Received: 30 Aug 2023 | Revised: 11 Sep 2023 | Accepted: 27 Sep 2023

Electronic Journal of Plant Breeding

Research Article

Genetic analysis of quality traits in non-aromatic rice varieties for export potential

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Abstract
Rice, a vital staple for millions globally, plays a pivotal role in food security and livelihoods. There is a steady increase in the export of non-basmati rice to other countries in recent years due to migration from India and changing dietary pattern. The quality of rice exported from India is compromised by millers to achieve market need. This study focuses on finding quality traits preferred by different markets and identifying varieties suitable for export. For this purpose, Representative export rice samples were collected and compared with the TNAU released rice varieties. Quality traits of 34 rice genotypes, comprising both TNAU rice varieties and rice samples collected from traders were evaluated. Key quality parameters namely kernel length, cooking characteristics, physicochemical attributes, and organoleptic traits were evaluated. Samples collected from traders fall into three categories, RNR 15048 type and BPT 5204 type for premium price and CO 51 type for low premium price. Varieties ADT 43 and TKM 15 can be recommended as alternates for CO 51 type, CO 55 for RNR 15048 type and TKM 13, CO 52 and CO 43 for BPT 5204 type. The genetics of various quality traits were studied which revealed high genetic advance and high heritability for kernel breadth, kernel breadth after cooking, length breadth ratio, gel consistency and gelatinization temperature. The Principal Component Analysis (PCA) offered insights into the inherent variation within the genotypes and classified them into four group. This study aided in identifying varieties with export potential which will fetch high price in international market.

Keywords: Export rice, traceability, non- basmati types, genetics, quality traits

INTRODUCTION

Rice plays a pivotal position within the global food landscape, serving as a fundamental dietary staple for half of the world's population while also exerting substantial influence over economic growth, employment dynamics, and social stability (Yadav and Kumar 2018). Its essential role is further emphasized by contributing 20% of the world's dietary energy supply (GRiSP 2013). However, as the UN projection indicates a population surge of 10% by 2030 and a staggering 42% by 2100, the challenge of feeding the burgeoning global populace while adhering to ecological limits becomes increasingly intricate (Rockström *et al.,* 2020). This predicament is amplified by the escalating impacts of climate change, which intensify environmental stresses that imperil agricultural productivity (FAO 2022a). In this context, the transformation of the current agrifood system emerges as an imperative.

Across the past two decades, rice production has exhibited greater stability in comparison to maize and wheat

(Valera and Pede 2023). Global rice (paddy) production has surged from 215 million tonnes in 1961 to a noteworthy 787.3 million tonnes in 2021, predominantly originating from the Asian continent. Notably, China, India, Indonesia, Bangladesh, Vietnam, Myanmar, and Thailand collectively account for over 80% of the world's rice production (FAO 2022b). At present, Asia accounts for 95% of global rice consumption, while its contribution to exports remains modest at 4% conversely (Valera and Pede 2023).

India, securing its position as the world's second-largest rice producer, has witnessed a surge in rice production from 53.6 million tons in 1980 to a significant 120 million tons in 2020-21 (Wikipedia 2023). Projected estimates indicate a further increase to 130.84 million tons by 2022-23 (PIB 2023). Notably, India's prominence extends to being the foremost global rice exporter, accounting for over 40% of the total rice trade. Furthermore, the Indian rice market is anticipated to record a Compound Annual Growth Rate (CAGR) of 2.7% during the period 2022-27 (Anonymous 2022). Importantly, evolving consumption trends have led to a rise in rice consumption in non-rice-eating countries and among Indian migrants seeking non-aromatic rice varieties in their diets. This transition is noteworthy considering that prior to 1989–1990, non-basmati rice comprised less than 10% of exports; the liberalization of trade, however, elevated this figure to 54% (Chand 1999). Notably, the Agricultural and Processed Food Products Export Development Authority (APEDA) highlights robust demand for non-basmati rice from the US and European markets (Anonymous 2022), resulting in exports worth Rs. 51,088.72 Crores (USD 6,355.74 Millions) in 2022–2023, amounting to 17,786,092.81 MT. Quantity and percentage share of non- basmati r ice in India's total export is provided in **Table 1** from 2017-18 to 2022- 23(Agri exchange-APEDA 2023).

Even though production and export of rice is increasing in India, quality is usually compromised in export. Quality manipulation by rice milling industries and traders presents a considerable risk, encompassing practices such as intermingling rice varieties and qualities, reprocessing deteriorated rice, introducing harmful chemicals, and employing inaccurate labelling. Due to the compromise in quality, price of rice exported rice will decrease. Determining quality traits significant for export and identifying varieties with similar traits will help traders make informed decisions without compromising quality by mixing different varieties to achieve market need. The conscious selection of varieties with good quality traits will fetch high market price and also aid as stepping stone for establishing traceability systems in rice export. Traceability systems, in accordance with EC regulation 178/2002, enable the tracking of food's journey from production to distribution (European Commission 2002). Such systems have the potential to mitigate consumer concerns by ensuring quality assurance and restoring confidence (Golan *et al.,* 2004, Van Rijswijk and Frewer 2008, Aung and Chang 2014).

