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Research Note

Combining ability and heterosis for yield and its attributes in Greengram (*Vigna radiata* L. Wilczek)

R. Narasimhulu*[1], N.V. Naidu[2], K.H.P. Reddy[1] and G. Mohan Naidu[1]
[1]Dept. of Genetics and Plant Breeding, S.V. Agricultural College, Tirupati 517502, A.P, India
[2]Director (seeds), SRTC, ANGRAU, Rajendranagar, Hyderabad 5000300, A.P, India
Email: narsi46@gmail.com

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Abstract
Five lines were crossed with four testers in line × tester fashion to determine the nature of gene action, combining ability and heterosis for yield and yield contributing traits in greengram. Analysis of variance for combining ability suggested the preponderance of non-additive type of gene action for majority of the traits except for tolerance to MYMV. Based on the *per se* performance and *gca* effects, the parents *viz.,* TM-96-2, LGG-460, MGG-351, WGG-37 and PM-112 were found to be the best general combiners. The *per se*, *sca* effects and standard heterosis indicated that the crosses LGG-460 × WGG-37, TM-96-2 × WGG-37 and MGG-351 × WGG-37 may be exploited through recombination breeding programme, while the crosses MGG-351 × PM-115, TM-96-2 × PM-112 and LGG-460 × PM-112 are the promising crosses for hybrid breeding programme. Biparental mating or diallel selective mating, followed by pedigree method of selection would be effective alternate approaches for the improvement of productivity in greengram.

Keywords
Combining ability, greengram, hybrid vigour and tolerance to MYMV.

Greengram [*Vigna radiata* L. Wilczek. 2n=22], is an economically important food legume grown worldwide in tropical and sub-tropical regions and it is one of the leading pulse crops in India. The importance of this legume is related to desirable characteristics such as high protein content (25-28%) and less flatulent than other pulses, broad adaptation, low need for agricultural inputs and its ability to increase soil fertility. Sprouts and green pods of mungbean are also rich in vitamins and minerals, thus are good and inexpensive source of dietary protein for poor people. Owing to its high demand, crop improvement involves strategies for enhancing yield potential and quality components. Though *per se* performance of genotypes provides clues, reliable information on the magnitude of heterosis for yield and yield attributing characters, *per se* performance along with combining ability are of more helpful in selecting appropriate parents and desirable cross combinations for the exploitation of hybrid vigour. Therefore, the present investigation was carried out with five lines and four testers to elucidate information on combining ability and nature of gene action for traits of economic importance and also to assess the magnitude of heterosis for different yield characters by adopting Line × Tester analysis (Kempthorne 1957).

Five lines *viz.*, MGG-295, MGG-351, WGG-42, LGG-460 and TM-96-2 were crossed with four testers WGG-37, PM-112, PM-115 and PM-110 in Line × Tester fashion and a total of 20 hybrids were generated. All the genotypes (nine parents and 20 F_1's) were evaluated in Randomized Block Design with two replications at the Sri Venkateswara Agricultural College Farm, Tirupati, Andhra Pradesh, India during *kharif,* 2013. Each genotype was grown in two rows of three meters length with a spacing of 30cm between rows and 15cm between plants. Recommended agronomic and plant protection package of practices were followed to raise healthy crop. 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*., plant height, number of branches/plant, clusters/plant, pods/cluster, pods/plant, seeds/pod, 100 seed weight, dry weight/plant, harvest index, tolerance to MYMV and seed yield/plant. However, data on days to 50% flowering and days to maturity were recorded on plot basis and the seed protein was estimated by Kjeldal method. Line × Tester analysis was carried out as given by Kempthorne (1957). The heterosis was estimated in terms of three parameters, *i.e.* relative heterosis, heterobeltiosis and standard heterosis. Mean values per replication for all traits were subjected to analysis of variance according to Panse and Sukhatme (1985).

Analysis of variance for combining ability (Table 1) revealed that parents had significant amount of variability for all the characters except for number of seeds/pod and seed yield/plant, while crosses had significant variability for all the characters except for number of seeds/pod. Comparison of mean squares due to parents *vs* crosses indicated the presence of substantial amount of heterosis in crosses for majority of the characters except for 100 seed weight and seed protein. The variance due to lines were significant for all the characters except for number of seeds/pod, while testers had significant variability for 11 characters except for number of pods/cluster, seeds/pod and 100 seed weight, suggesting the significant contribution of lines and testers towards general combining ability variance components for most of the traits. The variance due to interaction effect (lines × testers) showed significant difference for 12 characters except for plant height and number of seeds/pod revealed the significant contribution of crosses for specific combining ability variance components. The magnitude of *sca* variance was higher than the *gca* variance for all the characters except MYMV tolerance, which indicated preponderance of non-additive gene action in the inheritance of these traits. The ratio of variance due to general and specific combining ability ranged from 0.01 to 0.66 further conforming the major role of non-additive gene action for all the traits under study except for tolerance to MYMV (2.52).

