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Analysis of Combining Ability Variance and Their Effects for Yield and Its Contributory Traits in Progenitors and Offsprings of Greengram (*Vigna radiata* L. Wilczek)

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Authors' contributions

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

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ABSTRACT

The current investigation was conducted at the Student Instruction Farm of Chandra Shekhar Azad University of Agriculture and Technology Kanpur, encompassing a genetically diverse nineteen greengram genotypes (comprising 16 lines and 3 testers). These genotypes were crossed in a line x tester fashion during the *kharif* season of 2021, resulting in the production of 48 F_1 hybrids. Analysis of variance revealed that the mean sum of squares attributed to genotypes or treatments was highly significant for all traits in F_1 generation, except for the number of branches per plant, indicating limited variability among genotypes for this particular trait. The analysis of variance for combining ability unveiled highly significant disparities for all traits, excluding the number of branches per plant. There was a pronounced variance due to general combining ability (GCA) for traits such as days to 50% flowering, days to maturity, plant height, number of branches per plant, number of clusters per plant, number of pods per plant, and number of seeds per pod, suggesting the predominance of additive gene action for these characteristics. Conversely, for traits such as pod length, 100-seed weight, biological yield, harvest index, protein content, and seed yield per plant, the variance due to specific combining ability (SCA) was more substantial in magnitude. The level of dominance exhibited over dominance for traits including the number of branches per plant, number of clusters per plant, number of pods per plant, pod length, 100-seed weight, biological yield, harvest index, protein content, and seed yield per plant. Partial dominance was observed for traits like days to 50% flowering, days to maturity, plant height, and number of seeds per pod. Specific parental lines, namely SML664, HUM12, KM2426, KM2427, and KM2404, displayed desirable GCA effects and superior individual performances for seed yield per plant. These lines hold promise for utilization as parental components in breeding programs aimed at enhancing seed yield. Furthermore, cross combinations such as KM2403 X KM2241, KM2408 X KM2241, KM2399 X K851, KM2404 X K851, and SML681 X KM2241 exhibited favourable SCA effects for seed yield per plant along with superior individual performances. These combinations can be further exploited in selection schemes to obtain desirable transgressive segregants in subsequent generations.

Keywords: Combining ability; GCA; SCA; greengram.

1. INTRODUCTION

The greengram (*Vigna radiata*), a fundamental legume in India, assumes a central role in the nation's agricultural panorama due to its multifaceted significance. As a prominent pulse crop, greengrams contribute significantly to India's agricultural fabric, fostering food security and sustaining the livelihoods of myriad farmers. With an extensive geographical spread, greengram cultivation spans various agro-climatic zones in India, each presenting unique challenges and opportunities. Greengrams continue to be a cornerstone of global agriculture, with impressive statistics highlighting their prevalence and nutritional significance. The cultivated area for greengrams spans a substantial expanse worldwide, with key contributors being Asian nations such as India, China, and Myanmar. These regions collectively contribute to a significant portion of the global greengram production. In terms of production, greengrams exhibit a robust output, with millions of metric tons harvested annually. China remains a leading producer, followed closely by India, where the crop holds paramount importance in the agricultural spectrum. India produces about 2.62 million tonnes of greengrams annually from approximately 4.74 million hectares of land, with an average productivity of 553 kg/ha. The major cultivating states in India are Madhya Pradesh, Rajasthan, Uttar Pradesh, Maharashtra, Andhra Pradesh, and Tamil Nadu [1-7]. It covers an area of 83 thousand hectares in Uttar Pradesh, with a total production of 54.50 thousand tonnes and an average productivity of 656 kg/ha (Directorate of Economics and Statistics, 2022-23). The productivity of greengrams varies across regions, with advancements in agricultural practices and technology influencing yield levels. From a nutritional perspective, greengrams are highly esteemed for their health-promoting qualities. Packed with protein, fibre, vitamins, and minerals, they offer a nutritious complement to diets worldwide [8-13]. Their low-fat content, coupled with essential amino acids, renders them a valuable component for balanced nutrition. Per capita availability of pulses declined from 60.7 g/day in 1951 to 35.5 g/day in 2007 against the FAO/WHO recommendation of 80 g/day

(Economic Survey, 2008-09). In this context, the production potential of the greengram crop can be enhanced by developing high yielding genotypes through a planned hybridization program [14-17].

In India, the proliferation of numerous enhanced varieties that have bolstered agricultural production suggests that there is still abundant potential to enhance the yield capacity of cultivars through genetic refinement of the parent stock. The selection of a breeding method for yield improvement is contingent upon the nature of gene effects influencing quantitative traits. While Line x Tester analysis aids in the selection of parents based on their combining ability, it falls short in identifying epistasis—a formidable and intricate challenge for which obtaining reliable and precise results proves exceedingly challenging. Hence, acquiring information about the type of gene action governing the inheritance of various quantitative traits assumes paramount importance in devising an apt breeding program for trait improvement [18-24]. The scrutiny of intermediate generations, as proposed by Hayman (1958), furnishes a comprehensive insight into the properties controlling gene activity [25-31]. The presence or absence of epistasis can be discerned through an analysis of generational means, utilizing a scaling test that precisely measures epistasis, whether complementary (additive x additive) or duplicated (additive x dominance and dominance x dominance) at the digenic level. This method, a relatively uncomplicated first-order statistically analyzed technique, facilitates an understanding of the predominant genetic action responsible for effective variations in traits.

