Received: 16 Oct 2024 | Revised: 27 Feb 2025 | Accepted: 04 Mar 2025

Electronic Journal of Plant Breeding

Research Article

Rice kernel morphometrics: Exploring the physical dimensions of indigenous traditional landrace diversity through physio metric studies

S. Manju Devi[1], M. Raveendran[2], R. Pushpam[3], S.Muthuramu[4], R. Pushpa[5], N. Sritharan[6], R. Suresh[6] and A. John Joel[1*]

[1]Department of Plant Biotechnology, Centre for Plant Molecular Biology and Biotechnology, Tamil Nadu Agricultural University, Coimbatore.
[2]Directorate of Research, Tamil Nadu Agricultural University, Coimbatore.
[3] Department of Forage Crops, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore.
[4] Agricultural Research Station, Paramakudi.
[5] Tamil Nadu Rice Research Institute, Aaduthurai.
[6] Department of Rice, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore.
***E-Mail:** jnjoel@gmail.com

Abstract
Development and widespread adoption of modern rice varieties has led bottlenecking of many beneficial alleles and there is a significant decline in the cultivation of traditional landraces, which results in substantial loss of genetic diversity. The varied consumer preference in terms of eating habit and other preparations in rice sustains the diversity in the grains. Hence, present day market trend in rice revolves around the choice of consumers which are mainly based on the physical characteristics of rice. To categorize rice based on kernel characteristics, in this study, a total of 500 rice genotypes were taken for assessing the physical properties of kernel *viz.,* seed length, seed width, length/width ratio, seed thickness, bulk density, geometric mean diameter, sphericity, aspect ratio and hundred seed weight. All the traits exhibited ample amount of significant variations ($P<0.05$). High GCV was exhibited by bulk density and high heritability was observed by hundred seed weight, seed thickness, bulk density and seed width indicating that these traits were highly influenced by genetic factor and less influence of environment. Among these traits, hundred seed weight, seed thickness, bulk density and seed width exhibited high heritability coupled with high genetic advance as per cent of mean indicating the additive gene action and amenable for selection. Principal component analysis observed that the first three principle components explained most of the total variations present in the studied genotypes. Specifically, the first principal component (PC1) contributed the most, representing 35.24% of the variability followed by PC2 and PC3. In view of size and shape, most rice genotypes exhibited kernels that were predominantly short and narrow, succeeded by those that were short and of medium width. To categorise the seed diversity among the kernels of landraces, Mahalanobis D^2 statistics analysis was performed. Based on this the 500 rice landraces were grouped into five distinct clusters. Among the clusters, the Cluster II predominantly comprised kernels of medium and short lengths, medium widths. In contrast, Cluster V predominantly featured grains of very short lengths, narrow to very narrow widths. From the five clusters, four genotypes per cluster emphasising high mean value for bold and slender shape were selected for observation of cooking quality traits. During cooking, grain expands in all the dimensions but usually more in length. The gelatinization temperature based on alkali digestion values showed that 16 rice genotypes had low alkali spreading values, leading to stickier rice. Meanwhile, four genotypes exhibited intermediate alkali spreading values, which are preferred for parboiling. Therefore, an understanding on the kernel architecture and grouping them based on the physical dimensions like seed thickness, seed width, and bulk density, as well as kernel colour along with hundred seed weight will be useful in formulating breeding programme for kernel traits or consumer preferences. This selection aimed to align breeding goals with market needs, guaranteeing economic feasibility and sustainability in rice farming.

Keywords: Rice, physical properties,variability, principle components, diversity, cooking traits

INTRODUCTION

Rice (*Oryza sativa*) is one of the staple foods for millions of people in the world. It is the main source for calorific diet for most of the country especially Asia and has become a traditional crop in several regions. It is an essential energy reservoir of carbohydrates, proteins and trace minerals. Archaeological evidence establishes that rice became part of the Indian diet around 8000 BC, with agricultural activities in the second millennium BC encompassing rice cultivation in the Kashmir and Harrappan regions (Nene *et al.,* 2005). In India, rice consumption manifests in diverse forms, including whole cooked grains, as dish meals (white rice), and parboiled rice. Additionally, rice serves as a fundamental component in the preparation of numerous indigenous fermented foods, sweets, and various extruded products (Ghadge and Prasad, 2012). The market value of rice is significantly influenced by its physical properties (Correa *et al.,* 2007). The quality and appropriateness of rice seeds for different purposes are predominantly determined by their physical characteristics. Grain size affects the yield of rice as well as it is the important factor for appearance and quality (Li *et al.,* 2018). It is complex quantitative trait, closely associated with grain weight and is usually measured by length, width and length/width ratio (Zhang *et al.,* 2020).

Geographic segmentation plays a crucial role in influencing consumers' choices regarding desired rice characteristics. In India, consumers tend to favour rice varieties with physical appearance. The global demand for high-quality rice is dynamic (Calingacion *et al*., 2014). In South and Southeast Asia, there is a noticeable shift in consumer preferences towards fine and aromatic rice (Custodio *et al.,* 2016). This change could be attributed to the distinct preferences of a new generation of consumers or to evolving preferences over time, potentially influenced by trade liberalization, where importers introduce new preferences to the market. The majority of research into rice consumer preferences has traditionally centered on the needs of specific countries. However, with the rice market becoming increasingly global, there's a growing necessity for a broader view of consumer preferences regarding rice grain quality and its geographic variations (Anang *et al.,* 2011; Abazari *et al*., 2012). This broader perspective will enable a more focused strategy in developing and distributing new rice varieties that are more likely to be embraced and adopted. Hence, understanding the physical properties is crucial during harvest, transportation, during design of proper storage procedures for post-harvesting processing operations (Ghadge and Prasad, 2012). The knowledge on quality appearance of grain play a major role in trait selection and the markers developed from these genomic regions provide an efficient tool for marker assisted selection. This will pave way for further breeding programme to develop superior varieties to meet the market demand (Calingacion *et al.,* 2014).

Grain shape and size is the most important attributes in varietal improvement programme (Adair *et al.,* 1966). Grain length is more variable when compared with grain width. Grain shape and size significantly affect the cooking quality *viz.,* hardness, optimum cooking time, cohesiveness, adhesiveness and texture (Mohapatra and Bal, 2006). Details such as seed volume and bulk density are essential in determining the actual specific gravity of bulk grain (Mohsenin, 1986). Grain densities have been a focal point in studies related to breakage susceptibility and hardness (Morita *et al*., 1987). The wide and unique variation in the physical properties of grains is particularly noteworthy, especially when considering the differences among various genotypes.

