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GENETIC ANALYSIS IN TRADITIONAL RICE LANDRACES OF SOUTHERN INDIA FOR PUFFING QUALITY

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Abstract

The present investigation was carried out at Department of Plant Breeding and Genetics, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai during 2021 - 2022. The study comprising of 23 traditional rice varieties or landraces of Southern India were analyzed for 16 quality traits to study the extent of variability and character association. Norungan, Navarai, Chinnar and Thooyamalli are the landraces that had maximum value for amylose content, expansion volume, expansion ratio, bulk density and puffing yield. High PCV and GCV were observed for the traits bulk density, expansion of volume, expansion ratio and puffing yield. High heritability coupled with high genetic advance as per cent of mean recorded for most of the traits except hulling percentage, milling percentage and head rice recovery. This proved that these traits are governed by additive gene effects and the process of selection would be effective to improve these traits. Character association studies revealed that the improvement of the traits *viz.,* kernel length, hulling percentage, fat content, gelatinization temperature, gel consistency and bulk density are the key parameters to avail good puffing quality. Based on the overall performance, the genotypes Norungan, Navarai, Chinnar and Thooyamalli can be selected for future breeding programme to obtain new recombinant types for premium quality puffing.

Introduction

The crop of choice for more than 50% of the world's population, rice (*Oryza sativa* L.), is known as the "Global Grain" and accounts for around 20% of the world's caloric intake. In 2022-2023, 503.27 million metric tons of rice was produced on an area of 162.57 million hectares worldwide (USDA 2020). According to Singh *et al.* (2014), Asia produces and consumes almost 90% of the world's rice. With 118.87 million metric tons produced, India comes in second to China.In general, landraces are less productive than commercial cultivars, but in recent years, they have gained significance as sources of genetic diversity in the hunt for genes that can be used to tolerate or resist biotic and abiotic conditions that are essential in agriculture. Farmers have conserved these landraces for their medicinal, nutritional, culinary and cultural values (Muthuramu and Ragavan 2020).

Rice is loaded with carbohydrates, supplies about 60 to 70 per cent of the energy requirements, not only as a staple food but also as a convenience items such as breakfast cereals, multigrain flakes, puffed, popped, and extruded products (Joshi *et al*. 2014). About 10 per cent of produced rice is being utilized for the production of snack foods. Among the rice snack foods, puffed rice is one of the convenient and popular product in India, which is preferred by both rice eating and non-rice eating population of the country. It is commonly used in snacks, cereal drinks, ready-to-eat breakfast cereal, and infant food. Not only puffed rice a staple diet, and also serves as a chief source of carbohydrate, but also it contributes beneficial nutrients that includes dietary fiber, vitamins, minerals, *etc*. (Joshi *et al*. 2014).

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Genetic variation is the lifeline of plant breeding programme as it extends the span of selection. Although an extensive spectrum of genetic variability for quality traits has previously been reported, there is still unexplored inheritable variation in germplasm that is crucial for choosing the potential parents in order to maximize heterosis and produce superior recombinants with regard to quality components. Genetic parameters such as genotypic coefficient of variation and phenotypic coefficient of variation are useful in detecting the amount of variability present in the germplasm. Heritability coupled with high genetic advance helps in determining the influence of environment on the genotypic expression and reliability of characters (Devi *et al*. 2015).

Choice of genotypes for varietal improvement based on yield alone is often deceiving. Hence, understanding the association between characters is needed for a precise selection approach for the plant breeders to develop an efficient variety. Path coefficient analysis delivers helps to understand the influence of each causative character to yield directly as well as indirectly and also permits breeders to categorize the genetic features in agreement with their contribution (Devi *et al*. 2017). With this background knowledge, the present investigation was envisaged to study the genetic variability of rice land races and the association among grain quality traits.

Materials and Methods

The experimental material comprised of 23traditional rice landraces acquired from varied origin *viz*., Tamil Nadu Rice Research Institute, Aduthurai, Agriculture Research Station, Paramakudi, Rice Research Station, West Godavari, Andhra Pradesh and Agricultural College and Research Institute, Madurai (Table 1).

