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RESEARCH ARTICLE

Combining ability analysis for seed yield and its component traits in sesame (*Sesamum indicum* L.): A genetic study

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Abstract

Sesame (*Sesamum indicum* L.) is a vital oilseed crop cultivated extensively in India. Improving sesame yield requires effective breeding strategies that utilize parents and hybrids with strong combining ability. Line × Tester analysis was carried out in sesame to study gene action, combining ability of parents and hybrids, mean performance and to select promising hybrids based on mean, gene action and combining ablity effects for seed yield and component traits. A set of six lines (EC358033, EC346664, IC129607, IC204840, IC204557 and VS19078) and threetesters (TMV 3, VRI 5 and TMV 7) were crossed using a line × tester mating design. The gene action and combining ability were analysed for tenquantitative traits. All traits showed a preponderance of non-additive gene action. Among lines, IC 129607, IC204557 and VS19078 and testers TMV 3 and TMV 7 had significant and positive GCA effects for seed yield per plant and component traits. The hybrid TMV 7 × IC204557 exhibited high mean performance, significant GCA and non-significant SCA for seed yield per plant, number of capsules per plant and most of the other traits. Hence, this cross can be further handled through pedigree breeding to obtain high-yielding segregants due to the presence of additive gene action. Hybrids, TMV 3 × VS19078, TMV 7 × IC129607, TMV 3 x IC129607, TMV 3 × IC204557 and TMV 7 × VS19078 had high *per se*, good combining parents, but with significant SCA for seed yield or number of capsules per plant and other component traits. Hence, selection should be postponed to later generations in these crosses due to the presence of non-additive gene action.

Keywords: combining ability; gene action; pedigree breeding; seed yield; sesame

Introduction

Sesame is a member of the Pedaliaceae family (*Sesamum indicum* L.; 2n = 2x = 26). It is primarily a self-pollinating crop (1). Products made from sesame seed oil are used in the food, feed and cosmetics industries all over the world. The seed oil content of sesame is higher than that of soybean (~20 %), rapeseed (~40 %), sunflower (~45 %) and groundnut (45-56 %), with a range of 40 % to 60 % (2). The majority of the fatty acid composition is made up of unsaturated fatty acids, with oleic (35.9-42.3 %) and linoleic (41.5-47.9 %) acids accounting for 80 % of total fatty acids. Less than 20 % of the fatty acid content of sesame seeds is made up of saturated fatty acids, primarily palmitic (7.9-12 %) and stearic (4.8-6.1 %) acids. Due to the presence of natural antioxidants including sesamolin, sesamin and sesamol, the seed's 50-60 % oil has exceptional stability (3). The market demand for sesame seeds and oil has been steadily rising as more people become aware of the dietary and health advantages of this crop. Similarly, sesame is ideally suited to replace low-yield crops due to its low irrigation requirements, adaptability to various soil and weather types, minimal labour requirements and high yield, particularly in light of the current situation where crop productivity is being impacted by global warming in more and more traditional agricultural areas (4). Moreover, recent advancements such as artificial seed technology offer promising opportunities for the clonal propagation and conservation of elite sesame genotypes, thus supporting genetic improvement programs (5). Unfortunately, the absence of high-yielding varieties that are naturally resistant to a variety of biotic and abiotic stressors is the reason for the limited cultivation of sesame. Charcoal rot is one of the most destructive diseases, which usually causes sesame crops to decline by 30 % or even completely lose them. In sesame, charcoal rot generally happens from the end of flowering until maturity. When the weather is hot and dry or there are unfavourable environmental stressors, black spots start to appear on the root or stem (6). Therefore, efforts should be made to create cultivars with high yield potential that can adapt better to various climatic situations. Combining ability analysis is the method used to choose the best parents for hybridization in order to produce elite segregants in recombination breeding (7). With this background, an attempt has been made to assess the combining ability of six *Macrophomina* root rot-resistant genotypes of sesame for seed yield and component traits in a line × tester mating design. The present study was formulated with the following objectives: a) to assess the gene action involved for various traits, b) to identify good combining parents for various traits, c) to select promising hybrids based on *per se* performance and d) to formulate a breeding program for the selected hybrids.

