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Study on Combining Ability of Organo-leptic Traits in Rice (*Oryza sativa* L.)

M. Hemalatha[1], S. Geetha[1]*, R. Saraswathi[1], M. Raveendran[2] and G. Hemalatha[3]
[1]Centre for Plant Breeding and Genetics,
Tamil Nadu Agricultural University, Coimbatore (Tamil Nadu), India.
[2]Director of Research, Tamil Nadu Agricultural University, Coimbatore (Tamil Nadu), India.
[3]Department of Food Science and Nutrition,
Community Science College and Research Institute, Madurai (Tamil Nadu), India.

(Corresponding author: S. Geetha)*
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ABSTRACT: Recent changes in the lifestyle of people have made a huge impact in the requirement for quality products both in terms of appearance and nutritional value. Although rice production reached self-sufficiency in most of the countries, the quality aspects of rice grains have taken a back seat which is gaining importance in recent time. Plant breeders have made quality as their second most important objective next to yield to suffice the growing population. The current study aims to examine the general combining ability of nine rice genotypes and the specific combining ability of every feasible cross for grain yield and organo-leptic traits in 20 F_1s produced via Line x Tester mating design to identify good parents and their specific hybrid combinations outperforming in terms of grain yield and quality. The estimates of SCA variance were revealed greater than GCA variance for all the characters except days to per cent flowering, L/B ratio, kernel length after cooking and kernel breadth after cooking, indicating the preponderance of non-additive gene action for all other traits. Among the parents, Pusa Basmati 1121, Pusa Basmati 1, RNR 15048 and Improved White Ponni were adjudged as the best general combiners for most of the organo-leptic traits and yield related traits. The cross combinations, *viz*., Pusa Basmati 1121 × Palawan and Pusa Basmati 1121 × TRY 3 were the ideal specific combiners for single plant yield and most of the organo-leptic traits. Out of all the hybrids, these two hybrids showed high kernel elongation without increase in kernel girth after cooking, intermediate amylose content, medium alkali spreading value and soft gel consistency along with adequate amount of yielding ability. Hence, the aforesaid cross combinations may be used in the upcoming breeding programmes to create a higher heterosis for yield and organo-leptic traits and this study may focus on the importance of quality breeding in rice.

Keywords: Rice, Combining ability, organo-leptic traits, Line x Tester, GCA, SCA, Recombination Breeding.

INTRODUCTION

Rice occupies a predominant role in satisfying the nutritional aspects of mankind. On a global scale, 525.96 million tonnes of rice were produced from 165.25 million ha of rice area during the year 2021 – 22 (Statista, 2021). In India, Rice is grown on an estimated 463 lakh ha of land yielding 129.47 million tonnes with an average productivity of 2798 kg/ha during 2021 – 22 (Indiastat, 2022). A day wouldn't be complete in majority of Asian countries without Rice. According to projections, the amount of rice required to meet the world's increasing population from 450 million tonnes in 2011 to around 490 million tonnes in 2020 and nearly 650 million tonnes by 2050, i.e., a 40% increase in rice production to keep up with the world's population growth (Rajendran *et al.*, 2021).

The relevance of grain quality concerns has increased in recent years, particularly in the nations that are self-sufficient in rice production. Increasing per capita income, improved living standards and changing lifestyle patterns led to changes in common man's consumption preferences towards high quality rice grains (Rao *et al.*, 2022). This calls for the inclusion of desired grain quality characteristics as the primary goal after yield improvement. Therefore, the solution to the impending food security dilemma along with lifestyle changes is the creation of high yielding cultivars with good organo-leptic grain properties. In both the local and foreign markets, superfine slender grains with superior cooking qualities, attractive aromas and high cooked kernel elongation when cooking will fetch outstanding prices (Kaur *et al.*, 2011). Physico-chemical characteristics and cooking properties are the best *indica*tors of grain quality. The majority of customers like rice with a soft to medium gel consistency, intermediate amylose concentration and an intermediate gelatinization temperature (Bhattacharya and Sowbhagya 1971, Sidhu *et al.*, 1975). Due to the escalation of varied nutritional demands and living standards of global populations, rice breeders' key concerns now centre on the look and quality of rice grains (Bazrkar-Khatibani *et al.,* 2019).

A successful breeding effort that finally leads to the production of cultivars with desirable attribute is built on the careful selection of suitable genotypes as parents for hybridization. One of the crucial techniques for choosing the ideal parents and cross combinations for the exploitation of heterosis is combining ability analysis (Rashid *et al.,* 2007; Sarkar *et al.,* 2002). It caters details on the nature and magnitude of gene effects (*gca* and *sca* effects) governing various traits. Although there have been several studies on combining ability analysis for yield and its component traits, studies including both yield and quality traits are getting into light in the recent times to explore more possible combinations of parents yielding hybrids with good yield and quality. With this background the present study was formulated to identify good parents, best and potent hybrids combining both grain yield and organo-leptic traits through the assessment of combining ability.

MATERIAL AND METHODS

The present investigation was undertaken during *Rabi* 2021 and *Kharif* 2022 at the Department of Rice, Centre for Plant Breeding and Genetics, Coimbatore. The experimental material comprised of nine genotypes *viz.,* Pusa Basmati 1121, Pusa Basmati 1, Improved White Ponni, BPT 5204 and RNR 15048 as lines (female) and TRY 3, TPS 5, Palawan (tropical *japonica*) and Azucena (tropical *japonica*) as testers (male). During *Rabi* 2021, nine genotypes were selected on the basis of their quality and quantitative traits for making F_1 crosses and all the genotypes were sown in nursery at ten days interval three times to ensure floral synchrony and transplanted in crossing block at 25 – 30 days after sowing. Hybridization was made in Line × Tester mating design by employing Dr. Ramiah method of crossing (Ramiah, 1941). Thus, the set of twenty rice hybrids were generated. During *Kharif* 2022, the twenty F_1s produced were raised along with the parents and checks at a spacing of 30 × 30 cm in 3 m rows in randomized block design with two replications. All the standard agronomical practices were followed during the entire crop growth period.

True F_1s were confirmed based on morphological observations and tagged to record biometrical observation *viz.,* days to first flowering (DFF), plant height (PH) (cm), panicle length (PL) (cm), number of productive tillers per plant (NPT), number of filled grains per panicle (NFG), thousand grain weight (TGW) (g) and single plant yield (SPY) (g) and grain organo-leptic traits i.e., kernel length (KL) (mm), kernel breadth (KB) (mm), kernel L/B ratio (L/B), kernel length after cooking (KLAC) (mm), kernel breadth after cooking (KBAC) (mm), linear elongation ratio (LER), breadthwise elongation ratio (BER), amylose content (AC) (%), gel consistency (GC) (as gel length measured in mm), alkali spreading value (ASV), water uptake ratio (WUR) and volume expansion ratio (VER). Kernel dimensional analysis was done and recorded as per the standard evaluation system of IRRI (1996). LER and BER were calculated as the ratio of mean length/breadth of cooked rice to mean length /breadth of milled rice respectively (Juliano and Perez, 1984). AC was determined in the rice flour by the simplified calorimetric method as described by Sowbhagya and Bhattacharya (1971). Incubating six kernels of whole rice in 10 ml of 1.7% KOH for 23h as per Little (1958) to assess the ASV and their degree of spreading was measured using a 7-point scale.

