 x Linford)	-0.85	0.00	6.36**	-3.27**
C6 (Giza 111 x Crawford)	-1.89*	0.57**	3.17	-0.95*
C7 (Giza 111 x H H ₁₈ L ₅₄)	-5.14**	1.49**	0.1	-0.42
C8 (Giza 111 x Nc 92-2231)	2.57**	-0.28*	5.57**	-3.18**
C9 (Giza 111 x Linford)	0.52	-0.47**	4.14*	0.43
C10 (Crawford x H ₁₈ L ₅₄)	-9.48**	2.59**	-8.61**	-0.95*
C11 (Crawford x Nc 92-2231)	-4.43**	0.71**	-6.07**	1.42**
C12 (Crawford x Linford)	-2.14**	0.25*	12.93**	1.27**
C13 (H ₁₈ L ₅₄ x Nc92-2231)	-6.68**	1.63**	1.36	2.32**
C14 (H ₁₈ L ₅₄ x Linford)	1.94*	-0.84**	0.53	2.92**
C15 (Nc 92-2231 x Linford)	9.98**	-1.79**	-3.93*	0.69*
S.E (Sij)	0.49	0.07	1.36	0.27
LSD0.05 (Sij-gik)	1.47	0.22	4.11	0.80
LSD0.01 (Sij-gik)	1.96	0.29	5.51	1.07
LSD0.05 (gij-kl)	1.36	0.20	3.81	0.74
LSD0.01 (gij-kl)	1.82	0.27	5.10	0.99

* and **refer to significance at 0.05 and 0.01 levels of probability, respectively.

Heterosis

Heterosis over better parent is defined as the amount by which the mean of an F₁ hybrid exceeds its better parent. Breeders have adopted the convention that P₁ corresponds to the parent with the greater mean value and P₂ the parent with the smaller mean value, but according to the character under consideration, either P₁ or P₂ may be the better parent. In this investigation, the character earliness, usually implies that the F₁ has a lower value than its lower parent. On the other hand, heterosis such as yield or its components characters implies that the F₁ analysis its greater yielding parent. It must be mentioned that, germination percentage, oil and protein percentages and EC were determined in F₁ generation only.

However, it could be concluded from the data drawn in Tables 14, 15 and 16 that, the cross; C1 (Japanese 13 x Giza 111) showed highly significant better parent heterosis in negative direction for flowering and maturity dates in both generations and EC and in positive direction for number of pods and seed yield/plant in both generations. The cross; C2 (Japanese 13 x Crawford) have highly significant better parent heterosis in negative direction for flowering and maturity dates in both generations. The cross; C3 (Japanese 13 x H₁₈L₅₄) exposed highly significant better parent heterosis in negative direction for maturity date in both generations; in positive direction for plant height in F₁, number of pods and seed yield/plant in both generations, germination percentage and EC in negative direction. The cross; C5 (Japanese 13 x Linford) expressed highly significant better parent heterosis in negative direction for flowering and maturity dates in both generations, in positive direction for plant height, number of branches, pods and seed yield/plant in both generations and protein percentage and in negative direction for EC. The cross; C8 (Giza 111 x Nc92-2231) had highly significant better parent heterosis in negative direction for maturity date in both generations and EC and in positive direction for No. of pods and seed yield/plant in both generations and protein percentage. The cross; C9 (Giza 111 x Linford) showed highly significant better parent heterosis in negative direction for flowering and maturity dates in both generations, EC and in positive direction for protein percentage. The cross; C10 (Crawford x

H₁₈L₅₄) revealed highly significant better parent heterosis in negative direction for flowering and maturity dates in both generations, in positive direction for plant height in F₁, No. of branches/plant in both generations, number of pods/plant and seed yield/plant in F₁-generation. The cross; C13 (H₁₈L₅₄ x Nc92-2231) showed highly significant better parent heterosis in negative direction for flowering and maturity dates in both generations, number of pods and seed yield/plant in positive direction in F₁ and oil percentage. The cross; C14 (H₁₈L₅₄ x Linford) expressed highly significant better parent heterosis in positive direction for plant height, number of branches/plant, number of pods, seed yield/plant and oil percentage in F₁ generation and in negative direction for EC. The cross C15 (Nc92-2231 x Linford) exposed highly significant better parent heterosis in negative direction for maturity date in both generations, number of branches/plant in F₁, seed yield/plant in both generations, germination percentage, oil percentage and in negative direction for EC.

