



Genetic variability and association studies of grain quality traits in rice (*Oryza sativa*) in irrigated ecology

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ABSTRACT

Rice (*Oryza sativa* L.) grain quality traits are important for milling, cooking, physico-chemical and nutritional aspects. Three hundred thirty-three genotypes consisting of both germplasm and advanced lines of rice were evaluated during rainy (*khari*) seasons of 2021 and 2022 at ICAR-Central Rice Research Institute, Cuttack, Odisha to study variability, heritability and correlation coefficients of different grain quality traits at genotypic and phenotypic. The study revealed significant variations among all the quality traits studied. The rice grain quality characters, viz. kernel length to breadth ratio, water uptake and gel consistency were found to have high estimates of genotypic coefficients of variation and phenotypic coefficients of variation. Kernel length (99.13% and 32.66%), kernel breadth (98.99% and 23.08%), kernel length to breadth ratio (99.11% and 41.43%), alkali spreading value (65.90% and 27.01%), water uptake (87.46% and 39.25%), kernel length after cooking (97.49% and 33.35%) and gel consistency (99.22% and 47.72%) were found to show high heritability and genetic advance for respective year. The grain quality traits with high heritability and medium genetic advance values such as head rice recovery (99.54% and 15.14%), amylose content (80.89% and 13.033%) and linear kernel elongation ratio (91.55% and 13.44%) indicated mixed gene action of both additive and non-additive effects suggesting phenotypic selection is reliable with a slow progress. There was significant positive association of kernel length after cooking with linear kernel elongation ratio and kernel length to breadth ratio; alkali spreading value with water uptake and kernel length; and hulling percentage with milling percentage and head rice recovery percentage suggesting that these traits are of prime importance in future rice breeding to improve quality traits.

Keywords: Correlation, Genetic advance, Grain quality, Heritability, Variability

Rice (*Oryza sativa* L.) is a principal staple grain for more than 50% people of world and it has a pivotal importance in the sustenance and stability of food, economic and social security of major Asian agrarian countries (Jabeen *et al.* 2023, Hashim *et al.* 2024). India got rid of food grain deficit and became food surplus country with the success of green revolution during late 1970s. Increase in per capita income and purchase power of people enabled them for preference and choice for diverse quality food and living standards. Although there is a consistent demand for increase in total rice production and productivity for growing global population, there is steady market demand for high quality rice (Sultana *et al.* 2022, Zafar and Jianlong 2023). Thus, there is need to produce more quality rice from less available resources by minimising the production and post-harvest loss

and increasing the efficiency of biomass production with enhanced nutritional and other grain quality attributes. Rice is maximally eaten as whole grain and due to this aspect, grain quality consideration in rice is most important (Hossain *et al.* 2009). Quality rice refers to the physicochemical characteristics of rice grain such as grain shape, size, general appearance and uniformity (Cruz and Khush 2000), milling efficiency, cooking properties, aroma, chemical behaviour and nutritional factors. The chemical properties of rice such as gel consistency, amylose content and gelatinisation temperature directly influence the physico-chemical, cooking and eating properties in rice (Little *et al.* 1958).

In different parts of the world, rice grain quality preference is very diverse and distinct (Juliano *et al.* 1964). In China, people prefer sticky rice while Indian citizens like non-sticky medium slender grains with aroma or without aroma according to the cuisine of food. The rampant use of white rice made many rice eating people worldwide prone to diabetes due to high glycaemic index. In this regard, India and Indonesia are striving for developing rice varieties with high amylose content

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to manage a low glycaemic index which would maintain the blood glucose level in diabetic patients. It is most important to evaluate the genetic variation present in a population with relation to quality traits to integrate the desired potential traits in development of transgressive high yielding quality rice (Pandey *et al.* 2021). The grain quality traits of rice are most complex aspect and hence, it surmounts to study the association of different grain quality traits to develop a successful consumers' preferred variety (Singh *et al.* 2022). In this experiment, an attempt has been made to study the genetic variations and the associations of different quality traits in a diverse set of rice germplasm including both aromatic and non-aromatic accessions in irrigated ecology.