Combining ability analysis was carried out as per the model suggested by Kempthorne (1957) through TNAUSTAT (Manivannan, 2014). Character wise estimation of GCA effects of parental lines and SCA effects of cross combinations was carried out to ascertain the good combiners and good cross combinations (Sprague and Tatum, 1942). The significance of General Combining Ability and Specific Combining Ability effects were evaluated by t-test.

RESULTS AND DISCUSSION

A. Analysis of Variance (ANOVA) for combining ability

The current study was undertaken to find suitable genotypes to use as parents in hybridization programmes by evaluating the potential to combine yield and grain organo-leptic traits. Analysis of variance (ANOVA) for combining ability for yield related traits showed highly significant variation for the traits under study for hybrids, lines, testers and L x T interaction, proving that all the genotypes expressed significant differences for all the traits (Table 1). But the ANOVA for combining ability for the grain quality and organo-leptic traits revealed significant variation for hybrids for all the traits under study, for lines for all the traits under study except VER, for testers for all the traits under study except L/B ratio and VER and for L × T interaction, the traits, *viz.,* KL, KB, KLAC, KBAC, LER, BER and GC showed significant variation. This result was supported by the work of early researchers like (Ambikabathy *et al.,* 2021; Manivelan *et al.,* 2022; Shehab *et al.,* 2023; Vadivel, 2018).

B. Estimates of genetic components and proportional contribution by genotypes

The ratio of additive to dominance genetic variance was less than unity for all the traits except DFF, L/B, KLAC and KBAC (Table 2). This evidenced the preponderance of non-additive gene action for all the traits and DFF, L/B, KLAC and KBAC showed the ratio of additive to dominance genetic variance to be more than unity, i.e., exhibiting additive gene action. Therefore, DFF, L/B, KLAC and KBAC can be improved by employing simple pedigree selection.

Table 1: Analysis of variance (ANOVA) for combining ability for yield attributing and organo-leptic traits.

Sources of variation	df	DFF	PH	PL	NPT	NFG	TGW	SPY	KL	KB	L/B	KLAC	KBAC	LER	BER	AC	GC	ASV	WUR	VER
Replication	1	3.03	3.04	1.25	0.17	319.23	2.03	9.24	0.04	0.03	0.001	0.13	0.04	0.00	0.00	1.38	18.23	0.05	0.00	0.35
Hybrid	19	96.75**	367.00**	21.27**	44.66**	2346.57**	21.20**	353.05**	0.80**	0.02**	0.099**	9.17**	0.05**	0.09**	0.01**	30.55**	184.29**	0.79**	0.69**	0.18
Lines	4	93.54**	414.49**	77.28**	104.58**	5955.69**	65.74**	793.88**	2.96**	0.002	0.42**	40.14**	0.11**	0.34**	0.02**	9.28**	410.46**	2.52**	2.62**	0.35*
Testers	3	467.36**	1154.47**	3.17*	18.22*	1981.96**	4.81**	827.14**	0.40**	0.07**	0.02	2.16**	0.15**	0.08**	0.03**	179.61**	20.63**	1.59**	0.83**	0.09
L x T interaction	12	5.17**	154.31**	7.13**	31.30**	1234.69**	10.45**	87.58**	0.17**	0.02**	0.01	0.61**	0.01**	0.02**	0.01**	0.37	149.81**	0.01	0.01	0.14
Error	19	1.50	7.47	0.93	3.68	301.28	0.62	13.50	0.01	0.005	0.007	0.02	0.01	0.0002	0.001	0.47	0.86	0.01	0.01	0.11
σ^2 GCA		4.01	9.31	0.62	0.58	48.68	0.47	11.62	0.03	0.0002	0.004	0.38	0.002	0.004	0.0003	1.32	1.51	0.03	0.03	0.002
σ^2 SCA		1.84	73.42	3.10	13.81	466.70	4.92	37.04	0.08	0.0065	0.003	0.29	0.0002	0.014	0.002	-0.05	74.48	0.0008	-0.002	0.015
σ^2 GCA / σ^2 SCA		2.18	0.13	0.2	0.04	0.10	0.10	0.31	0.38	0.03	1.33	1.31	10	0.29	0.15	-26.4	0.02	37.5	-15	0.13

* - significant at 5% level, ** - significant at 1% level

Table 2: Estimates of genetic components for yield attributing and organo-leptic traits.

Source of variation	DFF	PH	PL	NPT	NFG	TGW	SPY	KL	KB	L/B	KLAC	KBAC	LER	BER	AC	GC	ASV	WUR	VER
Additive (F = 1)	8.02	18.62	1.24	1.17	97.35	0.94	23.24	0.05	0.0005	0.01	0.75	0.004	0.0069	0.001	2.64	3.02	0.07	0.06	0.003
Dominance (F = 1)	1.84	73.42	3.10	13.81	466.70	4.92	37.04	0.08	0.007	0.003	0.29	0.0002	0.0074	0.002	-0.05	74.78	0.001	-0.002	0.01
A / D	4.36	0.25	0.40	0.08	0.21	0.19	0.63	0.63	0.07	3.33	2.59	20.00	0.93	0.5	-52.8	0.04	70.00	-30.00	0.3

Similar results were observed by for the traits DFF, L/B and KLAC, Akanksha and Jaiswal (2019) for the traits DFF, KLAC and KBAC, Devi *et al.* (2017) and Behera *et al.* (2018) for KLAC and KBAC. While other traits were controlled by dominance and epistatic gene interaction offering scope for heterosis breeding by exploiting hybrid vigour and also these traits will not respond to simple pedigree selection and better segregating progenies has to be selected in later generations of breeding cycle. Parallel findings were obtained for the non-additive gene action of all the yield-related traits by previous researchers like Ambikabathy *et al.* (2021); AnandaLekshmi *et al.* (2020); Bano and Singh (2019); Manivelan *et al.* (2022); Shehab *et al.* (2023); Vadivel (2018). The proportional contribution to the total variance by lines, testers and interactions revealed that the testers and line x testers interaction have contributed more than lines for almost all the biometrical traits except PL (Fig. 1). The contribution for grain quality traits were mostly due to lines especially for KL, L/B ratio, KLAC, LER, ASV and WUR and remaining quality traits were contributed by testers and line x tester interaction (Fig. 1). This was supported by the literatures of Kargbo *et al.* (2019); Singh *et al.* (2019) and Nanditha *et al.* (2021) for all the yield related traits while the results of quality traits were concomitant with the results of Sreelakshmi and Babu (2017) for KL, L/B ratio, KLAC, LER, ASV, WUR and VER, Singh *et al.* (2019) for KL, KB, KLAC, KBAC, AC and GC, Manivelan *et al.* (2022) for the traits KB, L/B ratio, KBAC, BER, AC and GC.