This study focuses on evaluating important quality traits related to export and consumer preference, understanding the contribution of selected quality traits through principal component analysis and variability present in the genotypes. The study also aims to identify varieties that have quality traits similar to non- aromatic export rice samples collected, serving as a foundational step towards an export rice traceability system. By identifying domestically cultivated rice varieties that possess similar quality traits to major export counterparts, countries can reduce their reliance on a limited number of cultivars and broaden their range of exportable products. The results of this research could provide valuable insights for policymakers, farmers, and stakeholders within the

Table 1. Export scenario of rice in India and Tamilnadu (2017-18 to 2022-23)

Year	Scenario	Qty in 000'MT	Value in Rs.Crore	Value in USD Mill	Share in value (%)	Major importing countries
2017-18	India	8648.5	22967.8	3564.4	18.3	Bangladesh Pr,Benin, Senegal, Nepal, Sri Lanka Dsr
	Tamil Nadu	217.3	709.8	110.0	3.0	
2018-19	India	7599.7	21185.3	3047.8	15.7	Nepal, Benin, Bangladesh Pr, Senegal, Guinea
	Tamil Nadu	152.4	558.2	80.1	2.6	
2019-20	India	5040.7	14364.7	2014.6	12.1	Nepal, Benin, United Arab Emirates, Somalia, Guinea
	Tamil Nadu	117.9	475.2	66.5	3.3	
2020-21	India	13095.1	35476.6	4799.9	23.2	Benin, Nepal, Bangladesh Pr, Senegal, Togo
	Tamil Nadu	462.7	1,425.2	193.0	4.0	
2021-22	India	17262.2	45652.4	6124.3	24.7	Bangladesh Pr, Benin, China P Rp, Nepal, Cote D Ivoire
	Tamil Nadu	853.2	2,538.1	340.2	5.5	
2022-23	India	17786.1	51088.7	6355.7	23.1	Benin, China P Rp, Senegal, Cote D Ivoire, Togo
	Tamil Nadu	875.7	2,512.0	314.5	4.9	

Source: (Agri exchange-APEDA 2023)

rice value chain, fostering informed decision-making and promoting sustainable agricultural practices.

MATERIALS AND METHODS

The study was conducted at the Department of Genetics and Plant Breeding, Anbil Dharmalingam Agricultural College and Research Institute (ADAC&RI), Trichy. The genetic material consists of a total of 29 TNAU bred rice varieties and five rice samples collected from traders. TNAU paddy varieties were collected and raised at ADAC&RI. Non-aromatic rice samples (five numbers) were collected from the representative traders at Agro Food Trade Centre, Madurai (AFTC) (**Table 2 and Table 3**). AFTC provides infra structure for storage of agri products and integrates with export market by adopting common branding.

Table 2. Non - aromatic rice samples collected from traders

S. No.	Name of Variety	Price in the market	Grain type
1	RNR 15048	Premium	short slender
2	Amman Sona	Premium	short slender
3	JGL 1798	Premium	short slender
4	BPT 5204	Premium	medium slender
5	CO 51	Low Premium	medium slender

Table 3. List of TNAU varieties in the study

S. No	Name of Variety	Parentage
1.	CO 43	Dasal/IR 20
2.	CO (R) 50	CO 43/ADT 38
3.	CO 52	BPT 5204/CO (R) 50
4.	CO 53	PMK (R) 3 / Norungan
5.	CO 54	CB 04110 / CB 05501
6.	CO 55	ADT 43 /GEB 24
7.	TRY 1	RP 578-172-2-2/BR-1-2-B-1
8.	TRY (R) 2	RP 825-45-1-3/IR 36
9.	TRY 3	ADT 43/ Seeragasamba
10.	TRY 4	ADT 39/CO 45
11.	TRY 5	Mutant of TRY (R) 2
12.	ASD 17	ADT 31/ RATNA/ ASD 8/ IR 8
13.	ASD 18	ADT 31/IR 50
14.	ASD 19	Lalnakanda/IR 30
15.	ASD 20	IR 18348/IR 25863/IR 58
16.	ADT 39	IR 8/ IR 20
17.	ADT 42	ADT 9246/ADT 29
18.	ADT 43	IR 50/White ponni
19.	ADT (R) 45	IR 50/ADT 37
20.	ADT (R) 46	ADT 38/CO 45
21.	ADT 53	ADT 43/JGL 384
22.	TNAU Rice ADT 49	CR 1009/Seeragasamba
23.	TKM 6	CO 18/GEB 24
24.	TKM 13	WGL 32100/Swarrna
25.	TKM 15	TKM 12/IET 21620
26.	PMK (R) 3	UPLRI 7/CO 43
27.	ANNA(R)4	Pantdhan 10/IET 9911
28.	IR 64	IR 5657-33-2-1/IR 2061-465-1-5-3
29.	Improved White Ponni	Selection from White Ponni

TNAU varieties, raised at ADAC&RI, Trichy were harvested and processed to recover raw rice. Milling was done at Department of Rice, Centre for Plant Breeding and Genetics, TNAU, Coimbatore. Uniformly, six months old rice were used for analysis. All the necessary quality traits were analyzed using Completely Randomized blocks design with two replications. Grain quality traits namely, length, shape, amylose content, gel consistency, gelatinization temperature which were preferred in different countries in the global rice market recorded by (Suwannaporn *et al.,* 2008, Calingacion *et al.,* 2014) is provided in **Table 4**. Taking this into consideration, quality traits including Kernel length (KL), Kernel breadth (KB), Length breadth ratio (LBR), Kernel length after cooking (KLAC), kernel breadth after cooking (KBAC), Length Breadth ratio after cooking (LBAC), Linear elongation ratio (LER), Breadthwise elongation ratio (BER), amylose content (AC), gel consistency (GC), volume expansion ratio (VER), gelatinization temperature (GT) were analyzed for all the genotypes.