The success of any plant breeding programme largely depends on the appropriate choice of parents. The knowledge of general combining ability coupled with high *per se* performance would helps in the selection of potential parents with good reservoir of superior genes (Singh and Harisingh, 1985). In the present investigation, based on *per se* performance and *gca* effects, MGG-351 was found to be the best parent for plant height, number of branches/plant, clusters/plant, pods/plant and dry weight/plant (Table 2) followed by WGG-42 for days to 50 per cent flowering, days to maturity, 100 seed weight and tolerance to MYMV; LGG-460 for number of branches/plant and tolerance to MYMV. TM-96-2 had desirable performance for tolerance to MYMV while PM-115 for seed protein. The above mentioned parents for *gca* effects have good potential for respective characters and may be used in a multiple crossing programme to synthesize a dynamic population with most of the favourable genes accumulated (Griffing, 1956).

The *sca* effects are the index to determine the usefulness of a particular cross combination for exploitation of hybrid vigour. The results of specific combining ability effects (Table 3) of different cross revealed that none of the crosses showed consistently significant and desirable specific combining ability effects for all the characters. However, the cross combinations *viz.*, MGG-351 × PM-115, WGG-42 × PM-110, TM-96-2 × WGG-37, TM-96-2 × PM-112 and MGG-295 × PM-110 were adjudged as the best crosses for majority of the yield components. The *sca* effects signify the role of non-additive gene effects mainly dominance gene effects (Nadarajan and Gunasekaran, 2005). Cross combinations which exhibited high *sca* which derived from parents having high *gca* effects can also be used for recombination breeding. However, the selection of superior genotypes for cultivar development must be delayed to later generations to allow fixation of maximum homozygosity (Nadarajan and Gunasekaran, 2005). These include TM-96-2 × WGG-37 for seed yield/plant; LGG-460 × WGG-37 for number of pods/plant; MGG-351 × WGG-37 for number of branches/plant and dry weight/plant; LGG-460 × PM-112 and TM-96-2 × PM-112 for number of branches/plant and pods/plant.

Recombination breeding makes use of a fixable additive gene action. The criteria for the selection of crosses for recombination breeding to obtain outstanding recombinants in segregating generations are based on the following; the parents should have significant *gca* effect and corresponding crosses with non significant *sca* effects for the character whose improvement is sought. The segregation of such crosses are likely to throw desirable recombinants possessing favourable additive genes from both the parents (Khorgade *et al.*, 1989). Based on the aforesaid consideration, the lines and testers with significant *gca* effects, possible cross combinations and the promising crosses for recombination breeding are presented in Table 4. The cross LGG-460 × WGG-37 for number of branches/plant, clusters/plant, pods/clusters and seed yield/plant and TM-96-2 × WGG-37 for number of branches/plant, clusters/plant, pods/plant and dry weight/plant; MGG-351 × WGG-37 for plant height, number of clusters/plant and pods/plant, could be expected to produce superior recombinants. For harvest index, the cross combinations *viz.*, WGG-42 × PM-112, WGG-42 × PM-110, LGG-460 × PM-112 and LGG-460 × PM-110 were identified for the recombination breeding, while for number of pods/plant the crosses MGG-351 × PM-112 was considered along with MGG-351 × WGG-37 and TM-96-2 × WGG-37; for tolerance to MYMV the crosses WGG-42 × PM-110 and LGG-460 × PM-110 were considered for the recombination breeding. The lines MGG-295, LGG-460 and TM-96-2 and testers WGG-37 and PM-112 showed positive and highly significant *gca* effects for seed yield/plant. Among the crosses MGG-295 × PM-112, LGG-460 × WGG-37, LGG-460 × PM-112 and TM-96-2 × PM-112 had non-significant *sca* effects for seed yield/plant. Hence, these crosses can be recommended for improvement of seed yield through recombination breeding with early selection of desirable segregants. Similar results were reported by Patil and Navale (2006).

In general, the extent of heterosis has often been estimated over mid-parent or better parent with the objective of studying the nature of gene action involved in the parental combinations. However, the heterosis recorded over mid or better parent has little applied utility if parents involved have relatively poor *per se* performance. For commercial exploitation, the magnitude of heterosis should be at least 20-30 per cent higher in yield than best cultivated variety. Swaminathan *et al.* (1972) stressed the need for computing standard heterosis for commercial exploitation of hybrid vigour. The magnitude of standard heterosis was high for dry weight/plant, 100-seed weight, pods/plant and seed yield/plant and low for days to maturity and seed protein. The observation of the heterotic trends revealed that out of 20 crosses, ten crosses *viz.*, MGG-295 × PM-112, MGG-295 × PM-115, MGG-295 × PM-110, MGG-351 × WGG-37, MGG-351 × PM-115, WGG-42 × WGG-37, LGG-460 × WGG-37, TM-96-2 × WGG-37, TM-96-2 × PM-112 and TM-96-2 × PM-115 registered significant and high standard heterosis for seed yield contributing traits *viz*., days to 50 per cent flowering, days to maturity, number of branches/plant, clusters/plant, pods/cluster, pods/plant, seeds/pod, dry weight/plant and harvest index. These crosses were considered promising for their use for yield improvement because of having high heterotic effects for seed yield/plant. Similar results were also observed by Sujatha *et al.* (2011) and Sathya and Jayamani (2011).