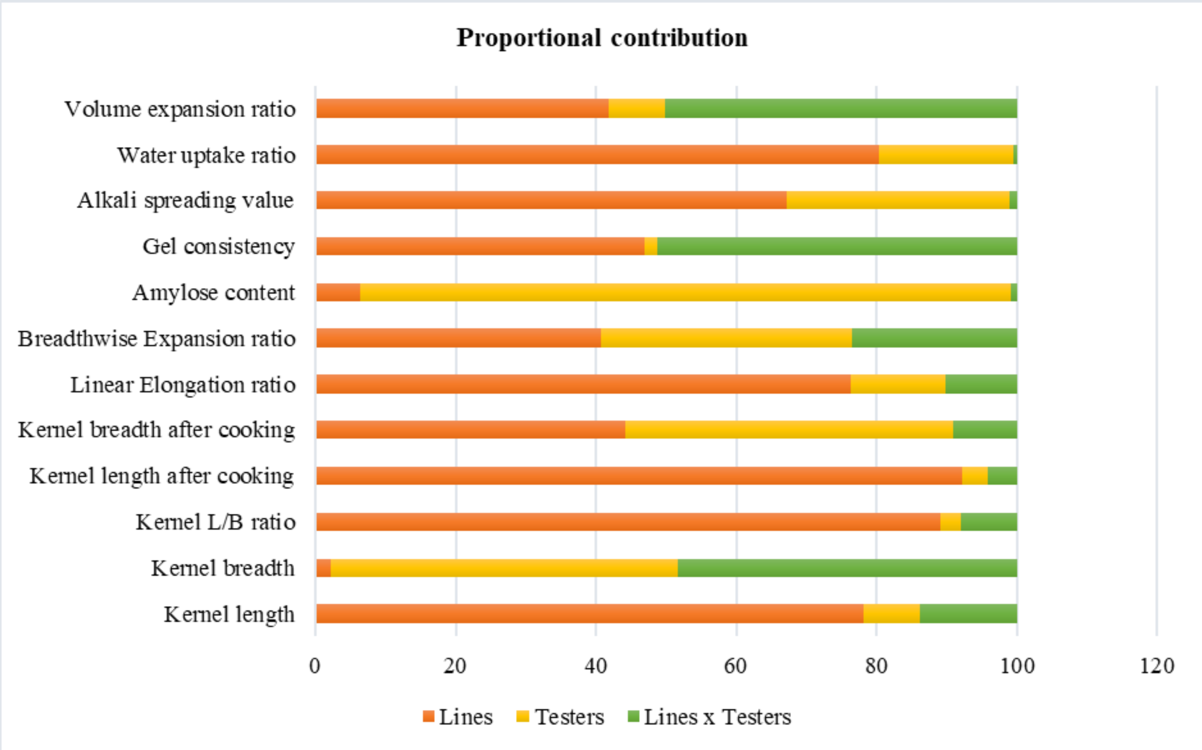

Fig. 1. Proportional contribution by lines, testers and line x tester for various yield attributing and organo-leptic traits.

C. Per se performance of parents and hybrids

The mean performance of parents and hybrids on different yield and grain quality traits were depicted in Table 3 and Table 4. Among parents, Pusa Basmati 1121, RNR 15048 and TPS 5 were found highly significant for DFF (early maturing), RNR 15048 and TPS 5 were found highly significant for PH (dwarf plants). The line Improved White Ponni showed significant mean values for NPT, NFG and SPY. The test weight was found significant in the lines Pusa Basmati 1121, Pusa Basmati 1 and the testers TRY 3 and Palawan. The grain dimensional traits KL, L/B ratio, KLAC, LER and ASV had significant mean values in the lines Pusa Basmati 1121 and Pusa Basmati 1, while these genotypes had significant mean values for KBAC and BER in the negative direction. AC was significant in the lines Improved white ponni, RNR 15048 and in the testers TRY 3 and TPS 5. GC was significant in the parents Improved white ponni, BPT 5204, RNR 15048, TRY 3 and Azucena.

The hybrids that show significant mean values for the traits studied were depicted in the Table 4. Among all the twenty hybrids, PB1121 × Palawan showed significant mean value for most of the yield related and grain quality traits. As per the mean significance, the hybrids *viz.*, Pusa Basmati 1121 × TRY 3, Pusa Basmati 1121 × TPS 5, Pusa Basmati 1121 × TPS 5, Improved white ponni x TPS 5, BPT 5204 x TPS 5, RNR 15048 × TPS 5 were adjudged as the early maturing hybrids and the hybrids, Pusa Basmati 1121 × Palawan, Pusa Basmati 1121 × Azucena, Pusa Basmati 1 × Palawan, Improved white ponni × Palawan, Improved white ponni × Azucena, RNR 15048 × TRY 3, RNR 15048 × TPS 5 and RNR 15048 × Palawan were found to be good yielders.

The length dimensions of kernel before and after cooking and LER were found significant in all the Basmati hybrid combinations which was similar to the work by Bano and Singh (2019); Behera *et al.* (2018) and Singh *et al.* (2019).

D. Estimation of combining ability effects of parents and hybrids

For both yield and quality attributes, the impacts of general combining ability (*gca*) and specific combining ability (*sca*) were calculated in the current investigation (Tables 5 and 6). While the *gca* has huge impact in identifying superior parents, *sca* aids in the discovery of desirable hybrid combinations. Negative *gca* and *sca* effects were regarded as desirable for DFF, PH, KB, KBAC and BER, while positive *gca* and *sca* effects were crucial for other traits. According the lines Pusa Basmati 1121, Pusa Basmati 1, RNR 15048 and the tester TPS 5 showed highly significant negative *gca* effect for DFF and therefore could be utilized for developing early duration varieties. Significant negative *sca* effects for DFF were observed by the hybrids, *viz.,* Pusa Basmati 1121 × TRY 3 and Pusa Basmati 1121 × TPS 5. Regarding plant height, the genotypes *viz.,* Pusa Basmati 1121, BPT 5204, TRY 3 and TPS 5 recorded desirable highly significant negative *gca* effect, hence could be best combiner for developing semi-dwarf varieties. Bano and Singh (2019) and Ananda Lekshmi *et al.* (2020) also found the parents suitable for earliness and dwarf plant type in their research work.

With regard to KB, KBAC and BER, all the lines except RNR 15048 showed significant negative *gca* for KB, Pusa Basmati 1121, Pusa Basmati 1 and RNR 15048 showed significant negative *gca* for KBAC and BER. The hybrids, *viz.,* Pusa Basmati 1121 × TPS 5 and Pusa Basmati 1121 × Palawan showed significant negative *sca* effect for KB. For the trait, KBAC and BER, the cross combinations namely Pusa Basmati 1121 × TRY 3 and Pusa Basmati 1121 × Palawan revealed significant negative *sca* effect. KB, KBAC and BER with negative significance with regard to *per se* performance, *gca* and *sca* effect led to genotypes that have fine grains and decreased cooked grain girth. This result was parallel to the findings of Bano and Singh (2019); Sreelakshmi and Babu (2017) and Manivelan *et al.* (2022).

Based on the *per se* performance and *gca* effects of the positive attributing traits with regard to yield, NPT showed positive significance in the line Improved White Ponni, NFG showed positive significance in the genotypes RNR 15048 and TPS 5, TGW showed positive significance in the line Pusa Basmati 1121 and SPY showed positive significance in the line Improved White Ponni. Hence these genotypes can be adjudged as best general combiners for the respective yield attributing traits. Parallel to these findings, the works of certain researchers (Ananda Lekshmi *et al.*, 2020; Bassuony and El Sherbiny, 2021; Hussein, 2021) identified superior parents for yield attributing traits. Based on the *per se* performance and *sca* effects, NPT showed positive significance in the hybrids Pusa Basmati 1121 × Azucena, Pusa Basmati 1 × TRY 3 and Pusa Basmati 1 × Palawan, NFG showed positive significance in the hybrids Pusa Basmati 1121 ×Palawan and RNR 15048 x TPS 5, TGW showed positive significance in Pusa Basmati 1121 × TPS 5, Pusa Basmati 1121 × Palawan and BPT 5204 × TRY 3 and SPY showed positive significance in Pusa Basmati 1121 × Palawan and Pusa Basmati 1121 × Azucena. These hybrids are therefore regarded as the best specific combiners for the yield related traits. Also, it was found that the idiotypic traits *viz.*, PL, NPT, NFG are contributed mainly by the tropical *japonica* testers used in the study. Thus, *indica* × *japonica* cross combinations were good yielders. The use of *japonica* types in yield improvement are reviewed by various researchers like Yano *et al.* (2019) and Donde *et al.* (2020).