Kernel length, Kernel breadth, of all genotypes were measured and classified based on Standard Evaluation System in rice (SES, IRRI, 2013). Grain shape was determined based on kernel length and length breadth ratio as per classification given by Ramaiah (1969). Kernel length after cooking, kernel breadth after cooking, length breadth ratio after cooking and volume expansion ratio were measured after cooking each genotype. Linear elongation ratio (LER) was measured as the ratio of mean length of cooked rice to mean length of milled rice (Juliano and Perez 1984). Breadthwise elongation ratio is the ratio of mean breadth of cooked rice to mean breadth of milled rice. Amylose content and gel consistency were analysed based on methods given by Juliano *et al.,* (1981) and Cagampang *et al.,* (1973) respectively. Alkali spreading value method suggested by Little *et al.,* (1958) was used for determining gelatinisation temperature and scoring was done as per (SES 2013).

Organoleptic test namely colour and appearance, taste, texture, elongation and overall acceptability were done for assessing the consumer preferences. Each genotype was evaluated by the sensory panel and grades (very good-5 to low -1) were given as suggested by Amerine *et al.,* (1965)

Statistical analyses: Variability parameters, heritability and genetic advance were calculated as per Johnson *et al.,* (1955). Analysis of variance and variability studies were carried out using TNAUSTAT (Manivannan 2014). Principal component analysis was done in R software V4.3.0 using packages namely *factoextra* & *factomine R*. Clustering was done from principal components based on Ward.D2 method using *stats* package in R software V4.3.0.

RESULTS AND DISCUSSION

Globally, each market has particular preferences for rice quality. Notably, the visual appearance of rice grain, such

Table 4. Grain quality traits in global rice markets

Country	Length	Shape	Amylose	Gel consistency	Gel temperature
Australia	Medium/ Long	Medium	Low		Low and intermediate
Egypt	Medium/ Long	Slender / Medium	Low		Intermediate
Ghana	Medium/ Long	Slender	High	Soft and intermediate	Low and intermediate
Uganda	Medium/ Long	Slender/ Medium	Intermediate and high	Soft and intermediate	Intermediate to high
Senegal	Medium/ Long	Slender/ Medium	High/ Intermediate	Soft	Intermediate and high
Colombia	Long	Slender	High		Low and intermediate
Brazil	Long		Intermediate		Intermediate and High
Uruguay	Long	Slender	Low		Intermediate
USA	Medium/ Long	Slender / Medium	Low		Intermediate
Indonesia	Medium	Slender	Intermediate		Intermediate
	Long	Slender	Intermediate		Intermediate
Bangladesh	Medium	Bold	Low		Low
Srilanka	Medium	Bold	High		Intermediate
India	Medium	Slender	Intermediate		Intermediate
	Long	Slender	Intermediate		Intermediate

Source: Suwannaporn and Linneman 2008; Calingacion *et al*,. 2014 as shape and size, is a key aspect of grain quality that heavily influences customer purchasing decisions and rice pricing (Bhonsle and Krishnan 2010). Apart from size and shape, taste, cooking quality is considered as important traits for repeated purchase(Cuevas *et al.,* 2016).

In the present investigation, quality characters of 34 genotypes consisting of 29 TNAU varieties and five representative non - aromatic export rice samples were evaluated. The Analysis of Variance (ANOVA) showed significant differences among genotypes for all the quality traits indicating the presence of substantial genetic variation among the genotypes (**Table 5**). The present study focuses on identifying alternatives for varieties being exported currently. To identify suitable varieties, quality characters of export samples and TNAU varieties were compared. Mean performance of all genotypes under study were provided in **Table 6.** In general, three export categories were observed and the available export samples (five) were collected from traders. Continuous availability through-out the year is important for preferring of specific varieties by traders. Among the collected samples, the first category consists of RNR 15048, JGL 1798 and Amman Sona (all early maturing varieties) which fetches premium price. Varieties like BPT 5204 also has premium price but the availability is restricted (due to season) which is the second category. Varieties like CO 51 falls under low premium (third) category and available throughout the year. The categories are mentioned as RNR 15048 type, BPT 5204 type and CO 51 type for better understanding.

Important traits as suggested by {Calingacion, 2014 #645@@author-year}Calingacion *et al* (2014) were observed for identification of preferred varieties in all the three categories. Among the 29 TNAU varieties studied, classification of varieties into these categories were done based on grain shape and duration, amylose content gel consistency and gelatinization temperature. Under CO 51 type, which is medium slender and early duration, seven varieties namely ADT 43, TKM 15, ADT R 45, CO 54, ADT 53, ASD 18 and TKM 6 were identified. In RNR 15048 type, CO 55 recorded similar short slender grain shape and early duration. In BPT 5204 type, nine varieties namely, ADT 49, CO (R) 50, TKM 13, Improved white Ponni, CO 52, CO 43, ASD 19, ADT 39 and TRY 4 were identified which are medium duration and medium slender varieties.The availability of these nine varieties is restricted in Tamil Nadu since these can be cultivated only in *samba /thaladi* season. All the export samples recorded intermediate amylose content, soft gel consistency and intermediate gelatinization temperature. All the identified varieties also recorded intermediate amylose content, soft gel consistency and intermediate gelatinization temperature. The varieties identified in each category is depicted in **Table 7**.