The progress in machinery and the establishment of standardized unit operations play a crucial role in minimizing broken rice accumulation during the milling process (Irtwange, 2012). Since, rice kernel being the final product of rice cultivation and the whole rice industry and people preferences revolves around its quality and suitability to different finished products *viz.,* flaked rice (Bhattacharya, 2011), canned rice products include soups with rice, meat and rice dinners, casseroles, Spanish rice, unflavored cooked rice, fried rice, biriyani and rice pudding (Luh, 2013), gluten free rice noodles (Tong, 2020) and south Indian diets include idli and dosa. . Parameters associated with density contribute to the proper selection of storage compartment sizes without compromising aeration and drying processes (Varnamkhasti *et al*., 2008). Given the existing lack of scientific knowledge concerning the physical properties of rice, the current research is dedicated to examining the physical characteristics of 500 traditional rice genotypes. This exploration is intended to facilitate the grouping, selection and identification of genotypes based on kernal traits and utilising them based on respective breeding objectives. And these data begin to attain its potential only when they are put to use in planting, harvesting, storing, milling and processing.

MATERIALS AND METHODS

The present study material comprised of 500 rice landraces received from NBPGR, New Delhi. The grains were subjected to physio metric analysis at Molecular Biology Laboratory, Department of Plant Biotechnology, Centre for Plant Molecular Biology and Biotechnology, Tamil Nadu Agricultural University, Coimbatore.

Physical properties of the seed: The shape of the rice was found to be cylindrical with three perpendicular dimensions, length (L), width (W) and thickness (T). The experiment was conducted in two replications to observe eleven traits *viz.,* kernel length, kernel width, kernel length/ width ratio, kernel thickness, bulk density, geometric mean diameter, sphericity, aspect ratio, hundred seed weight, kernel colour and grain colour.

https://doi.org/10.37992/2025.1601.008

The observations were measured using 10 seeds for each genotype in two replications and the mean value was taken for statistical analysis. Kernel length, width and thickness were measured using vernier calliper (0 to 150 mm). The ratio of kernel length to the kernel width provides kernel length/width ratio. The bulk density is the ratio of mass of the sample to its total volume and was measured using the formula given by Mohsenin, 1986.

$$\text{Bulk density (g/cm}^3\text{)} = \frac{\text{Weight of the sample}}{\text{Volume occupied by the sample}}$$

The geometric mean diameter of the rice kernel was determined using the relationship between length, width and thickness given by Mohsenin, 1986 as:

$$\text{Geometric mean diameter} = (LWT)^{1/3}$$

Sphericity and aspect ratio describes the shape of the seed. The grading of rice can be accomplished by assessing its aspect ratio, which also offers information about the extent of off-size in the graded product. Thus, the sphericity and aspect ratio (Maduako and Faborode, 1990) was computed as,

$$\text{Sphericity} = \frac{(LWT)1/3}{L} \times 100$$

$$\text{Aspect ratio} = \frac{\text{Width}}{\text{Length}} \times 100$$

The weight of the kernels was observed using electronic balance (Sartorius AG GOTTINGEN model CP423S - 16802777) to an accuracy of 0.001 g.

Cooking Quality Parameters: Determining cooking quality parameters is crucial as it serves as the standard for assessing the success of rice breeding in meeting consumer demands. The experiment was done in two replications and the seven parameters *viz.,* grain length before cooking, grain length after cooking, grain breadth before cooking, grain breadth after cooking, Linear elongation ratio by Verghese (1950) method, Breadthwise expansion ratio and Gelatinization temperature based on seven-point scale given by Little *et al.* (1958) were measured.

Statistical analysis: In the present study, the observations taken out of the 500 rice landraces were subjected to statistical analysis. Analysis of variance (ANOVA) was conducted using R studio software (Racine, 2012) using “agricole” package (de Mendiburu and de Mendiburu, 2019). Genetic analysis was done using “variability” package (Singh and Chaudhary, 1977). Correlation between studied traits was estimated using “corrplot” package (Wei *et al.,* 2017). Principal component analysis (PCA) was done using “FactoMineR” and “Factoshiny” packages. Clustering was performed by using the statistical package PBperfect by Ward.D^2 method with the Euclidean distance method (Allan, 2023).

RESULTS AND DISCUSSION

Statistical analysis revealed significant differences among all the genotypes and traits studied. Significant variation (**Table 1**) for the traits studied was also observed by the researchers Lalitha *et al.* (2019); Qadir and Wani, (2023); Lu *et al.* (2023) and Liu *et al.* 2009 in rice. The range of seed length varied from 3mm to 9mm with an average of 7.24±0.04, seed width varied from 1.17mm to 3.62mm with a mean of 2.55±0.01, seed thickness ranged from 1.02mm to 2.96mm with an average of 1.71±0.01, the length/ width ratio ranged from 0.96 to 4.91 with mean value of 2.88±0.03. The mean value of bulk density, geometric mean diameter, sphericity, aspect ratio and hundred seed weight was 0.37±0.01, 3.13±0.01, 31.16±0.24, 0.36±0.01 and 2.22±0.02 with range of 0.15g/cm^3 to 0.70g/cm^3, 1.94 to 4.14, 11.86 to 54.03, 0.20 to 1.04 and 1.00g to 3.47g respectively and these traits exhibited ample amount of variation among the 500 rice genotypes. Utami *et al.* (2019) observed bulk density of Indonesian rice varieties from 0.45 to 0.58g/cm^3. Understanding the genetic basis of seed length and width paved identification of seven and three QTLs for respective traits (Huang *et al.,* 2012).

