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Research Paper

Unearthing hybridization opportunities for augmenting biomass yield and harvest index in rajmash (*Phaseolus vulgaris* L.)

MT Gandhi[1], Manish Sharma[2*], MP Patel[2], NV Soni[1] and GS Dave[3]

[1]*Department of Genetics and Plant Breeding, CP College of Agriculture, SD Agricultural University. Gujarat-385506*
[2]*Pulses Research Station, SD Agricultural University, Gujarat- 385506*
[3]*Bio Science Research Centre, SD Agricultural University, Gujarat-385506*

***Corresponding author e-mail:** manisharmagpb@sdau.edu.in*

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ABSTRACT

In present study, 21 F_1 hybrids derived from crossing between seven female genotypes and three male testers following a line × tester mating design were evaluated for analyzing the component of genetic variation and heterosis of yield contributing traits. The components of variances due to *gca* and *sca* revealed the predominance of non-additive gene action for biomass and harvest index. The average better parent heterosis (BPH) and standard heterosis (SH) for Biomass yield (BY) was 43.71 and 114.67, respectively, and the average BPH and SH for the Harvest index (HI) was -13.04 and -20.45, respectively. The higher magnitude of the BPH and SH recorded for BY indicated that the scope for increasing the HI in Rajmash is limited and that further increases in productivity have to come mainly through enhanced BY. The parent RR-21-01 and GR 1 were good general combiners for biomass, TRCR 3, TRCR 2, SKAU-R-19 and RKR 1033 for harvest index. Cross combinations IPR-277-19 × HUR recorded positively significant *sca* effect for BY and IPR-277-19 × GR, TRCR 3 × GR 1, TRCR 2 × GR 1, IPR-205-19 × HUR, IPR-277-19 × GR 1, SKAU-R-19 ×RKR 1033, RR-21-01 × HUR and RR-21-12 × GR 1 for HI. These results demonstrate that the selection of parents should not only be based on per se performance but also on combining ability and heterosis for achieving genetic improvement in Rajmash,

***Key words*:** Biomass, Combining ability, Harvest index, Heterosis, Rajmash

INTRODUCTION

Rajmash (*Phaseolus vulgaris* L.) is one of the world's most important grain legume for direct human consumption (Goncalves *et al*. 2008). Rajmash serves as a valuable vegetable substitute due to its historical significance as a staple food in many developing nations, supplying essential plant-based protein to both rural and urban populations (Atilla *et al*. 2010). Its nutritional value is noteworthy, containing 25.81% crude protein, 72.42% carbohydrates, and 5.83 mg of iron. Furthermore, it possesses significant levels of ash content, crude fiber, and total sugars. The presence of amino acids like tryptophan and methionine, as well as phenolic compounds such as tannins and polyphenol oxides, contribute to its nutritional richness (Sood *et al*. 2003).

In general yield of pulses are low compared to cereals as they are grown under varied and stressed environmental conditions. Varietal disparities in terms of harvest index have been documented in pulse crops like peas and dry beans (Donald 1962, Wallace and Munger 1966). In any given environment, grain yield in any crop is a function of biomass (BY) and the harvest index (HI). The first factor that determines the harvest index is how well crops produce grain from dry matter. When compared to cereals, pulses are less effective at producing grain from assimilate because of the high energy cost of protein synthesis. Consequently, competition between reproductive and vegetative parts for photosynthesis causes a lower harvest index. Therefore, it produces disproportionately large vegetative growth and support lesser grains resulting in low yield levels. Therefore, grain yield can be increased either by increasing the BY or the HI, or both. For maximum yields to be attained, a pulse crop should have a high BY coupled with a high HI (Jain 1975, Jeswani 1986). The simultaneous improvement of biomass and harvest index has also been suggested by Singh (1987) as an approach to increase the genetic yield potential in chickpea. Similarly, for making yield improvement in lentil, it is very important to increase biological yield/plant, which had positive relationship with grain yield (Kumar and Srivastava 2015). Relatively little effort has been deliberately directed toward selection for, or evaluation of varieties on the basis of, variations in harvest index. There is evidence however that successful breeding of higher yielding varieties has arisen in part from unconscious selection for higher harvest index, particularly when reproductive organs are the plant fraction of economic interest (Wallace and Munger 1966), indicating that further improvement in terms of BY and HI is possible through the proper choice of the parents and by following an efficient breeding strategy.