Table 1. Passport details of the landraces incorporated in the present study.

Sl. No.	Traditional rice varieties	Place of collection
1.	Norungan	Agricultural Research Station, Paramakudi
2.	Sivappukavuni	AC&RI, Madurai
3.	Kothamalli samba	AC&RI, Madurai
4.	Arubathamkuruvai	Agricultural Research Station, Paramakudi
5.	Navarai	AC&RI, Madurai
6.	Seeraga samba	AC&RI, Madurai
7.	Karunguruvai	AC&RI, Madurai
8.	Kuliyadichan	Agricultural Research Station, Paramakudi
9.	Chinnar	AC&RI, Madurai
10.	Poongar	Agricultural Research Station, Paramakudi
11.	Mattaikar	Agricultural Research Station, Paramakudi
12.	Sivappuchiththiraikar	Agricultural Research Station, Paramakudi
13.	Chiththiraikar	Agricultural Research Station, Paramakudi
14.	Kallurudaikar	Agricultural Research Station, Paramakudi
15.	Mappillai samba	Tamilnadu Rice Research Institute, Aduthurai
16.	Kichili samba	Tamilnadu Rice Research Institute, Aduthurai
17.	Kullakar	Tamilnadu Rice Research Institute, Aduthurai
18.	Nootripathu	Agricultural Research Station, Paramakudi
19.	Milagu samba	Tamilnadu Rice Research Institute, Aduthurai
20.	Thooyamalli	Tamilnadu Rice Research Institute, Aduthurai
21.	Rakthasali	Rice Research Station, West Godavari
22.	Kumkumshali	Rice Research Station, West Godavari
23.	Manipuri black	Rice Research Station, West Godavari

Grains of all 23 rice landraces were cleaned properly, dried in hot air oven up to 12-14% moisture content and kept at room temperature for four months then used for grain quality parameter estimation at Department of Plant Breeding and Genetics, Agricultural College and Research Institute, Madurai, Tamilnadu, India during 2021-22. In this investigation, grain quality parameters of each rice samples were analysed in triplicates. All the standard protocol according to Indian Institute of Rice Research, Hyderabad, Formerly Directorate of Rice Research, India (DRR 2014)was followed for estimating sixteen grain quality parameters *viz*., Hulling percentage (H%), Milling percentage (M%), Head Rice Recovery percentage (HRR), Kernel Length (KL), Kernal Breadth (KB) and Kernal L/B ratio (KL/B), Expansion Volume (EV) and Expansion ratio (ER), Gel Consistency (GC), Gelatinization Temperature (GT), Puffing Yield percentage (PY), Bulk density (BD), Amylose Content (AC), Fat content (FAT), Fiber content (FIB) and Protein content (PRO).

Gel consistency test was conducted by the standard method (Cagampang *et al*. 1973). Alkali digestion value (Gelatinization Temperature) of samples was rated for degradation of kernels on scale of 1 to 7 (Little *et al*. 1958). Amylose content was determined by simplified calorimetric method (Sowbhagya and Bhattacharya 1971). Fiber content was estimated using the standard procedure (AOAC 2000) utilizing the FIBRA PLUS automated fiber estimation apparatus. The crude protein per cent was calculated by multiplying the predicted value of nitrogen by 6.25 using the Kjeldahl technique (Ma and Zuazaga1942) with Kelp plus Instrument. The crude protein content was calculated as a proportion of the total protein content. Genotypic and phenotypic co-efficient of variation were calculated following the methodology (Burton 1952), while the estimates of heritability and genetic advance were computed as per the procedures given by Johnson *et al.* (1955). Normal Pearson's correlation and path coefficient analysis was undertaken using R software (version 3.2.1). Furthermore, Genotypic and phenotypic correlation coefficients were calculated with META-R software.