Variability measures are the basic principle in any plant breeding programme. In the present study phenotypic coefficient of variation was higher than the genotypic coefficient of variation for all the traits studied indicating the influence of environment (**Table 2**). The influenced action of environment over phenotypic effects of rice kernel traits was also observed by Demeke *et al.* (2023); Pradhan *et al.* (2023); Kumar *et al.* (2023). High to moderate values of PCV was observed for bulk density, aspect ratio, length/ width ratio, sphericity, hundred seed weight, seed length, seed thickness and seed

Table 1. Mean squares from analysis of variance of nine physical properties of rice landraces

Source of variation	df	Seed length	Seed width	Seed thickness	Length/ width ratio	Bulk density	Geometric Mean Diameter	Sphericity	Aspect ratio	Hundred seed weight
Genotypes	499	2.08*	0.21*	0.17*	0.62*	0.02*	0.15*	59.12*	0.01*	0.33*
Replication	1	29.58	0.02	0.05	5.77	0.01	0.39	132.24	0.14	0.1
Error	499	1.4	0.01	0.01	0.23	0.01	0.04	16.04	0.01	0.01

* Significant at 5 per cent

Table 2. Genetic variability parameters of nine physical properties among 500 rice genotypes

Characters	Mean±SE	Range	PCV	GCV	Heritability	Genetic advance as per cent of mean
Seed length	7.24±0.04	3-9	18.26	8.06	19.49	7.33
Seed width	2.55±0.01	1.17-3.62	13.03	12.34	89.75	24.09
Seed thickness	1.71±0.01	1.02-2.96	17.63	16.89	91.77	33.33
Length/width ratio	2.88±0.03	0.96-4.91	22.86	15.29	44.77	21.08
Bulk density	0.37±0.01	0.15-0.70	30.18	28.36	91.24	62.2
Geometric Mean Diameter	3.13±0.01	1.94-4.14	9.93	7.51	57.22	11.7
Sphericity	31.16±0.24	11.86-54.03	19.66	14.89	57.31	23.22
Aspect ratio	0.36±0.01	0.20-1.04	26.33	15.6	35.11	19.03
Hundred seed weight	2.22±0.02	1.00- 3.47	18.51	18.45	99.30	37.87

width whereas, high GCV was exhibited by bulk density (**Table 2)**. Heritability estimates assist in efficient resource management by choosing favourable traits, facilitating maximum genetic improvement with minimal effort. Additionally, they offer insights into the degree to which a specific trait can be passed on to future generations and act as a good indicator of selection process (Kumar *et al.,* 2023). High heritability was observed by hundred seed weight (99.30 per cent), seed thickness (91.77 per cent), bulk density (91.24 per cent) and seed width (89.75 per cent) indicating that these traits were highly influenced by genetic factor and expected to remain stable under varied environmental situation. Genetic advance gives insights into the level of genetic improvement achievable through the selection of a specific genotype. High heritability along with high genetic advance as per cent of mean was exhibited by hundred seed weight, seed thickness, bulk density and seed width indicating the additive gene action. Chendake *et al.* (2023) and Kumar *et al.* (2023) also observed additive gene action for seed width and hundred seed weight in rice. Hence, selection of these traits would be more effective in early generation on basis of *per se* performance of the traits whereas other traits exhibited non additive gene action.

Principle component analysis is an exploratory tool provided by Pearson (1901) which helps to identify the unknown trends in the multi dimensional data used in the study. It also helps to categorize genotypes and depicts the similarities between them (Leonard and Peter, 2009). This measures the significance and contribution of each component to its total variance. Principle components that are selected by the eigen values more than one would be more rewarding (Brejda *et al.,* 2000). In this study, out of nine principle components, the first three principle components explained most of the total variations present in the studied genotypes. These three principle components with eigen value more than one contributed about 87.37 per cent of the total variability among the 500 rice genotypes evaluated for physical properties of the seed (**Table 3**). This depicts that these three principal components could be the ideal components to select the genotypes (Kasanaboina *et al.,* 2022). The remaining six principle components contributed only 20.70 per cent to the total variance. The principle component (PC1) contributed maximum variability of 35.24 per cent followed by PC2 with 30.98 per cent and PC 3 with 13.07 per cent respectively (**Fig. 1**). The interpretation of principal components involves the determination of which variables demonstrate the most robust correlations with each component. Eigen values approximating -1 or 1 indicate that the variable has a substantial influence on the component, while values approaching 0 suggest that the variable exerts only a minimal impact on the component. The characters that contributed positive factor loading value for PC1 were seed length of 0.485, geometric mean diameter of 0.445, sphericity of 0.442, length/width ratio of 0.368, seed thickness of 0.274 and hundred seed weight of 0.056 whereas, the traits *viz.,* length/width ratio and seed length contributed more to PC2. In PC3 the positive factor loading was observed in bulk density, hundred seed weight, seed length, seed width and length/width ratio (**Table 3**). This indicated a high degree of correlation among the studied traits under the principle components expressing more variability (Jain and Patel, 2016). Traits converging within various principal components may be accorded higher importance in breeding programs due to their tendency to coexist (Chakravorty *et al.*, 2013). PCA, as a whole, effectively detected key traits that played a pivotal role in explaining the diversity among the genotypes.

The magnitude of the vector corresponds to the character's contribution to the principal component. Furthermore, the angle between the character vectors reflects the correlation between variables. When the angle between two trait vectors is less than 90° (an acute angle), it indicates a positive correlation. The two vectors in the IV quadrant *viz.,* geometric mean diameter and sphericity were highly correlated traits whereas; thickness and hundred seed weight are highly correlated variables. Likewise, seed length and length/width ratio in III quadrant, aspect ratio and width in I quadrant are highly correlated with each other. If the angle between

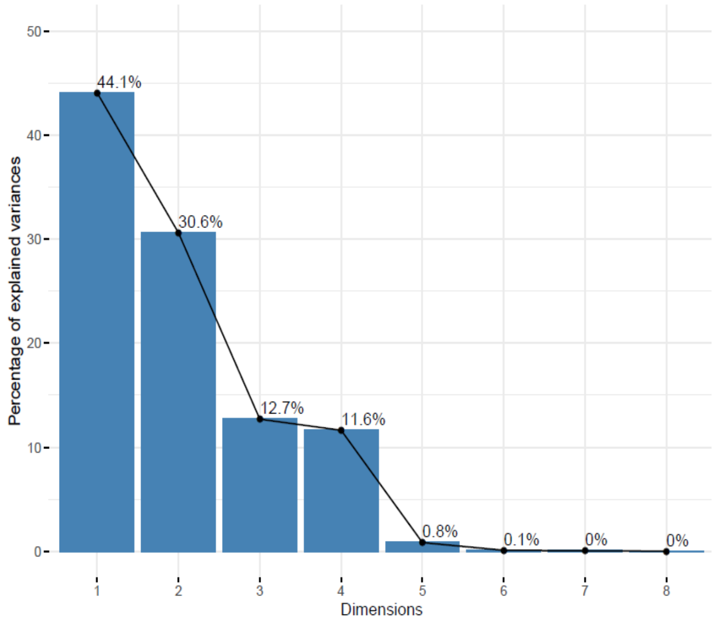

Fig 1. Scree plot depicting eight principal components of rice genotypes

Table 3. Eigenvalues and cumulative variance of the eight principal components in PCA are illustrated across diverse physical attributes of rice genotypes.