MATERIALS AND METHODS

This investigation was conducted during rainy (*kharif*) 2021 and 2022 season at ICAR-Central Rice Research Institute (CRRI), Cuttack (20.45°N, 85.93°E; at an elevation of 23.5 m amsl), Odisha. The experimental material contained 333 rice genotypes which included both aromatic and non-aromatic landraces, and varieties collected from ICAR-National Bureau of Plant Genetic Resources, Cuttack Base Centre; ICAR-CRRI, Cuttack; and Odisha University of Agriculture and Technology, Bhubaneswar. The genotypes were transplanted in a randomised block design with each treatment replicated thrice. Thirty days old rice seedlings were transplanted in field containing three rows of 3.0 m length with spacing of 0.2 m × 0.15 m in shallow lowlands. Basal dose and top dressing of fertiliser were applied with a dose of 60 kg N, 30 kg P₂O₅ and 30 kg K₂O/ha following the standard crop management practices in rice. After maturity, seeds were harvested separately replicationwise from each entry and packed in cotton cloth, dried to 14% moisture content and stored for breaking of seed dormancy.

Rice seeds (100 g of each sample) were de-husked by Sateke dehuller and polished in Sateke polisher. The obtained seeds after polishing were used for analysis of 14 grain quality traits such as hulling yield (HULL%), milling yield (MILL%), head rice recovery (HRR%), moisture content (%), kernel length (KL) (mm), breadth of the kernel (KB) (mm), ratio of kernel length to breadth (L/B Ratio), alkali spreading value (ASV), water uptake (WU) (g/100 g seeds), volume expansion ratio (VER), kernel length after cooking (KLAC) (mm), linear kernel elongation ratio (ER), apparent amylose content (AC%) and gel consistency (GC) (mm) following the standard protocols for analysis of each trait at Grain Quality Laboratory, ICAR-CRRI, Cuttack.

The analysis of variance (ANOVA) was estimated following the method of Federer (1956). The phenotypic and genotypic coefficients of variations were estimated by the methods of Burton and Devane (1953). The heritability (h^2_b in broad sense), genetic gain by genetic advance (GA), genetic advance by percent of mean (GAM), and correlation coefficients were estimated as per Burton and Devane (1953), Johnson *et al.* (1955), Comstock and Robinson (1952) and Searle (1961), respectively.

RESULTS AND DISCUSSION

The ANOVA revealed presence of highly significant variations among all the 14 grain quality traits across all genotypes (Ahmed *et al.* 2020). The genotypes with highest value of grain quality trait studied are mentioned in Table 1.

It was noted that the genotypes CR Dhan 101, Pooja, Jaya, Dharitree, Tapaswini, Basantibhog, Tulasibasa, Swarnakranti, IET25450 and Kakhru (Table 2) possessed correspondingly required effect of important quality traits, i.e. intermediate values for amylose content, gel consistency and alkali spreading value, grain superiority for higher kernel length during cooking and ratio of kernel length after cooking to kernel length before cooking. The intermediate ASV of 4–5 of 133 genotypes in this investigation showed medium disintegration of rice kernels by alkali digestion is a highly important quality trait in rice and similar observation was reported by Bansal *et al.* (2006).

All the phenotypic coefficient of variation (PCV) estimates in this study were found to be higher than their corresponding genotypic coefficient of variation (GCV) estimates, and there was very little difference between PCV and GCV (Table 3) which explained better correspondence

Table 1 Rice genotypes with highest observed estimates of quality traits

Sl no.	Quality trait	Name of genotype	Highest observed trait estimates	Aromatic/Non-Aromatic
1.	Hulling percentage	IET25469	81.5%	Aromatic
2.	Milling percentage	IET25444	74.77%	Non-aromatic
3.	Head rice recovery	Naveen	67.61%	Non-aromatic
4.	moisture content	Vanaprova	13.32%	Non-aromatic
5.	Kernel length	Sugandhadhan	9.2 mm	Aromatic
6.	Kernel length after cooking	Sugandhadhan	17.09 mm	Aromatic
7.	kernel breadth	Mugudhi	2.53 mm	Aromatic
8.	kernel length to breadth ratio	Geetanjali	4.979	Aromatic
9.	Alkali spreading value	Nababi, Kalakrushna 2	7	Aromatic
10.	Water uptake	IET25460	338.33 g/100 g	Aromatic
11.	Volume expansion ratio	IET25465	5.383	Aromatic
12.	Kernel elongation ratio	Taraori Basmati	2.16	Aromatic
13.	Amylose content	IC280581	28.29%	Aromatic
14.	Gel consistency	IET25472	82 mm	Aromatic