Consumer preference of a specific variety is highly dependent on appearance quality before and after cooking. So, for identifying best varieties in each category, score for kernel length and linear elongation ratio and overall acceptability score in organoleptic test were taken into consideration (**Table 8**). Overall acceptability scores of organoleptic tests indicated that varieties, CO 55, ADT 53, IWP, CO 52, ADT 39, ADT 49, TKM 6, TKM 13 recorded high overall acceptability scores (4 or 5). For kernel length and linear elongation ratio, score was given based on the percentage increase with respect to corresponding export sample in each category. The results indicated that ADT 43, CO 55, IWP recorded higher kernel length in their respective category. However, when linear elongation ratio was considered, TKM 15, ASD 18, CO 55, ADT 49, CO R 50, TKM 13, CO 52, CO 43 and ADT 39 recorded higher LER when compared to corresponding export samples in their respective category.

Cumulative score for identified varieties based on kernel length, linear elongation ratio and overall acceptability in organoleptic test is provided in **Table 8**. Based on best cumulative score (more than 5), best varieties in each category was selected which are ADT 43 and TKM 15 in the CO 51 type, CO 55 in RNR 15048 type and TKM 13, CO 52 and CO 43 in BPT 5204 type. High volume expansion ratio is preferred especially in low income groups as it obtains more cooked rice from less uncooked rice. In a study conducted in Philippines, the volume expansion of cooked rice was the most frequently referred reason for purchasing a certain rice (Abansi *et al.,* 1992, Hossain *et al.,* 2009). Among the best varieties selected, high volume expansion was recorded in ADT 43 in CO 51 type, CO 55 in RNR 15048 type, CO 52 and CO 43 in BPT 5204 type.

Variability studies: The genetics of the quality traits is well studied by variability which augments further development of rice varieties**.** Variability analysis for all traits revealed that phenotypic coefficient of variation was slightly higher than Genotypic coefficient of variation (**Table 6**). High GCV and PCV was observed for GT (29.70& 30.86)

Table 5. Analysis of variance for all Quality trait

Source of variation	df	KL	KB	LBR	KLAC	KBAC	LBAC	LER	BER	AC	GC	VER	GT
Treatment	33	0.36*	0.14*	0.45*	0.96*	0.70*	1.43*	0.02*	0.06*	8.89*	291.86*	0.19*	3.86*
Error	34	0.01	0.01	0.04	0.016	0.01	0.04	0.01	0.01	4.94	6.57	0.19	0.14

* significance at 5% level

Table 6. Mean performance of 34 Rice varieties with PCV, GCV, Heritability and Genetic Advance