With regard to organo-leptic traits of the grains, based on the *per se* performance and *gca* effects, it can be found that Pusa Basmati 1121 and Pusa Basmati 1 showed positive significance for the grain dimensional traits KL, L/B ratio, KLAC and LER, while AC was positively attributed by Improved White Ponni, RNR 15048, TRY 3 and TPS 5, GC was given positively by Improved White Ponni, BPT 5204, TRY 3and Azucena, ASV was positively loaded by Pusa Basmati 1121, Pusa Basmati 1, RNR 15048 and Palawan and WUR showed positive significance in Pusa Basmati 1121 and RNR 15048. These genotypes can be regarded as best general combiners for the respective organo-leptic traits. Based on the *per se* performance and *sca* effects, the hybrids Pusa Basmati 1121 × Palawan showed positive significance for all the grain dimensional traits KL, L/B ratio, KLAC and LER. GC was positively attributed by Pusa Basmati 1121 × TPS 5, Pusa Basmati 1121 × Azucena, Pusa Basmati 1 × Palawan, Pusa Basmati 1 × Azucena, Improved White Ponni × TRY 3, Improved White Ponni × TPS 5, BPT 5204 × Palawan and BPT 5204 × Azucena. Hence, these genotypes can be adjudged as the best hybrids for the grain dimensional traits and gel consistency. Unlike the yielding ability tropical *japonica* types were found to have poor organo-leptic grain properties, but the cross between *indica* and *japonica* in the current study led us to conclude that it may simultaneously improve yield while improving the quality attributes of *japonica* types. This was previously reported by Zhang *et al.* (2016) and Feng *et al.* (2017).

It was always said that high *sca* effects of hybrids result from the cross combination of parents with high x high (additive x additive), high × low (additive ×dominance), low × high (dominance × additive), low × low (dominance epistatic effect) *gca* effects (Ambikabathy *et al.,* 2019; Sudeepthi *et al.*, 2018). It was inadvertently found that the hybrids which showed high *sca* effects in the present study were formed from either of the following combination of parents having high and low *gca* effects in the order i.e., low × low, low × high, high × low or high × high. The cross-combination Pusa Basmati 1121 × Palwan showed high *sca* effects for most of the traits and fit into the combination of high × low especially for the grain dimensional traits. This was supported by the findings of Sreelakshmi and Babu (2017) and Bano and Singh (2019).

Table 3: Mean performance of parents for yield attributing and organo-leptic traits.

Parents	DFF	PH	PL	NPT	NFG	TGW	SPY	KL	KB	L/B	KLAC	KBAC	LER	BER	AC	GC	ASV	WUR	VER
LINES																			
Pusa Basmati 1121	98.00**	111.83	26.53	14.72	108.26	26.69**	30.93	8.10**	1.88	4.32**	19.65**	2.38**	2.43**	1.27**	21.97	86.85	6.75**	4.48**	4.72
Pusa Basmati 1	101.50	99.63	22.60	12.93	119.75	22.10**	32.93	7.39**	1.93	3.84**	15.03**	2.55	2.03*	1.33**	20.02	63.20	6.25**	1.97	4.26
Improved White Ponni	107.00	119.25	25.11	19.88*	226.23**	16.68	43.45**	5.63	1.78	3.17	11.05	2.85	1.96	1.61	23.98*	96.75**	5.00	2.26	3.93
BPT 5204	113.50	100.25	19.57	14.30	190.44	18.28	30.41	5.43	1.78	3.06	10.53	2.83	1.94	1.59	20.60	97.25**	4.00	2.51	3.56
RNR 15048	97.00**	96.37**	25.85	14.88	207.65*	12.83	21.42	5.63	1.83	3.08	8.53	2.53	1.52	1.38	23.89*	98.55**	6.19**	4.32**	4.22
Mean (Lines)	103.40	105.46	23.93	15.34	170.46	19.31	31.83	6.43	1.84	3.49	12.96	2.63	1.98	1.43	22.09	88.52	5.64	3.11	4.14
TESTERS																			
TRY 3	110.50	114.94	24.91	23.51	159.67	27.06*	36.21	4.95	2.65	1.87	6.25	2.90	1.26	1.10	24.20**	96.50**	4.00	2.17	5.90
TPS 5	87.00**	92.38**	23.02	15.35	260.58**	22.03	41.09	6.05	3.15	1.92	8.45**	3.45	1.40**	1.10	20.48**	78.35	3.00	2.98	5.40
Palawan	114.00	142.44	24.76	21.23	102.57	26.76*	29.95	5.13	3.08	1.67	6.10	3.13	1.19	1.02	8.91	62.45	5.00**	3.51**	5.91
Azucena	112.00	129.12	23.27	20.97	107.73	24.22	44.07	6.18	3.18	1.94	7.55*	3.30	1.22	1.04	7.36	85.65**	4.00	3.22*	5.63
Mean (Testers)	105.88	119.72	23.99	20.27	157.64	25.01	37.83	5.58	3.01	1.85	7.09	3.19	1.27	1.06	15.24	80.74	4.00	2.97	5.71
Mean (Parents)	104.50	111.80	23.95	17.53	164.76	21.85	34.49	6.05	2.36	2.76	10.35	2.88	1.66	1.27	19.04	85.06	4.91	3.05	4.84
SEd	**1.57**	**3.16**	**1.42**	**1.76**	**14.68**	**0.75**	**3.10**	**0.08**	**0.07**	**0.08**	**0.13**	**0.08**	**0.02**	**0.03**	**0.72**	**1.12**	**0.14**	**0.11**	**0.30**
CD at 5%	**3.22**	**6.48**	**2.92**	**3.60**	**30.09**	**1.54**	**6.36**	**0.15**	**0.15**	**0.16**	**0.26**	**0.17**	**0.04**	**0.06**	**1.49**	**2.30**	**0.28**	**0.23**	**0.62**
CD at 1%	**4.34**	**8.73**	**3.93**	**4.84**	**40.50**	**2.08**	**8.57**	**0.21**	**0.20**	**0.22**	**0.35**	**0.23**	**0.05**	**0.08**	**2.00**	**3.09**	**0.37**	**0.31**	**0.83**

* - significant at 5% level, ** - significant at 1% level

Table 4: Mean performance of hybrids for yield attributing and organo-leptic traits.