Table 2 Rice genotypes with best overall grain quality traits

Genotype	Hulling (%)	Milling (%)	HRR (%)	ASV	KLAC (mm)	ER	AC (%)	GC (mm)
CR Dhan 101	78.03	69.23	55.03	4.7	9.59	1.71	21.54	54.0
Pooja	77.53	68.77	64.49	4.8	9.443	1.72	23.37	59.7
Jaya	80.20	69.23	64.18	4.8	9.397	1.71	23.61	43.6
Dharitree	80.67	71.20	66.97	4.0	8.64	1.79	23.75	43.5
Tapaswini	80.33	69.07	62.33	4.2	10.897	1.7	23.6	45.4
Basantibhog	81.20	70.47	63.13	4.5	10.2	1.84	23.83	59.6
Tulasibasa	81.33	70.53	62.97	4.8	8.513	1.89	23.85	40.4
Swarnakranti	79.10	69.37	54.53	4.8	10.383	1.96	21.09	52.6
IET 25450	80.57	67.60	56.91	4.5	10.937	1.75	21.40	55.3
Kakhru	79.37	67.07	53.47	5.0	10.977	2.03	20.03	55.7

HRR, Head rice recovery; ASV, Alkali spreading value; KLAC, Kernel length after cooking; ER, Linear kernel elongation ratio; AC, Amylose content; GC, Gel consistency.

between PCV and GCV for grain quality traits in rice (Umamaheswar *et al.* 2024). This indicated that GCV mainly contributed to the PCV of each trait or the environmental component of variance is non-significant which is also evident from the high heritability values of traits. There was wide variation in the ranges of PCV and GCV estimates i.e. from 2.06% for hulling percentage to 23.35% for gel consistency and from 2.01% for hulling percentage to 23.26% for gel consistency. High estimates of PCV and GCV were recorded for gel consistency (23.348% and 23.257%), water uptake (21.785% and 20.373%), and L/B ratio (20.202% and 20.201%). Similar reports of high value estimates of GCV and PCV were corroborated in earlier reports (Chaudhari *et al.* 2007) in gel consistency and water uptake but Bandi *et al.* (2018) reported high estimates of PCV and GCV for gel consistency and moderate PCV and GCV for water uptake and low PCV and GCV for L/B ratio. Simple selection would be effective on these traits as they possess high degree of variation as evidenced from high PCV and GCV value. Low GCV and PCV values less than 10% were reported for the traits such as hulling percentage, milling percentage, head rice recovery, moisture content, linear kernel elongation ratio and amylose content. Allam *et al.* (2015) and Bandi *et al.* (2018) reported lower estimates of PCV and GCV for hulling percentage, milling percentage, head rice recovery percentage and kernel elongation ratio while Subbaiah *et al.* (2011) reported similar results for amylose content. Similarly Bhargavi *et al.* (2022) reported low PCV and GCV estimates for hulling percentage, milling percentage and volume expansion ratio. These traits having both low PCV and GCV estimates are believed to have narrow genetic base, and the genetic variability could be widened by mutagenesis or hybridisation. Moderate GCV and PCV of 10–20% range was found for ASV, KL, KB, VER and KLAC and similar moderate GCV and PCV estimates were earlier reported by Kundu *et al.* (2008)

and Gangashetty *et al.* (2013) for KL and KB, Subbaiah *et al.* (2011) for KLAC and Bandi *et al.* (2018) for volume expansion ratio. Presence of moderate degree of variations for these traits indicated that these traits could be improved by exploiting through selection in advanced generations.

Broad sense heritability (h^2_b) contains both additive (fixable) as well as dominant and epistatic (non-fixable) variances and provides reliable information about the reproducibility of the traits. High heritability (>60%) plus genetic advance by percentage of mean > 20% were observed for the traits such as kernel length (99.13% and 32.66%) (Table 3), kernel breadth (98.99% and 23.08%), kernel length to breadth ratio (99.11% and 41.43%), alkali spreading value (65.90% and 27.01%), water uptake (87.46% and 39.25%), kernel length after cooking (97.49% and 33.35%) and gel consistency (99.22% and 47.72%), respectively. These traits could be selected directly and effectively on its phenotypic performance as these traits are governed by additive genes which are highly stable across environments. These results corresponded similarly with the findings of Nayak *et al.* (2003), Sanjukta *et al.* (2007) and Dhanavath *et al.* (2025) for the trait of water uptake; and Chacko *et al.* (2023) and Umamaheswar *et al.* (2024) for the traits of kernel breadth and L/B ratio.