Hybrid vigour can be very well exploited through *per se* performance, *sca* effects and magnitude of heterosis. Selection based on any one of the criteria may be often misleading. The cross with high heterosis may also be observed with low mean performance and the cross with high mean value always may not record high *sca* effects. Therefore, all the three criteria have to be considered together for selection of superior crosses. Comparative study of promising crosses identified on the basis of heterosis, combining ability and *per se* performance (Table 5) revealed that the cross MGG-351 × PM-115 exhibited a superior performance for five characters *viz*., days to 50 per cent flowering, days to maturity, number of pods/plant, dry weight/plant and seed yield/plant and it was followed by crosses TM-96-2 × PM-112 and LGG-460 × PM-112 for number of branches/plant, clusters/plant, pods/plant and exhibited superior performance for dry weight/plant in addition to these traits in case of TM-96-2 × PM-112. The cross TM-96-2 × WGG-37 was identified for dry weight/plant and seed yield/plant and it was followed by MGG-295 × PM-115 for number of pods/plant and harvest index and MGG-351 × WGG-37 for number of branches/plant and dry weight/plant. The desired combination of *per se* performance, *sca* effects and standard heterosis were exhibited by the cross LGG-460 × WGG-37 for number of pods/plant, MGG-295 × PM-112 for dry weight/plant, MGG-295 × PM-110 for harvest index and seed protein. Similar results were also observed by Sunilkumar and Prakash (2011) for number of branches/plant, pods/plant, test weight and seed yield/plant and Srivastava and Singh (2013) for seed yield/plant. These crosses may be exploited commercially for the improvement of those specific traits. However, in greengram the exploitation of heterosis is still in its infancy due to biological constrains and uneconomical practice of hand emasculation for large scale production, so it could not feasible at present. Ideally in such situations, recurrent selection or diallel selective mating or the use of multiple crosses and biparental mating might be effective alternate approaches.

Thus, in the present investigation wide variation was revealed among the parents and the resultant crosses for almost all the traits studied indicating that direct selection in the segregants to isolate superior segregants is feasible. The present study also confirmed that high heterotic combinations were realized in the cross combinations involving the genetically diverse parents (good × poor) for seed yield and its components. Further, all the heterotic cross combinations had close correspondence with mean value, which suggested that the *per se* performance of crosses could be considered for judging heterosis for seed yield/plant. Most of the characters were controlled by non-additive components. However, in greengram owing to its autogamous genetic nature, commercial exploitation of heterosis is not readily useful. Therefore, breeder's interest rests in obtaining transgressive segregants from such crosses at later generations.

References

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. *Australian J. Biol Sci*., **9**:463-93.

Kempthorne, O. 1957. An introduction to genetic statistics. John Wiley and Sons, New York.

Khorgade, P.W., Deshmukh, A.V., Narkhede, M.N. and Rant, S.K. 1989. Combining ability for yield and its components in sesame. *J. Maharashtra Agric. Univ*., **14**(2): 164-166.

Nadarajan, N. and Gunasekaran, M. 2005. *Quantitative Genetics and Biometrical Techniques in Plant Breeding*. Kalyani Publ., New Delhi.

Panse, V.G. and Sukhatme, P.V. 1985. Statistical methods for Agricultural workers, Indian Council of Agricultural Research, New Delhi.

Patil, H.E. and Navale, P.A. 2006. Combining ability in cowpea (*Vigna unguiculata* (L.) Walp.). *Legume Res.,* **29**(4): 270-273.

Sathya, M. and Jayamani, P. 2011. Heterosis and combining ability studies in greengram. *J. Legumes.* **24**(4): 282-287.

Singh, N.B. and Harisingh. 1985. Heterosis and combining ability for kernel size in Rice. *Indian J. Genetics and Plant Breeding*, **45**(2): 181-185.

Srivastava, R.L. and Singh, G. 2013. Heterosis for yield and its contributing characters in mungbean (*Vigna radiata* (L.) wilczek). *Indian J. Sci. Res.*, **4**(1): 131-134.

Sujatha, K., Kajjidoni, S.T., Patil, P.V. and Guddadamath Somashekar. 2011. Heteosis for productivity related traits involving diverse parents for powdery mildew reaction in mungbean. *J. Legumes,* **24**(2): 101-105.