2. MATERIALS AND METHODS

Sixteen lines KM2399, KM2401, KM2403, KM2404, KM2408, KM2409, KM2414, KM2417, SML664, SML681, IP-7, IPM302, HUM12, KM2290, KM2426 and KM2427 were crossed with three testers K851, PDM139 and KM2241 in line x tester mating design to obtain 48 F_1s at Oilseed Research farm, C. S. Azad University of Agriculture and Technology, Kanpur during *kharif* 2021. All the genotypes (19 parents and 48 F_1s) were evaluated in randomized block design with three replications during in *kharif* 2022 at Student Instruction Farm, C. S. Azad University of Agriculture and Technology, Kanpur. Each genotype was grown within the plot size of 4m x 1.8m with row length of 4m with a spacing of 30cm between rows and 10cm between plants. Recommended agronomic and plant protection package of practices were followed to raise healthy crop [32-38]. Data were recorded on five randomly selected competitive plants in each genotype and replication. Mean values on per plant basis were recorded for the characters *viz*, Days to 50% flowering, Days to maturity, Plant height (cm), Number of branches per plant, Number of clusters per plant, Number of pods per plant, Pod length (cm), Number of seeds per pod, 100-seed weight (g), Biological yield (g), Harvest index (%), Seed yield per plant (g) and Protein content (%).The mean data was analysed to compute combining ability effect and their variances according to Kempthorne [39].

3. RESULTS AND DISCUSSION

Analysis of variance for combining ability (Table 1) showed highly significant difference for all the characters except number of branches per plant. The mean square of treatment was further portioned into two components, viz., parents and crosses. The mean sum of squares due to parents exhibited highly significant differences for all the crosses except number of branches per plant. The mean sum of squares due to crosses also exhibited highly significant differences for all the characters under study except number of branches per plant. The mean sum of squares due to crosses were partitioned into line effects, tester effects and line x tester effects. The line effect shows highly significant differences for all the crosses except number of branches, pod length, 100 seed weight, biological yield and harvest index. The tester effect shows significant difference for only days to 50% flowering. The variation due to line x tester were highly significant for pod length, 100 seed weight, biological yield, harvest index, protein content and seed yield per plant. The findings are in the conformity with the results of Gawande et al. [40], Kumar et al. [41] and Jayaprada et al. [42].

The higher magnitude of variance due to GCA for days to 50% flowering, days to maturity, plant height, number of branches per plant, number of clusters per plant, number of pods per plant and number of seeds per pod indicating the preponderance of additive gene action for these characters (Table 2). For pod length, 100 seed weight, biological yield, harvest index, protein content and seed yield per plant, variances due to sca was higher in magnitude. The degree of dominance exhibited over dominance for number of branches per plant, number of clusters per plant, number of pods per plant, pod length, 100 seed weight,

Table 1. Analysis of variance for combining ability in Line x Tester mating design for thirteen characters in greengram

Source of Variation	df	Days to 50% Flowering	Days to Maturity	Plant Height (cm)	Number of Branches Per Plant	Number of Clusters Per Plant	Number of Pods Per Plant	Pod Length (cm)	Number of Seeds Per Pod	100-Seed Weight (g)	Biological Yield (g)	Harvest Index (%)	Seed protein Content (%)	Seed yield Per Plant (g)
Replicates	2	6.27*	3.9	20.791**	0.662	0.75	17.75**	0.004	0.84	0.09	0.001	4.32	0.18	0.001
Treatments	66	15.21**	13.63**	37.45**	0.272	2.61**	12.37**	0.55**	5.52**	57.25**	60.80**	473.39**	2.91***	4.74**
Parents	18	20.27**	15.12**	38.86**	0.421	4.05**	17.38**	0.51**	5.32**	0.89**	111.06**	514.12**	3.45***	5.49**
Parents (Line)	15	16.57**	9.93**	38.66**	0.289	1.38	7.59**	0.39*	5.91**	0.94**	42.30**	584.23**	1.43**	4.69**
Parents (Testers)	2	0.44	0.33	1.44	0.333	0.11	2.11	0.19	0.11	0.62**	345.87**	205.34**	2.50**	0.12
Parents (L vs T)	1	115.44**	122.53**	116.67**	2.579**	51.94**	194.77**	2.89**	7.06	0.66**	672.89**	79.90**	35.74**	28.23**
Parents vs Crosses	1	158.54**	178.92**	204.45**	1.35*	25.83**	81.36**	6.51**	10.47*	37.37***	28.01**	333.36**	24.42**	41.95**
Crosses	47	10.22**	9.54**	33.36**	0.191	1.56**	8.99**	0.45**	5.49**	79.26***	42.25**	460.78**	2.24**	3.67**
Line Effect	15	28.21**	25.61**	102.41**	0.125	3.91**	26.20**	0.52	11.93**	84.48	33.39	453.46	5.22**	6.52**
Tester Effect	2	7.14*	4.64	2.38	0.507	1.25	2.50	0.12	5.39	83.75	46.81	526.52	0.97	3.01
Line x Tester Eff.	30	1.43	1.83	0.90	0.203	0.41	0.81	0.43**	2.28	76.35**	46.38**	460.06**	0.84**	2.28**
Error	132	1.63	2.59	3.26	0.258	0.86	2.89	0.21	2.33	0.08	0.34	2.55	0.51	0.05
Total	**200**	**6.16**	**6.25**	**14.7**	**0.266**	**1.44**	**6.17**	**0.32**	**3.37**	**18.95**	**20.29**	**157.95**	**1.30**	**1.60**