Hulling percent, milling percentage and moisture content recorded estimates of high heritability and low genetic advance suggested that these traits were under more influence of environmental factors and having non-additive gene action. This was supported by earlier report of Sanjukta *et al.* (2007) for hulling percentage. Phenotypic selection of these traits is avoided because these traits are controlled by non-additive gene action of dominance or epistatic effects rather than additive effects resulting very low or negligible genetic advance in next generation. High heritability and moderate genetic advance estimates were observed for head rice recovery (99.54% and 15.14%),

Table 3 Estimation of genetic parameters for yield and its component characters in 333 genotypes of rice

Statistical measure	HULL%	MILL%	HRR	MC%	KL	KB	L/B Ratio	ASV	WU	VER	KLAC	ER	AC	GC
Mean	78.466	67.771	58.747	12.275	5.933	2.123	2.835	5.104	180.144	3.928	10.382	1.753	23.506	45.752
Range	73.4–81.8	57.8–75.0	40.59–68.3	10.06–13.76	3.58–9.72	1.58–2.53	1.46–5.48	3–7	115–350	2.25–5.43	6.42–17.69	1.38–2.21	18.7–28.36	22.8–82
SE(m)	0.166	0.252	0.176	0.061	0.051	0.014	0.031	0.342	8.022	0.178	0.158	0.021	0.464	0.545
SE(d)	0.235	0.356	0.248	0.086	0.072	0.019	0.044	0.484	11.345	0.251	0.223	0.03	0.656	0.77
CD	0.461	0.699	0.488	0.169	0.142	0.038	0.087	0.951	22.282	0.493	0.438	0.059	1.289	1.513
CV	0.366	0.643	0.518	0.86	1.495	1.123	1.914	11.619	7.713	7.83	2.634	2.081	3.42	2.062
Variance	2.552	6.562	18.746	0.359	0.895	0.057	0.329	0.797	1411.356	0.131	2.923	0.015	2.950	113.514
SD	1.598	2.562	4.330	0.599	0.946	0.240	0.573	0.893	37.568	0.362	1.710	0.121	1.717	10.654
Genotypic variance (Vg)	2.524	6.499	18.712	0.355	0.893	0.057	0.328	0.68	1347.002	0.099	2.898	0.014	2.735	113.217
Phenotypic variance (Vp)	2.607	6.689	18.804	0.366	0.901	0.058	0.331	1.03	1540.069	0.195	2.973	0.015	3.381	114.107
Environmental variance (Ve)	0.083	0.19	0.092	0.011	0.008	0.001	0.003	0.35	193.067	0.095	0.075	0.001	0.646	0.89
Genotypic coefficient of variation	2.025	3.762	7.364	4.854	15.924	11.264	20.201	16.153	20.373	8.041	16.397	6.821	7.035	23.257
Phenotypic coefficient of variation	2.058	3.816	7.381	4.93	15.994	11.321	20.292	19.898	21.785	11.23	16.607	7.129	7.822	23.348
Genetic advance	3.22	5.176	8.892	1.208	1.938	0.49	1.174	1.379	70.707	0.466	3.463	0.236	3.064	21.833
Genetic advance (% of mean)	4.103	7.638	15.136	9.843	32.661	23.087	41.428	27.013	39.25	11.862	33.353	13.444	13.033	47.721
Heritability	96.798	97.148	99.545	96.91	99.133	98.997	99.108	65.901	87.464	51.275	97.494	91.549	80.886	99.22
F-value	92.78	103.612	608.345	96.584	341.436	302.77	335.365	6.798	21.931	4.163	117.291	33.208	13.694	382.639

HULL%, Hulling percentage; MILL%, Milling percentage; HRR, Head rice recovery; MC%, Moisture content; KL, Kernel length; KB, Kernel breadth; L/B ratio, Kernel length to breadth ratio; ASV, Alkali spreading value; WU, Water uptake; VER, Volume expansion ratio; KLAC, Kernel length after cooking; ER, Linear kernel elongation ratio; AC, Amylose content; GC, Gel consistency; SD, Standard deviation; SE, Standard error; CV, Coefficient of variation; CD, Critical difference.