Results and Discussion

The studies on analysis of variance among 23 rice genotypes for 16 quality characters revealed that the genotypes differed for all the characters, implied that the materials selected for the studies might be of diverse origin (Table 2). The success of any crop breeding programme depends on the choice of parents based on the mean performance. Among the 23 genotypes, the the highest protein content was in Rakthasali, while low protein content was observed in Thooyamalli. The fat content was more in Kumkumshali and less in Kuliyadichan. The highest fibre content was found in Milagu samba, while low fibre content was observed in Chithiraikar. The highest amylose content was found in Kumkumshali, while low amylose content was observed in Karunguruvai. The gel consistency was soft in Chinnar while it was hard in Thoyamalli. The alkali spreading value was the highest in Thooyamalli and Chithiraikar which infers that they need least time and temperature for cooking. Navarai had denser grains while Kuliyadichan had the least dense grains. Expansion volume was highest in SivappuChithiraikar and least in Poongar. Expansion ratio was highest in Thooyamalli while it was the least in Kuliyadichan. Puffing yield was higher in Norungan and lower in Kuliyadichan. With the mean values for the puffing quality observed, the genotypes Chinnar and Thooyamalli were the best suited varieties for making puffed rice. The varieties *viz.*,Norungan and Navarai can also be used to make puffed rice with good quality (Table 3, Fig. 1).

Knowledge on genetic variability within the available population is very essential for any crop improvement programme to improve yield and its attributing traits. So, the knowledge on genetic variability which is partitioned from the environmental effects is important. Since, the study on the parameters like phenotypic variance, genotypic variance and genetic advance is are useful, which in turn reflect the phenotypic coefficient of variation, genotypic coefficient of variation, heritability and genetic advance as per cent of mean (Dhanwani *et al*. 2013).The result obtained from the present study revealed that all the traits had more PCV than GCV. The differences between the PCV and GCV for the characters were very less which indicated the low environmental influence on the expression of these traits (Table 4).

Table 2.ANOVA for quality traits in traditional rice varieties.

Sl.No.	Characters	Replication MSS	Treatment MSS	Error MSS	S.Ed	C.D. (5%)
1	KL	0.0017	1.88**	0.01	0.07	0.20
2	KB	0.0001	0.24**	0.004	0.05	0.14
3	KL/B	0.0001	0.35**	0.006	0.06	0.16
4	H%	2.00	59.85**	8.42	2.05	6.00
5	M%	1.52	36.98**	4.61	1.52	4.44
6	HRR	6.34	49.37**	6.32	1.78	5.20
7	PRO	0.73	6.59**	0.59	0.54	1.59
8	FAT	0.07	2.96**	0.09	0.22	0.63
9	FIB	0.06	0.35**	0.08	0.19	0.58
10	AC	6.39	53.01**	7.69	1.96	5.74
11	GT	3.13	2.15**	0.59	0.54	1.58
12	GC	3.92	640.18**	7.59	1.95	5.71
13	BD	0.0001	0.04**	0.0009	0.02	0.06
14	EV	0.0006	46.32**	0.37	0.43	1.27
15	ER	0.01	11.87**	0.05	0.15	0.45
16	PY	52.02	1428.41**	56.39	5.31	15.54

** - Significant at 1 % level.*- Significant at 5% level.

Fig. 1.Puffed rice of promising traditional rice varieties.

In the present study, the quality traits *viz.* protein content, fat content, fibre content, gel consistency, gelatinization temperature, amylose content, expansion volume, expansion ratio, bulk density and puffing yield also had high magnitude of PCV and GCV. Contradictory finding was reported for Kernel length/breadth ratio (Dhurai *et al*. 2014), amylose content (Shankar *et al*. 2016), gel consistency and gelatinization temperature (Dhanwani *et al*. 2013). High PCV and GCV imply that the genotypes have high amount of variation. This variation may be highly useful for selection and choosing genotypes for further breeding programme.

Table 3. Mean performance of 23 traditional rice varieties for quality traits.