Sunilkumar, B. and Prakash, M. 2011. Heterosis for biometric and biochemical components in mungbean (*Vigna radiata* (L.) Wilczek.). *Karnataka J. Agric. Sci.,* **24**(4): 523-524.

Swaminathan, M.S., Siddiq, E.A. and Sharma, S.D. 1972. Out look for hybrid rice in India. *International Rice breeding*. IRRI, Manila, Philippines. 109-613.

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Table 1. Analysis of variance for combining ability and estimation of genetic components for different quantitative traits in greengram

Source	d.f.	Days to 50 % flowering	Days to maturity	Plant height (cm)	No. of branches/ plant	No. of clusters/ plant	No. of pods/ cluster	No. of pods/ plant	No. of seeds/ pod	100 seed weight (g)	Dry weight/ plant (g)	Harvest index (%)	Seed protein (%)	Tolerance to MYMV score (1-9 scale)	Seed yield/ plant (g)
Replications	1	2.48	3.38	0.05	0.09	0.28	0.04	10.41	0.61	0.02	0.60	0.61	0.31	0.01	0.64
Treatments	28	7.45**	8.30**	47.93**	0.92**	7.08**	0.28**	126.20**	1.24**	0.81**	42.82**	29.43**	1.41**	2.27**	12.13**
Parents	8	5.00**	8.25**	69.53**	0.82**	2.10**	0.15**	31.17**	0.86	0.84**	10.32**	16.30**	1.29**	3.45**	1.59
Crosses	19	8.39**	8.54**	39.45**	0.91**	9.47**	0.17**	154.10**	0.71	0.83**	55.33**	31.50**	1.12**	1.85**	12.85**
Lines	4	25.98**	22.35**	128.39**	2.02**	24.92**	0.40**	400.11**	0.64	3.36**	111.67**	61.19**	1.21**	8.32**	15.20**
Testers	3	3.80*	10.03**	27.08*	1.09**	5.66**	0.11	123.01**	1.25	0.09	94.11**	31.26**	1.08**	0.25**	15.46**
Lines × Testers	12	3.68**	3.57**	12.89	0.49**	5.27**	0.11*	79.87**	0.59	0.17*	26.85**	21.66**	1.10**	0.09*	11.42**
Parents vs Crosses	1	9.32**	4.10*	36.23*	1.90**	1.72**	3.34**	356.26**	14.43**	0.12	65.23**	95.31**	0.41	0.81**	82.68**
Error	28	1.09	0.92	6.55	0.06	0.41	0.04	4.09	0.49	0.07	1.04	1.43	0.15	0.02	0.72
***gca* variance**		0.21	0.22	1.16	0.02	0.18	0.00	3.25	0.01	0.03	1.25	0.43	0.00	0.08	0.06
***sca* variance**		1.26	1.43	2.67	0.23	2.43	0.04	37.62	0.05	0.04	12.83	10.00	0.47	0.03	5.26
GCA/SCA		0.16	0.15	0.44	0.08	0.08	0.07	0.09	0.10	0.66	0.10	0.04	0.00	2.52	0.01

*, ** Significant at 5% and 1% level of probability, respectively

Table 2. Mean performance and general combining ability (*gca*) of parents for yield contributing characters in greengram

Genotypes	Days to 50 % flowering		Days to maturity		Plant height (cm)		No. of branches/plant		No. of clusters/plant		No. of pods/cluster		No. of pods/plant	
	Mean	*gca* effect	Mean	*gca* effect	Mean	*gca* effect	Mean	*gca* effect	Mean	*gca* effect	Mean	*gca* effect	Mean	*gca* effect
Lines														
MGG-295	35.50	-0.08	66.50	0.43	41.10	1.13	1.00	-0.12	7.80	-0.02	3.60	0.16 *	27.95	-0.07
MGG-351	37.50	1.30 **	69.00	0.68 *	56.90	4.84 **	2.20	0.26 **	10.15	0.94 **	3.56	-0.04	36.26	4.50 **
WGG-42	33.50	-2.33 **	63.50	-2.58 **	38.55	-6.13 **	0.40	-0.82 **	6.90	-3.05 **	2.97	-0.33 **	20.85	-12.12 **
LGG-460	39.00	2.17 **	70.50	1.92 **	48.70	-0.91	2.30	0.28 **	9.85	0.93 **	3.57	0.25 **	28.90	5.12 **
TM-96-2	35.00	-1.08 *	66.00	-0.45	42.00	1.07	1.80	0.41 **	8.85	1.20 **	3.10	-0.03	29.00	2.58 **
Mean	**36.10**		**67.10**		**45.45**		**1.54**		**8.71**		**3.36**		**28.59**	
SE (g_i)		**0.38**		**0.30**		**0.97**		**0.07**		**0.23**		**0.07**		**0.76**
Testers														
WGG-37	36.00	-0.10	67.50	0.22	44.70	2.45 *	1.80	0.28 **	8.47	0.65 **	3.02	0.14 *	28.85	3.15 **
PM-112	37.00	-0.00	68.00	0.13	41.85	-0.69	2.00	0.27 **	9.65	0.29	3.09	-0.08	26.86	2.30 **
PM-115	36.50	-0.70	67.50	-1.38 **	39.10	-1.08	0.98	-0.16 *	9.00	0.15	3.22	0.03	28.35	-0.89
PM-110	37.00	0.80 *	69.00	1.02 **	39.55	-0.68	1.55	-0.38 **	8.85	-1.08 **	2.96	-0.08	26.70	-4.57 **
Mean	**36.63**		**68.00**		**41.30**		**1.58**		**8.99**		**3.07**		**27.69**	
SE (g_j)		**0.34**		**0.27**		**0.87**		**0.06**		**0.20**		**0.06**		**0.68**