Table 4 Genotypic and phenotypic character association of grain quality traits in rice

	HULL%	P	1	HULL%	MILL%	HRR	MC%	KL	KB	L/B ratio	ASV	WU	VER	KLAC	ER	AC	GC
HULL%		P	1														
	G																
MILL%		P	0.565**	1													
	G		0.580**														
HRR		P	0.333**	0.479**	1												
	G		0.339**	0.488**													
MC%		P	-0.333**	-0.767**		1											
	G		-0.429**	-0.810**		-0.439**											
KL		P	-0.053NS	0.017NS		-0.366**	0.060NS	1									
	G		-0.054NS	0.015NS		-0.368**	0.059NS										
KB		P	0.168**	0.338**		0.500**	-0.324**	-0.141**	1								
	G		0.175**	0.351**		0.517**	-0.340**	-0.148**									
L/B ratio		P	-0.126**	-0.164**		-0.548**	0.216**	0.837**	-0.638**	1							
	G		-0.128**	-0.168**		-0.551**	0.220**	0.838**	-0.654**								
ASV		P	-0.055NS	0.105**		0.036NS	-0.133**	0.371**	0.036NS	0.264**	1						
	G		-0.065*	0.126**		0.044NS	-0.171**	0.485**	0.048NS	0.318**							
WU		P	-0.003NS	0.068*		-0.060NS	-0.063*	0.029NS	-0.041NS	0.044NS	0.172**	1					
	G		-0.004NS	0.075*		-0.063*	-0.067*	0.032NS	-0.048NS	0.050NS	0.246**						
VER		P	-0.030NS	0.020NS		-0.013NS	-0.032NS	-0.019NS	0.009NS	-0.021NS	0.118**	0.553**	1				
	G		-0.048NS	0.026NS		-0.014NS	-0.047NS	-0.033NS	0.014NS	-0.034NS	0.207**	0.792**					
KLAC		P	-0.050NS	0.040NS		-0.309**	0.046NS	0.897**	-0.100**	0.731**	0.442**	0.145**	0.048NS	1			
	G		-0.049NS	0.041NS		-0.314**	0.047NS	0.909**	-0.107**	0.741**	0.529**	0.157**	0.068*				
ER		P	0.001NS	0.063*		0.091**	-0.041NS	-0.144**	0.072*	-0.155**	0.183**	0.259**	0.143**	0.295**	1		
	G		0.000NS	0.068*		0.095**	-0.043NS	-0.145**	0.081*	-0.159**	0.210**	0.286**	0.219**	0.274**			
AC		P	0.236**	0.097**		0.193**	-0.062*	0.202**	0.192**	0.044NS	0.127**	-0.017NS	-0.005NS	0.240**	0.086**	1	
	G		0.241**	0.099**		0.199**	-0.066*	0.207**	0.195**	0.048NS	0.171**	-0.024NS	-0.016NS	0.251**	0.096**		
GC		P	-0.071*	0.134**		0.056NS	-0.211**	-0.005NS	0.044NS	-0.034NS	0.170**	0.120**	0.087**	0.013NS	0.023NS	-0.368**	1
	G		-0.073*	0.137**		0.056NS	-0.215**	-0.004NS	0.045NS	-0.034NS	0.213**	0.128**	0.119**	0.013NS	0.025NS	-0.379**	

**, * Significant at 0.1% and 0.5% level of significance, respectively. NS, Non-significant; P, Phenotypic coefficient correlation coefficients; G, Genotypic correlation coefficients; HULL%, Hulling percentage; MILL%, Milling percentage; HRR, Head rice recovery; MC%, Moisture content; KL, Kernel length; KB, Kernel breadth; L/B ratio, Kernel length to breadth ratio; ASV, Alkali spreading value; WU, Water uptake; VER, Volume expansion ratio; KLAC, Kernel length after cooking; ER, Linear kernel elongation ratio; AC, Amylose content; GC, Gel consistency.

amylose content (80.89% and 13.033%) and linear kernel elongation ratio (91.55% and 13.44%). Thus, selection on these traits having high heritability and moderate genetic advance renders unproductive for improvement.

