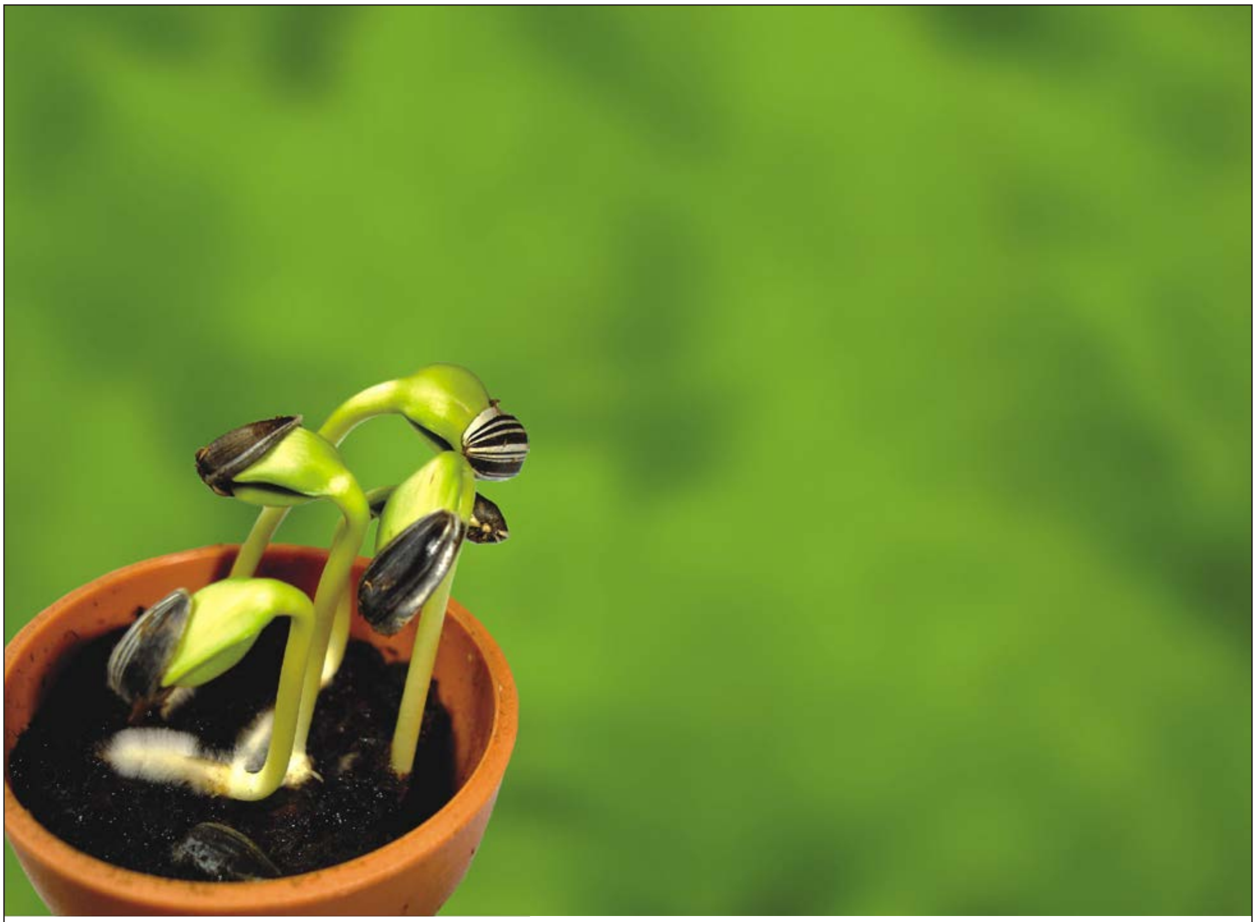

International Journal of
Plant Breeding and Genetics

ISSN 1819-3595

Academic Journals Inc.

www.academicjournals.com

International Journal of Plant Breeding and Genetics 3 (1): 11-21, 2009
ISSN 1819-3595

Combining Ability Analysis for Seed Yield and Some of its Component Characters in Sesame (*Sesamum indicum* L.)

P.P. Banerjee and P.C. Kole
Department of Crop Improvement, Institute of Agriculture, Visva-Bharati University, Sriniketan, Birbhum, West Bengal, 731 236, India

Abstract: Nature and magnitude of gene action and combining ability effects for some important yield contributing characters viz., plant height, branch number plant^{-1}, capsules plant^{-1}, seeds capsule^{-1}, 1000-seed weight, stick yield plant^{-1} and seed yield plant^{-1} in sesame were examined to decide breeding strategies and to identify parents and hybrids for future breeding programme. Seven parents (CST 2002, MT 34, OS-Sel-2, TKG 22, AAUDT 9304-14-4, B 67 and Rama) were crossed in a half diallel mating design. The parents, 21 F_1s (without reciprocals) and 21 F_2s were grown in summer, 2003, in a randomized block design with three replications in Agricultural Farm, Institute of Agriculture, Visva-Bharati University (23°39′N, 87°42′E). Analysis of combining ability was done following Method-2, Model-I of Griffing. Variances due to General Combining Ability (GCA) and Specific Combining Ability (SCA) for all the traits were highly significant in both F_1 and F_2 generations indicating importance of both additive and non-additive gene action for the inheritance of all the studied characters in both-generations. OS-Sel-2 appeared as best general combiner for seed yield plant^{-1} in both generations. GCA and mean performance of the genotypes suggested that the performance *per se* could be a valid indicator of its ability to transmit the desirable attributes to the progenies. Genetic divergence among the parents played a crucial role to produce crosses with significant SCA-effects on seed yield plant^{-1}. Considering SCA-effects, the cross CST 2002×TKG 22 appeared to be promising. AAUDT 9304-14-4×B67 and OS-Sel-2×AAUDT 9304-14-4 involving parents with high GCA and exhibiting significant and positive SCA for seed yield in F_1 could be utilized for the selection of superior genotypes in advance segregating generations.