Sl. No.	Genotypes	KL	KB	KL/B	H%	M%	HRR	PRO	FAT	FIB	AC	GT	GC	BD	EV	ER	PY
1	Norungan	7.25	3.02	2.40	83.66	69.18	58.44	8.75	2.16	0.44	24.64	4.50	86.45	0.40	6.08	4.30	81.66
2	Sivappukavuni	6.10	2.15	2.84	74.94	65.28	54.88	7.90	2.68	1.21	22.26	3.50	99.10	0.39	4.30	4.00	70.15
3	Kothamalli samba	4.38	2.74	1.60	86.67	68.71	57.80	5.66	2.24	1.17	21.11	2.00	94.55	0.39	4.72	4.79	70.78
4	Arubathamkur uvai	6.87	2.93	2.34	75.92	68.87	52.91	6.09	2.45	0.79	13.55	3.50	87.10	0.10	2.29	0.72	16.72
5	Navarai	6.11	2.83	2.16	78.16	66.83	60.22	7.40	3.11	1.21	23.96	3.50	71.00	0.52	7.73	4.84	75.66
6	Seeraga samba	4.30	1.92	2.24	71.10	59.92	56.46	8.34	3.34	0.94	25.45	4.50	104.35	0.38	14.60	7.28	78.42
7	Karunguruvai	5.66	2.75	2.06	77.97	68.02	60.86	6.14	2.18	1.03	12.44	5.00	58.20	0.08	2.38	1.27	15.80
8	Kuliyadichan	7.15	2.87	2.49	73.10	65.16	63.10	10.60	1.78	0.62	13.19	3.50	69.75	0.06	2.98	1.44	10.17
9	Chinnar	7.94	2.36	3.37	81.01	58.71	49.78	6.09	2.06	1.52	18.47	4.50	123.00	0.34	12.08	5.54	70.28
10	Poongar	6.86	3.05	2.25	77.00	68.48	61.45	8.36	2.84	1.10	20.20	5.00	85.35	0.10	0.59	2.51	15.84
11	Mattaikar	6.94	2.57	2.70	70.70	64.60	51.58	6.19	5.40	0.78	24.28	3.50	87.35	0.18	9.70	4.11	60.89
12	Sivappuchithth iraikar	6.95	2.80	2.48	82.82	74.74	64.75	7.08	3.51	0.70	24.07	5.00	81.25	0.47	16.33	5.48	75.88
13	Chiththiraikar	6.84	3.00	2.28	77.47	63.59	47.66	9.05	2.11	0.39	12.49	6.00	52.95	0.07	2.21	2.38	11.62
14	Kallurudaikar	7.03	2.85	2.46	74.09	64.64	59.25	7.21	4.45	0.48	19.81	5.00	71.39	0.36	9.33	4.10	69.29
15	Mappillai samba	6.69	2.83	2.36	82.13	74.78	60.09	10.42	2.08	0.91	24.84	4.00	92.20	0.41	10.99	6.30	67.01
16	Kichili samba	5.88	2.26	2.60	76.89	67.77	59.07	7.97	2.28	0.71	25.45	5.00	103.35	0.32	12.16	6.15	71.21
17	Kullakar	6.21	2.61	2.38	74.24	64.68	52.45	8.76	4.09	0.51	15.43	3.00	78.05	0.09	2.53	1.58	16.34
18	Nootripathu	5.85	3.04	1.93	80.92	75.94	57.45	6.88	4.63	0.78	26.66	3.00	91.95	0.36	10.33	4.67	80.60
19	Milagu samba	4.31	2.59	1.66	89.57	67.16	50.51	5.45	1.81	1.91	26.71	3.50	97.40	0.47	14.14	9.74	78.30
20	Thooyamalli	6.40	2.82	2.27	69.96	61.20	49.90	3.69	3.75	1.82	21.85	6.00	46.25	0.45	16.29	10.16	73.17
21	Rakthasali	5.38	2.05	2.62	71.66	65.20	56.03	11.17	2.23	0.91	16.70	4.50	87.35	0.34	9.04	3.77	40.44
22	Kumkumshali	6.12	2.15	2.85	76.96	67.06	47.20	6.08	6.34	1.53	28.76	2.50	91.05	0.34	7.37	3.52	67.79
23	Manipuri black	7.08	2.19	3.23	87.10	68.13	56.89	8.62	3.00	0.99	27.44	4.50	104.20	0.32	7.99	5.92	76.07
	Mean	**6.27**	**2.63**	**2.42**	**78.00**	**66.90**	**56.03**	**7.56**	**3.06**	**0.97**	**21.29**	**4.13**	**85.37**	**0.30**	**8.09**	**4.54**	**56.26**
	S.Ed	**0.07**	**0.05**	**0.06**	**2.05**	**1.52**	**1.78**	**0.54**	**0.22**	**0.19**	**1.96**	**0.54**	**1.95**	**0.02**	**0.43**	**0.15**	**5.31**
	C.D. 5%	**0.20**	**0.14**	**0.16**	**6.00**	**4.44**	**5.20**	**1.59**	**0.63**	**0.58**	**5.74**	**1.58**	**5.71**	**0.06**	**1.27**	**0.45**	**15.54**