Hybrids	DFF	PH	PL	NPT	NFG	TGW	SPY	KL	KB	L/B	KLAC	KBAC	LER	BER	AC	GC	ASV	WUR	VER
Pusa Basmati 1121 / TRY 3	100.00*	125.41	30.73*	28.23	125.00	21.34	32.95	7.07**	2.50	2.65*	12.97**	2.70*	1.84**	1.07**	22.80**	60.00	5.30**	3.22	4.87
Pusa Basmati 1121 / TPS 5	94.00**	104.00**	30.27*	20.02	88.00	28.72**	37.25	6.49**	2.28	2.84**	12.82**	2.88	1.98**	1.25	21.10**	77.00*	4.89	3.63**	5.08
Pusa Basmati 1121 / Palawan	107.00	121.61*	25.19*	26.50**	202.50*	24.78**	72.40**	7.17**	2.49	2.88**	15.00**	2.62**	2.09**	1.05**	15.00	63.00	5.82**	4.01**	5.08
Pusa Basmati 1121 / Azucena	104.00	133.00	29.95	33.50**	165.00	23.63**	62.90**	6.61**	2.44	2.72**	12.99**	2.82	1.97**	1.15	13.96	80.00**	5.35**	3.88**	5.11
Pusa Basmati 1 / TRY 3	105.50	130.32	32.21	34.10**	142.00	20.45	34.95	6.10*	2.21*	2.76**	10.42**	2.81	1.71**	1.27	21.57**	77.00*	5.05	2.12	5.08
Pusa Basmati 1 / TPS 5	91.50**	112.24**	29.14	25.75	146.50	19.90	34.85	6.54**	2.42	2.70**	10.43**	2.82	1.60	1.16	20.64**	70.00	4.53	2.40	4.66
Pusa Basmati 1 / Palawan	107.00	150.67	31.18**	34.17**	131.50	19.36	51.95**	6.20**	2.37	2.63	11.59**	2.61**	1.88**	1.11**	13.84	86.00**	5.57**	2.77	5.08
Pusa Basmati 1 / Azucena	104.50	142.08	30.69*	27.24	176.00	21.58*	44.55	6.80**	2.58	2.63	11.17**	3.01	1.64	1.17	13.31	82.50**	5.08**	2.62	5.22
Improved White Ponni / TRY 3	107.50	129.44	23.18	22.50	174.50	19.13	37.10	5.20	2.21*	2.37	8.54	2.92	1.64	1.32	23.70**	88.00**	4.37	2.21	5.05

Improved White Ponni / TPS 5	96.00**	130.33	26.15	25.00	140.00	20.85	36.00	5.88	2.50	2.36	8.64	3.18	1.47	1.27	22.92**	80.00**	4.15	2.58	4.92
Improved White Ponni / Palawan	111.50	140.35	25.23	21.88	177.00	17.50	56.05**	5.32	2.38	2.23	9.63	2.90	1.81**	1.21	17.05	68.50	5.03	2.90	4.21
Improved White Ponni / Azucena	112.50	136.08	23.83	19.08	172.50	21.00	49.55**	5.88	2.47	2.38	9.22	3.09	1.56	1.25	14.96	66.50	4.41	2.70	4.39
BPT 5204 / TRY 3	111.00	107.84**	22.15	19.88	158.50	21.70*	25.70	5.15	2.22*	2.33	8.30	2.94	1.61	1.32	21.72**	82.50**	3.85	2.42	4.78
BPT 5204 / TPS 5	97.00**	104.50**	24.30	20.50	155.00	16.98	17.65	5.69	2.45	2.32	8.19	3.10	1.44	1.26	19.95	72.00	3.42	2.86	4.24
BPT 5204 / Palawan	113.00	133.57	21.67	21.00	177.50	15.55	25.70	5.25	2.41	2.18	9.42	2.80	1.80**	1.16	15.18	88.50**	4.56	3.11	4.78
BPT 5204 / Azucena	111.50	139.10	24.91	25.34	157.50	17.10	28.82	5.84	2.50	2.33	9.13	3.08	1.57	1.24	12.89	86.50**	3.99	2.91	4.51
RNR 15048 / TRY 3	102.50	119.24**	25.78	22.11	193.00	18.69	36.75*	5.33	2.32	2.30	7.52	2.87	1.41	1.24	23.83**	67.50	5.15*	3.30	4.94
RNR 15048 / TPS 5	90.50**	135.60	26.08	25.50	229.50**	14.97	38.85*	5.82	2.42	2.40	8.40	2.92	1.45	1.21	21.77**	62.50	4.62	3.58**	4.65
RNR 15048 / Palawan	105.50	140.17	28.75	21.68	212.50**	17.44	48.35*	5.34	2.43	2.20	7.30	2.68*	1.37	1.11**	16.86	65.00	5.51**	3.88**	4.95
RNR 15048 / Azucena	104.50	144.50	29.25	28.00	218.50**	18.62	45.95	5.88	2.50	2.35	7.94	2.88	1.35	1.15	15.07	62.50	5.11*	3.69**	4.96
Mean (Hybrids)	103.83	129.00	27.03	25.10	167.13	19.96	40.91	5.98	2.40	2.48	9.98	2.88	1.66	1.20	18.41	74.28	4.79	3.04	4.83
SEd	**1.57**	**3.16**	**1.42**	**1.76**	**14.68**	**0.75**	**3.10**	**0.08**	**0.07**	**0.08**	**0.13**	**0.08**	**0.02**	**0.03**	**0.72**	**1.12**	**0.14**	**0.11**	**0.30**
CD at 5%	**3.22**	**6.48**	**2.92**	**3.60**	**30.09**	**1.54**	**6.36**	**0.15**	**0.15**	**0.16**	**0.26**	**0.17**	**0.04**	**0.06**	**1.49**	**2.30**	**0.28**	**0.23**	**0.62**
CD at 1%	**4.34**	**8.73**	**3.93**	**4.84**	**40.50**	**2.08**	**8.57**	**0.21**	**0.20**	**0.22**	**0.35**	**0.23**	**0.05**	**0.08**	**2.00**	**3.09**	**0.37**	**0.31**	**0.83**

* - significant at 5% level, ** - significant at 1% level

Table 5: General combining ability effects of parents for yield attributing and organo-leptic traits.

Parents	DFF	PH	PL	NPT	NFG	TGW	SPY	KL	KB	L/B	KLAC	KBAC	LER	BER	AC	GC	ASV	WUR	VER
Pusa Basmati 1121	-2.58**	-8.00**	2.00**	1.96**	-22.00**	4.65**	10.46**	0.86**	-0.02*	0.29**	3.46**	-0.13**	0.31**	-0.07**	-0.19	-4.28**	0.55**	0.65**	0.20
Pusa Basmati 1	-1.70**	4.82**	3.78**	5.22**	-18.13**	0.36	0.66	0.43**	-0.01*	0.20**	0.92**	-0.07*	0.05**	-0.02*	-1.06**	4.60**	0.27**	-0.56**	0.18
Improved White Ponni	3.05**	5.05**	-2.44**	2.98**	-1.13	-0.34	3.76**	-0.41**	-0.02*	-0.15**	-0.98**	0.14**	-0.04**	0.07**	1.25**	1.48**	-0.30**	-0.44**	-0.19
BPT 5204	4.30**	-7.75**	-3.77**	-3.42**	-5.00	-2.13**	16.45**	-0.49**	-0.01*	-0.19**	-1.22**	0.10**	-0.05**	0.05**	-0.95**	8.10**	-0.83**	-0.22**	-0.25*
RNR 15048	-3.08**	5.87**	0.43	-0.78	46.25**	-2.54**	1.56	-0.39**	0.01*	-0.16**	-2.19**	-0.04*	-0.26**	-0.02*	0.98**	-9.90**	0.31**	0.58**	0.05
SE	0.43	0.97	0.34	0.68	6.14	0.28	1.30	0.03	0.02	0.03	0.05	0.03	0.01	0.01	0.24	0.33	0.04	0.03	0.12

TRY 3	1.48**	-6.55**	-0.22	0.27	-8.52	0.30	-7.42**	-0.21**	-0.11	0.00	-0.43**	-0.03	-0.02**	0.05**	4.32**	0.73*	-0.04	-0.38**	0.11
TPS 5	-10.02**	-11.67**	0.16	-1.74**	15.32*	0.32	-7.99**	0.11**	0.01	0.05	-0.29**	0.10**	-0.07**	0.03**	2.87**	-1.98**	-0.47**	-0.03	-0.12
Palawan	4.97**	8.27**	-0.63	-0.05	13.07*	-1.04**	9.98**	-0.12**	0.01	-0.06*	0.61**	0.16**	0.13**	0.07**	-2.82**	-0.08	0.51**	0.30**	-0.01
Azucena	3.58**	9.95**	0.69*	1.53*	10.77	0.42	5.44**	0.22**	0.09	0.01	0.11*	0.10**	-0.04**	-0.01	-4.37**	1.33**	0.00	0.12**	0.01
SE	0.39	0.86	0.30	0.61	5.49	0.25	1.16	0.02	0.02	0.03	0.04	0.03	0.005	0.01	0.22	0.29	0.03	0.03	0.11

* - significant at 5% level, ** - significant at 1% level

Table 6: Specific combining ability effects of hybrids for yield attributing and organo-leptic traits.