**5% level of significance, ** 1% level of significance*

Table 2. Estimates of components of variance, its ratio [σ^2sca / σ^2GCA] and degree of dominance [(σ^2sca/ σ^2GCA)$^{0.5}$]

	Days to 50% Flowering	Days to Maturity	Plant Height (cm)	Number of Branches Per Plant	Number of Clusters Per Plant	Number of Pods Per Plant	Pod Length (cm)	Number of Seeds Per Pod	100-Seed Weight (g)	Biological Yield (g)	Harvest Index (%)	Seed Protein Content (%)	Seed Yield Per Plant (g)
σ^2GCA	0.56	0.44	1.72	0.002	0.06	0.40	0.004	0.22	2.94	1.39	17.10	0.09	0.16
σ^2sca	-0.06	-0.25	-0.78	-0.01	-0.15	-0.69	0.07	-0.01	25.42	15.34	152.50	0.10	0.74
σ^2sca/ σ^2GCA	-0.10	-0.56	-0.45	-5	-2.5	-1.72	17.5	-0.045	8.64	7.94	8.91	1.11	4.62
(σ^2sca/ σ^2GCA)$^{0.5}$	0.31	0.74	0.67	2.23	1.5	1.31	4.18	0.21	2.93	2.81	2.98	1.05	2.14
σ^2A/ σ^2D	-16.67	-3.47	-4.38	-0.22	-0.79	-1.16	0.10	-29.01	0.23	0.18	0.22	1.67	0.44

Table 3. Estimates of general combining ability effects and mean of parents for thirteen characters in greengram

Parents Characters	Days to 50% Flowering		Days to maturity		Plant Height (cm)		Number of Branches Per Plant		Number of Clusters Per Plant		Number of Pods Per Plant		Pod Length (cm)	
	GCA Effects	Mean	GCA Effects	Mean	GCA Effects	Mean	GCA Effects	Mean	GCA Effects	Mean	GCA Effects	Mean	GCA Effects	Mean
KM2399	-1.74**	37.00	-0.63	64.66	2.43**	37.66	-0.10	2.00	1.00**	7.00	0.20	23.33	0.07	4.36
KM2401	-0.07	38.33	0.70	66.66	1.87**	37.33	0.22	2.33	0.22	6.66	-1.68**	22.33	0.22	4.53
KM2403	-1.18 **	36.33	-3.96**	61.33	2.20**	38.00	-0.10	3.00	-1.44**	5.66	2.20**	25.66	0.05	4.63
KM2404	-0.41	38.00	1.14*	66.66	-4.56**	30.66	-0.21	2.66	0.77*	7.66	3.76**	27.00	0.13	5.00
KM2408	0.59	39.00	1.59**	67.33	-4.68**	31.00	0.11**	2.00	-0.44	6.00	-1.12	23.66	0.10	4.26
KM2409	-1.52**	36.33	1.14*	66.33	-4.23**	31.66	-0.10	2.66	0.22	7.00	-2.01**	22.66	0.19	4.83
KM2414	1.36**	40.00	2.25**	68.00	-4.68**	30.66	0.007	2.33	-0.77*	5.66	-2.90**	21.00	0.34*	4.23
KM2417	1.70**	39.66	-0.29	66.00	4.54**	43.66	0.007	2.33	0.33	7.00	0.20	24.66	-0.22	5.26
SML664	-1.63**	35.66	0.03	65.00	-0.68	35.00	0.11	2.66	0.00	7.33	0.76	23.66	-0.16	5.06
SML681	3.03**	41.66	-0.18	65.33	5.98**	39.33	0.11	2.33	-1.00**	5.66	-0.23	25.33	0.32*	4.43
IP-7	-1.29**	37.33	0.03	66.66	2.09**	37.33	-0.10	2.33	0.22	6.66	0.87	25.00	-0.09	5.20
IPM302	-2.18**	33.66	-2.85**	62.33	0.87	36.33	0.007	2.33	-0.44	6.33	1.43*	25.33	0.13	5.06
HUM12	0.59	40.33	1.59**	67.33	-1.68**	33.00	0.11	3.00	0.22	7.00	0.31	23.66	-0.58	5.16
KM2290	-1.96**	36.00	1.25*	67.00	1.20*	36.33	0.007	2.00	0.44	7.00	-1.79**	21.66	-0.48**	4.50
KM2426	3.14**	42.33	0.03	65.33	1.54*	36.66	-0.10	2.33	0.55	7.66	-0.79	23.33	-0.39*	4.60
KM2427	1.59**	39.66	-1.85**	64.33	-2.36	33.66	0.007	2.33	0.11	7.33	0.76	25.00	-0.15	5.16
SE (gi) lines (±)	0.42		0.53		0.60		0.16		0.31		0.56		0.15	
K851	0.04*	41.66	0.22	70.00	0.13	39.66	-0.11	3.33	-0.13	4.00	-0.13	19.00	-0.002	5.56
PDM139	-0.14	42.33	0.12	69.33	0.11	38.66	0.04	3.00	0.18	4.00	0.26	19.66	0.05	5.10
KM2241	-0.29	42.33	-0.35	69.66	-0.25	40.00	0.06**	2.66	-0.04	4.33	-0.13	18.00	-0.05	5.50
SE (gi) testers (±)	0.18		0.23		0.26		0.07		0.13		0.24		0.06	