Although there are various methods of choosing the most suitable parents for a breeding programme, there is no consensus on how best to choose parents that will produce high-yielding progenies, and the selection of parental genotypes remains one of the critical unanswered questions in plant breeding (Baker, 1984) despite the numerous theoretical and empirical studies that have been carried out to identify useful parents (Sharma and Sridevi 2016, Sharma and Shadakshari 2021). In terms of choosing the best time- and resource-efficient strategy, in principle, the selection of parents based on estimable parameters relevant to gene action should be preferred to the visual observation of desirable attributes to be improved (Arunachalam 1989), and a more rational approach is to select parents based on combining ability effects and F_1 heterosis.

Plant breeders can choose parental lines for crossing and get insight into the type of gene actions involved in the inheritance of HI and BY characteristics by using combining ability analysis. Therefore, present study was carried out for understanding the intricate interplay of gene action and heterosis for economically significant traits in Rajmash using high-yielding adapted Rajmash genotypes as parents with the following objectives: (1) to identify the predominant type of gene action governing BY and the HI, (2) to estimate the magnitude of heterosis, (3) to estimate combining ability effects.

MATERIALS AND METHODS

The experimental material chosen for this study consisted of three testers *viz*., GR 1, RKR 1033 and HUR and the 7 diverse genotypes used as lines *viz*., TRCR 3, TRCR 2, IPR 205-19, IPR 277-19, SKAU-R-19, RR-21-01 and RR 21-12 to develop 21 F_1 hybrids. The parents were selected based on their high yielding ability and variability for different yield attributes. These hybrids along with 10 parents were grown in a randomized block design with three replications at the Pulses Research Station, SDAU, Sardarkrushinagar, Gujarat. Geographically, it is situated at 24°19′26″ North latitude and 72°18′53″ East longitude with an altitude of 172.00 metres above the mean sea level. The soil of the experimental field was deep, light brown and sandy loam. The weather conditions during cropping period were normal and favourable for normal growth and development of the crop. Each entry was represented by a single row of 4 m length with a row to row spacing of 45 cm and plant to plant distance of 15 cm. Recommended production and protection practices were followed to ensure good crop growth. The observations were recorded for biological yield (BY) and harvest index (HI) on five randomly selected plants from each. The crop was harvested when the plants were completely dry. All harvested plant samples were then dried again uniformly under natural sunlight for one week. The total above-ground plant material, referred to as BY, was obtained by weighing the sun-dried plants. These were then threshed, cleaned and weighed to record grain yield (GRY). The HI was calculated following the standard formula (ratio of GRY to BY). The analysis of variance and general and specific combining ability (SCA) effects were estimated according to Kempthorne (1957). The significance of GCA and SCA effects were tested by t-tests utilizing the respective standard errors. The parents with positive significant GCA effects were defined as good combiners, whereas those with negative significant and non-significant GCA effects were designated poor combiners. The percentages of heterosis in F_1 over the better parent (BP) and standard parent (SP) were calculated using standard formulae. For each cross combination, relative better parent heterosis (BPH) and standard heterosis (SH) were calculated as (1) BPH = 100 × (F_1-BP)/BP and (2) SH = 100 × (F_1-SH)/SH. The significance of the heterosis value was identified by the t-test utilizing the error variance of the experiment. Variance analysis was done by using the means of investigated traits. The line × tester method (Kempthorne 1957, Singh and Chaudhary 1979) was followed to analyze genetic components of each characteristic using TNAUSTAT-Statistical package.

RESULTS AND DISCUSSION

The analysis of variance (Table 1) indicated significant discrepancy among hybrid for both BY and HI and among parents for HI. The variation due to parents versus that due to hybrids was significant for BY, indicating a substantial difference between parental and hybrid means. The ratio of general to specific combining ability variances was below the unity. However, the estimates of SCA variance were much higher than the GCA variance for both characters, indicating predominance of non-additive variance in controlling the expression of these characters. Similarly, Bhardwaj *et al*. (2009) reported a predominance of non-additive gene action for BY and Sharma *et al*. (2023) for HI.

GCA and per se performance

The per se performance and *gca* effects of the parents used in the study for BY and HI are given in Table 2. It was possible to select parents showing favorable *gca* for BY and HI, and the genotypes that proved to be good general combiners for BY on the basis of their desirable *gca* effects and per se performance are RR-21-01 among the females and GR 1 among the testers. The parents that showed favorable *gca* effect for HI were TRCR 3, TRCR 2, and SKAU-R-19 among the lines and RKR 1033 among the testers. These parents identified as good combiners that can be utilized in breeding programs aiming for improving these economic importance traits leading to enhance rajmash productivity. Similarly, Gadekar *et al.* (2013) recorded good general combiner for biomass yield in chickpea, and Kumar *et al.* (2017) for harvest index in blackgram.