Hybrids	DFF	PH	PL	NPT	NFG	TGW	SPY	KL	KB	L/B	KLAC	KBAC	LER	BER	AC	GC	ASV	WUR	VER
Pusa Basmati 1121 / TRY 3	-2.72**	10.95**	1.92*	0.90	-11.60	-3.58**	-11.00**	0.44**	0.19**	-0.12*	-0.04	-0.02*	-0.01**	-0.11**	0.27	-10.73**	0.00	-0.08	-0.28
Pusa Basmati 1121 / TPS 5	-2.77**	-5.34*	1.08	-5.30**	-41.80**	3.78**	-6.13*	-0.45**	-0.15**	0.02	-0.34**	0.03	0.08**	0.09**	0.01	8.98**	0.02	-0.03	0.16
Pusa Basmati 1121 / Palawan	0.78	-7.66**	-3.22**	-0.51	44.30**	1.20*	11.05**	0.46**	-0.05**	0.17**	0.95**	-0.02*	0.11**	-0.21**	-0.39	-6.92**	0.03	0.03	0.05
Pusa Basmati 1121 / Azucena	-0.82	2.05	0.22	4.90**	9.10	-1.41*	6.09*	-0.45**	-0.09	-0.06	0.57**	-0.03	0.04**	0.03	0.11	8.68**	0.01	0.08	0.06
Pusa Basmati 1 / TRY 3	1.90*	3.05	1.62*	3.52*	1.52	-0.17	0.80	-0.10	-0.07	0.08	-0.05	0.03	0.02	0.05*	-0.09	-2.60**	0.04	0.02	-0.05
Pusa Basmati 1 / TPS 5	-0.60	-9.92**	-1.82*	-2.82	12.82	-0.74	1.27	0.03	0.02	-0.03	-0.19	-0.09	-0.04**	-0.05*	0.43	-6.90**	0.07	-0.04	-0.23
Pusa Basmati 1 / Palawan	-0.10	8.57**	1.00	3.90**	-30.58*	0.08	0.40	-0.09	-0.04	0.00	0.08	-0.04	0.04**	0.00	-0.68	7.20**	0.00	0.00	0.08
Pusa Basmati 1 / Azucena	-1.20	-1.70	-0.81	-4.60**	16.23	0.83	-2.46	0.17**	0.09	-0.05	0.16	0.11	-0.02*	-0.00	0.34	2.30**	0.02	0.02	0.20
Improved White Ponni / TRY 3	-0.85	1.94	-1.20	0.12	17.02	0.79	-0.15	-0.16**	-0.07	0.03	-0.04	-0.06	0.04**	0.01	-0.27	11.52**	0.08	-0.00	0.29
Improved White Ponni / TPS 5	-0.85	7.95**	1.40	4.63**	-10.68	0.91	-0.68	0.20**	0.10	-0.02	-0.08	0.06	-0.08**	-0.02	0.39	6.22**	0.13	0.01	0.40
Improved White Ponni / Palawan	-0.35	-1.97	1.26	-0.18	-2.07	-1.08	1.40	-0.13*	-0.02	-0.05	0.01	0.04	0.06**	0.02	0.21	-7.18**	0.03	0.01	-0.42
Improved White Ponni / Azucena	2.05*	-7.92**	-1.46*	-4.57**	-4.27	0.96	-0.56	0.09	-0.01	0.04	0.10	-0.03	-0.02	-0.01	-0.33	10.57**	-0.08	-0.02	-0.26
BPT 5204 / TRY 3	1.40	-6.86**	-0.89	-2.06	4.90	3.57**	8.66**	-0.12*	-0.06	0.04	-0.03	-0.01	0.02	0.03	-0.04	-0.60	-0.06	-0.02	0.09
BPT 5204 / TPS 5	-1.10	-5.09*	0.89	0.57	8.20	-1.17*	1.18	0.11*	0.04	-0.01	-0.29**	0.02	-0.09**	-0.01	-0.36	8.40**	-0.06	0.06	-0.22
BPT 5204 / Palawan	-0.10	4.05*	-0.96	-0.62	2.30	-1.25*	-8.74**	-0.11*	0.01	-0.06	0.06	-0.02	0.06**	-0.01	0.57	6.20**	0.09	-0.01	0.21
BPT 5204 / Azucena	-0.20	7.90**	0.96	2.12	-15.40	-1.16	-1.09	0.13*	0.01	0.04	0.27*	0.00	0.01	-0.00	-0.18	2.80**	0.03	-0.03	-0.08
RNR 15048 / TRY 3	0.28	-9.09**	-1.46*	-2.48	-11.85	0.96	1.70	-0.06	0.01	-0.02	0.16	0.07	0.04**	0.02	0.13	2.40**	0.10	0.07	-0.05

RNR 15048 / TPS 5	-0.23	12.39**	-1.55*	2.92*	31.45*	-2.78**	4.37	0.12*	-0.00	0.04	0.90**	-0.01	0.12**	-0.00	-0.48	0.10	-0.02	-0.01	-0.11
RNR 15048 / Palawan	-0.22	-2.98	1.91*	-2.59	-13.95	1.05	-4.10	-0.13*	-0.00	-0.06	-1.10**	-0.00	-0.16**	0.00	0.29	0.70	-0.10	-0.03	0.08
RNR 15048 / Azucena	0.17	-0.32	1.09	2.15	-5.65	0.77	-1.96	0.07	-0.01	0.03	0.04	-0.05	-0.00	0.02	0.05	-3.20**	0.01	-0.04	0.07
SE	0.87	1.93	0.68	1.36	12.27	0.56	2.60	0.05	0.05	0.06	0.09	0.06	0.01	0.02	0.48	0.65	0.07	0.06	0.23

* - significant at 5% level, ** - significant at 1% level

Table 7: Best parents and hybrids identified for various yield attributing and organo-leptic traits.