Materials and Methods

Experimental materials and sites

The experimental material of the present study consisted of nine genotypes, which were crossed in line × tester mating design during December to February, 2023-24 at the Regional Research Station, Tamil Nadu Agricultural University, Vriddhachalam. The parental details were presented in Table 1. The male lines were EC 358033, EC346664, IC129607, IC204840, IC204577 and VS19078. All these genotypes are *Macrophomina* root rot resistant. The female testers were TMV 3, VRI 5 and TMV 7. All these genotypes are released varieties in Tamil Nadu. The 18 newly synthesised F_1 crosses, nine parents were evaluated in a randomized complete block design (RCBD) with three replications during June- September, 2024.

Crossing procedure

Each line and tester was raised in an adjacent row manner under field conditions. The crossing was made during Dec-Feb, 2023-24. The recommended agronomic practices were uniformly followed throughout the season. Emasculation was done between 4 PM and 6 PM, one day before anthesis. It was carried out by completely removing the corolla by pulling its tip along with the epipetalous stamens. Other young flowers located close to the emasculated flowers were removed to avoid confusion. Emasculated flowers were covered by a butter paper bag to avoid pollen contamination. In the next day, early morning between 6 AM and 8 AM, the pollen from the desired male flower was dusted on the stigma of the emasculated flower by rubbing the staminal column of the male parent. After the pollination, the pollinated flowers were tagged and covered with a butter paper cover. After maturity, the hybrid seeds were harvested and stored.

Data collection and statistical analysis

The quantitative traits such as days to 50 % flowering (DFF) (days), days to maturity (DTM) (days), plant height (PH) (cm), number of branches (NBP), number of capsules per plant (NCP), capsule length (CL) (cm), capsule width (CW) (cm), number of seeds per capsule (NSC), 1000-seed weight (TSW (g) and seed yield per plant (SYP) (g) were recorded on randomly chosen five plants per genotype from each replication. The collected data were subjected to combining ability analysis (8) using L × T analysis package in TNAUSTAT software (9).

Results and Discussions

The ANOVA for combining ability analysis was presented in Table 2. The mean sum of squares due to crosses, lines, testers and hybrids was significant for all traits. This indicated that a considerable amount of variability was present in lines, testers and their hybrids for the studied traits. This variation enhances yield by gathering beneficial genes from genetically diverse genotypes. Research indicates that the results are significant and at par with those reported in previous studies (10).

Gene action

The knowledge of the gene action of the characters is crucial to plan a suitable breeding procedure. The SCA variances were found to be greater than the GCA variances for all the studied quantitative traits (Table 3). This indicated that these traits were governed by predominantly non-additive gene action. Research indicated the predominance of non-additive gene action for

Table 1. Source/pedigree and features of lines used

Genotypes	Pedigree	Origin	Features
TMV 3	South Arcot local × Malabar	Oilseeds Research Station, Tindivanam	Black seed coat
TMV 7	SI 250 × ES 22	Oilseeds Research Station, Tindivanam	Brown seed coat
VRI 5	VRI 3 × EC370840	Regional Research Station, Vriddhachalam	Mono-stem/shy branching, multi-capsule with white seed coat
EC358033	-	Bangladesh	Dark brown with rough seed coat
EC346664	-	Singapore	Brown with rough seed coat
IC129607	-	Jabalpur, Madhya Pradesh	White seed coat
IC204840	-	Cuttack, Odisha	White seed coat
IC204557	-	Cuttack, Odisha	White seed coat
VS19078	TMV 7 × ORM 14	Regional Research Station, Vriddhachalam	Profuse branching, small sized capsules with brown seed coat