Key words: *Sesamum indicum* L., genetic divergence, diallel, combining ability, genetic effect

INTRODUCTION

Sesame (*Sesamum indicum* L.) is one of the most important ancient oilseed crops (Bedigian and Harlan, 1986). It is grown throughout the tropical and sub-tropical regions of the world (Ashri, 1998). About 3,321,458 tons of sesame was produced in 7,554,200 ha in the world (Uzun *et al*., 2007). India, Sudan, Myanmar and China are the most important sesame producers with 68% of the total world production (Laurentin and Karlovsky, 2006). Sesame contains about 50-60% seed oil (Arslan *et al*., 2007), which is of superior quality, nearly matching olive oil (Kapoor, 1990). Sesame oil is highly stable compared to other edible oils mainly due to the presence of antioxidants (Namiki, 1995) like sesamin, sesaminol, sesamol, sesamolinol and squalene (Mohamed and Awatif, 1998) and also contains large level of polyunsaturated fatty acids (Davidson, 1999). Sesame oil has a reducing effect on the plasma cholesterol and in conjunction with blood pressure lowering medicine, it also lowers blood

Corresponding Author: Partha Protim Banerjee, Scientist-Corn Breeding, Hytech Seed India Pvt. Ltd., International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Bldg. No. 303, Room No. 15-23, Patancheru, Hyderabad 502 324, India

pressure (Sankar *et al*., 2005). Despite high nutritional value and oil quality, research on sesame has been scarce (Bedigian, 2003). Average productivity of this important oilseed crop in India is only 453 kg ha^{-1}, which is far below the average productivity in China (1127 kg ha^{-1}) and Egypt (1211 kg ha^{-1}).

Successful breeding programme depends on the variability present among the different genotypes and in-depth understanding of the underlying gene action and genetic architecture of traits related to yield. Sesame is plant breeder's dream because of its great variability (Janick and Whipkey, 2002). Phenotypic selection of parents for hybridization based on their performance *per se* alone may not always be a viable procedure, since phenotypically superior genotypes may yield inferior hybrids and/or poor recombinants in the segregating generations. It is, therefore, essential that parents are selected on the basis of their genetic worth. Griffing's diallel analysis (Griffing, 1956) provides an efficient estimation of combining ability and the nature of gene action involved. Sprague and Tatum (1942) introduced the concepts of General Combining Ability (GCA) and Specific Combining Ability (SCA). GCA and SCA are related to additive and non-additive (dominance and epistasis) genetic effects, respectively (Rojas and Sprague, 1952) and the relative importance of these genetic effects could be readily assessed (Hallauer and Miranda, 1988). The knowledge on combining ability and type of gene action controlling the expressions of different characters would help in proper planning of a successful breeding programme. Again, genetic diversity or allelic divergence among the parents is very important in selecting parents for hybridization programme for identifying heterotic crosses and obtaining desirable recombinants in the segregating generations.

The objectives of the present study were to assess the nature and magnitude of gene action controlling the inheritance of seed yield and some important yield components in F_1 and F_2 generations and to suggest breeding strategies for sesame improvement. The study also aimed at classification of parental genotypes and their crosses based on their combining ability effects. Such classification would help identify good combining parents to be used as donors for improvement of traits and crosses for development of hybrids and/or selection of superior segregates in advance generations of segregation. An attempt was also made to find out the genetic distance among the parents and to assess its possible role in producing hybrids with significant specific combining ability for seed yield.

MATERIALS AND METHODS

Seven morphologically diverse sesame genotypes, representing different sesame growing regions of India, namely CST 2002 and MT 34 from Uttar Pradesh (northern India), OS-Sel-2 from Orrisa (south-eastern India), TKG 22 from Madhya Pradesh (central India), AAUDT 9304-14-4 from Assam (north-eastern India), B 67 and Rama from West Bengal (eastern India), were crossed in a half diallel mating system (excluding reciprocals) during summer (March-June), 2002 to produce 21 F_1 hybrids. Among the selected parents TKG 22 (Duhoon *et al*., 2004), Rama and B67 are used as national and zonal checks in different breeding programmes in India. CST 2002, OS-Sel-2, AAUDT 9304-14-4, B 67 and Rama are tall statured with high branch number and high yield potential. MT 34 is a medium tall line with high branch number and medium yield potential. TKG 22 is a well-adapted but comparatively old cultivar of medium plant height and comparatively lower yield potential than the other parents. In post-rainy season (August-November) 2002, a small portion of the seeds of each of the 21 F_1s (produced in summer 2002) were sown (2 rows each) and allowed to self pollinate to produce 21 F_2s. The selfing was ensured by protecting plants with insect proof net to prevent out-crossing through insect pollination, mainly by honey bees. All the seven parents, 21 F_1s and 21 F_2s were grown in a randomized complete block design with three replications during summer (March-June), 2003 in Agricultural Farm, Institute of Agriculture, Visva-Bharati University, Sriniketan (23°39′N, 87°42′E and 58.9 msl), located in sub-humid, subtropical belt of West Bengal, India. The soil in the experimental plots was sandy loam (61% sand, 10.7% silt and 28.3% clay) in texture and acidic in nature (pH 5.2), representing more or less red and lateritic soils with total available N: 235.4 kg ha^{-1}, P: 20.4 kg ha^{-1}, K: 172.3 kg ha^{-1} and organic C: 0.5%. The average meteorological data during the period of crop growth were as follows: maximum and minimum temperature: 34.6°C (39.9-29.6°C) and 22.5°C (27.1-16.8°C), respectively, relative humidity: 71% (58.9-83.6%) and sunshine hours: 7.38 h day^{-1} (6.5-8.6 h day^{-1}) with total rainfall of 23.4 mm. All parents and F_1s were grown in 5 rows of 3 m length, while all F_2s were grown in 10 rows of 3 m length. A uniform spacing of 30 cm between rows and 15 cm between plants was followed. Sowing was done manually in optimum moisture condition in furrows by placing two to three seeds per hill (at 15 cm interval) followed by covering with soil. Thinning was done after 20 days of sowing to maintain proper plant stand. Standard agronomic package of practice and suitable plant protection measures were taken to raise a healthy crop.