Sr. No	Characters	Best parents as per mean performance and gca effect	Best hybrids as per mean performance and sca effect	Hybrids chosen based on non-significant sca effects for recombination breeding
1	Days to 50% flowering	Pusa Basmati 1121 RNR 15048 TPS 5	Pusa Basmati 1121 / TRY 3 Pusa Basmati 1121 / TPS 5	Pusa Basmati 1 / TPS 5 RNR 15048 / TPS 5
2	Plant height	TPS 5	Pusa Basmati 1121 / TPS 5 Pusa Basmati 1121 / Palawan Pusa Basmati 1 / TPS 5 BPT 5204 / TRY 3 BPT 5204 / TPS 5 RNR 15048 / TRY 3	-
3	Panicle length	-	Pusa Basmati 1121 / TRY 3	Pusa Basmati 1121 / Azucena
4	No. of Productive tillers per plant	Improved White Ponni	Pusa Basmati 1121 / Azucena Pusa Basmati 1 / TRY 3 Pusa Basmati 1 / Palawan	-
5	No. of filled grains per panicle	RNR 15048 TPS 5	Pusa Basmati 1121 / Palawan RNR 15048 / TPS 5	-
6	Thousand grain weight	Pusa Basmati 1121	Pusa Basmati 1121 / TPS 5 Pusa Basmati 1121 / Palawan BPT 5204 / TRY 3	-
7	Single plant yield	Improved White Ponni	Pusa Basmati 1121 / Palawan Pusa Basmati 1121 / Azucena	BPT 5204 / Palawan BPT 5204 / Azucena
8	Kernel length	Pusa Basmati 1121 Pusa Basmati 1	Pusa Basmati 1121 / TRY 3 Pusa Basmati 1121 / Palawan Pusa Basmati 1 / Azucena	-
9	Kernel breadth		-	-
10	Kernel L/B ratio	Pusa Basmati 1121 Pusa Basmati 1	Pusa Basmati 1121 / Palawan	-
11	Kernel length after cooking	Pusa Basmati 1121 Pusa Basmati 1 Azucena	Pusa Basmati 1121 / Palawan	-
12	Kernel breadth after cooking	Pusa Basmati 1121	Pusa Basmati 1121 / TRY 3	-

			Pusa Basmati 1121 / Palawan	
13	Linear elongation ratio	Pusa Basmati 1121 Pusa Basmati 1	Pusa Basmati 1121 / TPS 5 Pusa Basmati 1121 / Palawan Pusa Basmati 1121 / Azucena Pusa Basmati 1 / Palawan Improved White Ponni / Palawan BPT 5204 / Palawan	-
14	Breadthwise expansion ratio	Pusa Basmati 1121 Pusa Basmati 1	Pusa Basmati 1121 / TRY 3 Pusa Basmati 1121 / Palawan	-
15	Amylose content	Improved White Ponni RNR 15048 TRY 3 TPS 5	-	-
16	Gel consistency	Improved White Ponni BPT 5204 TRY 3 Azucena	Pusa Basmati 1121 / TPS 5 Pusa Basmati 1121 / Azucena Pusa Basmati 1 / Palawan Pusa Basmati 1 / Azucena Improved White Ponni / TRY 3 Improved White Ponni / TPS 5 BPT 5204 / Palawan BPT 5204 / Azucena	Improved White Ponni / Azucena
17	Gelatinization temperature	Pusa Basmati 1121 Pusa Basmati 1 RNR 15048 Palawan	-	-
18	Water uptake ratio	Pusa Basmati 1121 RNR 15048	-	-
19	Volume Expansion ratio	-	-	-

E. Recombination breeding

Recombination breeding aids in the isolation of superior segregants which possess additive genetic variance which is fixable in subsequent generations. Through recombination breeding, it is possible to identify superior segregants by using hybrids with non-significant *sca* effects (lack of dominance) and parents with strong *gca* effects (presence of additive gene action). Significant *gca* effect was shown by the parents Pusa Basmati 1, RNR 15048 and TPS 5 for DFF. Among possible combinations, the crosses Pusa Basmati 1 × TPS 5 and RNR 15048 × TPS 5 showed non-significant *sca* effects. Hence, these crosses could also be utilized for getting early segregants. The use of recombination breeding in improving early segregants was previously reported by AnandaLekshmi *et al.* (2020); Bano and Singh (2019) and Nanditha *et al.* (2021). The panicle length was positively attributed by the parents Pusa Basmati 1121, Pusa Basmati 1 and Azucena while among the possible combinations, the hybrid Pusa Basmati 1121 × Azucena gave out non-significant *sca* effect. Hence this cross can be used to get segregants with good panicle length through recombination breeding. The genotypes Pusa Basmati 1121, Improved White Ponni, BPT 5204, Palawan and Azucena showed significant *gca* effects for SPY. Among the feasible cross combinations, BPT 5204 × Palawan and BPT 5204 × Azucena showed non-significant *sca* effects for the trait. Hence good yielding segregants can be obtained from these hybrids through recombination breeding. Similar findings were reported by Panchal *et al.* (2021) and Ramakrishna *et al.* (2022) for PL and SPY. Pusa Basmati 1, Improved White Ponni, BPT 5204, TRY 3 and Azucena are the parents with significant *gca* effects for GC while the cross Improved White Ponni × Azucena alone showed non-significant *sca* effects. Hence this hybrid combination can be used to obtain segregants with soft gel consistency using recombination breeding. Best parents, promising hybrids for heterosis breeding and potential hybrids for recombination breeding for each of the studied traits identified from this study are tabulated in the Table 7 and it can be seen that no parent or hybrid is best for all the traits studied.

CONCLUSION

To summarize we can see that the *indica* and *japonica* (Palawan and Azucena) genotypes used in the present study are having positive and negative sides in different aspects. The *indica* genotypes showed both good yielding capacity and organo-leptic properties, while the *japonica* genotypes showed only good plant type giving out yield but poor organo-leptic traits. The parents, Pusa Basmati 1121 and Pusa Basmati 1 gave out good performance with respect to grain dimensional properties, while the genotypes of *japonica* type (Palawan and Azucena) along with Improved White Ponni showed good plant types with desirable yielding ability. The cross combination, Pusa Basmati 1121 × Palawan showed good *per se* performance and *sca* effects for most of the studied yield attributing traits and the organo-leptic traits. The most important attribute of a premium marketable rice is that it must show good kernel elongation but with decreased breadthwise expansion while cooking, intermediate amylose content, medium alkali spreading value and soft gel consistency. This was providently made by the hybrids, Pusa Basmati 1121 × TRY 3 and Pusa Basmati 1121 × Palawan which can be forwarded to get still more superior recombinants with good yielding as well as good grain dimensional properties fetching premium price in the global rice market.

FUTURE SCOPE

This study has good future scope for forwarding the best cross combinations to further generations to identify superior recombinants with premium quality in rice grains.

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Author contributions. Conceptualization of research (SG); Designing of the experiments (MH, SG, RS, GH, MR); Contribution of experimental materials (SG, RS); Execution of field/lab experiments and data collection (MH); Analysis of data and interpretation (MH, SG); Preparation of the manuscript (MH, SG, RS).

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REFERENCES

Akanksha and Jaiswal, H. (2019). Combining ability studies for yield and quality parameters in basmati rice (*Oryza sativa* L.) genotypes using diallel approach. *Electronic Journal of Plant Breeding, 10*(1), 9-17.

Ambikabathy, A., Banumathy, S., Gnanamalar, R., Arunchalam, P., Jeyaprakash, P., Amutha, R. and Venkatraman, N. (2019). Heterosis and combining ability for yield and yield attributing traits in rice. *Electronic Journal of Plant Breeding*, *10*(3), 1060-1066.

Ambikabathy, A., Banumathy, S., Gnanamalar, R., Arunchalam, P., Jeyaprakash, P., Amutha, R. and Venkatraman, N. (2021). Studies on combining ability and heterosis for yield and drought tolerance traits in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding*, *12*(4), 1292-1299.