*-Significant at 5% level.** - Significant at 1% level.

Moderate PCV and GCV were found for the traits *viz.*, kernel length, kernel breadth and kernel length / breadth ratio. This result was in accordance with earlier findings (Sahu *et al*. 2017, Akshay *et al*. 2022). Presence of wide spectrum of variability in given crop species will enhance the chance of selecting a desirable genotype. The moderate to high GCV indicates high degree of genetic variability and this does greater scope for selection of the traits with moderate to high

GCV. The extent of PCV and GCV was found to be low for the traithulling percentage, milling percentage and head rice recovery. Similar findings were reported by two workers (Sahu *et al*. 2017, Balaji *et al*. 2022). Low PCV and GCV estimates indicate narrow genetic base for these traits. Improvement in these characters can be brought about by hybridization or induced mutagenesis to widen the genetic base followed by pedigree selection in advanced generations.

Even though heritability estimates provide an indication of the relative value of selection based on the phenotypic expression, heritability and genetic advance are then considered together, that give more reliable information in predicting the result of selection. Because, heritability could be even 100 per cent when the genotypic variance is of small or large value; but the genetic progress will be larger only when the genotypic variance is high. All the traits except hulling percentage, milling percentage, head rice recovery and gelatinization temperature had high heritability coupled with high genetic advance (Table 4). The traits exhibiting high heritability coupled with high genetic advance revealed that high heritability may be due to additive genetic effects and the process of selection would be effective to improve these traits. These results were contradictory to early findings (Sahu *et al.* 2017, Akshay *et al*. 2022) for the traits kernel length, kernel breadth, kernel length/breadth ratio, milling percentage, head rice recovery, gel consistency, gelatinization temperature and amylose content.The traits hulling percentage, milling percentage and head rice recovery showed high heritability coupled with moderate genetic advance. This would also facilitate selection strategy to be adopted for improving these traits. This was similar with the various workers (Devi *et al*. 2017, Dhanwani *et al*. 2013,Balaji *et al*. 2022).

Table 4. Variability and genetic parameters for various quality traits in 23 traditional rice varieties.

Characters	Mean	Range	GCV	PCV	Heritability %	G.A (%) Mean
KL	6.27	4.31 – 7.94	15.45	15.53	98.92	31.64
KB	2.63	1.92 – 3.05	13.20	13.44	96.54	26.72
KL/B	2.42	1.60 – 3.37	17.25	17.56	96.49	34.91
H%	78.00	69.96 – 89.57	6.50	7.49	75.35	11.63
M%	66.90	58.71 – 75.94	6.01	6.81	77.83	10.93
HRR	56.03	47.20 – 64.75	8.28	9.42	77.31	14.99
PRO	7.56	3.69 – 11.17	22.90	25.06	83.49	43.10
FAT	3.06	1.78 – 6.34	39.11	40.35	93.95	78.09
FIB	0.97	0.39 – 1.91	37.79	47.37	63.65	62.11
AC	21.29	12.44 – 28.76	22.36	25.87	74.66	39.80
GT	4.13	2.00 – 6.00	21.39	28.29	57.16	33.32
GC	85.37	46.25 – 123.00	20.83	21.08	97.65	42.41
BD	0.30	0.06 – 0.52	49.10	50.15	95.88	99.04
EV	8.09	0.59 – 16.33	59.23	59.71	98.40	121.02
ER	4.54	0.72 – 10.16	53.50	53.72	99.19	109.76
PY	56.26	10.17 – 81.66	46.55	48.43	92.40	92.18