**5% level of significance, ** 1% level of significance*

Parents Characters	Number of Seeds Per Pod		100-Seed Weight (g)		Biological Yield (g)		Harvest Index (%)		Seed Protein Content (%)		Seed Yield Per Plant (g)	
	GCA Effects	Mean	GCA Effects	Mean	GCA Effects	Mean	GCA Effects	Mean	GCA Effects	Mean	GCA Effects	Mean
KM2399	2.12**	7.00	11.42**	4.01	0.71**	21.88	-1.23*	23.28	-0.53*	22.11	0.36**	5.25
KM2401	1.45**	5.66	-0.79**	3.13	0.20	11.49	1.31*	33.99	0.53*	22.04	0.61**	4.15
KM2403	0.56	10.00	-0.83**	2.90	-2.07**	16.16	-4.26**	37.96	0.69**	23.12	-1.33**	6.07
KM2404	-0.65	9.33	-0.81**	3.33	-0.80**	15.81	7.10**	42.35	-0.79**	21.24	0.53**	6.63
KM2408	0.56	9.00	-1.10**	2.91	-0.73**	9.14	-3.48**	76.39	-0.53*	22.24	-0.83**	6.76

Parents Characters	Number of Seeds Per Pod		100-Seed Weight (g)		Biological Yield (g)		Harvest Index (%)		Seed Protein Content (%)		Seed Yield Per Plant (g)	
KM2409	-0.09	7.33	-0.34**	3.61	-0.27	11.83	3.21**	35.32	-0.05	22.86	0.32**	4.26
KM2414	1.34**	9.33	-1.14**	3.36	2.51**	12.79	-16.67**	44.38	0.22	22.32	-1.86**	5.85
KM2417	-0.98	8.00	-1.04**	3.20	-1.87**	14.18	2.14**	42.40	0.76**	22.61	-0.32**	5.89
SML664	0.23	7.00	-0.38	4.14	-3.52**	21.22	16.22**	32.35	1.21**	23.81	0.80**	7.22
SML681	-1.87**	5.00	-0.32**	4.17	-0.04	14.71	-3.82**	21.68	1.43**	22.89	-0.66**	3.43
IP-7	0.56	7.00	-0.44**	3.70	4.23**	15.99	-5.63**	35.51	-0.56	22.04	1.07**	6.1
IPM302	-2.09**	9.66	-0.33**	3.84	0.78**	17.41	6.81**	44.28	0.13	22.79	0.61**	7.79
HUM12	-0.31	7.33	-1.06**	4.13	2.11**	19.07	-3.44**	36.24	-1.17**	21.48	0.35**	7.12
KM2290	0.34	8.00	-1.37**	4.16	-1.46**	19.83	0.86	34.34	-0.79**	22.42	-0.73**	7.17
KM2426	-0.31	7.66	-0.64**	4.99	1.12**	11.33	-1.71**	65.07	-0.57*	21.37	0.70**	6.93
KM2427	-0.87	8.33	-0.78**	3.74	-0.90**	13.19	2.58**	51.66	-0.02	21.71	0.35**	6.88
SE (gi) lines (±)	0.50		0.09		0.19		0.53		0.24		0.07	
K851	-0.31	6.66	-0.77**	3.589	-0.16	36.2934	-0.97**	41.1642	0.15	19.404	-0.23**	4.257
PDM139	0.35	7.00	1.52**	2.8975	-0.89**	23.0967	3.69**	43.9239	-0.11	19.872	0.26**	3.936
KM2241	-0.04	7.00	-0.75**	3.762	1.05**	15.0234	-2.71**	28.4149	-0.04	21.168	-0.03	4.312
SE (gi) testers (±)	0.22		0.04		0.08		0.23		0.10		0.03	

**5% level of significance, ** 1% level of significance*

Table 4. Estimates of specific combining ability effects and mean of crosses for thirteen characters in greengram

Crosses	Days to 50% Flowering		Days to Maturity		Plant Height (cm)		Number of Branches Per Plant		Number of Clusters Per Plant		Number of Pods Per Plant		Pod Length (cm)	
	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean
KM2399 X K851	-0.54	35.00	-0.11	63.66	-0.47	36.00	-0.10	2.00	0.02	8.00	0.02	24.66	-0.27	4.26
KM2399 X PDM139	0.03	35.00	0.65	64.33	0.21	36.66	0.06	2.33	0.04	8.33	0.29	25.33	-0.16	4.43
KM2399 X KM2241	0.51	35.33	-0.53	62.66	0.25	36.33	0.04	2.33	-0.06	8.00	-0.31	24.33	0.43	4.93
KM2401 X K851	0.11	37.33	0.21	65.33	-0.25	35.66	-0.10	2.33	-0.20	7.00	-0.09	22.66	-0.25	4.43
KM2401 X PDM139	0.03	36.66	-0.01	65.00	-0.56	35.33	-0.27	2.33	0.15	7.66	0.51	23.66	0.49	5.23
KM2401 X KM2241	-0.15	36.33	-0.20	64.33	0.81	36.33	0.37	3.00	0.04	7.33	-0.42	22.33	-0.23	4.40
KM2403 X K851	-0.10	36.00	-0.45	60.00	0.41	36.66	-0.10	2.00	-0.20	5.33	-0.31	26.33	0.18	4.70
KM2403 X PDM139	-0.85	34.66	-0.01	60.33	-0.22	36.00	0.39	2.66	-0.18	5.66	0.29	27.33	0.25	4.83
KM2403 X KM2241	0.95	36.33	0.46	60.33	-0.18	35.66	-0.29	2.00	0.38	6.00	0.021	26.66	-0.43	4.03
KM2404 X K851	-0.21	36.66	-0.56	65.00	-0.47	29.00	0.007	2.00	-0.09	7.66	-0.53	27.66	-0.59**	4.00
KM2404 X PDM139	1.03	37.33	0.87	66.33	0.21	29.66	0.17	2.33	-0.40	7.66	-0.26	28.33	0.11	4.76
KM2404 X KM2241	-0.81	35.33	-0.31	64.66	0.25	29.33	-0.18	2.00	0.49	8.33	0.79	29.00	0.48	5.03