Data were recorded on plant height in cm (PH), branch number plant^{-1} (BN), capsules plant^{-1} (CP), seeds plant^{-1} (SC), 1000-seed weight in g (TW), stick yield plant^{-1} in g (STY) and seed yield plant^{-1} in g (SY) from 10 randomly selected plants in each plot for parents and F_1s and 30 plants from each plot for F_2s in each replication. Genetic dissimilarity was estimated among the parents based on the above-mentioned seven characters and additionally for days to initiate flowering (DIF) days to complete flowering (DCF) and days to maturity (DM) (data not presented). As sesame is an indeterminate crop, data were recorded for days to initiate and complete flowering rather than days to 50% flowering.

Statistical Analysis

Combining Ability Analysis

Mean values per replication for all traits were subjected to analysis of variance according to Panse and Sukhatme (1985) for randomized complete block design. Analysis of combining ability was carried out following Method-2, Model-I of Griffing (1956). This method was most suitable for the present study where only parents and one set of F_1s (without reciprocals) were included. The same method was used for F_2 data also. This approach partitions the variance due to diallel progenies into two components: due to GCA and due to SCA based on means over replications. From the mean sum of squares, estimates of GCA-effects (g_i) for each parent and SCA-effects (s_{ij}) for each cross combination were calculated according to Singh and Chaudhary (1985).

The statistical model for the mean value of a cross (i × j) is:

$$Y_{ij} = \mu + g_i + g_j + s_{ij} + 1/b \ \Sigma\Sigma \ e_{ijkl}$$

Where:

Y_{ij} = Mean of (i × j) th cross over replications k (k = 1, 2,..., b)
μ = General mean
g_i and g_j = GCA-effects of ith and jth parent, respectively
s_{ij} = SCA-effect for the cross involving ith and jth parent
$1/b \ \Sigma\Sigma \ e_{ijkl}$ = Mean error effect

The estimates of genetic components were obtained based on the expectations of the mean squares as:

$$\sigma^2_g = (MS_{GCA} - MS'_{error})/2b$$
$$\sigma^2_s = (MS_{SCA} - MS'_{error})/b$$

Where:

MS_{GCA} = Variance due to GCA
MS_{SCA} = Variance due to SCA
MS'_{error} = Error variance/b
b = No. of replications

The relative importance of general and specific combining ability in determining progeny performance was assessed, according to Baker (1978), by the ratio:

$$2\ \sigma^2_g/(2\ \sigma^2_g + \sigma^2_s)$$

For determining the overall best combiner among the parents for seven morphological characters, each parent was given a score for each trait as per their GCA-effect. A score of '+1' was assigned for any significant GCA-effect in the desirable direction, while '–1' for any significant GCA-effect in undesirable direction. A score of '0' was assigned for any non-significant GCA-effect in either direction The sum total of the scores over the seven characters for each parent was used for judging the overall combining ability effects.

Clustering of Parents

Genetic dissimilarity among the parents was estimated from the Eucledian distance matrix. Euclidean distance is a multivariate generalization of the Pythagorean Theorem. Euclidean distance was estimated by the following formula:

$$D_{rs} = [\Sigma\ (X_{rj}-X_{sj})^2]^{½}$$

where, X_{rj} and X_{sj} is the rth and sth object measured on jth variable.

Once the distance matrix was found, dendogram was constructed based on Unweighted Pair Group Method using Arithmatic average (UPGMA) (Sneath and Sokal, 1973). Hierarchical clustering was performed using R-Statistical software and the 'agricolae' package written by Felipe de Mendiburu (http://tarwi.lamolina.edu.pe/~fmendiburu).

Clustering pattern of the seven parents was also confirmed by plotting parental genotypes on first and second principal component (PC1 and PC2) axis. Plotting was done using R-statistical software.

RESULTS AND DISCUSSION

Nature of Gene Action

The analysis of variance revealed that mean sum of squares due to genotypes (parents, F_1s and F_2s) for all seven traits studied was significant, indicating the existence of genetic variability among the tested genotypes. Analysis of variance for combining ability (Table 1) revealed that variances due to GCA and SCA for all seven traits were highly significant in both F_1 and F_2. This indicated the importance of both additive and non-additive gene action for the inheritance of yield component characters in both generations. Chakraborti and Basu (2000) and Krishnaiah *et al*. (2002) emphasized the importance of both additive and non-additive gene action for the inheritance of yield and other important yield contributing characters in sesame.

Baker (1978) suggested that the relative importance of general and specific combining ability in determining progeny performance should be assessed by estimating the components of variance and expressing them in the ratio $2\ \sigma^2_g/(2\ \sigma^2_g+\sigma^2_s)$. The closer the ratio is to unity, the greater the predictability of progeny performance based on the GCA alone. The higher the involvement of additive gene actions for the inheritance of character, the better is the transmission of trait to the progenies. The ratios (Table 1) indicated that TW was mainly controlled by additive gene action in both F_1 and F_2 generations. These findings agree with earlier evidences reported by Ganesan (2005). For improvement of TW, any method of pureline breeding would be effective. STY and SY were mainly under non-

Table 1: ANOVA for combining ability in a 7×7 half diallel mating design for seven characters in F_1 and F_2 generations of sesame

	F_1						F_2					
	Mean sum of squares						Mean sum of squares					
Variables	GCA	SCA	Error	σ^2_g	σ^2_s	V_A/V_G	GCA	SCA	Error	σ^2_g	σ^2	V_A/V_G
df	6	21	54				6	21	54			
PH	391.62**	121.02**	8.210	42.60	112.81	0.43	473.32**	44.66**	13.870	51.05	30.79	0.77
BN	0.59**	0.24**	0.023	0.06	0.22	0.37	1.05**	0.17**	0.027	0.11	0.14	0.61
CP	517.15**	123.27**	14.470	55.85	108.80	0.51	396.95**	28.44**	14.050	42.54	14.39	0.86
SC	142.27**	62.68**	29.440	12.54	33.24	0.43	221.46**	63.69**	11.760	23.30	51.93	0.47
TW	0.21**	0.037**	0.006	0.02	0.03	0.59	0.13**	0.021**	0.002	0.01	0.02	0.60
STY	1.23**	1.58**	0.120	0.12	1.46	0.14	2.57**	3.58**	0.480	0.23	3.10	0.13
SY	1.54**	0.99**	0.039	0.17	0.95	0.26	1.75**	0.86**	0.095	0.18	0.77	0.32