Generally, it could be observed from the data shown in the present investigation that, there is equivalence between the data concerning better parent heterosis and specific combining ability effects (S_{ij}) in many studied crosses i.e., C1, C5, C7, C9, C10, C11, C13, C14 and C15 for many characters. This could be attributed to the non-additive genes especially dominance, responsible for exposing both parameters. As mentioned before the present genetic material for all studied traits are controlled in their inheritance by non-additive genes. Therefore, the expected selection program in these materials in the advanced segregating generations would be not limited to the superior specific hybrids and the expected improvement would be fruitful and the bulk method is the more suitable in such case. These results are similar to those obtained before by Mansour et al [9], Pandini et al [28], Gravina et al [29], Ramana and Satyanarayana [30], El-Shaboury et al [18], EL-Garhy et al [15], Fayiz [11], Perez et al [16], Yang and Gai [32], Sudaric et al [33], Yin, and Yi [34], Nassar [22], AbouSen [27] and Waly and Ibrahim [13].

Table 14: Estimates of Heterosis over Better Parent (B.P.%) for days to flowering, days to maturity, plant height and number of branches per plant characters.

Crosses	Days to flowering		Days to maturity		Plant height		Number of branches per plant	
	F ₁	F ₂	F ₁	F ₂	F ₁	F ₂	F ₁	F ₂
C1 (Japanese 13 x Giza 111)	-10.38**	-12.06**	-8.19**	-12.54**	-29.30 **	-19.30 **	-24.49 *	-41.33 **
C2 (Japanese 13 x Crawford)	-9.28**	-9.36**	-8.81**	-12.18**	2.99 ns	7.54 ns	32.80 ns	-2.67 ns
C3 (Japanese 13 x H H ₁₈ L ₅₄)	10.42**	2.29	-8.22**	-27.41**	31.44 **	7.17 ns	25.86 ns	4.56 ns
C4 (Japanese 13 x Nc 92-2231)	0.63	33.14**	-5.43**	-16.44**	-12.59 **	-31.21 **	-14.13 ns	-63.47 **
C5 (Japanese 13 x Linford)	13.19**	-15.56**	-16.39**	-28.75**	16.58 **	2.82 ns	34.53 *	-22.67 ns
C6 (Giza 111 x Crawford)	33.32**	18.01**	-18.65**	-11.63**	3.10 ns	-14.85 **	-46.84 **	-40.61 **
C7 (Giza 111 x H H ₁₈ L ₅₄)	-5.54	25.82**	-21.99**	-28.81**	-6.13 ns	-15.65 **	-36.75 **	-42.64 **
C8 (Giza 111 x Nc 92-2231)	48.07**	33.64**	-2*	-13.82**	5.07 ns	-9.39 **	-43.13 **	-23.91 **
C9 (Giza 111 x Linford)	-11.47**	-11.35**	-19.08**	-27.96**	-12.08 **	-21.09 **	-50.96 **	-56.73 **
C10 (Crawford x H ₁₈ L ₅₄)	39.57**	-8.75**	-12.57**	-25.79**	12.14 **	-11.89 **	121.86 **	66.92 **
C11 (Crawford x Nc 92-2231)	-2.63	-6.32*	-2.77*	-25.57**	-16.47 **	-22.95 **	8.17 ns	-35.31 **
C12 (Crawford x Linford)	32.34**	4.47	-0.65	-12.38**	-21.67 **	-1.20 ns	-4.58 ns	-12.57 ns
C13 (H ₁₈ L ₅₄ x Nc92-2231)	-28.16**	-11.64**	-13.97**	-19.42**	-8.24 *	-27.55 **	-18.96 ns	-46.34 **
C14 (H ₁₈ L ₅₄ x Linford)	25.99**	5.77*	13.88**	-15.15**	10.55 **	-3.34 ns	70.16 **	8.29 ns
C15 (Nc 92-2231 x Linford)	13.42**	8.23**	-7.85**	-12.28**	-10.66 **	-17.44 **	28.52 *	-20.09 *
LSD0.05	2.15	1.92	2.24	4.09	13.65	8.74	4.14	3.35
LSD0.01	2.88	2.56	3.18	5.81	19.42	12.43	5.89	4.76

* and **refer to significance at 0.05 and 0.01 levels of probability, respectively.

Table 15: Estimates of Heterosis over Better Parent (B.P.%) for number of pods per plant, 100-seed weight and seed yield per plant characters.

Crosses	Number of pods per plant		100-seed weight		Seed yield per plant	
	F ₁	F ₂	F ₁	F ₂	F ₁	F ₂
C1 (Japanese 13 x Giza 111)	51.04 **	6.76 ns	-9.36 ns	-11.19 ns	142.28 **	45.36 **
C2 (Japanese 13 x Crawford)	17.56 ns	-4.78 ns	-34.43 **	-19.76 *	-37.68 **	-19.07 *
C3 (Japanese 13 x H H ₁₈ L ₅₄)	119.79 **	5.28 ns	-9.68 ns	-8.18 ns	106.63 **	31.41 **
C4 (Japanese 13 x Nc 92-2231)	4.18 ns	-20.66 **	-15.14 **	-13.38 ns	7.48 ns	8.42 ns
C5 (Japanese 13 x Linford)	124.03 **	31.59 **	6.84 ns	-0.41 ns	145.53 **	63.40 **