S. No	Varieties	KL (mm)	KB (mm)	LBR	KLAC (mm)	KBAC (mm)	LBAC	LER	BER	AC (%)	GC (mm)	VER	GT
1	CO 43	5.65	1.93	2.93	8.95	2.84	3.15	1.58	1.47	22.96	81.92	3.60	6
2	CO (R) 50	5.75	1.90	3.03	8.78	3.40	2.58	1.53	1.79	20.17	86.22	3.99	4
3	CO 52	5.68	1.92	2.96	9.00	2.67	3.37	1.59	1.39	23.44	93.26	4.30	6
4	CO 53	5.58	2.28	2.45	7.44	3.74	1.99	1.33	1.64	20.61	74.99	3.85	6
5	CO 54	5.70	1.94	2.95	8.70	2.85	3.06	1.53	1.47	24.47	89.19	3.99	4
6	CO 55	5.80	1.66	3.49	9.71	2.88	3.38	1.67	1.73	23.86	90.98	4.52	4
7	TRY 1	5.47	2.20	2.49	8.00	3.69	2.17	1.46	1.68	19.25	94.15	3.81	4
8	TRY (R) 2	6.41	1.75	3.67	9.13	3.62	2.53	1.42	2.07	21.63	86.28	3.78	4
9	TRY 3	5.60	2.30	2.43	8.60	3.92	2.20	1.54	1.70	23.47	89.35	4.25	6
10	TRY 4	5.70	1.91	2.99	7.53	3.75	2.01	1.32	1.97	21.20	77.14	3.88	4
11	TRY 5	6.23	1.63	3.84	9.54	2.44	3.91	1.53	1.50	21.62	97.27	3.97	5
12	ASD 17	5.14	2.24	2.31	7.25	3.53	2.06	1.41	1.58	22.55	83.54	4.01	7
13	ASD 18	5.62	1.93	2.91	8.69	2.71	3.22	1.55	1.40	20.02	84.19	3.81	5
14	ASD 19	5.38	1.55	3.47	7.61	2.30	3.33	1.41	1.49	19.57	69.94	3.85	4
15	ASD 20	6.35	1.68	3.89	9.15	2.55	3.61	1.44	1.54	18.87	88.50	4.20	5
16	ADT 39	5.51	1.93	2.86	8.41	2.79	3.02	1.53	1.45	20.23	83.46	4.53	4
17	ADT 42	6.39	1.64	3.90	9.30	2.55	3.66	1.46	1.56	20.40	87.57	4.24	4
18	ADT 43	5.78	1.93	3.00	9.31	2.36	3.96	1.61	1.22	22.62	87.68	4.27	4
19	ADT (R) 45	5.70	1.92	2.98	8.63	2.98	2.90	1.51	1.56	21.41	68.14	4.25	5
21	ADT (R) 46	6.30	1.78	3.55	9.09	2.89	3.15	1.44	1.63	22.74	67.42	4.26	3
22	ADT 53	5.58	2.00	2.80	8.91	3.12	2.87	1.60	1.56	24.01	94.54	4.16	4
23	TNAU Rice ADT 49	5.46	1.82	3.00	8.50	2.92	2.92	1.56	1.61	22.60	85.29	4.85	4
24	TKM 6	5.65	1.60	3.57	8.08	2.15	3.76	1.43	1.36	21.59	74.95	4.25	6
25	TKM 13	5.68	1.90	2.99	9.21	2.97	3.10	1.62	1.56	19.64	82.01	3.26	4
26	TKM 15	5.73	1.93	2.98	9.25	2.85	3.25	1.61	1.48	21.81	93.30	4.42	5
27	PMK (R) 3	6.36	1.90	3.35	9.95	3.71	2.69	1.57	1.95	21.14	48.08	4.04	3
28	ANNA(R) 4	6.32	1.59	3.99	9.59	2.30	4.18	1.52	1.45	24.27	70.92	4.21	4
29	IR 64	6.28	1.92	3.27	9.33	2.75	3.41	1.49	1.43	22.09	58.90	4.22	6
30	IWP	5.78	1.95	2.97	8.63	2.71	3.19	1.49	1.40	22.74	75.13	4.20	3
31	CO 51	5.75	1.92	3.00	8.82	2.87	3.08	1.53	1.50	22.59	85.07	4.20	4
32	BPT 5204	5.75	1.91	3.02	8.65	2.94	2.95	1.51	1.54	21.36	60.92	3.95	3
33	RNR 15048	5.75	1.61	3.57	9.48	1.80	5.26	1.65	1.12	21.36	82.50	4.42	4
34	AMMAN SONA	5.44	1.37	3.99	9.65	1.74	5.55	1.77	1.28	24.69	76.68	4.43	2
35	JGL1422	4.30	1.22	3.54	7.65	1.50	5.11	1.78	1.23	23.39	73.25	4.61	6
	MEAN	5.75	1.84	3.18	8.78	2.84	3.25	1.53	1.54	21.89	80.67	4.13	4.34
	SE(M)	0.08	0.07	0.15	0.28	0.08	0.14	0.05	0.06	1.57	1.81	0.12	0.27
	CD (P=0.05)	0.24	0.22	0.43	0.82	0.25	0.41	0.15	0.19	4.47	5.15	0.35	0.77
	CV%	2.08	6.02	6.82	4.67	4.45	6.37	5.17	6.42	10.44	3.21	4.21	8.35
	Variability studies												
	PCV (%)	7.57	15.08	15.81	8.57	21.04	26.48	7.86	12.35	12.35	15.29	8.06	30.86
	GCV (%)	7.27	13.82	14.27	7.19	20.56	25.70	5.92	10.55	6.59	14.95	6.86	29.70
	Heritability (%)	92.43	84.03	81.40	70.30	95.50	94.19	56.66	72.96	28.51	95.59	72.63	92.66
	GAM	14.41	26.10	26.52	12.42	41.39	51.40	9.18	18.57	7.25	30.12	12.06	58.90

(KL – Kernel length (mm), KB - Kernel breadth (mm), LBR – L/B ratio, KLAC – Kernel Length After Cooking (mm), KBAC - Kernel Length After Cooking (mm), LBAC - L/B ratio after cooking, LER – Linear Elongation Ratio, BER – Breadthwise Elongation Ratio, AC – Amylose Content (%), GC – Gel consistency (mm), VER – Volume expansion ratio, GT- Gelatinization Temperature, SE (M)- Standard error of mean, CD- Critical Difference, CV- Coefficient of variation, PCV - Phenotypic Coefficient of Variation, GCV – Genotypic Coefficient of Variation, GAM- Genetic advance as per cent of mean)

Table 7. Preferences of rice varieties according to grain quality traits in global market

Type	Varieties	L/B (MS or SS)	Amylose content (intermediate)	Gel consistency (soft)	Gelatinization temperature (intermediate)	Whether selected
CO 51 type	ADT 43					Yes
	TKM 15					Yes
	ADT 45					Yes
	CO 54					Yes
	ADT 53					Yes
	ASD 18					Yes
	TKM 6					Yes
RNR 15048 type	CO 55					Yes
BPT 5204 type	ADT 49					Yes
	CO (R) 50					Yes
	TKM 13					Yes
	IWP					Yes
	CO 52					Yes
	CO 43					Yes
	ASD 19					Yes
	ADT 39					Yes
	TRY 4					Yes

Table 8. Cumulative scores for varieties recommended for Export

TYPE	Varieties	LER (Score)*	Kernel length (score)*	Organoleptic score	Cumulative score
CO 51 type	ADT 43	0	1	4	**5**
	TKM 15	5	-1	4	**8**
	ADT (R) 45	-2	-1	3	0
	CO 54	0	-1	3	2
	ADT 53	-4	-3	4	-3
	ASD 18	1	-2	4	-3
	TKM 6	-7	-1	1	-7
RNR 15048 type	CO 55	2	1	5	**8**
BPT 5204 type	ADT49	3	-3	4	4
	CO(R) 50	1	-2	4	3
	TKM 13	7	-2	4	**9**
	IWP	-1	1	4	4
	CO 52	5	-2	3	**6**
	CO 43	4	-2	3	**5**
	ASD 19	-3	-3	3	3
	ADT 39	1	-2	4	3
	TRY 4	-4	-1	2	-3