Crosses	Days to 50% Flowering		Days to Maturity		Plant Height (cm)		Number of Branches Per Plant		Number of Clusters Per Plant		Number of Pods Per Plant		Pod Length (cm)	
	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean
KM2408 X K851	0.78	38.66	0.32	66.33	-0.02	29.33	0.007	2.33	0.46	7.00	0.68	24.00	-0.34	4.23
KM2408 X PDM139	-0.96	36.33	0.09	66.00	0.32	29.66	-0.1	2.33	-0.51	6.33	-0.37	23.33	0.17	4.80
KM2408 X KM2241	0.18	37.33	-0.42	65.00	-0.29	28.66	0.15	2.66	0.04	6.66	-0.31	23.00	0.17	4.70
KM2409 X K851	-0.10	35.66	-0.56	65.00	0.19	30.00	-0.10	2.00	0.13	7.33	0.57	23.00	0.43	5.10

Crosses	Number of Seeds Per Pod		100-Seed Weight (g)		Biological Yield (g)		Harvest Index (%)		Seed Protein Content (%)		Seed Yield Per Plant (g)	
	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean
KM2399 X K851	0.31	10.33	-10.99**	4.28	3.44**	20.04	-1.68	39.53	0.85*	23.23	1.06*	8.00
KM2399 X PDM139	0.64	11.33	21.79**	3.94	-1.29**	14.56	4.61**	50.50	-0.80	21.30	0.30*	7.74
KM2399 X KM2241	-0.95	9.33	-10.80**	4.49	-2.15**	15.66	-2.93**	36.55	-0.05	22.12	-1.36**	5.78
KM2401 X K851	-0.68	8.67	0.97**	4.03	-2.03**	14.04	7.15**	50.91	0.05	23.50	0.10	7.30
KM2401 X PDM139	0.31	10.33	-1.32**	4.03	0.97**	16.33	1.75	50.18	0.66	23.84	0.25**	8.45
KM2401 X KM2241	0.37	10.00	0.35*	3.43	1.06**	18.36	-8.90**	33.12	-0.72	22.52	-0.86**	6.53
KM2403 X K851	-0.13	8.33	0.59**	3.61	-3.25**	10.55	2.27*	40.45	0.64	24.24	-1.01**	4.22
KM2403 X PDM139	-0.46	8.67	-1.52**	3.79	-0.23	12.84	-7.00**	35.84	-0.18	23.14	-0.79**	4.95
KM2403 X KM2241	0.59	9.33	0.92**	3.96	3.48**	18.51	4.73**	41.18	-0.45	22.94	1.80**	7.25
KM2404 X K851	-0.24	7.00	1.02**	4.07	4.85**	19.92	-10.67**	38.89	-0.13	21.98	0.87**	7.99
KM2404 X PDM139	0.75	8.67	-0.96**	4.38	-3.57**	10.76	21.54**	75.77	-0.27	21.56	0.71**	8.33
KM2404 X KM2241	-0.51	7.00	-0.06**	2.99	-1.27**	15.02	-10.87**	36.95	0.41	22.32	-1.59**	5.72
KM2408 X K851	-0.46	8.00	0.45**	3.20	1.34**	16.49	-5.19**	33.77	-0.71	21.66	-0.16	5.57
KM2408 X PDM139	-0.79	8.33	-1.57**	3.47	2.74**	17.16	-13.09**	30.54	0.57	22.67	-0.99**	5.24
KM2408 X KM2241	1.26	10.00	1.12**	3.90	-4.08**	12.28	18.29**	55.53	0.14	22.31	1.16**	7.10
KM2409 X K851	-0.79	7.00	0.85**	4.36	-3.39**	12.21	13.34**	59.00	-0.21	22.64	0.22	7.13