PCs	Eigen value	Percent variance	Cumulative variance (%)
PC 1	3.53	44.06	44.06
PC 2	2.45	30.60	74.67
PC 3	1.02	12.70	87.37
PC 4	0.93	11.63	99.00
PC 5	0.07	0.83	99.83
PC 6	0.01	0.10	99.93
PC 7	0.00	0.05	99.98
PC 8	0.00	0.02	100.00
Factor loadings			
	PC1	PC2	PC3
Seed length	0.485	0.136	0.072
Seed width	-0.027	-0.512	0.047
Seed thickness	0.274	-0.282	-0.134
Length/width ratio	0.368	0.444	0.028
Bulk density	-0.027	-0.008	0.703
Geometric Mean Diameter	0.445	-0.363	-0.035
Sphericity	0.442	-0.367	-0.031
Aspect ratio	-0.395	-0.411	-0.006
Hundred seed weight	0.056	-0.083	0.690

two traits exceeds 90° (forming an obtuse angle), it signifies a negative correlation (**Fig. 2**). Conversely, when the angle equals 90°, it indicates no correlation between the characters. The character length/width ratio observed negative correlation with aspect ratio. Therefore, principal component analysis proved to be valuable in uncovering the substantial genetic variation within the population and elucidating the specific traits that contribute to genetic diversity among the different genotypes within the population.

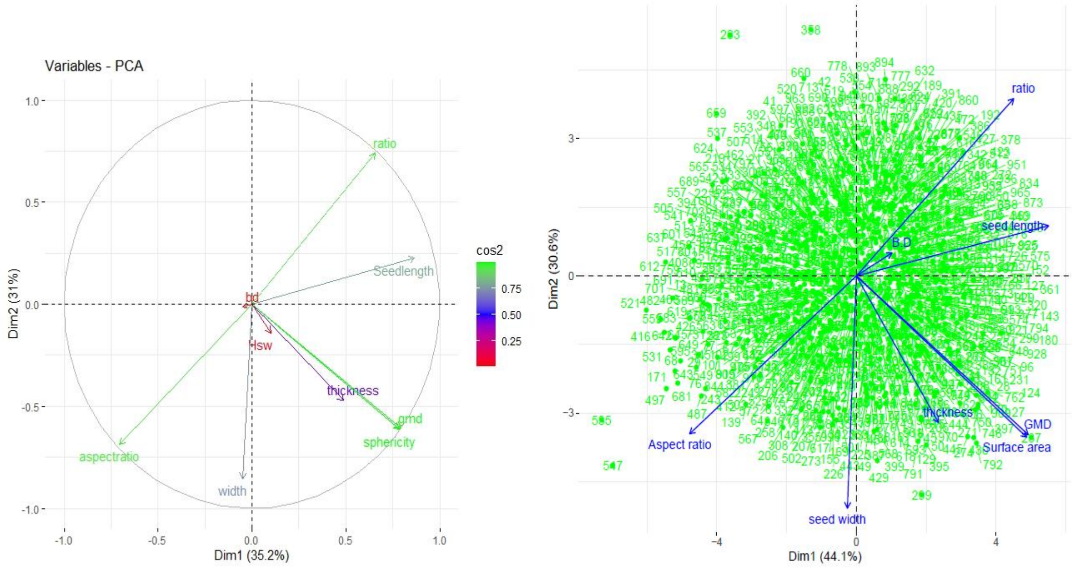

Fig.2. Biplot of two principal components depicting the contribution of traits and the rice genotypes

Based on length and width classification with respect to DUS characteristics length was classified into medium (8.6-10.5 mm), short (6.1-8.5 mm) and very short (< 6.0 mm), whereas, width was classified as broad (3.1-3.5 mm), medium (2.6-3.0 mm), narrow (2.1-2.5 mm) and very narrow (<2.0 mm). In this study, the rice genotypes had maximum of short and narrow type of kernels (130:77) followed by short and medium type of kernels (130:69) (**Fig. 3**). The short and narrow type has lower breakage recovery and higher milled rice recovery than long slender grains (Wang *et al.,* 2021). The values of length/width ratio of above 3.0 is considered as slender and below 3.0 as bold (IRRI International Rice Research Institute,1980) The length/ width ratio depicts the shape of the seed. A total of 199 genotypes exhibiting higher mean values of length/width ratio than the general mean depicts the boldness of the seed and more than 3.0 were categorized as slender in shape and the same was observed by Kaur *et al.* (2011) in rice.

The correlation coefficient serves as a vital measure for breeders when deciding which traits to incorporate into the selection process. In the present study, seed length was significantly inter correlated with length/width ratio (r=0.73), geometric mean diameter (r=0.55), sphericity (r=0.54) and negatively correlated with aspect ratio (-0.76). Seed width was significantly intercorrelated with geometric mean diameter (r=0.48), sphericity (r=0.49) and aspect ratio (0.61) **(Fig. 4)**. Hoque *et al.* (2022) also observed similar results accordance with our study. Seed thickness was correlated with geometric mean diameter (r=0.48) and sphericity (r=0.49). Length/width ratio was

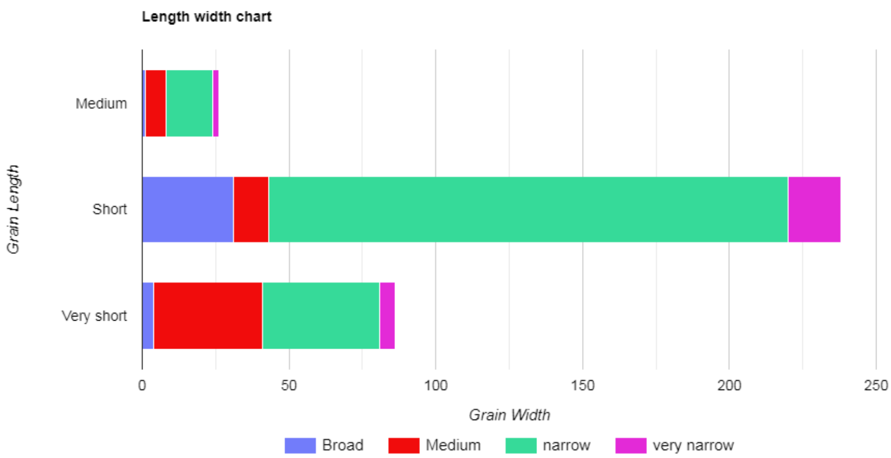

Fig. 3. Classification of seed length *Vs* seed width chart of 500 rice genotypes