The estimates of correlation coefficients provide scope for whether a trait could be improved indirectly via improvement in other correlated trait. Hulling percentage was significantly and positively correlated with the economically important quality traits, i.e. milling percentage ($r = 0.580$) and head rice recovery ($r = 0.339$) (Table 4). Their positive significant association indicated that selection for one milling trait will bring improvement of other two milling traits. Nayak *et al.* (2003) and Singh *et al.* (2022) have reported similar corroborating reports. It is noteworthy that these three milling traits are highly important from economic stand point. Head rice recovery presented negative significant associations with kernel length ($r = -0.368$) and kernel length to breadth ratio ($r = -0.551$). The study found that the long slender seed genotypes are more liable to break than the genotypes bearing short, bold or medium grains. There was a positive non-significant association of HRR with ASV ($r = 0.044$) and AC ($r = 0.199$). It was also noted that kernel breadth had a negative significant association with kernel length ($r = -0.654$) and negative non-significant association with water uptake ($r = -0.048$) (Table 4).

Kernel length after cooking (KLAC) is a very important cooking quality character in rice which is mostly preferred by the consumers. The KLAC was positively and non-significantly associated with volume expansion ratio inferring that the rice grain which increases more in length after cooking also has more final cooked volume. In cooking of rice grain, there is expansion of the grain in all dimensions such as grain length, breadth and thickness but expansion of grain in direction of length during cooking is the most important cooking quality trait. Most of the rice eating people prefer rice varieties whose grains have high grain length elongation property during cooking. However, KLAC was significantly positively associated with ER ($r = 0.274$) and kernel length to breadth (L/B) ratio ($r = 0.741$) (Table 4) and were highly interrelated (Nirmaladevi *et al.* 2015, Divya *et al.* 2020). The kernel L/B ratio was found to be a good yardstick for KLAC with the generalisation of 'higher the L/B ratio, more shall be the kernel length after cooking'. The association between alkali spreading value (ASV) and water uptake (WU) was positively significant ($r = 0.207$) and it signifies that rice genotypes with high WU will have corresponding low gelatinisation temperature reading which corroborated with the previous findings of Choi *et al.* (1999) and Shivani *et al.* (2007). A progress of selection for the highly significant and positively associated characters will ultimately lead improvement of the overall quality traits of a genotype or variety.

The amylose content (AC) of rice grain is an important physico-chemical quality trait as it primarily regulates the texture of cooked rice. The AC had a significant positive association with cooking quality trait KLAC which is

supported by the investigation of Rithesh *et al.* (2018). Consumers generally prefer rice varieties with intermediate values of both AC and GC. The existence of significant negative correlation ($r = -0.379$) between these two important physico-chemical quality characters provides more chances of selecting a desirable rice variety or genotype with intermediate values of one trait will ultimately lead to auto selection of intermediate value of GC as evidenced by Shivani *et al.* (2007). Selection for comparatively high amylose containing rice genotypes for diabetic people will be significantly helpful.

The foremost requirement of a crop breeding programme is the presence of enough variation in the breeding population. In this investigation, it was concluded that all the rice genotypes have adequate variations for all the quality traits. Taking into account of the important grain quality characters, the outstanding genotypes identified were CR Dhan 101, Pooja, Jaya, Dharitree, Tapaswini, Basantibhog, Tulasibasa, Swarna Kranti, IET25450 and Kakhru. These varieties or genotypes may be used in further varietal development or disbursed to farmers for cultivation of quality rice. Rice grain quality traits like grain length, grain breadth, grain length to breadth ratio, alkali digestion value, water uptake, kernel length during cooking and cooked rice gel consistency showed high heritability coupled with high genetic advance by percentage of mean. Thus, these traits are of primary importance during selection. From the study of character associations of rice genotypes, kernel length, head rice recovery, kernel length during cooking, milling percentage, elongation ratio, amylose content, hulling percentage, gel consistency and alkali spreading could be selection criteria for future quality improvement in rice.