*, **: Significant at p = 0.05 and 0.01, respectively, df: Degree of freedom, PH: Plant height, BN: Branch No. plant^{-1}, CP: Capsule plant^{-1}, SC: Seeds capsule^{-1}, TW: 100-seed weight, STY: Stick yield plant^{-1}, SY: Seed yield plant^{-1}, GCA: General combining ability, SCA: Specific combining ability, σ^2_g: GCA variance, σ^2_s: SCA variance, V_A/V_G: $2\sigma^2_g/(2\sigma^2_g+\sigma^2_s)$

additive gene action in both generations in line with previous reports by Mothilal and Manoharan (2005) and Vidhyavati *et al*. (2005). No report related to the nature of gene action controlling STY in sesame was available; however, Devasena *et al*. (2001) reported on the importance of both additive and non-additive gene action for the inheritance of total dry matter production in sesame. Therefore, hybrid breeding might be effective for improvement of STY and SY. Importance of both additive and non-additive types of gene action in both F_1 and F_2 was observed in case of SC. For utilization of both additive and non-additive types of gene actions in this character, reciprocal recurrent selection or diallel selective mating system could be followed. Babu *et al*. (2004) reported similar results for the inheritance of SC in sesame. In case of PH and CP, both additive and non-additive gene actions were important in F_1, while, preponderance of additive gene action was observed for these traits in F_2. Importance of both additive and non-additive types of gene action for the inheritance of PH was reported by Babu *et al*. (2004). Importance of both additive and non-additive gene actions for the inheritance of CP was reported by Ganesan (2005), while, Vidhyavati *et al*. (2005) reported additive gene action for this trait in sesame. Non-additive type of gene action was important for BN in F_1 whereas, preponderance of additive type of gene action was found for this trait in F_2. Kumar *et al*. (2004) reported non-additive type of gene action for the control of BN, while Mothilal and Manoharan (2005) reported importance of additive type of gene action for the inheritance of this trait. Therefore, for improvement of these characters, selection should be deferred to later generations of segregation for dissipation of non-additive gene action.

In the present study, PH, BN, CP and TW exhibited reduced SCA variances in F_2 compared to F_1. This might be due to reduction of heterozygosity in F_2. But in case of SC, STY and SY the magnitude of SCA variance were higher in F_2 than in F_1. Such an increase in SCA variance might due to wide array of segregates in F_2.

Combining Ability

General Combining Ability (GCA)

Selection of parents based on their performance *per se* alone, may not always be a sound procedure, since phenotypically superior genotypes may yield inferior hybrids and/or poor recombinants in the segregating generations. It is, therefore, essential that parents are selected on the basis of their genetic worth. Large GCA-effects of the parents are mainly due to additive and additive×additive gene actions (Griffing, 1956) which is fixable in the segregating generations (Mather and Jinks, 1982). Thus, to enable isolation of superior segregates in the F_2 and subsequent generations, selection of parents for hybridization should be made on the basis of their GCA-effects.

Table 2: Mean performance of seven parental sesame genotypes for seven characters

Parents	PH	BN	CP	SC	TW	STY	SY
CST 2002	116.6	3.2	56.2	98.9	3.0	10.3	6.6
MT 34	80.7	4.1	60.9	65.9	3.5	11.5	5.0
OS-Sel-2	105.0	1.9	72.0	68.1	3.0	12.7	7.1
TKG 22	84.8	2.9	47.6	82.5	2.5	10.4	4.1
AAUDT 9304-14-4	120.1	3.6	85.8	68.9	2.8	10.1	7.6
B 67	110.8	3.2	74.0	71.8	3.0	8.6	6.0
Rama	113.9	3.6	75.3	59.2	2.9	8.5	5.7

PH: Plant height (cm), BN: Branch No. plant^{-1}, CP: Capsule plant^{-1}, SC: Seeds capsule^{-1}, TW: 100-seed weight (g), STY: Stick yield plant^{-1} (g), SY: Seed yield plant^{-1} (g)

Table 3: GCA-effects of parents in F_1 and correlation with performance *per se* for seven characters in sesame

Parents	PH	BN	CP	SC	TW	STY	SY	Score
CST 2002	4.15**	-0.14**	-11.32**	7.03**	-0.06**	0.62**	0.16**	1
MT 34	-7.86**	0.32**	-6.14**	-2.95	0.33	0.14	-0.16**	-2
OS-Sel-2	-0.32	-0.25**	3.00*	-2.09	0.04	0.16	0.44**	0
TKG 22	-9.78**	-0.28**	-5.44**	3.59*	-0.11**	0.04	-0.81**	-4
AAUDT 9304-14-4	8.35**	0.08	8.93**	0.56	-0.06**	-0.18	0.30*	2
B 67	1.85*	0.35**	5.85**	-3.45*	-0.05*	-0.53**	0.15*	1
Rama	3.61**	-0.08	5.12**	-2.69	-0.09**	-0.25*	-0.09	0
r	0.98**	0.65	0.89**	0.91**	0.88**	0.59	0.93**	
SE (g_i)	0.08	0.05	1.17	1.68	0.02	0.11	0.06	
SE (g_i-g_j)	1.35	0.07	1.79	2.56	0.04	0.16	0.09	

*, **: Significant at p = 0.05 and 0.01, respectively, r: Simple correlation coefficient, PH: Plant height, BN: Branch No. plant^{-1}, CP: Capsule plant^{-1}, SC: Seeds capsule^{-1}, TW: 100-seed weight, STY: Stick yield plant^{-1}, SY: Seed yield plant^{-1}

Table 4: GCA-effects of parents in F_2 and correlation with performance *per se* for seven characters in sesame