https://doi.org/10.37992/2025.1601.008

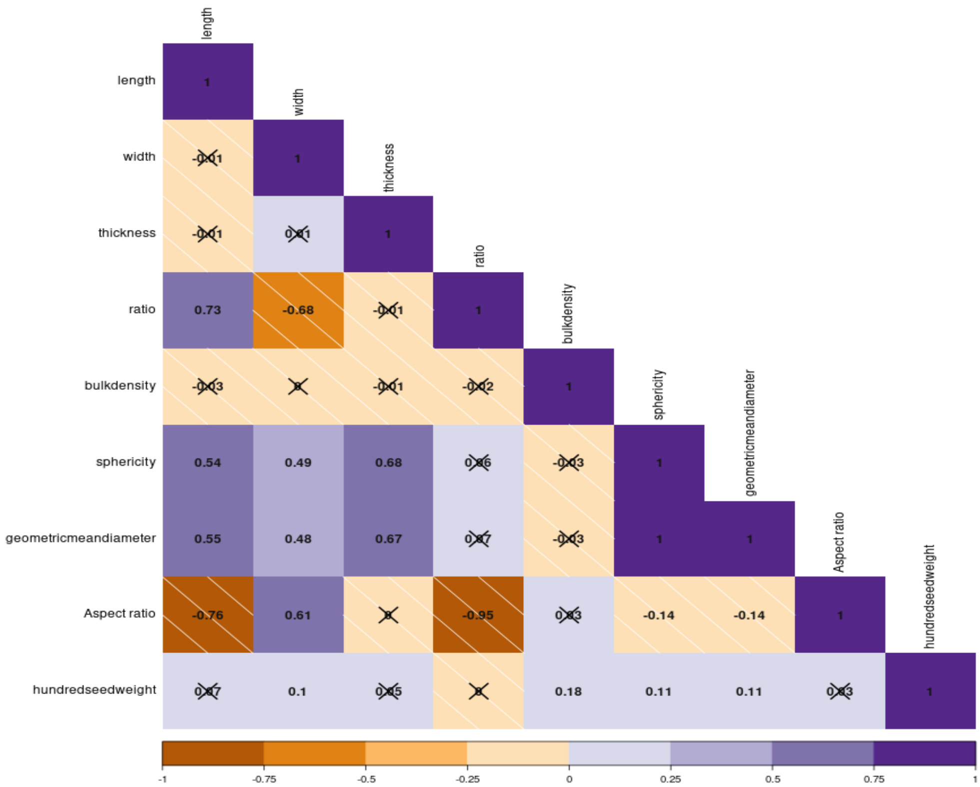

Fig.4. Association studies among the nine physical properties of rice

significantly correlated with seed length (r=0.73) and seed width (r=0.68). Geometric mean diameter and sphericity was correlated with length (r=0.55, r=0.54), width (r=0.48, r=0.49) and thickness (0.67, r=68). Hundred seed weight was significantly correlated with seed width (r=0.1), bulk density (r=0.18), geometric mean diameter (r=0.11) and sphericity (r=0.11) **(Fig. 4)**.

The information of genetic diversity present among the physical properties of the rice genotypes provides knowledge and idea of genetic variability (Awad-Allah *et al.,* 2022). Multivariate analysis by Mahalanobis D^2 statistics helps in quantifying the degree of divergence among the rice genotypes and helps in selection of promising genotypes based on particular trait. In this study, 500 rice genotypes were grouped into five clusters based on the traits studied (**Fig. 5**). Among these clusters, cluster II was the highest with 148 genotypes followed by cluster I with 114 genotypes and cluster IV observed to have least number of genotypes. Rice researchers like Islam *et al.* (2004); Ranjith *et al.* (2018) and Subudhi *et al.* (2021) grouped different rice genotypes into respective clusters. The contribution of the respected traits with respect to cluster was represented in **Fig. 6**. Cluster II observed to have more of medium (8.6 – 10.5 mm) and short (6.1-8.5 mm) length grains, medium width grains (2.6-3.0 mm). Cluster V observed to have very short length grains, narrow and very narrow grain width. Cluster I observed to have more number of grains with presence of awn. The highest hundred seed weight observed to be occupied in cluster II with 3.41 g (RL 5888). With regard to the distance matrix between genotypes, RL4060 in cluster V and RL4519 in cluster IV (31.30) observed to have the maximum genetic disparity followed by RL784 and RL4519 (30.53).

From each cluster based on the length/width ratio, four genotypes per cluster observing higher mean values for slender type and bold types *viz.,* RL4999, RL5279, RL4259, RL478, RL2319, RL5888, RL4622, RL1665, RL541, RL284, RL190, RL1393, RL707, RL2847, RL1650, RL1124, RL4167, RL4060, RL2306 and RL1230 were selected for analysis of cooking quality parameters. Cooking quality is important characteristic of rice. When rice is cooked it absorbs water, swells, volume increases through increase in length or breadth and starch granules swell. Grain expands in all the dimensions but usually more in length. Slender type grains have a greater surface area relative to their volume, facilitating efficient water absorption. This characteristic often results in a shorter cooking time and a tendency for the grains to elongate without significant increase in girth during cooking whereas, bold type grains absorb water differently, and become sticky which can affect their cooking time and texture. Grain length before cooking ranged from 5.40mm to 7.20mm with mean of 6.36mm±0.11 in which RL5888

https://doi.org/10.37992/2025.1601.008

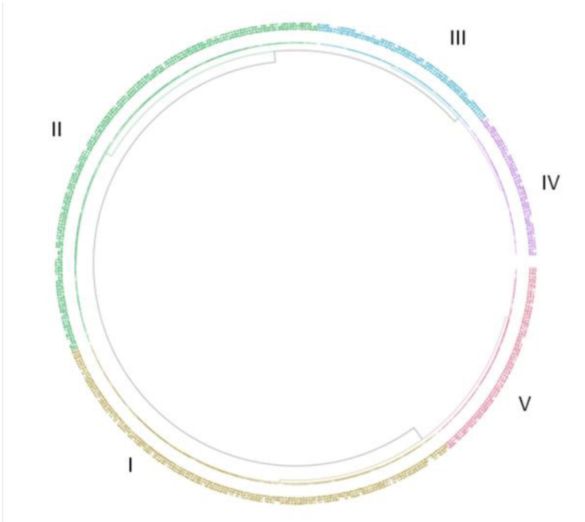

Fig.5. Circlized dendrogram showing diversity based on physical properties of 500 rice genotypes