(Score- Percentage increase of test variety compared to check variety) followed by LBAC (25.70& 26.48) and KBAC (20.56& 21.04). Intermediate GCV and PCV was recorded in GC (14.95 & 15.29), LBR (14.27& 15.81) and KB (13.82& 15.08). Similarly intermediate PCV and GCV for LBR was recorded by Sadhana *et al.,* (2022) in rice. Higher and intermediate GCV values suggest trait selection for significant improvement (Roychowdhury and Tah 2011).

As classified by (Johnson *et al.,* 1955), all quality traits showed high heritability except AC (28.51) which recorded low heritability. High heritability was observed in GC (95.59) followed by KBAC (95.50), LBAC (92.43), GT (92.66) and KL (92.43). Similar observations were recorded by Nirmaladevi *et al.,* (2015) in rice. Based on classification given by Johnson *et al.,* (1955), high genetic advance as per cent of mean was recorded in GT (58.90) followed by LBAC (51.40), KBAC (41.39) and GC (30.12).

High heritability estimates combined with high genetic advance is useful in predicting gain under selection as it indicates additive gene action (Singh and Narayanam 2007). High heritability and high genetic advance were observed in GC, LBAC, KBAC, GT, LBR and KB. Similar results for KB and KBAC (Priyanka *et al.,* 2017), LBR (Devi *et al.,* (2017) and Govintharaj *et al.,* (2016) in rice were recorded.

Principal component analysis: The primary goal of principal component analysis is to minimize the dimension of a huge dataset while enhancing interpretability and avoiding information loss. Principal component analysis (PCA) was used in this study to summarize the variation contributed by all quality traits into principle components, so that major traits contributing to total variation can be delineated from principal components. PCA revealed 12 principal components among which, PC1, PC2, PC3 and PC4 recorded eigen values more than 1, and contributes 79.45% of total variation (**Table 9, Fig. 1**). PCA of quality traits in a study conducted by Pokhrel *et al.,* (2020), recorded 73.8% of total variation is retained in first four principal components. PC1 accounts for 41.77% variation with high positive loadings for LBAC, LBR, LER, KLAC, AC and VER and negative loadings for KB, KL, KBAC and BER. This revealed that cooking and physico-chemical quality traits contributed to majority of variation in this component. PC2, which contributed 18.66 per cent of total variation, recorded positive loadings for KL, KLAC, LBR and negative loadings for AC and VER. In PC3 high positive loading is recorded for AC and KLAC.

PCA biplot between PC1 and PC2 depicted in **Fig. 2** revealed that genotypes ADT 42, Anna (R) 4, Amman Sona and RNR 15048 placed in quadrant 2 had high KLAC, LBR and LBAC. Similarly, genotypes PMK (R) 3, ADT 46, TRY 2, BPT 5204 with high KL, BER and KBAC were placed in quadrant 1. In a study conducted by Gunasekaran *et al.,* (2023) in rice, they concluded that close vector angle between grain yield per plant with plant height, panicle length, length of primary branches, flag leaf area, and the number of spikelets in primary branches indicated strong association between these traits. Similarly, close vector angle was observed between LER, VER, AC and LBAC indicating strong association among these traits. Vector direction in the biplot revealed negative association of KL, BER, KBAC, KB, GC and GT with all other trait.

The genotypes were classified into four groups by Ward. D2 method of hierarchical clustering as depicted in the biplot (**Fig. 2**). Among the four groups obtained, group

Table 9. Eigenvalues, percentage of variance of first four principal component values with factor loadings

	PCA 1	PCA 2	PCA 3	PCA 4
Eigenvalue	5.01	2.24	1.25	1.03
Percentage of variance	41.77	18.66	10.41	8.61
Cumulative percentage of variance	41.77	60.43	70.84	79.45
Factor loadings				
Linear Elongation ratio	0.77	-0.18	0.28	-0.16
Kernel length	-0.14	0.88	0.20	0.13
Kernal breadth	-0.87	-0.04	0.32	-0.29
L / B ratio	0.76	0.45	-0.23	0.35
Kernel length after cooking	0.49	0.69	0.45	-0.03
Kernel breadth after cooking	-0.90	0.13	0.32	-0.08
L/B after cooking	0.97	0.00	-0.04	0.00
Breadthwise elongation ratio	-0.72	0.34	0.01	0.24
Amylose content	0.41	-0.30	0.68	-0.07
Gel consistency	-0.14	-0.22	0.38	0.77
Volume expansion ratio	0.55	-0.31	0.27	-0.02
Gelatinisation temperature	-0.28	-0.62	-0.01	0.35