Parents	PH	BN	CP	SC	TW	STY	SY	Score
CST 2002	4.63**	0.02	-4.26**	10.05**	-0.01	0.67**	0.23*	3
MT 34	-11.84**	0.33**	-3.91**	-3.34**	0.16**	0.27	-0.22*	-2
OS-Sel-2	0.39	-0.68**	1.55	-4.32**	0.08**	0.63**	0.46**	1
TKG 22	-8.20**	-0.15**	-10.73**	2.80*	-0.21**	-0.09	-0.82**	-4
AAUDT 9304-14-4	7.65**	0.13*	8.52**	-1.76	-0.09**	-0.30	0.18	2
B 67	3.03*	0.05	3.44**	-1.70	0.06**	-0.61**	0.35**	3
Rama	4.34**	0.29**	5.40**	-1.74	0.01	-0.56*	-0.18	2
r	0.99**	0.98**	0.99**	0.93**	0.93**	0.82*	0.86*	
SE (g_i)	1.15	0.05	1.16	1.06	0.01	0.22	0.10	
SE (g_i-g_j)	1.76	0.08	1.77	1.62	0.02	0.33	0.15	

*, **: Significant at p = 0.05 and 0.01, respectively, r: Simple correlation coefficient, PH: Plant height, BN: Branch No. plant^{-1}, CP: Capsule plant^{-1}, SC: Seeds capsule^{-1}, TW: 100-seed weight, STY: Stick yield plant^{-1}, SY: Seed yield plant^{-1}

It is very important to identify parents with high GCA value for the trait to be improved. Performance *per se* (Table 2) and the GCA-effects of the seven parents estimated both in F_1 and F_2 (Table 3, 4) revealed that CST 2002 was the best general combiner for SC and STY in both F_1 and F_2. MT 34 was the best general combiner for TW in both the generations and for BN in F_2. AAUDT 9304-14-4 exhibited highest combining ability for PH and CP in both F_1 and F_2. The variety, B 67, was the best general combiner for BN in F_1. OS-Sel-2 appeared as best general combiner for SY in both generations, which also exhibited positive and significant combining ability effects for CP in F_1 and TW and STY in F_2. CST 2002 and B 67 in both generations and AAUDT 9304-14-4 in F_1 exhibited positive and significant GCA-effects for SY.

Estimates of the GCA-effects of seven parents revealed that none of the parents had good general combining ability for all traits. The scoring of parents on the basis of GCA revealed that AAUDT 9304-14-4 (score +2) was the best overall general combiner in F_1, whereas CST 2002 and B 67 (score +3 each) were best general combiners in F_2. TKG 22 (score-4 in both F_1 and F_2) appeared to be poorest combiner in both the generations. In absence of obtaining parents, having desirable combining

Table 5: SCA-effects for 7×7 diallel set of crosses in F_1 for seven characters in sesame

F_1s	PH	BN	CP	SC	TW	STY	SY
CST 2002×MT34	11.18**	0.23	5.21	-0.06	0.40**	-1.32**	0.55**
CST 2002×OS-Sel-2	3.15	-0.03	-3.73	-2.09	-0.03	-0.81*	-0.12
CST 2002×TKG22	8.77**	-0.44**	1.27	-4.91	-0.07	2.34**	1.57**
CST 2002×AAUDT9304-14-4	-7.03**	-0.13	-7.40	0.69	-0.19**	-0.27	-0.88**
CST 2002×B67	7.27**	-0.23	-5.11	-6.96	-0.10	0.25	-0.59**
CST 2002×Rama	-27.89**	-0.11	-2.22	0.34	-0.12	2.77**	0.32
MT 34×OS-Sel-2	11.90**	0.10	-14.58**	-12.74*	0.01	0.27	0.46*
MT 34×TKG22	-0.01	0.16	12.99**	5.54	-0.06	-0.11	-0.25
MT 34×AAUDT9304-14-4	-13.65**	-0.53**	-12.08**	9.97*	0.16*	0.35	0.97**
MT 34×B67	-1.08	0.17	4.41	4.18	0.08	-0.13	0.89**
MT 34×Rama	10.99**	-0.80	3.53	6.22	-0.07	-0.38	0.26
OS-Sel-2×TKG22	-18.95**	0.30*	8.75	-2.22	0.20**	-1.09**	-0.22
OS-Sel-2×AAUDT9304-14-4	-1.55	-0.06	-9.42**	7.38	0.11	-0.74*	0.80**
OS-Sel-2×B67	1.62	1.14**	20.00**	2.79	-0.09	-0.22	-0.91**
OS-Sel-2×Rama	4.65	0.00	12.78**	18.96**	0.01	-1.10**	0.99**
TKG 22×AAUDT9304-14-4	10.34**	-0.50**	15.32**	2.16	0.10	0.01	-1.08**
TKG 22×B67	-6.99**	0.10	0.30	1.17	0.27**	0.10	1.08**
TKG 22×Rama	10.15**	-0.34*	-9.88**	4.28	0.26**	-0.78*	1.02**
AAUDT 9304-14-4×B67	6.64*	0.28*	6.80	0.67	-0.04	-0.01	1.16**
AAUDT 9304-14-4×Rama	10.48**	0.30*	16.69**	0.28	0.08	0.87**	-1.40**
B67×Rama	-9.55**	-0.30*	-5.23	2.54	-0.27**	1.79**	0.49**
SE (s_{ij})	2.57	0.14	3.41	4.87	0.07	0.31	0.18
SE (s_{ij}-s_{ik})	3.82	0.20	5.07	7.24	0.10	0.46	0.27
SE (s_{ij}-s_{kl})	3.57	0.19	4.74	6.77	0.10	0.43	0.25

*, **: Significant at p = 0.05 and 0.01, respectively, PH: Plant height (cm), BN: Branch No. plant^{-1}, CP: Capsule plant^{-1}, SC: Seeds capsule^{-1}, TW: 100-seed weight, STY: Stick yield plant^{-1}, SY: Seed yield plant^{-1}

ability for majority of the component characters, multiple crosses involving more than two parents would be an option to develop hybrids and /or selection of superior recombinants in the segregating generations.

In general, for most of the traits, parents with desirable and significant GCA-effects also had desirable performance *per se* in both F_1 and F_2 generations, with few exceptions. Correlation coefficients were computed between GCA-effects and performance *per se* of the parents (Table 3, 4). In F_1, GCA-effects for all the traits, except BN and STY (0.65 and 0.59, respectively), exhibited positive and significant association with performance *per se*. However, in F_2 for all the seven traits this association was positive and significant. Thus, for initiating hybridization programme in sesame, parents could be selected based on their desirable performance *per se*. However, it would be advisable to select parent based on both performance *per se* as well as GCA-effects to initiate any breeding programme.