Genotypes	No. of seeds/pod		100 seed weight (g)		Dry weight/plant (g)		Harvest index (%)		Seed protein (%)		Tolerance to MYMV score (1-9 scale)		Seed yield/plant (g)	
	Mean	*gca* effect	Mean	*gca* effect	Mean	*gca* effect	Mean	*gca* effect	Mean	*gca* effect	Mean	*gca* effect	Mean	*gca* effect
Lines														
MGG-295	9.20	-0.37	3.78	0.02	16.15	0.75	32.60	0.05	24.94	0.31 *	4.20	1.30 **	8.78	0.70 *
MGG-351	9.50	-0.01	3.70	-0.30 **	19.45	4.61 **	35.39	-4.34 **	24.54	0.08	4.00	0.89 **	11.75	0.20
WGG-42	11.30	0.39	5.60	1.11 **	11.50	-5.64 **	42.92	2.58 **	23.40	-0.68 **	1.30	-0.50 **	10.16	-2.43 **
LGG-460	9.50	0.13	3.37	-0.49 **	16.25	-0.89 *	35.66	2.19 **	24.33	0.16	1.40	-0.78 **	10.10	0.70 *
TM-96-2	10.00	-0.13	4.07	-0.34 **	14.10	1.18 **	37.69	-0.49 *	24.24	0.13	1.10	-0.91 **	9.74	0.82 *
Mean	**9.90**		**4.10**		**15.49**		**36.85**		**24.29**		**2.40**		**10.11**	
SE (g_i)		**0.25**		**0.10**		**0.38**		**0.46**		**0.14**		**0.05**		**0.34**
Testers														
WGG-37	10.10	0.50 *	3.60	-0.01	15.00	3.62 **	35.83	-2.55 **	23.18	-0.26	1.20	0.09	9.50	0.88 **
PM-112	9.45	-0.15	3.99	0.05	13.50	-0.01	36.74	1.25 *	24.06	-0.14	1.00	0.17 **	9.00	0.80 *
PM-115	9.20	-0.03	4.31	-0.13	13.30	0.27	38.84	0.18	25.90	0.48 **	1.00	-0.06	9.74	0.10
PM-110	10.00	-0.31	4.23	0.09	14.20	-3.88 **	35.84	1.12 **	24.24	-0.08	1.00	-0.19 **	9.05	-1.79 **
Mean	**9.69**		**4.03**		**14.00**		**36.81**		**24.35**		**1.05**		**9.32**	
SE (g_j)		**0.22**		**0.09**		**0.35**		**0.41**		**0.12**		**0.05**		**0.30**

*Significant at 5% level of probability **Significant at 1% level of probability

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Table 3. Mean performance and Specific combining ability (*sca*) effects of crosses for yield contributing characters in greengram