The phenotypic correlation coefficients and genotypic correlation coefficients exhibited similar trend. However, the value of genotypic correlation coefficient is found to be greater among the traits revealing that there is less environmental influence in the expression of traits. This may be due to the reason that rice genotypes had grown in a conducive environment for good genetic expression of traits (Johnson *et al.* 1955). When puffing quality parameters are taken into account, the association of the physical and chemical traits of rice with puffing yield helps us to understand the importance of the traits to be taken care for getting high puffing yield. Hulling percentage, amylose content, gel consistency, expansion volume, expansion ratio and bulk density had strong positive association with puffing yield (Table 5).

Table 5. Genotypic correlation coefficients of quality traits in 23 traditional rice varieties (Puffing yield as dependent variable).

Character	KL	KB	KL/B	H%	M%	HRR	PRO	FAT	FIB	AC	GT	GC	BD	EV	ER	PY
KL	1.000	0.349	0.645**	-0.113	0.004	0.049	0.153	0.070	-0.362	-0.222	0.397	-0.100	-0.276	-0.174	-0.326	-0.192
KB		1.000	-0.487*	0.196	0.465*	0.294	-0.124	-0.125	-0.321	-0.333	0.128	-0.564**	-0.232	-0.305	-0.257	-0.307
KL/B			1.000	-0.217	-0.349	-0.208	0.223	0.172	-0.045	0.090	0.237	0.386	-0.055	0.069-	0.095	0.089
H %				1.000	0.524**	0.089	-0.140	-0.369	0.281	0.487*	-0.256	0.407*	0.384	0.088	0.270	0.404*
M%					1.000	0.538**	0.188	0.042	-0.303	0.376	-0.349	0.037	0.158	-0.030	-0.109	0.112
HRR						1.000	0.444*	-0.307	-0.406*	0.028	0.013	-0.051	0.069	-0.055	-0.176	-0.011
PRO							1.000	-0.336	-0.663**	-0.189	0.090	0.085	-0.235	-0.307	-0.372	-0.310
FAT								1.000	0.025	0.401*	-0.307	-0.082	0.069	0.169	-0.015	0.236
FIB									1.000	0.333	-0.256	0.208	0.499*	0.409*	0.667**	0.388
AC										1.000	-0.305	0.499*	0.775**	0.632**	0.709**	0.905**
GT											1.000	-0.467*	-0.098	0.245	0.218	-0.184
GC												1.000	0.283	0.238	0.214	0.450*
BD													1.000	0.733**	0.775**	0.916**
EV														1.000	0.855**	0.750**
ER															1.000	0.770**
PY																1.000

*-Significant at 5% level. **-Significant at 1% level.

Table 6. Path coefficient analysis of quality traits in 23 traditional rice varieties (Puffing yield as dependent variable).