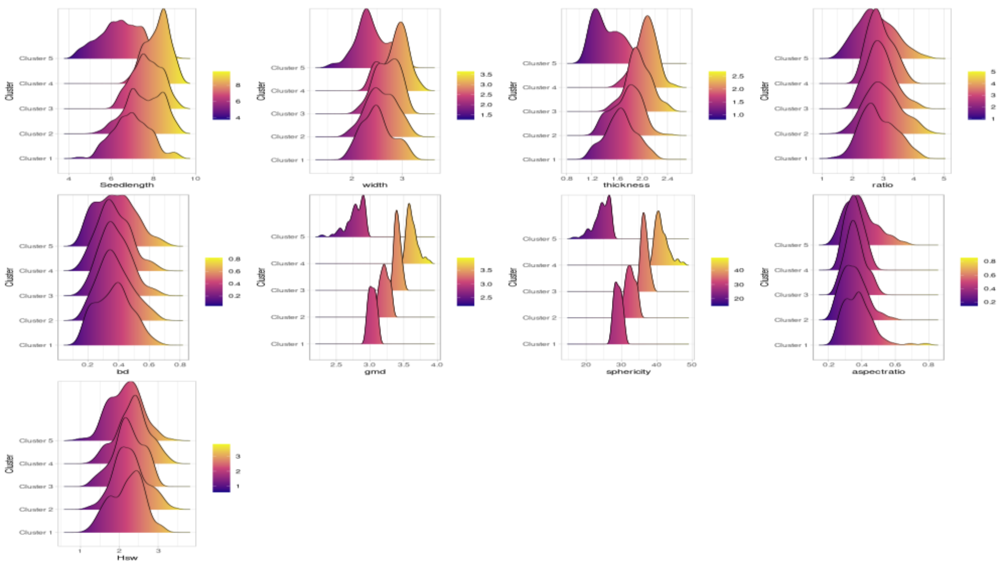

Fig.6. Cluster Ridge plot of nine physical traits of rice genotypes

observed to have the highest length followed by RL5259, RL1665, RL190 and RL4167. The range of 2mm to 4.50mm with mean of 2.75mm ±0.50 was observed for grain width before cooking and the highest was observed for RL4999 followed by RL4259. Grain length after cooking observes mean of 9.08mm±0.47 which ranges from 8.10mm to 9.75mm. RL1230 succeeded by RL1665, RL284 and RL190 observed to have highest grain length after cooking. RL 4999 followed by RL4259 had the highest mean value for grain width after cooking which is ranged from 3.60mm to 5.85mm with mean of 4.21±0.53. The water absorption and swelling characteristics are dependent not only on the chemical composition of the rice grain but also on the surface area of the kernel (Halick and Kelly, 1959). The highest increase in percentage of grain length before and after cooking was observed for bold grain type RL1650 followed by RL4259 and is ranged from 21 to 56 percent. This suggests that bold grains have a larger cross-sectional area, allowing for greater water absorption, leading to more overall swelling. Likewise, higher increase in percentage for grain width before and after cooking was observed slender grain type RL5279 followed by RL2306. This suggests that slender grains have compact starch structure, thinner pericarp, and controlled elongation behaviour leading to grain width expansion. The range for grain elongation ratio and breadthwise expansion ratio was 1.21 to 1.56 and 1.30 to 1.80 with mean of 1.43±0.09 and 1.55±0.10

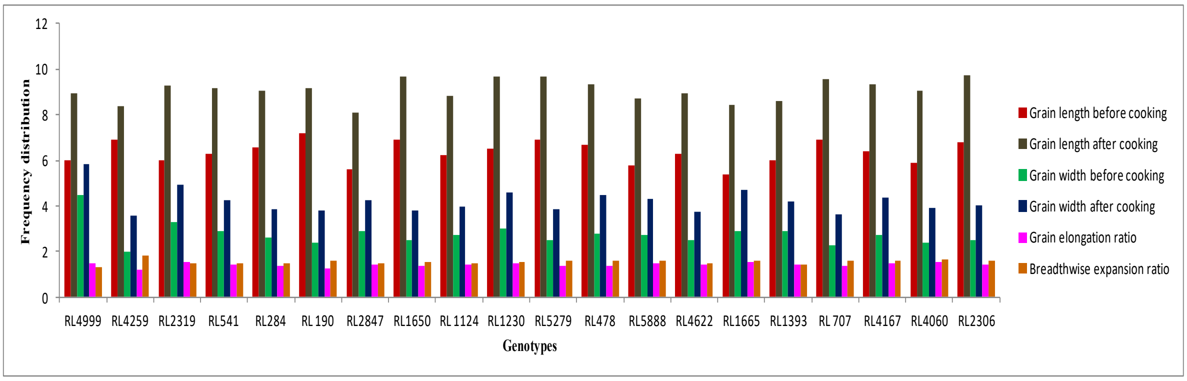

Fig. 7. Frequency distribution for six cooking quality traits among 20 rice genotypes

respectively (**Fig. 7**). Regarding alkali digestion value, 16 rice genotypes *viz.,* RL5888, RL5279, RL1665, RL190, RL4167, RL1230, RL1393, RL2319, RL284, RL4060, RL478, RL2847, RL4999, RL4259, RL1124 and RL2306 observed to have low alkali spreading value which finally resulted in stickier rice whereas, four genotypes *viz.,* RL541, RL707, RL4622 and RL1650 expressed intermediate alkali spreading value and is desirable for parboiling purpose (Beachell and Stansel, 1963) due to medium disintegration.