Cross	Days to 50 % flowering		Days to maturity		Plant height (cm)		No. of branches/ plant		No. of clusters/ plant		No. of pods/ cluster		No. of pods/ plant	
	Mean	*sca* effect	Mean	*sca* effect	Mean	*sca* effect	Mean	*sca* effect	Mean	*sca* effect	Mean	*sca* effect	Mean	*sca* effect
MGG-295 × WGG-37	36.50	-0.52	69.00	0.28	48.20	-0.70	1.90	-0.21	8.15	-1.69 **	3.88	-0.17	30.80	-5.83 **
MGG-295 × PM-112	37.00	-0.13	68.00	-0.63	44.80	-0.95	2.00	-0.09	9.00	-0.48	3.72	-0.11	33.50	-2.28
MGG-295 × PM-115	37.50	1.08	67.50	0.38	41.77	-3.59	1.60	-0.06	9.50	0.17	4.27	0.33 *	33.20	0.61
MGG-295 × PM-110	37.50	-0.43	69.50	-0.02	51.00	5.24 *	1.80	0.36 *	10.10	2.00 **	3.78	-0.04	36.40	7.49 **
MGG-351 × WGG-37	40.00	1.60 *	70.50	1.52 *	50.70	-1.90	2.85	0.36 *	10.70	-0.09	3.71	-0.14	39.70	-1.50
MGG-351 × PM-112	39.50	1.00	69.50	0.63	50.40	0.94	1.60	-0.87 **	10.90	0.47	3.72	0.10	40.70	0.35
MGG-351 × PM-115	35.00	-2.80 **	64.50	-2.88 **	51.60	2.53	2.50	0.46 **	11.00	0.71	3.83	0.09	43.38	6.22 **
MGG-351 × PM-110	39.50	0.20	70.50	0.73	47.90	-1.57	1.88	0.05	7.97	-1.09 *	3.57	-0.06	28.40	-5.08 **
WGG-42 × WGG-37	33.50	-1.27	64.50	-1.22	42.13	0.50	1.00	-0.41 **	8.20	1.39 **	3.34	-0.22	27.40	2.82
WGG-42 × PM-112	34.50	-0.37	65.50	-0.12	38.83	0.34	1.23	-0.17	3.88	-2.58 **	3.25	-0.08	14.00	-9.73 **
WGG-42 × PM-115	35.00	0.83	66.00	1.88 **	37.48	-0.63	1.13	0.16	5.88	-0.43	3.67	0.22	21.50	0.96
WGG-42 × PM-110	36.50	0.83	66.00	-0.52	38.30	-0.20	1.15	0.41 **	6.70	1.62 **	3.41	0.08	22.80	5.94 **
LGG-460 × WGG-37	40.50	1.23	71.00	0.78	49.95	3.09	2.75	0.24	11.25	0.46	4.36	0.23	46.60	4.78 **
LGG-460 × PM-112	39.50	0.13	69.50	-0.62	42.43	-1.28	3.16	0.67 **	11.71	1.28 *	3.94	0.03	46.54	5.57 **
LGG-460 × PM-115	38.50	-0.17	69.00	0.38	43.83	0.50	1.65	-0.41 **	8.90	-1.39 **	3.67	-0.35 *	30.73	-7.05 **
LGG-460 × PM-110	39.00	-1.17	70.50	-0.52	41.40	-2.32	1.35	-0.49 **	8.70	-0.36	4.00	0.09	30.80	-3.30 *
TM-96-2 × WGG-37	35.00	-1.02	66.50	-1.35 *	47.85	-0.99	2.65	0.01	10.98	-0.08	4.15	0.30 *	39.00	-0.28
TM-96-2 × PM-112	35.50	-0.62	68.50	0.75	46.65	0.95	3.10	0.47 **	12.00	1.30 **	3.69	0.06	44.52	6.09 **
TM-96-2 × PM-115	36.50	1.08	66.50	0.25	46.50	1.19	2.05	-0.15	11.50	0.95	3.45	-0.29 *	34.50	-0.74
TM-96-2 × PM-110	37.50	0.58	69.00	0.35	44.55	-1.15	1.65	-0.33 *	7.15	-2.17 **	3.56	-0.07	26.50	-5.06 **
Mean	**37.20**		**68.08**		**45.31**		**1.95**		**9.21**		**3.75**		**33.55**	
SE (S_{ij})		**0.76**		**0.60**		**1.94**		**0.13**		**0.46**		**0.13**		**1.52**

Contd.,

Electronic Journal of Plant Breeding, 7(3): 784-793 (September 2016)
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Table 3. Contd.,