Table 2. ANOVA of combining ability for quantitative traits in sesame

Traits\ Source of variation	Replication	Crosses	Lines	Testers	Hybrids	Error
df	2	17	2	5	10	34
DFF	0.42	26.34**	7.89*	79.37**	3.51**	1.12
DTM	3.59	89.86**	32.66**	222.30**	35.07**	2.78
PH	18.84	1038.07**	5050.03**	1163.45**	172.99**	15.80
NBP	0.23	8.83**	48.14**	5.58**	2.59**	0.32
NCP	3.67	5145.03**	33196.08**	2647.77**	783.44**	12.61
CL	0.04	0.18**	0.65**	0.24**	0.06*	0.03
CW	0.01	0.01	0.04*	0.00	0.01	0.01
NSC	9.12	71.45**	17.04	177.57**	29.27	12.81
TSW	0.00	0.51**	0.71**	1.33**	0.07**	0.01
SPY	0.41	49.67**s	259.41**	38.30**	13.40**	0.84

*, ** - significant at 5 and 1 % respectively

Table 3. Estimates of combining ability variances and contribution of lines, testers and interaction

Traits	GCA	SCA	SCA/ GCA	Degree of dominance	Proportion contributions (%)		
					Lines	Testers	Interaction
DFF	0.56	0.80	1.42	1.19	3.52	88.63	7.85
PH	21.22	52.40	2.47	1.57	57.23	32.96	9.8
NBP	0.15	0.76	4.96	2.23	64.14	18.6	17.26
NCP	106.99	256.95	2.40	1.55	75.91	15.14	8.96
CL	0.00	0.01	3.47	1.86	42.12	38.94	18.95
CW	0.00	0.00	0.00	0.00	36.68	10.73	52.59
NSC	1.03	5.49	5.30	2.30	2.81	73.1	24.1
DTM	1.34	10.79	8.03	2.83	4.28	72.76	22.96
TSW	0.01	0.02	1.81	1.35	16.25	76.07	7.68
SPY	0.89	33.40	37.54	6.13	61.45	22.68	15.87

seed yield and its contributing traits (11-13).

Contributions of combining ability variances

The contribution of lines was higher for the traits plant height, number of branches per plant, number of capsules per plant, capsule length and seed yield per plant. The testers' contribution showed higher for the traits such as days to 50 % flowering, capsule width, number of seeds per capsule, days to maturity and thousand seed weight. The line × tester interaction contributed more to capsule width alone. These results indicated that both lines and testers had more variability for their general combining ability effects for various traits. However, hybrids had more variation for their specific combining ability for capsule width only than the combining ability effects of the parents. Research indicated the significant at par results in previous studies (12, 14).

General combining ability

Good parents are necessary for the hybridization breeding program in order to create more variability. The average performance of a genotype in a set of hybrids is used to estimate the general combining ability (GCA). The GCA effects result from additive gene action and are fixable. Hence, it is used to choose the good parents (15). For earliness, negative GCA is ideal for days to 50 % flowering and days to maturity traits. Among the lines, IC 129607, IC204557 and VS19078 and the testers TMV 3 and TMV 7 had significant and positive *GCA* effects for seed yield per plant (Table 4). Hence, these genotypes can be considered as good combiners for seed yield per plant. Among these genotypes, line IC 129607 had good combining ability for plant height, number of branches per plant, number of capsules per plant, number of seeds per capsule and 1000-seed weight. The line IC204557 had good combining ability for days to 50 % flowering, plant height, number of capsules per plant, capsule length and days to maturity. The line VS19078 had good combining ability for the number of capsules per plant and 1000-seed weight. In the case of testers, TMV 3 had good combining ability for the number of capsules per plant, while TMV 7 had good combining ability for plant height, number of branches per plant, number of capsules per plant and 1000-seed weight. Hence, lines IC 129607, IC204557 and VS19078 and testers TMV 3 and TMV 7 could be used in hybridization programme to generate high genetic variability. Research indicates significant GCA effects in lines for plant height, number, number of capsules per plant and seed yield per plant (11, 16-18).