Charac ter	KL	KB	KL/B	H%	M%	HRR	PRO	FAT	FIB	AC	GT	GC	BD	EV	ER	PY
KL	**1.386**	-0.394	-1.223	-0.039	-0.001	0.008	0.017	0.059	-0.072	0.016	0.289	-0.079	-0.262	0.062	0.040	-0.192
KB	0.483	**-1.132**	0.923	0.067	-0.100	0.048	-0.014	-0.106	-0.064	0.024	0.093	-0.448	-0.221	0.108	0.032	-0.307
KL/B	0.894	0.551	**-1.895**	-0.074	0.075	-0.034	0.025	0.147	-0.009	-0.006	0.172	0.306	-0.052	-0.024	0.011	0.089
H %	-0.157	-0.222	0.411	**0.343**	-0.113	0.014	-0.016	-0.315	0.056	-0.035	-0.186	0.323	0.365	-0.031	-0.033	0.404*
M%	0.005	-0.526	0.661	0.180	**-0.215**	0.088	0.021	0.035	-0.060	-0.027	-0.254	0.029	0.149	0.010	0.013	0.112
HRR	0.067	-0.332	0.393	0.030	-0.116	**0.164**	0.050	-0.262	-0.080	-0.002	0.009	-0.040	0.065	0.019	0.022	-0.011
PRO	0.212	0.140	-0.421	-0.048	-0.040	0.073	**0.114**	-0.287	-0.132	0.013	0.065	0.067	-0.224	0.109	0.04	-0.310
FAT	0.097	0.141	-0.326	-0.126	-0.009	-0.050	-0.038	**0.855**	0.004	-0.029	-0.224	-0.065	0.065	-0.060	0.001	0.236
FIB	-0.501	0.363	0.086	0.096	0.065	-0.067	-0.075	0.020	**0.199**	-0.024	-0.186	0.165	0.475	-0.145	-0.083	0.388
AC	-0.307	0.377	-0.171	0.167	0.081	-0.004	-0.021	0.343	0.066	**-0.072**	-0.222	0.397	0.737	-0.225	-0.088	0.905**
GT	0.551	-0.144	-0.448	-0.087	0.075	0.002	0.010	-0.262	-0.051	0.022	**0.728**	-0.371	-0.093	-0.087	-0.027	-0.184
GC	-0.138	0.638	-0.730	0.139	-0.007	-0.008	0.009	-0.070	0.041	-0.036	-0.340	**0.795**	0.268	-0.084	-0.026	0.450*
BD	-0.382	0.262	0.104	0.131	-0.034	0.011	-0.027	0.059	0.099	-0.056	-0.071	0.224	**0.952**	-0.261	-0.096	0.916**
EV	-0.241	0.345	-0.129	0.030	0.006	-0.009	-0.035	0.144	0.081	-0.045	0.178	0.189	0.698	**-0.356**	-0.106	0.750**
ER	-0.452	0.291	0.180	0.092	0.023	-0.029	-0.042	-0.012	0.132	-0.051	0.158	0.170	0.737	-0.304	**-0.124**	0.770**

*-Significant at 5% level; **-Significant at 1% level. Residual Effect = 0.2525; The number in bold represents direct effects.

Amylose content had strong positive association with expansion volume, expansion ratio, bulk density and puffing yield. Amylose content plays an important role in deciding the puffing characteristics, as high amylose content rice are composed of linear chain that align themselves in the shear field. Thus high amylose rice is hard to shear and this leads to the sudden expansion of the endosperm, makingit a highly puffed product compared to their low amylose counterparts. This association of amylose content with puffing yield was previously reported by many workers (Goodman and Rao 1983, Chinnaswamy and Battacharya 1984, Chandrasekar and Chattopadhyay1991, Joshi *et al*. 2014, Akter *et al*. 2018).

Bulk density is of importance in this investigation as highly dense materials have closely packed starch molecules and are thus harder and denser, which ultimately affect the puffing quality of grains. Denser grains tend to prevent breakage during puffing process. Hence denser grains lead to increased puffing yield. This was opposed to other findings (Joshi *et al*. 2014).When puffing yield is taken as effect with other quality characters as its cause, path analysis showed that the kernel length, bulk density, fat content, gel consistency and gelatinization temperature showed high direct effect on puffing yield. Other characters showed negligible direct and indirect effect. The residual effect (0.2525) suggests that still some more characters need to be exploited to find out their contribution in puffing yield (Table 6).Long kernels for soft gel consistency, medium sized grain for good head rice recovery are the traits for indirect selection at field level. The amylose content may serve as an indicator for breeding varieties with good gel consistency and cultures with moderate cooking time. Bulk density and amylose content are key factors in the process of puffing. This result is also obtained from the path analysis.

Among the 23 rice landraces studied Norungan, Navarai, Chinnar and Thooyamalli were found to be superior in most of the quality traits. These genotypes had maximum value for amylose content, expansion volume, expansion ratio, bulk density and puffing yield. Association analysis clearly indicates that, puffing yield had strong association with amylose content, expansion volume, expansion ratio and bulk density. Path coefficient analysis revealed that five traits had high and positive direct effect *viz*., kernel length, bulk density, fat content, gel consistency and gelatinization temperature. Based on the overall performance of quality analysis, the present study indicated that the genotypes Norungan, Navarai, Chinnar and Thooyamalli can be selected for future breeding programme to obtain new recombinant types for premium quality puffing performance.

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