Table 1. Analysis of variance for biomass and the harvest index characters in Rajmash

Source of variation	d.f.	Biomass	Harvest index
Replications	2	13.89	0.81
Genotypes	30	452.94**	150.47**
Parents	9	84.73	165.96**
Lines	6	75.35	227.86**
Testers	2	56.69	17.67**
Lines *vs*. Testers	1	197.13**	91.15
Crosses	20	209.62*	152.08**
Parents *vs*. Crosses	1	7713.95**	32.13
Error	60	40.52	1.44
σ^2 GCA		-83.033	6.81
σ^2 SCA		500.784**	27.8**
σ^2 GCA / σ^2 SCA		-0.166	0.24

Table 2. Per se performance of parents, estimates of GCA effects for biomass and harvest index in rajmash

Genotype	Biomass (g/plant)		Harvest index (%)	
	Mean	GCA	Mean	GCA
Females				
TRCR 3	43.60	-0.92	48.83	8.57**
TRCR 2	49.13	-9.62**	37.01	3.50**
IPR-205-19	38.97	-0.42	38.17	-2.33**
IPR-277-19	37.13	4.32	19.85	-9.25**
SKAU-R-19	33.93	-0.77	40.13	3.55**
RR-21-01	43.67	10.66**	33.22	-4.74**
RR-21-12	39.67	-3.25	35.68	0.69
Males				
GR 1	36.13	3.93*	42.53	-0.28
RKR 1033	39.13	-1.25	37.73	1.76**
HUR	30.57	-2.68	39.54	-1.48**

Heterosis and SCA

The per se performance of crosses, BPH, SH and estimates of *sca* effects for BY and HI are given in Table 3. The average BPH observed for BY was 43.71 and ranged from -7.73 to 87.07. The average SH observed for BY was 114.67 and ranged from 65.81 to 158.05. The average BPH and SH recorded for HI was -13.04 and -20.45, respectively and ranged from -50.13 to 16.23 for BPH and 56.45 to 13.92 for SH. Positive and significant heterosis was exhibited by 19 F_1 hybrids over better parent, twenty-one hybrids over standard check for biomass yield (Table 3). For harvest index two hybrid recorded significant and positive heterosis over better parent and only one hybrid recorded significant standard heterosis in desirable direction. The low levels of heterosis recorded for HI in our study as well as that of others under similar environmental conditions might be due to the high per se performance of the parents involved. The rationale for this is that heterosis depends on the mean performance of parents involved and, therefore, there can be a cross with high per se performance but low heterosis if parental performance is also high (Sharma and Shadakshari 2021). The previously mentioned findings concerning harvest index, coupled with the increased levels of better parent heterosis and standard heterosis identified for biomass yield in our present study, strongly imply that the potential to elevate the harvest index in rajmash and achieve further improvements in its productivity primarily hinges on enhancing biomass yield. These findings are similar to the observation made in chickpea (Hegde *et al*. 2007).

Certainly, the results obtained in this study unveil a promising avenue for the development of hybrid varieties in rajmash with the aim of augmenting biomass yield and ultimately enhancing its overall productivity. The observed direction and magnitude of heterosis underscore the potential benefits that hybridization could bring. However, the intrinsic challenges of rajmash's highly self-pollinating breeding system, coupled with the absence of available male sterile lines, stand as substantial impediments to the large-

Table 3. Per se performance, better-parent heterosis (BPH), standard heterosis (SH) and estimates of *sca* effects for biomass and harvest index in rajmash hybrids