Specific Combining Ability (SCA)

Unlike GCA-effects, the SCA-effects (Table 5, 6) are the result of non-additive gene action. For all traits, except SC and STY, the number of crosses with positive and significant SCA-effects was larger in F_1 than in F_2. This might be due to the reduction of heterozygosity brought about by segregation in F_2. In F_1, the majority of crosses showing positive and significant SCA-effect for SY also exhibited positive and significant SCA-effects for one or two of the component traits. In F_1, CST 2002 × TKG 22 exhibited maximum SCA-effect for SY along with positive and significant SCA-effects for PH and STY. The cross AAUDT 9304-14-4 × B 67 also exhibited high SCA-effect for SY and positive and significant SCA-effects for PH and BN. These two crosses could be utilized as high yielding hybrids. In F_1, when yield and other component characters were considered, Rama, TKG 22 and AAUDT 9304-14-4 were involved more frequently than the other parents in the hybrids exhibiting positive and significant SCA-effects. However, in F_2, Rama, B 67 and AAUDT 9304-14-4 were involved more frequently.

Table 6: SCA-effects for 7×7 diallel set of crosses in F_2 for seven characters in sesame

F_2s	PH	BN	CP	SC	TW	STY	SY
CST 2002×MT34	-6.67	0.06	-0.70	-2.22	-0.18**	-0.12	0.10
CST 2002×OS-Sel-2	-6.20	-0.77**	-0.36	-3.93	0.10*	-0.68	-0.64*
CST 2002×TKG22	1.92	0.18	-0.15	0.31	0.03	-0.26	1.60**
CST 2002×AAUDT9304-14-4	-1.30	0.36*	1.50	2.60	-0.08*	2.82**	-0.53**
CST 2002×B67	0.72	0.10	-5.95	-9.46**	-0.09*	-2.87**	-1.10**
CST 2002×Rama	2.35	-0.14	1.55	-2.55	-0.10*	4.41**	-0.07
MT 34×OS-Sel-2	-1.03	-0.01	-3.75	-11.55**	0.01	1.43*	0.40
MT 34×TKG22	0.96	-0.50**	-8.33*	-13.11**	-0.05	-0.12	-0.76**
MT 34×AAUDT9304-14-4	1.75	0.11	0.38	13.35**	-0.24**	-1.24	1.01**
MT 34×B67	-11.54**	-0.21	-1.90	-0.94	0.10*	-0.26	0.41
MT 34×Rama	13.39**	-0.21	2.34	11.67**	-0.25**	-0.35	-0.33
OS-Sel-2×TKG22	3.26	0.07	0.24	2.38	-0.18**	-1.45*	-0.73*
OS-Sel-2×AAUDT9304-14-4	-6.72*	-0.95**	-13.71**	-4.26	-0.01	0.13	0.33
OS-Sel-2×B67	5.63	0.40**	2.47	0.48	-0.07	-0.93	0.53
OS-Sel-2×Rama	2.19	0.86**	2.74	5.69	0.09*	-0.17	0.36
TKG 22×AAUDT9304-14-4	9.16**	0.13	4.27	1.78	0.07	-2.08**	-0.92**
TKG 22×B67	3.92	-0.32*	-3.81	-5.32	-0.09*	3.53**	0.11
TKG 22×Rama	-16.09**	0.07	-5.01	2.46	0.11**	0.48	0.91**
AAUDT 9304-14-4×B67	-1.50	0.09	0.50	-4.22	-0.02	2.34**	0.68*
AAUDT 9304-14-4×Rama	-5.50	-0.29*	-5.06	-11.71**	-0.02	-2.11**	-2.22**
B 67×Rama	-1.15	-0.20	-0.15	11.43**	0.01	-0.17	0.70*
SE (s_{ij})	3.343	0.148	3.364	3.078	0.039	0.627	0.227
SE (s_{ij}-s_{ik})	4.966	0.219	4.998	4.572	0.059	0.931	0.412
SE (s_{ij}-s_{kl})	4.645	0.205	4.675	4.277	0.055	0.871	0.385

*, **: Significant at p = 0.05 and 0.01, respectively, PH: Plant height, BN: Branch No. plant^{-1}, CP: Capsule plant^{-1}, SC: Seeds capsule^{-1}, TW: 100-seed weight, STY: Stick yield plant^{-1}, SY: Seed yield plant^{-1}

Diversity in parental GCA-effects played an important role for the production of hybrids with significant positive SCA-effects for SY in F_1. Out of 11 F_1 hybrids showing significant and positive SCA-effects for SY, eight involved one of the parents having high GCA-effect for SY, while, the other had low GCA-effect for the trait. Reddy and Arunachalam (1981) reported that diversity in parental GCA-effects was necessary for the development of specific combinations with high value. This kind of superiority of High × Low crosses might involve dominant × recessive type of gene interaction and therefore, might tend to be unfixable (Singh and Gupta, 1969). Crosses involving at least one parent with high GCA-effect could produce good segregates, only if the additive genetic system present in the good general combiner and the complementary epistatic effects in the other act in the same direction to maximize the desirable plant attribute (Singh and Chaudhary, 1995). Two of the F_1 crosses (AAUDT 9304-14-4 × B67, OS-Sel-2 × AAUDT9304-14-4) having significant and positive SCA-effects for SY involved both the parents with high GCA-effects for SY. Superiority of such hybrid might be due to additive and additive × additive gene actions, which is fixable (Singh *et al*., 1971). Therefore, high yielding genotypes could be obtained in the segregating generations of these crosses. Arunachalam (1977) reported that pure additive gene action at individual loci coupled with favorable additive × additive interaction could produce heterotic combinations. Also the realized heterosis was related to GCA of parents and SCA of crosses (Reddy and Arunachalam, 1981). If so, then it would be possible to recover homozygous lines as good as or close to the heterotic hybrids from a cross involving parents with good GCA and F_1 hybrids with satisfactory SCA.