Crosses	Days to 50% flowering		Days to Maturity		Plant Height (cm)		Number of Branches Per Plant		Number of Clusters Per Plant		Number of Pods Per Plant		Pod Length (cm)	
	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean
KM2409 X PDM139	-0.52	34.66	0.20	65.66	-0.11	29.67	0.06	2.33	0.48	8.00	-0.48	22.33	-0.08	4.63
KM2409 X KM2241	0.62	35.66	0.35	65.33	-0.07	29.33	0.04	2.33	-0.61	6.67	-0.09	22.33	-0.35	4.27
KM2414 X K851	0.34	39.00	-1.67	65.00	-0.36	29.00	0.11	2.33	-0.20	6.00	0.13	21.67	-0.04	4.77
KM2414 X PDM139	-0.07	38.00	0.76	67.33	-0.007	29.33	0.28	2.67	0.15	6.67	-0.26	21.67	-0.13	4.73
KM2414 X KM2241	-0.26	37.66	0.91	67.00	0.36	29.33	-0.40	2.00	0.04	6.33	0.13	21.67	0.17	4.93
KM2417 X K851	0.67	39.66	1.88*	66.00	-0.58	38.00	-0.21	2.00	0.02	7.33	0.02	24.67	0.02	4.27
KM2417 X PDM139	-0.07	38.33	-1.34	62.66	-0.22	38.33	-0.04	2.33	0.04	7.67	0.29	25.33	-0.23	4.07
KM2417 X KM2241	-0.59	37.66	-0.53	63.00	0.81	39.00	0.26	2.67	-0.06	7.33	-0.31	24.33	0.20	4.40
SML664 X K851	-0.66	35.00	-0.11	64.33	0.63	34.00	-0.32**	2.00	0.68	7.67	-0.20	25.00	-0.29	4.00
SML664 X PDM139	0.59	35.67	-0.01	64.33	-0.34	33.00	0.17	2.67	0.04	7.33	0.06	25.67	-0.11	4.23
SML664 X KM2241	0.06	35.00	0.13	64.00	-0.29	32.67	0.15	2.67	-0.72	6.33	0.13	25.33	0.41	4.67
SML681 X K851	-0.66	39.67	0.43	64.67	1.30	41.33	0.007	2.33	-0.31	5.67	-0.86	23.33	0.04	4.83
SML681 X PDM139	-0.07	39.67	0.54	64.67	-0.34	39.67	-0.16	2.33	-0.29	6.00	0.06	24.67	-0.008	4.83
SML681 X KM2241	0.73	40.33	-0.97	62.67	-0.96	38.67	0.15	2.67	0.60	6.67	0.79	25.00	-0.03	4.70
IP-7 X K851	-0.66	35.33	0.88	65.33	-0.13	36.00	0.56	2.67	-0.20	7.00	0.02	25.33	-0.009	4.37
IP-7 X PDM139	0.92	36.33	-1.01	63.33	0.54	36.67	-0.27	2.00	0.15	7.67	0.29	26.00	-0.16	4.27
IP-7 X KM2241	-0.26	35.00	0.13	64.00	-0.41	35.33	-0.29	2.00	0.04	7.33	-0.31	25.00	0.17	4.50

Crosses	Number Of Seeds Per Pod		100-Seed Weight (g)		Biological Yield (g)		Harvest Index (%)		Seed Protein Content (%)		Seed Yield Per Plant (g)	
	SCA effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean
KM2409 X PDM139	0.86	9.33	-1.82**	3.98	-0.35	14.51	0.31	50.65	-0.25	22.33	0.106	7.50
KM2409 X KM2241	-0.06	8.00	0.96**	4.49	3.75**	20.58	-13.66**	30.26	0.47	23.13	-0.33*	6.76
KM2414 X K851	-0.57	8.67	1.23**	3.94	2.14**	20.53	-1.43	24.33	0.23	23.36	0.23	4.95
KM2414 X PDM139	0.75	10.67	-1.55**	3.45	0.48	18.15	-1.63	28.81	0.32	23.18	0.12	5.34
KM2414 X KM2241	-0.18	9.33	0.31	3.04	-2.63**	16.98	3.06**	27.10	-0.55	22.37	-0.35**	4.56
KM2417 X K851	0.75	7.67	0.40*	3.21	3.72**	17.73	-14.75**	29.84	0.08	23.76	-0.51**	5.74
KM2417 X PDM139	0.42	8.00	-1.45**	3.65	0.62	13.90	-4.65**	44.61	-0.50	22.90	-0.08	6.66
KM2417 X KM2241	-1.18	6.00	1.05**	3.88	-4.35**	10.88	19.41**	62.28	0.42	23.90	0.60**	7.06
SML664 X K851	0.20	8.33	0.33	3.79	-2.00**	10.34	8.65**	67.34	-0.11	24.01	0.01	7.40
SML664 X PDM139	-0.46	8.33	-1.50**	4.26	1.36**	12.98	-3.19**	60.15	0.16	24.01	0.17	8.05
SML664 X KM2241	0.26	8.67	1.17**	4.65	0.64	14.22	-5.46**	51.47	-0.05	23.86	-0.19	7.39
SML681 X K851	0.31	6.33	0.82**	4.35	-4.52**	11.31	7.48**	46.11	0.15	24.50	-0.52**	5.38

Crosses	Number Of Seeds Per Pod		100-Seed Weight (g)		Biological Yield (g)		Harvest Index (%)		Seed Protein Content (%)		Seed Yield Per Plant (g)	
	SCA effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean
SML681 X PDM139	-0.02	6.67	-1.41**	4.41	1.53**	16.64	-7.10**	36.19	0.57	24.64	-0.32*	6.08
SML681 X KM2241	-0.29	6.00	0.59**	4.14	2.99**	20.05	-0.38	36.51	-0.72	23.42	0.85**	6.96
IP-7 X K851	0.86	9.33	1.10**	4.51	-2.96**	17.16	6.95**	43.76	-0.67	21.67	0.25	7.90
IP-7 X PDM139	-0.13	9.00	-1.63**	4.07	2.05**	21.44	-4.47**	37.01	0.62	22.70	-0.04	8.10
IP-7 X KM2241	-0.73	8.00	0.53**	3.96	0.90**	22.24	-2.48**	32.59	0.04	22.18	-0.21	7.63