REFERENCES

- Ahmed A, Bilal M, Jabbar S, Mumtaz A, Khalid N, Asghar M, Amir R M, Ameer K and Malik A M. 2020. Physicochemical and sensory evaluation of indigenous rice genotypes. *Journal of Agriculture Research* **58**(2): 89–96.
- Allam C R, Jaiswal H K, Qamar A, Challa V and Reddy Y S. 2015. Variability, heritability and genetic advance studies in some indigenous genotypes of basmati rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding* **6**(2): 506–11.
- Bandi H R K, Satyanarayana P V, Ratna Babu D, Chamundeswari N, Srinivasa Rao V and Krishnam Raju S. 2018. Genetic variability estimates for yield and yield components traits and quality traits in rice (*Oryza sativa* L.). *International Journal of Current Microbiology and Applied Science* **7**(5): 551–59. <https://doi.org/10.20546/ijcmas.2018.705.069>
- Bansal U K, Kaur H and Saini R. 2006. Donors for quality characteristics in aromatic rice. *Oryza* **43**(3): 197–202.
- Bhargavi B, Suneetha Y, Aravind Kumar J, Violina B, Venkata Ratnam T and Srinivas T. 2022. Genetic variability and trait associations for quality traits in high protein landraces of rice. *Scientist* 861–72. <https://doi.org/10.5281/zenodo.7268295>
- Burton G W and Devane E M. 1953. Estimating heritability in fall fescue (*Festuca circunclinaceae*) from replicated clonal-material. *Agronomy Journal* **45**: 478–81. <https://doi.org/10.2134/agronj1953.00021962004500100005x>