Genetic Diversity Among the Parents and its Role in SCA for Seed Yield in F_1

It is evident from the UPGMA dendogram (Fig. 1) that the seven parents could be assigned to three clusters at about 29 unit linkage distance. Cluster I was constituted by OS-Sel-2 (from Orissa), B67 and Rama (from West Bengal) and AAUDT 9304-14-4 (from Assam) representing the eastern parts of India. CST 2002 (from Uttar Pradesh, northern India) appeared as a separate monogenotypic cluster II. TKG 22 (from Madhya Pradesh) and MT 34 (from Uttar Pradesh) representing central and

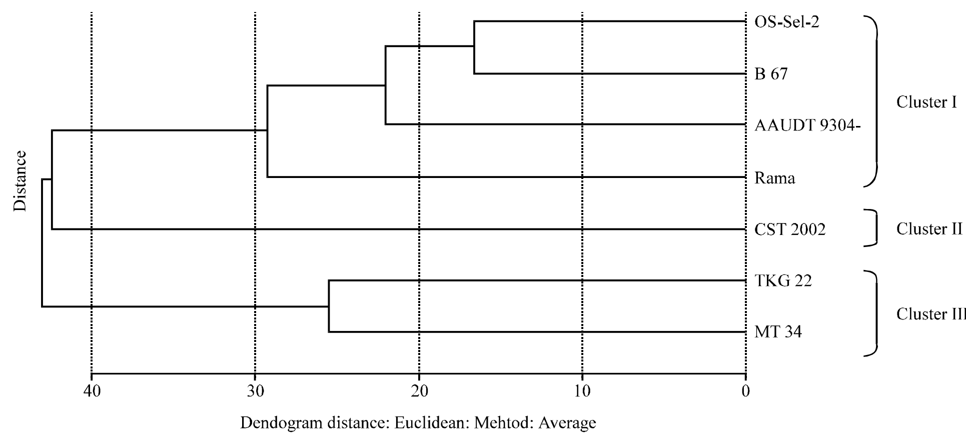

Fig. 1: UPGMA Dendogram for seven parents based on the Euclidean distance matrix

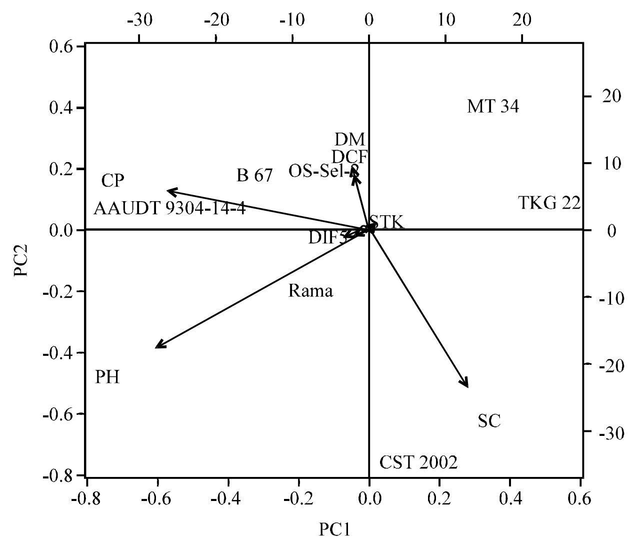

Fig. 2: Distribution pattern of seven sesame parents on first and second principal component (PC1 and PC2, respectively)

northern India formed cluster III. Figure 2 explained the distribution pattern of the seven parents on first and second principal component axis (PC1 and PC2). From the principal component analysys, PC1 and PC2 cumulatively accounted for 82% of the total variation among the parents. Distribution of genotypes are in well in agreement with the clustering pattern derived from UPGMA dendogram.

An attempt was made to determine the possible role of genetic diversity present among the parents in determining SCA-effects of the F_1 hybrids for SY. Among 11 of the F_1 hybrids exhibiting positive and significant SCA for seed yield, seven hybrids viz., CST 2002 × TKG 22, TKG 22 × B 67, TKG 22 × Rama, MT 34 × AAUDT 9304-14-4, MT 34 × B 67, CST 2002 × MT 34 and MT 34 × OS-Sel-2 were inter-cluster crosses indicating the possible role of genetic diversity. Ramanujam *et al*. (1974) reported that the hybrids between genetically diverse parents were more heterotic. The remaining four F_1s, viz., AAUDT 9304-14-4 × B 67, OS-Sel-2 × Rama, OS-Sel-2 × AAUDT 9304-14-4 and B 67 × Rama were intra-cluster crosses. This might be due to higher intra-cluster diversity in cluster I. However genetic diversity among parents could not provide a satisfactory explanation for crosses with negative and significant SCA for SY. Among five of such crosses, three hybrids were intra-cluster crosses while two were inter-cluster cresses. Melchinger (1999) reported relationship of genetic diversity and heterosis, although the correlation was not strong enough to be used as an accurate predictive tool.

CONCLUSION

Considering the nature and magnitude of gene action, improvement of TW in sesame could be achieved through simple pedigree method as this trait was mainly under additive gene control. For improving PH, BN, CP and SC, pedigree methods might be useful along with recurrent selection and bi-parental mating, as additive gene action was important along with non-additive type for the expression of these traits. In such cases, selection might be more effective in advance generations. But for improvement of SY and STY, which were controlled by mainly non-additive gene action, heterosis breeding would be most effective.

In recent years, production and cultivation of sesame hybrids by means of cytoplasmic and genetic male sterility system on commercial scale is being attempted. Considering SCA-effect for all the characters in the generations, the crosses CST 2002 × TKG 22, TKG 22 × Rama and AAUDT 9304-14-4 × B 67 appeared to be promising.

Genetic divergence among the parents played an important role to produce good specific combinations in the present study, though it may not be the sole factor. The concept of heterotic grouping of parental lines can be also applied in sesame breeding. This might reduce the number of crosses to be attempted. However, some intra-cluster crosses can be also attempted between genotypes having good GCA and performance *per se*. These crosses can be advanced to isolate superior recombinants without altering their known heterotic pattern.