Mean performance of hybrids

The *per se* performance of hybrids is one of the important criteria for the selection of superior crosses (11). Among hybrids, seven hybrids, viz., TMV 3 × IC129607, TMV 3 × IC204557, TMV 3 × VS19078, TMV 7 × EC358033**,** TMV 7 × IC129607, TMV 7 × IC204557 and TMV 7 × VS19078 recorded superior mean performance for seed yield than the general mean (Table 5). Hybrids TMV 3 × IC129607, TMV 7 × EC358033, TMV 7 × IC129607, TMV 7 × IC204557 and TMV 7 × VS19078 recorded superior mean performance for five or more traits, especially for plant height, number of branches per plant and number of seeds per capsule. Hybrids, TMV 3 × IC204557, TMV 7 × IC204557 and TMV 7 × VS19078 showed superior performance for earliness in addition to the above traits. Hence, considering the superior performance for seed yield and other traits, hybrids TMV 3 × IC129607, TMV 7 × EC358033, TMV 7 × IC129607, TMV 7 × IC204557 and TMV 7 × VS19078 may be considered as superior. Research also indicated some superior hybrids based on the hybrids' *per se* performance.

Specific combining ability

Specific combining ability effects help the breeder to assess the nature of the gene involved in the particular cross. The specific combining ability effects are the deviation from the predicted value based on their parents' GCA effects (18). The non-significant and significant SCA effects indicate the presence of additive and epistatic effects, respectively. Hybrids with high mean performance, good combining parents and non-significant SCA effects for seed yield and component characters are desirable for a pedigree breeding programme (11). Due to the presence of additive gene action in these types of crosses,

Table 4. General combining ability (GCA) effect for various quantitative traits

Traits	DFF	PH	NBP	NCP	CL	CW	NSC	DTM	TSW	SPY
					Testers					
TMV 3	0.65 *	-6.92 **	0.04	11.34**	-0.05	0.02	-0.62	0.65	-0.07**	0.59 **
VRI 5	-0.67 *	-12.18 **	-1.65 **	-47.48 **	0.21 **	-0.05 *	1.12	-1.55 **	-0.16 **	-4.06 **
TMV 7	0.02	19.10 **	1.62 **	36.13 **	-0.16 **	0.04	-0.50	0.89 *	0.22 **	3.47 **
					Lines					
EC358033	-0.55	-0.37	0.69 **	-1.40	0.15 **	-0.02	3.70 **	1.97 **	0.09 **	0.41
EC346664	0.26	-12.49 **	-0.59 **	-23.30 **	-0.05	-0.01	0.68	-2.25 **	-0.34 **	-3.32 **
IC129607	2.93 **	19.13 **	1.02 **	3.85 **	0.09	0.03	4.83 **	2.71 **	0.25 **	1.55 **
IC204840	-3.64 **	-10.65 **	-1.11 **	-15.41 **	-0.11 *	-0.02	-2.99 *	-7.33 **	-0.31 **	-1.67 **
IC204557	-2.77 **	2.98 *	-0.07	20.96 **	0.16 **	0.03	0.95	-2.10 **	-0.30 **	1.15 **
VS19078	3.77 **	1.41	0.06	15.31 **	-0.25 **	-0.01	-7.17 **	7.01 **	0.61 **	1.88 **