In post-harvest processing and the design of handling equipment, the physical characteristics of seeds are pivotal. Our study specifically underscores traits related to kernel shape and size, which hinge on seed length, width and thickness. Traits *viz.,* seed thickness, bulk density, seed width, and hundred seed weight, when considered together, allow for immediate selection. Notably, traits such as seed length and length/width ratio show a strong correlation in principal components, attaining higher importance due to their close association. When rice genotypes are categorized based on length and width, a majority (130: 77 genotypes) exhibits short and narrow kernels. These kernels, characterized by lower breakage recovery and higher milled rice recovery, are predominantly found in clusters II and V, with most genotypes featuring straw-colored kernels. The genotypes *viz.,* RL195 followed by RL2363, RL561, RL4018 have high bulk density and generally associated with more compact and well-filled grains. Bulk density plays a role in the sorting and grading processes of rice, potentially impacting the segregation of various grain sizes and qualities in the course of processing and grading activities. The selection of genotypes for the development of post-harvest equipment can be guided by marketing preferences and consumer demand, highlighting the significance of these specific traits.

Funding acknowledgement statement: Thanks to the support from the Department of Biotechnology (DBT), Ministry of Science and Technology, Government of India for funding this network project (Grant number: SAN No.102/IFD/SAN/4188/2019-20).

REFERENCES

Abazari, A., Mojaverian, S.M. and Hosseini-Yekani, S.A. 2012. Effective factors on rice consumers preferences: A case study of urban consumers in mazandaran province of iran. *American Journal of Scientific Research,* 70–79.

Adair, C.R., Beachell, H.M., Jodon, N.E., Johnston,T.H.,Thysell, J.R.,Green, V.E. Jr., Webb, B.D. and Atkins, J.G. 1966. 'Rice breeding and testing methods in the US.'. In: US. Dept. of Agric. Rice in the US: Varieties and production. USDA Agr. Res. Sew. Handbook 289. Pp 19-64.

Allan, V. 2023. PB-Perfect: A Comprehensive R-Based Tool for Plant Breeding Data Analysis, PB - Perfect. https://allanbiotools.shinyapps.io/pbperfect/

Anang, B.T., Adjetey, S.N.A. and Abiriwe, S.A. 2011. Consumer preferences for rice quality characteristics and the effects on price in the Tamale metropolis, northern region, Ghana. *International Journal of AgriScience,* 1: 67–74.

Awad-Allah, M.M.A., Shafie, W.W.M., Alsubeie, M.S., Alatawi, A., Safhi, F.A., ALshamrani, S.M., Albalawi, D.A., Al-Amrah, H., Alshehri, D., Alshegaihi, R.M., Basahi, M.A. and Masrahi, A.S. 2022. Utilization of genetic resources, genetic diversity and genetic variability for selecting new restorer lines of rice (*Oryza sativa* L.). *Genes* (Basel), **13**(12):2227. [Cross Ref]

Beachell, H.M. and Stansel, J.W. 1963. Selecting rice for specific cooking characteristics in a breeding program. International Rice Commission Newsletter (Special issue) Pp. 25-40.

Bhattacharya, K. R. 2011. Product-making quality of rice. Rice quality: A guide to rice properties and analysis, Woodhead Publishing Ltd. Cambridge, UK. Pp 298-336. [Cross Ref]

Brejda, J. J., Moorman, T. B., Karlen, D. L. and Dao, T. H. 2000. Identification of regional soil quality factors and indicators I. Central and Southern High Plains. *Soil Science Society of America Journal*, **64**(6): 2115-2124. [Cross Ref]

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

Chakravorty, A., Ghosh, P.D. and Sahu, P.K. 2013. Multivariate analysis of landraces of rice of 507 West Bengal. *American Journal of Experimental Agriculture*, **3**(1):110-123. [Cross Ref]

Chendake, S. A., Kunkerkar, R. L., Desai, S. S., Chavan, S. S., Dhopavkar, R. V. and Sarak, K. S. 2023. Assessment of genetic variability for grain yield and its components in fine rice (*Oryza sativa* L.). *The Pharma Innovation Journal,* **12**(2):802-806.

Correa, P. C., Da Silva, F. S., Jaren, C., Junior, P. A. and Arana, I. 2007. Physical and mechanical properties in rice processing. *Journal of Food Engineering*, **79**(1): 137-142. [Cross Ref]

Custodio, M. C., Demont, M., Laborte, A. and Ynion, J. 2016. Improving food security in Asia through consumer-focused rice breeding. *Global Food Security*, **9**: 19-28. [Cross Ref]

De Mendiburu, F. and de Mendiburu, M.F. 2019. Package 'agricolae'. R Package, Version, 1.3. Available from: https://cran.r- project.org/web/packages/agricolae/agricol ae.pdf.

Demeke, B., Dejene, T. and Abebe, D. 2023. Genetic variability, heritability, and genetic advance of morphological, yield related and quality traits in upland rice (*Oryza Sativa* L.) genotypes at Pawe, Northwestern Ethiopia. *Cogent Food & Agriculture*, **9**(1): 2157099. [Cross Ref]

Ghadge, P. N. and Prasad, K. 2012. Some physical properties of rice kernels: Variety PR-106. *Journal of Food Process Technology*, **3**(8): 1-5. [Cross Ref]

Halick, J.V. and Kelly, V.J. 1959. Gelatinization and pasting characteristics of rice varieties as related to cooking behaviour. *Cereal Chemistry*. 36: 91.

Hoque, N., Islam, M. Z., Rahman, F., Mahmud, N., Rahman, M. and Biswas, B. 2022. Grain physical properties analysis of some improved rice varieties. *Asian Journal of Crop*, **6**(02): 242-250.

Huang, X., Zhao, Y., Wei, X., Li, C., Wang, A., Zhao, Q., ... and Han, B. 2012. Genome-wide association study of flowering time and grain yield traits in a worldwide collection of rice germplasm. *Nature genetics*, **44**(1): 32-39. [Cross Ref]

IRRI International rice Research Institute. 1980. Annual report for 1980 (pp.25-38).Los Banos.

Irtwange, S. 2012. Engineering Properties of African yam bean (*Sphenostylis stenocarpa*): Effect of accession and moisture content on some engineering properties of African yam bean (*Sphenostylis stenocarpa*). Lap Lambert Academic Publishing.

Islam, M. R., Faruquei, M. A. B., Bhuiyan, M. A. R., Biswas, P. S. and Salam, M. A. 2004. Genetic diversity in irrigated rice. *Pakistan Journal Biological Sciences*, **2**: 226-229. [Cross Ref]

Jain, S. K. and Patel, P. R. 2016. Principal component and cluster analysis in sorghum (*Sorghum bicolor* (L.) Moench). *Forage Research*, **42**(2): 90-95.