Fig. 1. Scree plot showing Eigen value variation in 12 Principal components

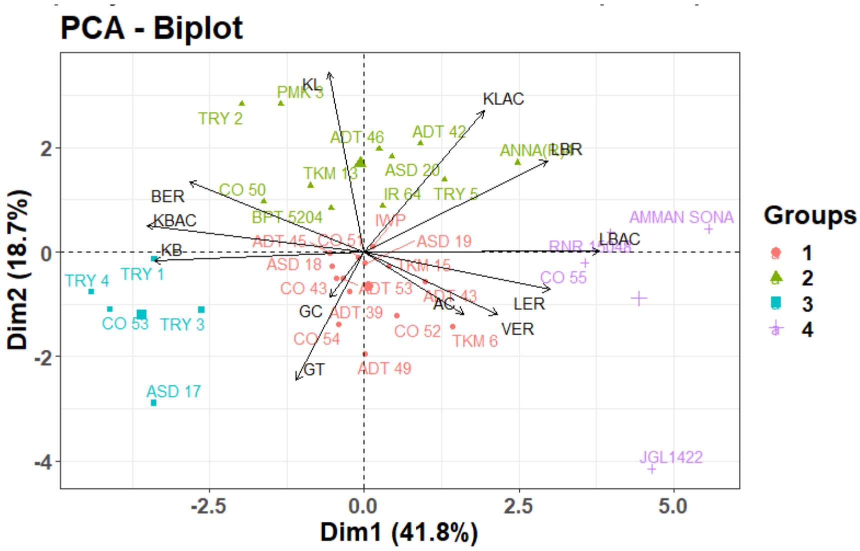

Fig. 2. Biplot of quality traits and varieties across first two Principal Components

4 consisted of three non- aromatic rice samples and TNAU variety CO 55 indicating the similarity between the genotypes. Genotypes recording high kernel breadth were classified together in group 3. Group 1 consisted of all medium slender varieties except BPT 5204, TKM 13 and CO 50. These three genotypes recorded high KBAC and BER than all medium slender varieties and were grouped with long slender varieties viz., TRY 2, PMK 3, ADT 42, Anna (R) 4, ASD 20, TRY 5 and IR 64 which also recorded high KBAC and LER

The multifaceted role of rice in global food security and economic stability emphasizes the urgency of addressing its production and export challenges. As the global population expands, climate change disrupts established agricultural norms, and consumer anxieties escalate, innovative solutions, traceability systems, and diversified export strategies assume paramount importance. The important quality traits preferred by consumers are discussed in this study including length breadth ratio, length, amylose content, gel consistency, linear and organoleptic traits. Cumulative scoring for preferred traits helped in identifying varieties with export potential *viz,* ADT 43 and TKM 15 for CO 51 type, CO 55 for RNR 15048 type and TKM 13, CO 52 and CO 43 in the BPT 5204 type. Production of these varieties in large quantities can be achieved through farmer producer organisation. Increasing production of selected varieties will enable the traders to choose good quality varieties instead of mixing different varieties. This will help largely in ensuring quality and fetching high prices for rice exported in the international market. Identification of varieties with export potential and adoption of these varieties by traders can also help in regularizing traceability systems which increases confidence in buying a produce. **This study is done as a first step for traceability**. Variability studies indicated that traits with high heritability and high genetic advance including gel consistency, length breadth after cooking, kernel breadth after cooking, gelatinization temperature, length breadth ratio and kernel breadth can be selected to achieve high genetic gain for further crop improvement. In addition, principal component analysis assisted in determining inter relationship between different quality traits and major traits contributing to total variation. Grouping done based on PCA helped in determining the similarities present among the genotypes. Most of the medium slender varieties were grouped together and CO 55, a short slender variety was grouped with short slender export samples.

ACKNOWLEDGEMENT

The financial support by Trichy Agri Business Incubation Forum, ADAC&RI campus, Trichy. The Agro Food Trade Centre. Madurai is also kindly acknowledged for providing necessary support during the study.

REFERENCES

Abansi, C., Duff, B., Lantican, F. and Juliano, B. 1992. In *Consumer demand for rice grain quality*, 37-57. Los Baños: International Rice Research Institute.

Agri exchange-APEDA. 2023. India's export analytical report. Available from: standard https://agriexchange.apeda.gov.in/indexp/Globalexport/India_Export_Statistics.aspx#.

Amerine, M., Pangborn, R. and Roessler, E. 1965. Principles of sensory evaluation of food In, 235-241. New York/London: Academic Press.

Anonymous. 2022. Traceability in rice supply chain. Available from: https://tracextech.com/traceability-in-rice-supply-chain/.

Aung, M.M. and Chang, Y.S. 2014. Traceability in a food supply chain: Safety and quality perspectives. *Food control*, **39**:172-184. [Cross Ref]

Bhonsle, S.J. and Krishnan, S. 2010. Grain quality evaluation and organoleptic analysis of aromatic rice varieties of Goa, India. *Journal of Agricultural Science*, **2** (3):99-107. [Cross Ref]

Cagampang, G.B., Perez, C.M. and Juliano, B.O. 1973. A gel consistency test for eating quality of rice. *Journal of the Science of Food and Agriculture*, **24** (12):1589-1594. [Cross Ref]

Calingacion, M., Laborte, A., Nelson, A., Resurreccion, A., Concepcion, J.C., Daygon, V.D., Mumm, R., Reinke, R., Dipti, S. and Bassinello, P.Z. 2014. Diversity of global rice markets and the science required for consumer-targeted rice breeding. *PloS one*, **9** (1):e85106. [Cross Ref]

Chand, R. 1999. Effects of trade liberalization on agriculture in India: Commodity aspects. INDIA: CGPRT Centre.