Cross	No. of seeds/ pod		100 seed weight (g)		Dry weight/plant (g)		Harvest index (%)		Seed protein (%)		Tolerance to MYMV score		Seed yield/plant (g)	
	Mean	***sca* effect**	**Mean**	***sca* effect**	**Mean**	***sca* effect**	**Mean**	***sca* effect**	**Mean**	***sca* effect**	**Mean**	***sca* effect**	**Mean**	***sca* effect**
MGG-295 × WGG-37	10.50	-0.51	3.90	-0.08	19.40	-2.10 *	32.71	-4.39 **	23.65	-0.89 **	3.60	0.16	10.38	-3.54 **
MGG-295 × PM-112	10.50	0.14	3.88	-0.16	20.10	2.23 **	38.95	-1.96 *	25.87	1.20 **	3.40	-0.12	14.09	0.24
MGG-295 × PM-115	10.90	0.42	4.15	0.29	15.80	-2.35 **	43.84	4.00 **	24.35	-0.93 **	3.30	0.00	13.90	0.75
MGG-295 × PM-110	10.15	-0.05	4.03	-0.05	16.20	2.21 *	43.13	2.35 *	25.34	0.62 *	3.10	-0.06	13.80	2.55 **
MGG-351 × WGG-37	11.10	-0.28	3.72	0.05	27.40	2.05 *	28.88	-3.83 **	24.18	-0.14	3.30	0.27 *	11.94	-1.49 *
MGG-351 × PM-112	10.25	-0.47	3.86	0.14	16.90	-4.82 **	40.15	3.63 **	24.29	-0.15	3.20	0.09	12.70	-0.64
MGG-351 × PM-115	11.05	0.21	3.71	0.17	28.90	6.91 **	33.80	-1.65	25.18	0.12	2.80	-0.10	15.80	3.16 **
MGG-351 × PM-110	11.10	0.54	3.41	-0.36	13.70	-4.15 **	38.23	1.85	24.67	0.17	2.50	-0.26 *	9.72	-1.03
WGG-42 × WGG-37	11.38	-0.40	5.00	-0.08	14.50	-0.59	43.41	3.77 **	23.19	-0.37	1.40	-0.23 *	12.66	1.87 *
WGG-42 × PM-112	11.65	0.54	5.46	0.33	10.30	-1.17	41.56	-1.88	23.80	0.12	1.90	0.18	8.75	-1.96 **
WGG-42 × PM-115	10.75	-0.49	4.44	-0.51 *	9.80	-1.94 *	41.03	-1.34	24.89	0.59 *	1.70	0.20	8.26	-1.75 *
WGG-42 × PM-110	11.30	0.35	5.44	0.26	11.30	3.70 **	42.76	-0.55	23.39	-0.34	1.20	-0.15	9.96	1.84 *
LGG-460 × WGG-37	11.95	0.44	3.36	-0.12	21.25	1.41	39.23	-0.02	24.88	0.48	1.30	-0.06	15.01	1.08
LGG-460 × PM-112	10.60	-0.26	3.25	-0.29	16.60	0.39	44.42	1.37	23.66	-0.85 **	1.30	-0.14	14.88	1.03
LGG-460 × PM-115	10.75	-0.23	3.62	0.26	13.75	-2.75 **	41.79	-0.19	25.32	0.18	1.20	-0.02	11.32	-1.83 *
LGG-460 × PM-110	10.75	0.05	3.73	0.15	13.30	0.96	41.76	-1.16	24.76	0.19	1.30	0.22	10.97	-0.28
TM-96-2 × WGG-37	12.00	0.75	3.85	0.23	21.15	-0.77	41.04	4.47 **	25.29	0.92 **	1.10	-0.13	16.12	2.08 **
TM-96-2 × PM-112	10.65	0.05	3.66	-0.02	21.65	3.36 **	39.20	-1.17	24.18	-0.31	1.30	-0.01	15.29	1.33
TM-96-2 × PM-115	10.80	0.08	3.29	-0.21	18.70	0.13	38.49	-0.81	25.15	0.04	1.00	-0.09	12.94	-0.32
TM-96-2 × PM-110	9.55	-0.89	3.72	-0.00	11.70	-2.72 **	37.75	-2.49	23.90	-0.65 *	1.20	0.25 *	8.28	-3.08 **
Mean	**10.88**		**3.97**		**17.12**		**39.61**		**24.50**		**2.06**		**12.34**	
SE (S_{ij})		**0.50**		**0.20**		**0.77**		**0.91**		**0.28**		**0.11**		**0.67**