*, ** - significant at 5 and 1 % respectively

Table 5. Mean performance of hybrids for various quantitative traits

Hybrids	DFF	PH	NBP	NCP	CL	CW	NSC	DTM	TSW	SPY
TMV 3 × EC358033	34.67	108.00	5.00	98.67	2.83	0.69	62.00	99.33	2.73	5.60
TMV 3 × EC346664	35.11	105.78	3.89	70.22	2.52	0.69	58.45	85.00	2.13	3.29
TMV 3 × IC129607	37.00	126.33	6.44	121.00	2.58	0.79	61.56	98.56	2.90	12.07
TMV 3 × IC204840	33.33	90.33	4.56	97.11	2.73	0.76	58.44	89.44	2.38	5.59
TMV 3 × IC204557	32.33	118.33	5.22	144.22	2.68	0.69	61.11	95.22	2.48	11.52
TMV 3 × VS19078	38.33	116.24	4.00	100.44	2.47	0.71	51.56	102.11	3.23	8.72
VRI 5 × EC358033	32.00	109.17	4.39	48.72	3.08	0.72	63.44	93.11	2.63	4.86
VRI 5 × EC346664	34.67	86.78	2.67	40.89	2.95	0.63	62.22	94.33	2.23	1.58
VRI 5 × IC 129607	37.67	132.78	2.56	50.22	3.12	0.68	65.33	95.67	2.63	2.58
VRI 5 × IC 2045840	29.50	104.00	2.33	31.33	2.57	0.61	52.33	84.67	2.40	2.85
VRI 5 × IC 204557	31.44	99.22	3.22	51.56	3.06	0.65	64.89	88.33	2.17	2.76
VRI 5 × VS19078	37.56	101.56	3.78	56.00	2.57	0.62	55.33	100.33	3.25	4.27
TMV 7 × EC358033	35.11	135.00	7.11	130.22	2.58	0.65	64.08	96.33	3.03	12.39
TMV 7 × EC346664	34.44	123.24	6.11	100.78	2.43	0.77	59.78	96.78	2.75	6.78
TMV 7 × IC129607	37.55	151.55	8.50	122.11	2.63	0.72	66.00	96.78	3.35	11.63
TMV 7 × IC204840	29.67	127.00	4.22	107.11	2.41	0.69	58.67	86.78	2.42	8.17
TMV 7 × IC204557	31.33	144.66	5.78	148.89	2.80	0.88	55.26	93.00	2.58	10.78
TMV 7 × VS19078	38.83	139.72	6.84	171.29	2.27	0.74	50.02	101.44	3.47	14.27
GMean	34.48	117.76	4.81	93.93	2.68	0.71	59.47	94.29	2.71	7.21
S.E.	0.61	2.29	0.32	2.05	0.10	0.05	2.07	0.96	0.05	0.53
C.D.(5 %)	1.74	6.52	0.92	5.83	0.27	0.14	5.87	2.74	0.14	1.50

selection can be practised in the early generation itself. The crosses with high mean, good GCA parents with significant SCA can also be utilised to evolve varieties. However, the selection should be postponed for generations till to attain homozygosity is attained to avoid biased selection due to the influence of non-additive gene action (16). Among the high-yielding hybrids, TMV 3 × VS19078, TMV 7 × IC129607 and TMV 7 × IC204557 had non-significant SCA for seed yield with good combining parents (Table 6). The cross TMV 7 × IC204557 also had non-significant SCA for days to 50 % flowering, number of branches per plant, number of capsules per plant, capsule length, days to maturity and 1000-seed weight. Hybrids TMV 3 × VS19078 and TMV 7 × IC129607 had non-significant SCA for days to 50 % flowering, plant height, capsule length, capsule width, number of seeds per capsule and days to maturity. Hence, these crosses can be used in a pedigree breeding programme. High-yielding hybrids, TMV 3 × IC129607, TMV 3 × IC204557 and TMV 7 × VS19078 had significant SCA for seed yield with good combining parents. All these hybrids had significant SCA for the number of capsules per plant. However, these hybrids had non-significant SCA for most of the other traits. Hence, these crosses can also be used for breeding programmes, but the selection needs to be postponed to the later generations. Research indicates the good specific combinations for the number of branches per plant, the number of capsules per plant and seed yield per plant (15, 19-22).