REFERENCES

Arslan, C., B. Uzun, S. Ulger and M.I. Cagirgan, 2007. Determination of oil content and fatty acid composition of sesame mutants suited for intensive management conditions. J. Am. Oil Chem. Soc., 84: 917-920.

Arunachalam, V., 1977. Heterosis for characters governed by two genes. J. Genet., 63: 15-24.

Ashri, A., 1998. Sesame breeding. Plant Breed. Rev., 16: 179-228.

Babu, D.R., P.V.R. Kumar, C.V.D Rani and A.V. Reddy, 2004. Studies on combining ability for yield and yield components in sesame, *Sesamum indicum* L. J. Oilseeds Res., 21: 260-262.

Baker, R.J., 1978. Issues in diallel analysis. Crop Sci., 18: 533-536.

Bedigian, D. and J. Harlan, 1986. Evidence for cultivation on sesame in the ancient world. Econ. Botany, 40: 137-154.

Bedigian, D., 2003. Evolution of sesame revisited: Domestication, diversity and prospects. Genet. Res. Crop Evol., 50: 779-787.

Chakraborti, P. and A.K. Basu, 2000. Combining ability analysis of oil content and fatty acid components in sesame under alluvial and saline conditions. Crop Res., 19: 505-511.

Davidson, A., 1999. The Oxford Companion to Food. Oxford University Press, London.

Devasena, N., V. Muralidharan and D. Punitha, 2001. Studies on combining ability for yield related traits in sesame (*Sesamum indicum* L.). Res. on Crops, 2: 409-413.

Duhoon, S.S., A. Jyotishi, M.R. Deshmukh and N.B. Singh, 2004. Optimization of sesame (*Sesamum indicum* L.) production through bio/natural inputs. 4th International Crop Science Congress, Brisbane.

Ganesan, K.N., 2005. Variability studies in determinate type sesame, *Sesamum indicum* L. germplasm lines for yield and its component traits. J. Oilseeds Res., 22: 176-177.

Griffing, B., 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci., 9: 463-493.

Hallauer, A.R. and J.B. Miranda, 1988. Quantitative Genetics in Maize Breeding. 2nd Edn., Iowa State University Press, USA.

Janick, J. and A. Whipkey, 2002. Trends in New Crops and New Uses. ASHS Press, Alexandria.

Kapoor, L., 1990. Handbook of Ayurvedic Medicinal Plants. CRC Press, Boca Raton, FL.

Krishnaiah, G., K.R. Reddy, G.L.K. Reddy and M.R. Sekhar, 2002. Combining ability in sesame. Crop Res., 24: 72-76.

Kumar, P.S., R. Puspha, P. Karuppiah and J. Ganesan, 2004. Studies on combining ability in sesame (*Sesamum indicum* L.). Crop Res., 27: 99-103.

Laurentin, H.E. and P. Karlovsky, 2006. Genetic relationship and diversity in sesame (*Sesamum Indicum* L.) germplasm collection using amplified fragment length polymorphism (AFLP). BMC Genet., 7: 10-10.

Mather, K. and J.L. Jinks, 1982. Biometrical Genetics. 3rd Edn. Chapman and Hall Ltd., London, ISBN-10: 0412228904.

Melchinger, A.E., 1999. Genetic Diversity and Heterosis. In: The Genetics and Exploitation of Heterosis in Crops, Coors, J.G. and S. Pandey (Eds.). Crop Science Society of America, Madison, WI., pp: 99-118.

Mohamed, H.M.A. and I.I. Awatif, 1998. The use of sesame oil unsaponifiable matter as a natural antioxidant. Food Chem., 62: 269-276.

Mothilal, A. and V. Manoharan, 2005. Diallel analysis for the estimation of genetic parameters in sesame (*Sesamum indicum* L.). Agric. Sci. Dig., 25: 133-135.

Namiki, M., 1995. The chemistry and physiological functions of sesame. Food Rev. Int., 11: 281-329.

Panse, V.G. and P.V. Sukhatme, 1985. Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research, New Delhi, India, pp: 359.

Ramanujam, S., A.S. Tiwari and R.B. Mehra, 1974. Genetic divergence and hybrid performance in mungbean. Theor. Appl. Genet., 45: 211-214.

Reddy, B.B. and V. Arunachalam, 1981. Evaluation of heterosis through combining ability in pearl millet. I. Single crosses. Indian J. Genet., 41: 59-65.

Rojas, B.A. and G.F. Sprague, 1952. A comparison of various components in corn yield traits. General and specific combining ability and their interaction with locations and years. Agron. J., 44: 462-466.

Sankar, D., G. Sambandam, R.M. Ramakrishna and K.V. Pugalendi, 2005. Modulation of blood pressure lipid profiles and redox status in hyper-tensive patients taking different edible oils. Clin. Chim. Acta, 355: 97-104.

Singh, K.B. and V.P. Gupta, 1969. Combining ability in wheat. Indian J. Genet., 29: 227-232.

Singh, T.H., S.P. Gupta and P.S. Phul, 1971. Line x tester analysis of combining ability in cotton. Indian J. Genet., 31: 316-321.

Singh, R.K. and B.D. Chaudhary, 1985. Biometrical Methods in Quantitative Genetic Analysis. Kalyani Publishers, New Delhi, pp: 300.

Singh, S. and B.S. Choudhary, 1995. Combining ability for some metric traits in rice. Madras Agric. J., 82: 165-169.

Sneath, P.H.A. and R.R. Sokal, 1973. Numerical Taxonomy. 1st Edn., Freeman and Co. Publishers, San Francisco. STATSOFT Inc., USA., pp: 573.

Sprague, G.F. and L.A. Tatum, 1942. General vs. specific combining ability in single cross of corn. J. Am. Soc. Agron., 34: 923-932.

Uzun, B., C. Arslan, M. Karhan and C. Toker, 2007. Fat and fatty acids of white lupin (*Lupinus albus* L.) in comparison to sesame (*Sesamum indicum* L.). Food Chem., 102: 45-49.

Vidhyavati, R., N. Manivannan and V. Muralidharan, 2005. Line x tester analysis in sesame (*Sesamum indicum* L.). Indian J. Agric. Res., 39: 225-228.