C6 (Giza 111 x Crawford)	17.15 ns	-25.66 **	-16.78 **	-14.76 ns	83.54 **	-45.02 **
C7 (Giza 111 x H H ₁₈ L ₅₄)	10.31 ns	19.41 ns	-21.58 **	-7.26 ns	-12.19 ns	18.87 ns
C8 (Giza 111 x Nc 92-2231)	30.93 **	18.66 *	2.36 ns	-14.11 ns	37.44 *	46.88 **
C9 (Giza 111 x Linford)	3.72 ns	-4.51 ns	-4.01 ns	-12.63 ns	-21.55 ns	13.59 ns
C10 (Crawford x H ₁₈ L ₅₄)	39.89 **	-16.58 *	-9.19 ns	1.04 ns	42.71 **	-14.85 ns
C11 (Crawford x Nc 92-2231)	13.86 ns	-25.39 **	-4.27 ns	-3.00 ns	-21.32 ns	-37.35 **
C12 (Crawford x Linford)	7.45 ns	-25.36 **	-17.94 **	-18.02 ns	-19.41 ns	-30.40 **
C13 (H ₁₈ L ₅₄ x Nc92-2231)	45.26 **	-30.32 **	-12.74 *	-20.75 ns	141.64 **	-27.70 *
C14 (H ₁₈ L ₅₄ x Linford)	107.52 **	-10.46 ns	-15.41 **	17.04 ns	174.73 **	-2.31 ns
C15 (Nc 92-2231 x Linford)	12.48 ns	-28.12 **	-2.22 ns	-9.01 ns	79.35 **	63.04 **
LSD0.05	70.19	66.30	2.91	1.89	8.53	25.40
LSD0.01	99.84	94.30	4.14	2.69	12.13	36.13

* and **refer to significance at 0.05 and 0.01 levels of probability, respectively.

Table 16: Estimates of Heterosis over Better Parent (B.P.%) for germination %, EC, protein %and oil %characters in F₁generation.

Crosses	Germination %	EC	Protein %	Oil %
C1 (Japanese 13 x Giza 111)	-2.30 *	-6.76**	-0.37 ns	1.72 ns
C2 (Japanese 13 x Crawford)	0.00 ns	3.06	-2.01 ns	-6.51 **
C3 (Japanese 13 x H H ₁₈ L ₅₄)	1.75 *	-57.66**	-28.49 **	-29.00 **
C4 (Japanese 13 x Nc 92-2231)	0.00 ns	-3.83	24.45 **	-7.06 **
C5 (Japanese 13 x Linford)	3.45 **	-30.36**	47.73 **	-21.81 **
C6 (Giza 111 x Crawford)	-12.12 **	18.96**	13.56 *	-10.04 **
C7 (Giza 111 x H H ₁₈ L ₅₄)	-17.54 **	18.9**	-12.19 *	-7.39 **
C8 (Giza 111 x Nc 92-2231)	-0.40 ns	-9.67**	16.71 **	-17.98 **
C9 (Giza 111 x Linford)	-1.16 ns	-30.78**	15.24 *	-4.75 **
C10 (Crawford x H ₁₈ L ₅₄)	-21.05 **	103.31**	-39.78 **	-7.44 **
C11 (Crawford x Nc 92-2231)	-11.36 **	42.48**	-20.80 **	9.33 **
C12 (Crawford x Linford)	-5.30 **	11.27**	40.37 **	9.04 **
C13 (H ₁₈ L ₅₄ x Nc92-2231)	-15.79 **	42.39**	-2.15 ns	6.17 **
C14 (H ₁₈ L ₅₄ x Linford)	-3.51 **	-45.35**	-20.97 **	8.10 **
C15 (Nc 92-2231 x Linford)	13.57 **	-66.61**	-16.63 **	6.28 **
LSD0.05	1.31	0.11	5.81	0.98
LSD0.01	1.87	0.16	8.27	1.40

* and **refer to significance at 0.05 and 0.01 levels of probability, respectively.

CONCLUSION

From the data shown in the present investigation, there is equivalence between the data concerning better parent heterosis and specific combining ability effects (\hat{S}_{ij}) in many studied crosses i.e., C1(Japanese 13 x Giza 111), C5(Japanese 13 x Linford), C7(Giza 111 x H₁₈L₅₄), C9 (Giza 111 x Linford), C10 (Crawford x H₁₈L₅₄), C11 (Crawford x Nc 92-2231), C13(H₁₈L₅₄ x Nc 92-2231), C14 (H₁₈L₅₄ x Linford) and C15 (Nc 92-2231 x Linford) for many characters. This could be attributed to the non-additive genes especially dominance responsible for influencing both parameters. As mentioned the genetic material for all studied traits is controlled by non-additive genes, making the bulk method more suitable for selection in advanced segregating generations. The genetic material for all studied traits is controlled by non-additive genes, making the bulk method more suitable for selection in advanced segregating generations.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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