AnandaLekshmi, L., Geetha, S., Amudha, K., Muthuvijayaragavan, R. and Uma, D. (2020). Combining ability and gene action analysis for yield and yield attributing traits in rice (*Oryza sativa*. L). *Electronic Journal of Plant Breeding, 11*(03), 901-906.

Bano, D. A. and Singh, S. (2019). Combining ability studies for yield and quality traits in aromatic genotypes of rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding, 10*(2), 341-352.

Bassuony, N. N. and El Sherbiny, H. A. (2021). Line × Tester Analysis for grain yield and quality traits in Rice (*Oryza sativa* L.). *Egyptian Journal of Plant Breeding*, *25*(1).

Bazrkar-Khatibani, L., B. A. Fakheri, M. Hosseini-Chaleshtori, A. Mahender, N. Mahdinejad and J. Ali. (2019). Genetic mapping and validation of quantitative trait loci (QTL) for the grain appearance and quality traits in rice (*Oryza sativa* L.) by using recombinant inbred line (RIL) population. *International Journal of Genomics*, 2019.

Behera, M., Sharma, D., Singh, O. and Verma, R. (2018). Combining ability analysis for yield and quality related traits in non-basmati aromatic rice (*Oryza sativa* L.). *International Journal of Current Microbiology and Applied Sciences, 7*(10), 1908-1922.

Bhattacharya, K. and C. Sowbhagya. 1971. Water uptake by rice during cooking. *Cereal Science Today*, *16*(12), 420-424.
Devi, R. K., Parimala, K., Venkanna, V., Lingaiah, N. and Hari, Y. (2017). Gene action for yield and grain quality traits in rice (*Oryza sativa* L.).
Donde, R., Mohapatra, S., Baksh, S. Y., Padhy, B., Mukherjee, M., Roy, S., Chattopadhyay, K., Anandan, A., Swain, P. and Sahoo, K. K. (2020). Identification of QTLs for high grain yield and component traits in new plant types of rice. *PLoS One, 15*(7), e0227785.
Hussein, F. A. (2021). Heterosis and combining ability of some colored rice genotypes for yield characteristics and grain micronutrient content using Line × Tester analysis. *Journal of Plant Production*, *12*(6), 635-643.
Indiastat. (2022). State/Seaon - wise Area, Production and Productivity of Rice in India (2021-2022). Retrieved from https://www-indiastat-com/table/agriculture/state-season-wise-area-production-productivity-ric/1440252
IRRI. (1996). *Standard evaluation system for rice*: IRRI, International Rice Research Institute.
Juliano, B. and Perez, C. (1984). Results of a collaborative test on the measurement of grain elongation of milled rice during cooking. *Journal of Cereal Science, 2*(4), 281-292.
Kargbo, S. S., Showemimo, F., Akintokun, P. and Porbeni, J. (2019). Combining ability analysis and gene action for yield and yield related traits in rice (*Oryza sativa* L.) under saline conditions. *Journal of Plant Breeding and Genetics, 7*(2), 63-74.
Kaur, S., P. S. Panesar and M. B. Bera (2011). Studies on evaluation of grain quality attributes of some basmati and non-basmati rice cultivars. *Journal of Food Quality*, *34*(6), 435-441.
Kempthorne, O. (1957). *An introduction to genetic statistics*.
Little, R. R. (1958). Differential effect of dilute alkali on 25 varieties of milled white rice. *Cereal Chem., 35*, 111-126.
Manivannan, N. (2014). TNAUSTAT-Statistical package. In.
Manivelan, K., Hepziba, S. J., Suresh, R., Theradimani, M., Renuka, R. and Gnanamalar, R. (2022). Combining ability and heterosis for yield and grain quality characters in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding, 13*(2), 410-418.
Nanditha, R., Pushpam, R., Geetha, S., Surendar, K. K. and Ganesamurthy, K. (2021). Assessment of combining ability, gene action and heterosis for yield and grain characters in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding, 12*(3), 976-982.
Panchal, R., Mistry, P., Patel, P. and Lad, Y. (2021). Determination of Combining ability for Yield and its Attributes in Rice (*Oryza sativa* L.). *Journal of Agriculture Research and Technology, 46*(2), 128.
Rajendran, P. A., Devi, J. N. and Prabhakaran, S. V. (2021). Breeding for grain quality improvement in rice. In *Plant Breeding-Current and Future Views*: IntechOpen.
Ramakrishna, T., Krishna, L., Mohan, Y. C., Shankar, V. G. and Naik, D. S. (2022). Studies on gene action and combining ability in rice (*Oryza sativa* L.) hybrids. *Electronic Journal of Plant Breeding, 13*(4), 1312-1318.
Ramiah, K. (1941). Agriculture: Plant Breeding and Genetical Work in India. *Current Science, 10*(3), 151-153.
Rao, C. R., Raju, B., Josily, S., Rao, A., Kumar, R. N., Rao, M. S., Swapna, N., Siva, G. S., Meghana, Y. and Prabhakar, M. (2022). Impact of climate change on productivity of food crops: a sub-national level assessment for India. *Environmental Research Communications*, *4*(9), 095001.
Rashid, M., Cheema, A. A. and Ashraf, M. (2007). Line × tester analysis in basmati rice. *Pakistan Journal of Botany, 39*(6), 2035-2042.
Sarkar, C. G., Zaman, F. and Singh, A. (2002). Genetics of fertility restoration of'WA'based cytoplasmic male sterility system in rice (*Oryza sativa* L.) using basmati restorer lines. *Indian Journal of Genetics and Plant Breeding, 62*(04), 305-308.
Shehab, M. M., El-Naem, S. A., Daher, E.-H. M. and Hamed, H. S. (2023). Estimation of combining ability and heterosis for grain yield, yield components and some grain quality traits in rice under water deficit conditions. *Egyptian Journal of Agricultural Research, 101*(2), 438-460.
Singh, R., Pandey, D. P. and Kumari, A. (2019). Combining ability and gene action studies for physiological, phenological and yield traits in rice (*Oryza sativa* L.). *Journal of Cereal Research, 11*(3), 231-241.
Sowbhagya, C. and Bhattacharya, K. (1971). A simplified colorimetric method for determination of amylose content in rice. *Starch-Stärke*, *23*(2), 53-56.
Sprague, G. F. and Tatum, L. A. (1942). General vs. specific combining ability in single crosses of corn *Agronomy journal*, *34*(10), 923-932.
Sreelakshmi, C. and Babu, P. R. (2017). Combining ability analysis for grain quality traits in Rice (*Oryza sativa* L.). *The Journal of Research, ANGRAU, XLV*(4), 24-28.
Statista. (2021). World Rice acreage from 2012 to 2021. Retrieved from https://www.statista.com/statistics/271969/world-rice-acreage-since-2008/worldwide.
Sudeepthi, K., Jyothula, D. and Suneetha, Y. (2018). Heterosis and combining ability studies for yield and yield component traits in rice (*Oryza sativa* L.). *Int. J. Curr. Microbiol. App. Sci.*, *7*(10), 1205-1211.
Vadivel, K. (2018). Studies on combining ability and heterosis in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding, 9*(3), 1115-1121.
Yano, K., Morinaka, Y., Wang, F., Huang, P., Takehara, S., Hirai, T., Ito, A., Koketsu, E., Kawamura, M. and Kotake, K. (2019). GWAS with principal component analysis identifies a gene comprehensively controlling rice architecture. *Proceedings of the National Academy of Sciences, 116*(42), 21262-21267.

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