Crosses	Days to 50% Flowering		Days to Maturity		Plant Height (cm)		Number of Branches Per Plant		Number of Clusters Per Plant		Number of Pods Per Plant		Pod Length (cm)	
	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean
IPM302 X K851	-0.77	34.33	-0.56	61.00	0.083	35.00	0.11	2.33	-0.20	6.33	-0.20	25.67	0.30	4.90
IPM302 X PDM139	0.81	35.33	-0.12**	61.33	0.104	35.00	-0.04	2.33	0.15	7.00	-0.26	26.00	-0.35	4.30
IPM302 X KM2241	-0.04	34.33	0.68	61.67	-0.18	34.33	-0.06	2.33	0.04	6.67	0.46	26.33	0.05	4.60
HUM12 X K851	1.11	39.00	0.32	66.33	-0.36	32.00	0.007	2.33	0.13	7.33	-0.42	24.33	0.05	4.47
HUM12 X PDM139	-0.29	37.00	0.09	66.00	0.66	33.00	0.17	2.67	0.15	7.67	-0.15	25.00	-0.03	4.43
HUM12 X KM2241	-0.81	36.33	-0.42	65.00	-0.29	31.67	-0.18	2.33	-0.28	7.00	0.57	25.33	-0.02	4.33
KM2290 X K851	0.007	35.33	-0.34	65.33	-0.25	35.00	-0.21	2.00	0.24	7.67	0.02	22.67	0.68*	4.67
KM2290 X PDM139	-0.07	34.67	-0.23	65.33	0.10	35.33	-0.04	2.33	-0.06	7.67	0.29	23.33	0.268	4.30
KM2290 X KM2241	0.06**	34.67	0.57	65.67	0.14	35.00	0.26	2.67	-0.17	7.33	-0.31	22.33	-0.95**	2.97
KM2426 X K851	0.56	41.00	-0.11	64.33	0.08	35.67	0.22	2.33	0.13	7.67	0.02	23.67	0.22	4.30
KM2426 X PDM139	-0.18	39.67	-0.01	64.33	-0.56	35.00	-0.27	2.00	-0.18	7.67	-0.04	24.00	0.004	4.13
KM2426 X KM2241	-0.37	39.33	0.13	64.00	0.47	35.67	0.04	2.33	0.04	7.67	0.02	23.67	-0.22	3.80
KM2427 X K851	0.11	39.00	0.43	63.00	0.19	32.00	0.11	2.33	-0.42	6.67	1.13	26.33	-0.14	4.17
KM2427 X PDM139	-0.29	38.00	-0.45	62.00	0.21	32.00	-0.04	2.33	0.26	7.67	-0.26	25.33	-0.03	4.33
KM2427 X KM2241	0.18	38.33	0.02	62.00	-0.41	31.00	-0.06	2.33	0.16	7.33	-0.86	24.33	0.17	4.43
SE (Sij) (±)	0.73		0.93		1.04		0.29		0.53		0.98		0.26	

Crosses	Number of Seeds Per Pod		100-Seed Weight (g)		Biological Yield (g)		Harvest Index (%)		Seed protein Content (%)		Seed Yield Per Plant (g)	
	SCA effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean	SCA Effects	Mean
IPM302 X K851	-0.13	5.67	0.60**	4.13	-2.86**	13.80	0.74	50.01	-0.52	22.52	-0.49**	6.69
IPM302 X PDM139	-0.13	6.33	-1.15**	4.67	-4.85**	11.08	18.65**	72.59	-0.15	22.61	0.69**	8.38
IPM302 X KM2241	0.26	6.33	0.54**	4.08	7.71**	25.59	-19.39**	28.13	0.68	23.52	-0.19	7.20
HUM12 X K851	0.75	8.33	0.84**	3.64	5.19**	23.19	-13.58**	25.42	0.20	22.00	-0.72**	6.20
HUM12 X PDM139	-0.57	7.67	-1.58**	3.50	0.90**	18.17	-4.53**	39.14	-0.08	21.44	0.06	7.49
HUM12 X KM2241	-0.18	7.67	0.73**	3.54	-6.10**	13.11	18.11**	55.39	-0.12	21.46	0.66**	7.80
KM2290 X K851	-1.9*	6.33	0.95**	3.43	-2.00**	12.41	9.32**	52.64	-0.13	21.98	0.75**	6.60
KM2290 X PDM139	0.42	9.33	-1.60**	3.17	-2.80**	10.88	4.55**	52.53	-0.33	21.50	-0.32*	6.01
KM2290 X KM2241	1.48	10.00	0.65**	3.15	4.81**	20.45	-13.87**	27.70	0.46	22.37	-0.43**	5.61
KM2426 X K851	1.09	8.67	0.73**	3.94	3.25**	20.26	-4.58**	36.15	0.23	22.57	0.82**	8.10
KM2426 X PDM139	-0.57	7.67	-1.50**	4.00	1.64**	17.91	-8.23**	37.17	-0.21	21.85	-0.69**	7.08
KM2426 X KM2241	-0.51	7.33	0.76**	3.98	-4.90**	13.33	12.81**	51.81	-0.01	22.12	-0.13	7.35
KM2427 X K851	0.64	7.67	0.05	3.12	-0.90**	14.07	-4.01**	41.02	0.04	22.93	-0.91**	6.01
KM2427 X PDM139	-1.02	6.67	-1.17**	4.19	0.77*	15.02	2.48**	52.19	-0.11	22.50	0.33*	7.76
KM2427 X KM2241	0.37	7.67	1.12**	4.21	0.12	16.33	1.53	44.83	0.06	22.75	0.57**	7.70
SE (Sij) (±)	0.88		0.16		0.34		0.92		0.41		0.13	