Cross	Biomass (g/plant)				Harvest index (%)			
	Mean	BPH (%)	SH (%)	SCA	Mean	BPH (%)	SH (%)	SCA
TRCR 3 × GR 1	59.93	37.46 **	119.27 **	-1.76	39.61	-18.87 **	-12.5 **	-4.69**
TRCR 3 × RKR1033	58.13	33.33 **	112.68 **	1.63	51.57	5.62 **	13.92 **	5.23**
TRCR 3 × HUR	55.20	26.61 **	101.95 **	0.13	42.56	-12.83 **	-5.98 **	-0.54
TRCR 2 × GR1	55.60	13.16 **	103.41 **	2.61	42.73	0.47	-5.61 *	3.49**
TRCR 2 × RKR 1033	46.13	-6.11	68.78 **	-1.67	39.41	4.48	-12.94 **	-1.86*
TRCR2 × HUR	45.43	-7.53 *	66.22 **	-0.94	36.40	-7.93 **	-19.59 **	-1.63*
IPR-205-19 × GR 1	69.33	77.93 **	153.66 **	7.14	29.08	-31.63 **	-35.77 **	-4.33**
IPR-205-19 × RKR1033	47.80	22.15 **	74.88 **	-9.2*	36.28	-4.94	-19.86 **	0.84
IPR-205-19 × HUR	57.63	47.9 **	110.85 **	2.06	35.68	-9.75 **	-21.18 **	3.48**
IPR-277-19 × GR 1	62.87	69.29 **	130 **	-4.07	35.30	-17 **	-22.02 **	8.81**
IPR-277-19 × RKR 1033	56.67	44.8 **	107.32 **	-5.08	25.28	-33.76 **	-44.16 **	-3.24**
IPR-277-19 × HUR	69.47	87.07 **	154.15 **	9.15*	19.72	-50.13 **	-56.45 **	-5.57**
SKAU-R-19 × GR 1	63.13	74.72 **	130.98 **	1.29	34.73	-18.33 **	-23.28 **	-4.55**
SKAU-R-19 ×RKR 1033	62.23	59.03 **	127.68 **	5.57	46.65	16.24 **	3.05	5.33**
SKAU-R-19 × HUR	48.37	42.53 **	76.95 **	-6.86	37.30	-7.07 **	-17.61 **	-0.79
RR-21-01 × GR 1	67.33	54.2 **	146.34 **	-5.93	28.10	-33.93 **	-37.93 **	-2.9**
RR-21-01 × RKR 1033	70.13	60.61 **	156.59 **	2.05	32.03	-15.09 **	-29.25 **	-1.00
RR-21-01 × HUR	70.53	61.53 **	158.05 **	3.88	33.69	-14.78 **	-25.57 **	3.90**
RR-21-12 × GR 1	60.07	51.43 **	119.76 **	0.71	40.59	-4.56	-10.34 **	4.16**
RR-21-12 × RKR 1033	60.87	53.45 **	122.68 **	6.7	33.15	-12.12 **	-26.77 **	-5.31**
RR-21-12 × HUR	45.33	14.29 **	65.85 **	-7.41	36.37	-8.01 **	-19.66 **	1.15
Range		-7.73 to 87.07	65.81 to 158.05			-50.13 to 16.23	-56.45 to 13.92	
Mean	58.68	43.71	114.67		36.01	-13.04	-20.45	