Cuevas, R.P., Pede, V.O., McKinley, J., Velarde, O. and Demont, M. 2016. Rice grain quality and consumer preferences: a case study of two rural towns in the Philippines. *PloS one*, **11** (3):e0150345. [Cross Ref]

Devi, K.R., Chandra, B.S., Lingaiah, N., Hari, Y. and Venkanna, V. 2017. Analysis of variability, correlation and path coefficient studies for yield and quality traits in rice (*Oryza sativa* L.). *Agricultural Science Digest*, **37** (1):1-9. [Cross Ref]

European Commission. 2002. Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety. In *Official Journal of the European Communities*.

FAO. 2022a. FAO Strategy on Climate Change 2022-2031, FAO, Rome.

FAO. 2022b. World food and agriculture statistical yearbook 2022. Food and Agricultural Organisation of United Nations Rome.

Golan, E.H., Krissoff, B., Kuchler, F., Calvin, L., Nelson, K.E. and Price, G.K. 2004. Traceability in the US food supply: economic theory and industry studies.

Govintharaj, P., Shalini, T., Manonmani, S. and Robin, S. 2016. Estimates of genetic variability, heritability and genetic advance for blast resistance gene introgressed segregating population in rice. *International Journal of Current Microbiology and Applied Sciences*, **5** (12):672-677. [Cross Ref]

GRiSP. 2013. Rice Almanac (4th edition). *Los Baños, Philippines: Global Rice Science Partnership*.

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** (4):320-325. [Cross Ref]

Johnson, H.W., Robinson, H.F. and Comstock, R.E. 1955. Estimates of genetic and environmental variability in soybeans 1. *Agronomy journal*, **47** (7):314-318. [Cross Ref]

Juliano, B., Perez, C., Blakeney, A., Castillo, T., Kongseree, N., Laignelet, B., Lapis, E., Murty, V., Paule, C. and Webb, B. 1981. International cooperative testing on the amylose content of milled rice. *Starch - Starke*, **33** (5):157-162. [Cross Ref]

Juliano, B.O. and Perez, C.M. 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. [Cross Ref]

Little, R., Hilder GB. and EH, D. 1958. Differential effect of dilute alkali on 25 varieties of milled white rice. *Cereal Chemistry*, **35**:111-126.

Manivannan, N. 2014. TNAUSTAT-Statistical package.

Nirmaladevi, G., Padmavathi, G., Kota, S. and Babu, V. 2015. Genetic variability, heritability and correlation coefficients of grain quality characters in rice (*Oryza sativa* L.). *SABRAO journal of Breeding and Genetics*, **47** (4):424-433.

PIB. 2023. Third Advance Estimates of Production of major crops released by Shri Narendra SinghTomar.Availablefrom:https://pib.gov.in/PressReleasePage.aspx?PRID=1927272.

Pokhrel, A., Dhakal, A., Sharma, S. and Poudel, A. 2020. Evaluation of physicochemical and cooking characteristics of rice (*Oryza sativa* L.) landraces of lamjung and Tanahun Districts, Nepal. *International journal of food science*:1-11. [Cross Ref]

Priyanka, R.M., Thiyagarajan, K., Bharathi, S.P. and Rajendran, R. 2017. Studies on genetic variability for floral and grain quality traits in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding*, **8** (2):609-614. [Cross Ref]

Ramaiah, K. 1969. Grain Classification- Rice Research in India. ICAR Publication, New Delhi

Rockström, J., Edenhofer, O., Gaertner, J. and DeClerck, F. 2020. Planet-proofing the global food system. *Nature Food*, **1** (1):3-5. [Cross Ref]

Roychowdhury, R. and Tah, J. 2011. Genetic variability study for yield and associated quantitative characters in mutant genotypes of *Dianthus caryophyllus* L. *International Journal of Biosciences*, **1** (5):38-44.

Sadhana, P., Raju, C.D., Rao, L. and Kuna, A. 2022. Studies on variability, correlation and path coefficient analysis for yield and quality traits in rice (*Oryza sativa* L.) genotypes. *Electronic Journal of Plant Breeding*, **13** (2):670-678. [Cross Ref]

SES, I. 2013. Standard evaluation system for rice. *International Rice Research Institute, Philippines*. doi: http://www.knowledgebank.irri.org/images/docs/rice-standard-evaluation-system.pdf.

Singh, P. and Narayanam, S.S. 2007. Heritability and genetic advance. In *Biometical Techniques in Plant Breeding*, 164-173. Kalyani publishers.

Suwannaporn, P., Linnemann, A. and Chaveesuk, R. 2008. Consumer preference mapping for rice product concepts. *British Food Journal*, **110** (6):595-606. [Cross Ref]

Valera, H.G. and Pede, V.O. 2023. “What do we know about the future of rice in relation to food system transformation?”. Available from: https://www.cgiar.org/news-events/news/what-do-we-know-about-the-future-of-rice-in-relation-to-food-system-transformation/#:~:text=Global%20rice%20production%20remains%20more,source%20-of%20rice%20through%202050.

Van Rijswijk, W. and Frewer, L.J. 2008. Consumer perceptions of food quality and safety and their relation to traceability. *British Food Journal*, **110** (10):1034-1046. [Cross Ref]

Wikipedia. 2023. Rice production in India. Available from: https://en.wikipedia.org/wiki/Rice_production_in_India#cite_note-3.

Yadav, S. and Kumar, V. 2018. Feeding the world while caring for the planet. *Direct Seed Rice Consort Newsl*, **1** (2):3-4.