*Significant at 5% level of probability **Significant at 1% level of probability

Table 4. Promising cross combinations identified for recombination breeding

Sl. No.	Characters	Significant *gca* effects: Lines	Significant *gca* effects: Testers	Possible cross combinations	*sca* effects	Superior crosses for recombination breeding
1	Days to 50 % flowering	WGG-42, TM-96-2	-	-	-	-
2	Days to maturity	WGG-42	PM-115	WGG-42 × PM-115	1.88**	-
3	Plant height (cm)	MGG-351	WGG-37	MGG-351 × WGG-37	-1.90	MGG-351 × WGG-37
4	Number of branches/plant	MGG-351, LGG-460 TM-96-2	WGG-37 PM-112	MGG-351 × WGG-37 MGG-351 × PM-112 LGG-460 × WGG-37 LGG-460 × PM-112 TM-96-2 × WGG-37 TM-96-2 × PM-112	0.36* -0.87** 0.24 0.67** 0.01 0.47**	LGG-460 × WGG-37 TM-96-2 × WGG-37
5	Number of clusters/plant	MGG-351, LGG-460, TM-96-2	WGG-37	MGG-351 × WGG-37 LGG-460 × WGG-37 TM-96-2 × WGG-37	-0.09 0.46 -0.08	MGG-351 × WGG-37 LGG-460 × WGG-37 TM-96-2 × WGG-37
6	Number of pods/cluster	MGG-295, LGG-460	WGG-37	MGG-295 × WGG-37 LGG-460 × WGG-37	-0.17 0.23	MGG-295 × WGG-37 LGG-460 × WGG-37
7	Number of pods/plant	MGG-351, LGG-460, TM-96-2	WGG-37 PM-112	MGG-351 × WGG-37 MGG-351 × PM-112 LGG-460 × WGG-37 LGG-460 × PM-112 TM-96-2 × WGG-37 TM-96-2 × PM-112	-1.50 0.35 4.78** 5.57** -0.28 6.09**	MGG-351 × WGG-37 MGG-351 × PM-112 TM-96-2 × WGG-37
8	Number of seeds/pod	-	WGG-37	-	-	-
9	100 seed weight (g)	WGG-42	-	-	-	-
10	Dry weight/plant (g)	MGG-351, TM-96-2	WGG-37	MGG-351 × WGG-37 TM-96-2 × WGG-37	2.05* -0.77	TM-96-2 × WGG-37
11	Harvest index (%)	WGG-42 LGG-460	PM-112 PM-110	WGG-42 × PM-112 WGG-42 × PM-110 LGG-460 × PM-112 LGG-460 × PM-110	-1.88 -0.55 1.37 -1.16	WGG-42 × PM-112 WGG-42 × PM-110 LGG-460 × PM-112 LGG-460 × PM-110
12	Seed protein (%)	MGG-295	PM-115	MGG-295 × PM-115	-0.93**	-
13	Tolerance to MYMV score (1-9 scale)	WGG-42, LGG-460, TM-96-2	PM-110	WGG-42 × PM-110 LGG-460 × PM-110 TM-96-2 × PM-110	-0.15 0.22 0.25*	WGG-42 × PM-110 LGG-460 × PM-110
14	Seed yield/plant (g)	MGG-295, LGG-460 TM-96-2	WGG-37 PM-112	MGG-295 × WGG-37 MGG-295 × PM-112 LGG-460 × WGG-37 LGG-460 × PM-112 TM-96-2 × WGG-37 TM-96-2 × PM-112	-3.54** 0.24 1.08 1.03 2.08** 1.33	MGG-295 × PM-112 LGG-460 × WGG-37 LGG-460 × PM-112 TM-96-2 × PM-112

Electronic Journal of Plant Breeding, 7(3): 784-793 (September 2016)
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Table 5. The best heterotic cross combinations identified for yield and yield components based on *per se* performance, *sca* effects and standard heterosis

SI. No.	Characters	Best heterotic crosses	*Per se* performance	*Sca* effects	Standard heterosis	*Gca* status of parents
1	Days to 50 % flowering	MGG-351 × PM-115	35.00	-2.80**	-10.26**	Poor × Average
2	Days to maturity	MGG-351 × PM-115	64.50	-2.88**	-8.51**	Poor × Good
		TM-96-2 × WGG-37	66.50	-1.35*	-5.67**	Average × Average
3	Plant height (cm)	-	-	-	-	
4	Number of branches/plant	MGG-351 × WGG-37	2.50	0.36*	23.91*	Good × Good
		LGG-460 × PM-112	3.16	0.67**	37.61**	Good × Good
		TM-96-2 × PM-112	3.10	0.47**	34.78**	Good × Good
5	Number of clusters/plant	LGG-460 × PM-112	11.71	1.28*	18.88**	Good × Average
		TM-96-2 × PM-112	12.00	1.30**	21.83**	Good × Average
6	Number of pods/cluster	MGG-295 × PM-115	4.27	0.33*	19.47**	Good × Average
7	Number of pods/plant	MGG-351 × PM-115	43.38	6.22**	50.09**	Good × Average
		LGG-460 × WGG-37	46.60	4.78**	61.25**	Good × Good
		LGG-460 × PM-112	46.54	5.57**	61.04**	Good × Good
		TM-96-2 × PM-112	44.52	6.09**	54.07**	Good × Good
8	Number of seeds/pod	-	-	-	-	
9	100 seed weight (g)	-	-	-	-	
10	Dry weight/plant (g)	MGG-295 × PM-112	20.10	2.23**	23.69**	Average × Average
		MGG-351 × WGG-37	27.40	2.05*	68.62**	Good × Good
		MGG-351 × PM-115	28.90	6.91**	77.85**	Good × Average
		TM-96-2 × PM-112	21.65	3.36**	33.23**	Good × Average
11	Harvest index (%)	MGG-295 × PM-115	43.84	4.00**	22.94**	Average × Average
		MGG-295 × PM-110	43.13	2.35*	20.95**	Average × Good
12	Seed protein (%)	MGG-295 × PM-110	25.34	0.62*	4.17*	Good × Average
13	Tolerance to MYMV score (1-9 scale)	-	-	-	-	
14	Seed yield/plant (g)	MGG-351 × PM-115	15.80	3.16**	56.44**	Average × Average
		TM-96-2 × WGG-37	16.12	2.08**	59.55**	Good × Good