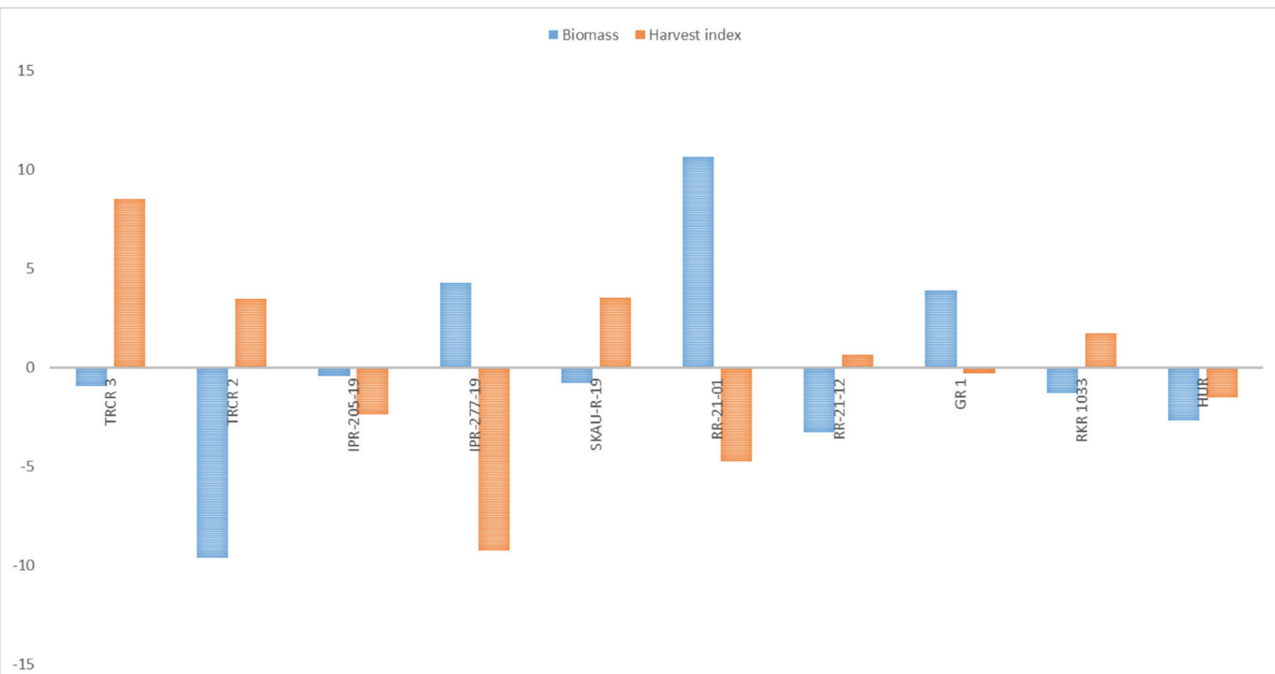

Fig. 1. gca effect of parents for biomass and harvest index

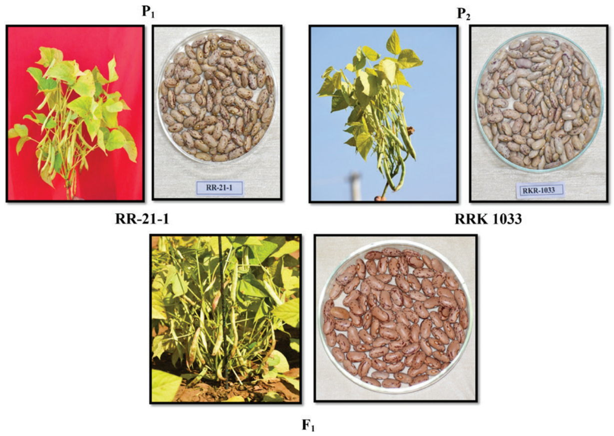

Fig. 2. Parents and their F_1

scale commercial production of hybrids. Notably, despite these challenges, the study identifies certain high-performing heterotic cross combinations that involve parents, where at least one exhibits commendable general combining ability. These specific combinations can yield superior F_6 progenies within rajmash, presenting an opportunity for their advantageous integration into breeding programs aimed at segregating productive pure lines. This strategy could serve as a workaround to the limitations of hybrid development in rajmash. Given the context, it's crucial to recognize that while heterotic response provides an estimation of potential hybrid performance, the realized value of per se performance should not be overlooked (Patel *et al*. 2021). This realization emphasizes the importance of considering both aspects when selecting cross combinations for further development. As such, a holistic approach that integrates both per se performance and heterotic response should guide the selection process, enabling more informed decisions in the pursuit of enhancing rajmash productivity and establishing superior lines for cultivation (Katiyar 1979).

The *sca* effects for BY and HI were found nonsignificant for most of the crosses. Only one cross IPR-277-19 × HUR recorded significant positive *sca* effect with significant positive BPH and SH for Biomass yield. Seven crosses TRCR 3 × RKR1033, TRCR 2 × GR1, IPR-205-19 × HUR, IPR-277-19 × GR 1, SKAU-R-19 × RKR 1033, RR-21-01 × HUR and RR-21-12 × GR 1 recorded positively significant *sca* effect for harvest index. Similar observation recorded by Reddy*et al.* (2004) in pigeon pea for biomass and Gadekar *et al.* (2013) for harvest index. The estimation of combining ability has illuminated the roles of specific parental lines in contributing to the superior performance of hybrids (Singh and Singh 2009, Sathya and Jayamani 2011). By identifying parents with strong general combining ability and hybrids with high specific combining ability for either trait, present experiment has laid the foundation for more targeted breeding strategies aimed at developing high-yielding rajmash varieties.

CONCLUSION

As the global demand for nutritious and high-yielding crops continues to rise, the insights gained from this study have significant implications for rajmash breeding programs. The potential for increasing biomass yield and optimizing harvest index offers a pathway towards sustainable agricultural practices and improved food security. In conclusion, our research underscores the importance of heterosis, and combining ability for HI and BY in shaping the productivity of rajmash crops. By applying these insights, we can drive forward the development of rajmash varieties that not only meet the demands of a growing population but also contribute to a more sustainable and resilient agricultural future.

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