Conclusion

To conclude, the present study found a predominance of non-additive gene action for seed yield and other yield components. Among the lines IC 129607, IC204557 and VS19078 and the testers TMV 3 and TMV 7 had significant and positive GCA effects for seed yield per plant and component traits. Among hybrids, TMV 7 × IC204557 had high *per se* performance, significant GCA and non-significant SCA for seed yield per plant, number of capsules per plant and most of the other traits. Hence, this cross can be further advanced through pedigree breeding to obtain high-yielding segregants due to the presence of additive gene action. Hybrids, TMV 3 × VS19078, TMV 7 × IC129607, TMV 3 × IC129607, TMV 3 × IC204557 and TMV 7 × VS19078 had high *per se*, good combining parents but with significant SCA for seed yield or number of capsules per plant and other component

Table 6. Specific combining ability effects (SCA) of crosses for various quantitative traits

Crosses	DFF	PH	NBP	NCP	CL	CW	NSC	DTM	TSW	SPY
TMV 3 × EC358033	0.09	-2.46	-0.54	-5.21 *	0.05	-0.01	-0.55	2.42 *	-0.00	-2.61 **
TMV 3 × EC346664	-0.28	7.44 **	-0.37	-11.75 **	-0.07	-0.02	-1.08	-7.69 **	-0.17 **	-1.19 *
TMV 3 × IC129607	-1.06	-3.63	0.57	11.88 **	-0.15	0.04	-2.12	0.90	0.00	2.71 **
TMV 3 × IC204840	1.85 **	-9.85 **	0.81 *	7.25 **	0.21 *	0.05	2.58	1.83	0.05	-0.54
TMV 3 × IC204557	-0.02	4.52	0.44	17.99 **	-0.12	-0.07	1.31	2.38 *	0.14 **	2.58 **
TMV 3 × VS19078	-0.56	3.99	-0.91 **	-20.15 **	0.08	0.01	-0.13	0.16	-0.02	-0.96
VRI 5 × EC358033	-1.26 *	3.95	0.54	3.66	0.04	0.08	-0.85	-1.60	-0.01	1.30 *
VRI 5 × EC346664	0.60	-6.31 **	0.10	17.74 **	0.10	-0.01	0.95	3.85 **	0.02	1.75 **
VRI 5 × IC 129607	0.93	8.07 **	-1.62 **	-0.08	0.14	0.01	-0.08	0.22	-0.17 **	-2.12 **
VRI 5 × IC 2045840	-0.66	9.07 **	0.28	0.29	-0.21 *	-0.02	-5.27 *	-0.75	0.16 **	1.37 *
VRI 5 × IC 204557	0.41	-9.34 **	0.14	-15.85 **	0.00	-0.04	3.35	-2.30 *	-0.09	-1.54 **
VRI 5 × VS19078	-0.01	-5.44 *	0.56	-5.77 **	-0.07	-0.02	1.91	0.59	0.09	-0.76
TMV 7 × EC358033	1.17	-1.49	-0.00	1.55	-0.09	-0.07	1.41	-0.82	0.01	1.31 *
TMV 7 × EC346664	-0.31	-1.13	0.27	-5.99 **	-0.04	0.04	0.13	3.85 **	0.15 **	-0.57
TMV 7 × IC129607	0.13	-4.44	1.05 **	-11.80 **	0.01	-0.05	2.21	-1.12	0.17 **	-0.59
TMV 7 × IC204840	-1.18	0.79	-1.10 **	-7.54 **	0.00	-0.03	2.69	-1.08	-0.21 **	-0.83
TMV 7 × IC204557	-0.39	4.82 *	-0.58	-2.13	0.12	0.10 *	-4.66 *	-0.08	-0.05	-1.04
TMV 7 × VS19078	0.58	1.45	0.35	25.91 **	-0.00	0.01	-1.78	-0.75	-0.07	1.72 **

*, ** - significant at 5 and 1 % respectively

traits. Hence, selection should be postponed for generations in these crosses due to the presence of non-additive gene action.

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Authors' contributions

SKR drafted the manuscript. MN and MA supervised and worked on the manuscript. SK, SRG and JM were involved in planning and provided critical feedback on the manuscript. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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