Kasanaboina, K., Chandra, M.Y., Krishna, L., Parimala, G. and Jagadeeshwar, R. 2022. Multivariate analysis-based prediction of phenotypic diversity associated with yield and yield component traits in germplasm lines of rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding*, **13**(3):764-771. [Cross Ref]

Kaur, S., Panesar, P. S. and Bera, M. B. 2011. Studies on evaluation of grain quality attributes of some basmati and non-basmati rice cultivars. *Journal of Food Quality*, **34**(6): 435-441. [Cross Ref]

Kumar, K.D., Devi, M.S., Sreelakshmi, C. and Paramasiva, I. 2023. Assessment of genetic variability, heritability and genetic advance for yield and quality traits in indigenous landraces of rice (*Oryza sativa* L.). *Agricultural Sciences*, **127**. [Cross Ref]

Lalitha, R., Mothilal, A., Arunachalam, P., Senthil, N. and Hemalatha, G. 2019. Genetic variability, correlation and path analysis of grain yield, grain quality and its associated traits in EMS derived M4 generation mutants of rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding*, **10**(3): 1140-1147. [Cross Ref]

Leonard, K. and Peter, R.J. 2009. Finding Groups in Data: An Introduction to Cluster Analysis. *John Wiley & Sons*, Vol. 344.

Li, N., Xu, R., Duan, P. and Li, Y. 2018. Control of grain size in rice. *Plant Reproduction*, **31**: 237–251. https://doi.org/10.1007/s00497-018-0333-6. [Cross Ref]

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**: 111-126

Liu, K., Cao, X., Bai, Q., Wen, H. and Gu, Z. 2009. Relationships between physical properties of brown rice and degree of milling and loss of selenium. *Journal of Food Engineering*, **94**(1): 69-74. [Cross Ref]

Lu, Z., Fang, Z., Liu, W., Lu, D., Wang, X., Wang, S., ... and He, X. 2023. Grain quality characteristics analysis and application on breeding of Yuenongsimiao, a high-yielding and disease-resistant rice variety. *Scientific Reports*, **13**(1): 6335. [Cross Ref]

Luh, B.S., 2013. Rice: Volume I. Production. Springer Science & Business Media.

Maduako, J.N. and Faborode, M.O. 1990. Some physical properties of cocoa pods in relation to primary processing. *Ife Journal of Technology,* **2**: 1–7.

Mohapatra, D. and Bal, S. 2006. Cooking quality and instrumental textural attributes of cooked rice for different milling fractions. *Journal of food engineering*, **73**(3): 253-259. [Cross Ref]

Mohsenin, N.N. 1986. Physical Properties of Plant and Animal Materials. Second revised. Gordon and Breach Sci. Publ., New York.

Morita, H., Ariyuki, F., Inomata, N., Nishimura, K., Hasegawa, Y., Miyamoto, M. and Watanabe, T. 1987. Spontaneous Malformations In Laboratory Animals: Frequency of External, Internal and skeletal malformations in rats, rabbits and mice. *Congenital Anomalies*, **27**(2):147-206. [Cross Ref]

Nene, Y. L. 2005. Rice research in South Asia through ages. *Asian Agri-History*, **9**(2): 85-106.

Pearson, K. 1901. LIII. On lines and planes of closest fit to systems of points in space. *The London, Edinburgh, and Dublin philosophical magazine and journal of science,* **2**(11): 559-572. [Cross Ref]

Pradhan, A. K., Vemireddy, L. N. R. and Tanti, B. 2023. Assessment of the genetic variability and population structure in boro rice cultivars of Assam, India using candidate gene based SSR markers. *Genetic Resources and Crop Evolution*, **70**(6): 1747-1765. [Cross Ref]

Qadir, N. and Wani, I. A. 2023. Physical properties of four rice cultivars grown in Indian temperate region. *Applied Food Research*, **3**(1): 100280. [Cross Ref]

Racine, J. S. 2012. RStudio: a platform-independent IDE for R and Sweave. [Cross Ref]

Ranjith, P., Sahu, S., Dash, S. K., Bastia, D. N. and Pradhan, B. D. 2018. Genetic diversity studies in Rice (*Oryza sativa* L.). *Journal of Pharmacognosy and Phytochemistry*, **7**(2): 2529-2531.

Singh, R.K. and Chaudhary, B.D. 1977. Biometrical method in quantitative genetic analysis. Kalyani Publisher, Ludhiana, India.

Subudhi, H. N., Meher, J., Dash, S.K., Bose, L.K., Sarkar, S. and Mohapatra, S. 2021. Genetic diversity studies of popular rice varieties based on grain quality characters. *International Journal of Current Microbiology and Applied Sciences*, **10**(01): 2974-2980. [Cross Ref]

Tong, L. T. 2020. Gluten-free noodles. In Asian noodle manufacturing. Woodhead Publishing. Pp 125-149. [Cross Ref]

Utami, I., Rusmana, R., Eris, F. R. and Sjaifuddin, S. 2019. Physical properties on Indonesian local rice varieties. In IOP Conference Series: Earth and Environmental Science (Vol. 383, No. 1, p. 012026). IOP Publishing. [Cross Ref]

Varnamkhasti, M. G., Mobli, H., Jafari, A., Keyhani, A. R., Soltanabadi, M. H., Rafiee, S. and Kheiralipour, K. 2008. Some physical properties of rough rice (*Oryza sativa* L.) grain. *Journal of Cereal Science*, **47**(3): 496-501. [Cross Ref]

Verghese, E. J. 1950. A standard process for cooking rice for experimental purposes. *Madras Agricultural Journal*, **37**(6): 1. [Cross Ref]

Wang, Z., Zhang, M., Liu, G., Deng, Y., Zhang, Y., Tang, X., ... and Wei, Z. 2021. Effect of the degree of milling on the physicochemical properties, pasting properties and in vitro digestibility of Simiao rice. *Grain & Oil Science and Technology*, **4**(2): 45-53. [Cross Ref]

Wei, T., Simko, V., Levy, M., Xie, Y., Jin, Y. and Zemla, J. 2017. Package 'corrplot'. *Statistician*, **56**(316), e24.

Zhang, L., Ma, B., Bian, Z., Li, X., Zhang, C., Liu, J., Li, Q., Liu, Q. and He, Z., 2020. Grain size selection using novel functional markers targeting 14 genes in rice. *Rice*, **13**: 1-16. [Cross Ref]