**5% level of significance, ** 1% level of significance*

Table 5. Proportional Contribution of Lines, Testers and their interaction to the total variance for different characters in Greengram

Proportional Contribution	Days to 50% Flowering	Days to Maturity	Plant Height (cm)	Number of Branches Per Plant	Number of Clusters Per Plant	Number of Pods Per Plant	Pod Length (cm)	Number of Seeds Per Pod	100 Seed Weight (g)	Biological Yield (g)	Harvest Index (%)	Seed Protein Content (%)	Seed Yield Per Plant (g)
Line	88.07	85.63	97.97	20.93	79.76	93.01	36.94	69.30	34.02	25.22	31.41	74.17	56.69
Tester	2.97	2.07	0.30	11.27	3.42	1.19	1.17	4.18	4.50	4.71	4.86	1.84	3.50
Line X Tester	8.96	12.29	1.72	67.80	16.82	5.81	61.88	26.52	61.49	70.07	63.73	23.99	39.81

biological yield, harvest index, protein content and seed yield per plant (Table 2). The degree of dominance exhibited partial dominance for days to 50% flowering, days to maturity, plant height and number of seeds per pod (Table 2). The findings are in the conformity with the results of Jayaprada et al. [42], Sathya and Jayamani (2011), Narsimhulu et al. (2014) and Singh et al. [43].

The general combining ability effects of parents (Table 3) showed that line IPM302 was good general combiner and had high *per se* performances for days to 50% flowering, days to maturity, number of pods per plant, harvest index and seed yield per plant followed by SML664 for Days to 50% flowering, protein content and seed yield per plant. In testers, only one tester KM2241 designated as good general combiner and had high per se performance for number of branches per plant. The result confirms the same view observed by Kumar et. al. (2017), Anamika et al. (2017), Samantaray et. al. [44], Rathod et al. [45] and Kohakade et. al. (2021).

The negative estimates of specific combining ability were desirable for day to 50% flowering, days to maturity and plant height. However, for rest of the characters positive estimates of specific combining ability were considered desirable. Out of forty-eight crosses studied, fifteen crosses KM2403 X KM2241, KM2408 X KM2241, KM2399 X K851, KM2404 X K851, SML681 X KM2241, KM2426 X K851, KM2290 X K851, KM2404 X PDM139, IPM302 X PDM139, HUM12 X KM2241, KM2417 X KM2241, KM2427 X KM2441, KM2427 X PDM139, KM2399 X PDM139 and KM2401 X PDM139 showed significant and positive SCA effects for seed yield per plant and some other yield components (Table 4). The results are in agreement with those of Iqbal et al*.* [46], Kute et al [47], Kumar et. al. [41], Elizabeth et al. [48] and Patel and Intwala (2021).

The cross KM2403 X KM2241 was found most promising as it had highly significant sca effects for grain yield per plant along with 100 seed weight, biological yield and harvest index. KM2408 X KM2241 for 100 seed weight and harvest index. KM2399 X K851 for biological yield and protein content. KM2404 X K851for 100 seed weight and biological yield. SML681 X KM2241 for 100 seed weight and biological yield. KM2426 X K851for 100 seed weight and biological yield. KM2290 X K851for pod length and harvest index. KM2404 X PDM139 for harvest index. IPM302 X PDM139 for harvest index. HUM12 X KM2241 for 100 seed weight and harvest index. KM2417 X KM2241for 100 seed weight and harvest index. KM2427 X KM2241for 100 seed weight. KM2427 X PDM139for biological yield and harvest index. KM2399 X PDM139for 100 seed weight and harvest index and KM2401 X PDM139for biological yield. The results are in agreement with those of Gill et al*.* (2015), Iqbal et al*.* [46], Kute et al*.* [9] and Nath et al*.* (2008).

The maximum contribution of lines was recorded for plant height followed by number of pods per plant, days to 50% flowering, days to maturity and number of clusters per plant. The minimum contribution of lines was recorded for number of branches per plant followed by biological yield, harvest index, 100 seed weight and pod length (Table 5). The maximum contribution of testers was recorded for number of branches per plant followed by harvest index, biological yield, 100 seed weight and number of seeds per pod. The minimum contribution of testers was recorded for plant height followed by pod length, number of pods per plant, protein content and days to maturity. Lines x testers component displayed greater contribution for biological yield followed by number of branches per plant, pod length, 100 seed weight and seed yield per plant (Table 5). Similar observations were also reported by Narasimhulu et. al. (2016), Rathod et al. [45], Latha et al. (2018) and Nath et al. (2019).

4. CONCLUSION

On the basis of experimental findings and discussions as discussed in light of the available literatures, it can be concluded that parents namely SML664, HUM12, KM2426, KM2427 and KM2404 showed desirable GCA effects and higher *per se* performances for seed yield per plant and they may be utilized as parental lines in crossing programs aiming to higher seed yield. The cross combinations namely KM2403 X KM2241, KM2408 X KM2241, KM2399 X K851, KM2404 X K851 and SML681 X KM2241 showed desirable sca effects for seed yield per plant with higher *per se* performances and can be further utilized in suitable selection scheme for getting desirable transgressive segregants in advanced generations.

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 writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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