- Chacko A, Jayalekshmy V G, and Shahiba A M. 2023. Studies on PCV, GCV, heritability, and genetic advance in rice genotypes for yield and yield components. *International Journal of Plant and Soil Science* **35**(16): 324–30. <https://doi.org/10.9734/ijps/2023/v35i163266>
- Chaudhari M, Motirmani N K and Pravin J. 2007. Variability and genetic divergence of aromatic rice (*Oryza sativa* L.). *Annals of Agricultural Research News Series* **28**(3 and 4): 268–72.
- Choi H, Cho J and Chi S Y. 1999. Varietal difference in water absorption characteristics of milled rice and its relation to the other grain quality components. *Korean Journal of Crop Science* **44**: 288–95.
- Comstock R and Robinson H. 1952. Genetic parameters, their estimation and significance. (In) *Proceedings of the 6th International Grassland Congress*, State College, PA, USA, August 17–23, pp. 248–91.
- Cruz N D and Khush G S. 2000. Rice grain quality evaluation procedures. (In) *Aromatic Rice*, pp. 15–28. Singh R K, Singh U S and Khush G S (Eds). Oxford and IBH Publishing Company Private Limited, New Delhi.
- Dhanavath A, Siddi S, Chimmili S R and Mangrauthia S R. 2025. Investigations on variability, heritability and genetic advance in short and medium slender grain rice (*Oryza sativa* L.) genotypes. *International Journal of Advanced Biochemistry Research* **9**(8S): 195–204. [10.33545/26174693.2025.v9.i8Sc.5120](https://doi.org/10.33545/26174693.2025.v9.i8Sc.5120)
- Divya P K S, Nirmala Devi G, Lakshmi K and Chamundeswari N. 2020. Evaluation of grain quality traits in popular rice varieties of Andhra Pradesh. *Journal of Pharmacognosy and Phytochemistry* **9**(5): 217–24. <https://doi.org/10.22271/phyto.2021.v10.i1Sd.13443>
- Federer W T. 1956. Augmented designs. *Hawaiian Planters Record* **55**: 191–208.
- Gangashetty P, Salimath P and Hanamaratti N. 2013. Genetic variability studies in genetically diverse non-basmati local aromatic genotypes in rice (*Oryza sativa* L.). *Rice Genomics and Genetics* **4**(2): 4–8. <https://doi.org/10.5376/RGG.2013.04.0002>
- Hashim N, Ali M M, Mahadi M R, Abdullah A F, Wayayok A, Kassim M S M and Jamaluddin A. 2024. Smart farming for sustainable rice production: An insight into application, challenge, and future prospect. *Rice Science* **31**(1): 47–61. <https://doi.org/10.1016/j.rsci.2023.08.004>
- Hossain M S, Singh A K and Fasih-uz-Zaman. 2009. Cooking and eating characteristics of some newly identified inter sub-specific (*indica/japonica*) rice hybrids. *Science Asia* **35**: 320–25.
- Jabeen A, Subrahmanyam D and Krishnaveni D. 2023. The global lifeline: A staple crop sustaining two-thirds of the world's population. *Agriculture Archives*. <https://doi.org/10.51470/AGRI.2023.2.3.15>
- Johnson H W, Robinson H F and Comstock R E. 1955. Genotypic and phenotypic correlations in soybeans and their implication in selection. *Agronomy Journal* **47**: 477–83. <https://doi.org/10.2134/agronj1955.00021962004700100008x>
- Juliano B O, Cagampang G B, Cruz L J and Santiago R G. 1964. Some physicochemical properties of rice in Southeast Asia. *Cereal Chemistry* **41**(4): 275–86.
- Kundu A, Senapati B K, Bakshi A and Mandal G S. 2008. Genetic variability of panicle characters in tall *indica* Aman rice. *Oryza* **45**(4): 320–23.
- Little R R, Hilder G B and Dawson E H. 1958. Differential effect of dilute alkali on 25 varieties of milled white rice. *Cereal Chemistry* **35**: 111–26.
- Nayak A R, Chaudhary D and Reddy J N. 2003. Genetic variability and correlation study among quality characters in scented rice. *Agricultural Science Digest* **23**(3): 175–78.
- Nirmaladevi G, Padmavathi G, Suneethakota and Babu V R. 2015. Genetic variability, heritability and correlation coefficients of grain quality characters in rice (*Oryza sativa* L.). *SABRAO Journal of Breeding and Genetics* **47**(4): 424–33.
- Pandey J, Scheuring D C, Koym J W, Coombs J, Novy R G, Thompson A L, Holm D G, Douches D S, Miller J C and Vales M I. 2021. Genetic diversity and population structure of advanced clones selected over forty years by a potato breeding programme in the USA. *Scientific Reports* **11**: 1–18. <https://doi.org/10.1038/s41598-021-87284-x>
- Rithesh B N, Ramchander S, Rajeswari S, Uma D, Robin S, Jeyaprakash P. 2018. Characterisation of physico chemical properties of starch among traditional and commercial varieties of rice (*Oryza sativa* L.) using rapid visco analyser. *International Journal of Current Microbiology and Applied Science* **7**(10): 1490–503. <https://doi.org/10.20546/ijemas.2018.710.167>
- Sanjukta D, Subudhi H N and Reddy J N. 2007. Genetic variability in grain quality characteristics and yield in lowland rice genotypes. *Oryza* **44**(4): 343–46.
- Searle S R. 1961. Phenotypic, genotypic and environmental correlations. *Biometrics* **17**(3): 474–80. <https://doi.org/10.2307/2527838>
- Shivani D, Viraktamath B C and Shobha Rani N. 2007. Correlation among various grain quality characteristics in rice. *Oryza* **44**(3): 212–15.
- Singh M, Avtar R, Kumar N, Punia R, Pal A, Lakra N, Kumari N, Kumar D, Naruka A and Bishnoi M. 2022. Genetic analysis for resistance to *Sclerotinia* stem rot, yield and its component traits in Indian mustard [(*Brassica juncea* L.) Czern & Coss.]. *Plants* **11**(5): 671. <https://doi.org/10.3390/plants11050671>
- Subbaiah P V, ReddiSekhar M, Reddy K H P and Eswara Reddy N P. 2011. Variability and genetic parameters for grain yield and its components and kernel quality attributes in CMS based rice hybrids (*Oryza sativa* L.). *International Journal of Applied Biology and Pharmaceutical Technology* **2**(3): 603–09.
- Sultana S, Faruque M and Islam M R. 2022. Rice grain quality parameters and determination tools: A review on the current developments and future prospects. *International Journal of Food Properties* **25**(1): 1063–78. DOI: [10.1080/10942912.2022.2071295](https://doi.org/10.1080/10942912.2022.2071295)
- Umamaheswar N, Suvendu Roy S K, Kundu A, Hijam L, Chakraborty M, Shubhrajyoti Sen, Das B, Barman R and Vishnupriya S. 2024. Genetic variability and character association studies in diverse rice (*Oryza sativa* L.) genotypes for agro-morphological traits in Terai region of West Bengal. *Journal of Advances in Biology and Biotechnology* **27**(5): 805–20. <https://doi.org/10.9734/jabb/2024/v27i5843>
- Zafar S and Jianlong X. 2023. Recent advances to enhance nutritional quality of rice. *Rice Science* **30**(6): 523–36. <https://doi.org/10.1016/j.rsci.2023.05.004>