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Genetic Variability in Biochemical Quality Traits of Rice Genotypes: Amylose Contents, Gel Consistency and Gelatinization Temperature

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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Abstract

The biochemical qualities of rice, amylose content (AC), gelatinisation temperature (GT)/alkali spreading value (ASV), and gel consistency (GC) strongly influence consumer preference. In Nigeria, consumers generally prefer intermediate AC (20–25%) for soft, non-sticky rice, yet many local varieties fall outside this range, producing firmer gels and harder cooked rice. This study evaluated cooking and eating qualities of sixteen rice genotypes sourced from Malaysia and the Africa Rice Centre, Nigeria, focusing on biochemical attributes and genetic variability. A field experiment used a randomised complete block design with three replications; standard crop management practices were applied until harvest. Laboratory assays measured AC colourimetrically with iodine after methanol defatting and starch gelatinisation at 40 °C for 48 hours; solutions were titrated to pH 4.5–4.7 and read at 620 nm. GC was determined from flour obtained by grinding 8–10 milled grains for 40 seconds. GT/ASV was estimated from the extent of spreading and clearing of ten intact milled kernels in alkaline solution. Analysis of variance showed highly significant variation for most traits, except grain length and width. Coefficients of variation ranged from 22.7% (tillers per hill) to 1.0% (days to panicle initiation and maturity). AC among genotypes ranged from 9.3% (MRQ 74) to 21% (NL 19). All genotypes produced soft gels (GC 61–80 mm). ASV and GT profiling identified MRQ 76, MRQ 269, NL 19, NL 25, NL 11, BW 348-1, FARO 44, FARO 57, IRRI 154, and NL 34 as high-GT genotypes. Three genotypes—WITA 4, NL 30 and MRQ 74— exhibited high ASV and low GT, making them preferable for desirable cooking and eating quality. These findings highlight substantial genetic variation in key biochemical traits, offering targets for breeding programmes aimed at aligning local varieties with consumer preferences. Selecting genotypes with intermediate AC and low GT could improve texture consistency and market acceptance, while maintaining agronomic performance under cultivation conditions.

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Keywords: Biochemical qualities; colorimetric; gel length; opacity; rice endosperm.

1. Introduction

In agriculture, rice (*Oryza sativa* L.) is described as the most important food crop in the world and plays a crucial role in global food security (Osekita, 2018; Rahman *et al.,* 2024). Rice constitutes a staple dietary component across many regions globally, particularly within developing countries in Asia, Africa, and Latin America. In Nigeria, rice ranks sixth among cultivated food crops—after millet, sorghum, cowpea, maize, and yam—while remaining a widely consumed staple. The country possesses an estimated 4.6 to 4.9 million hectares of land suitable for rice cultivation; however, only approximately 1.7 million hectares are currently under production. Nigeria has land suitable for rice production that could help meet domestic demand and support exports (Anonymous, 1997). Rice plays a significant role in Nigeria for multiple reasons. Primarily, it constitutes a key commodity in both domestic and sub-regional trade. It is also the principal staple food for many populations along the Niger–Benue river axis, which traverses the country and broadly delineates it into three ecological zones: the Sokoto–Rima basin in the north-west, the Chad depression in the north-east, the Hadejia–Jama' are system in the extreme north, and the Cross River basin in the south. Furthermore, rice cultivation is often regarded as more adaptable than other high-input staples such as maize under conditions of declining soil fertility, largely due to the wide range of varieties available, which farmers can rotate or switch between annually (Singh *et al*., 1997).

The anticipated growth of the global population to approximately nine billion by 2050, alongside worsening water scarcity, a decline in available arable land, and the ongoing emergence of new pathogens and pests, is expected to pose substantial challenges for rice breeders and agricultural scientists. These difficulties are likely to be further intensified by the potential adverse impacts of climate change (Khush, 1999; Mew *et al*., 2004; Peng *et al*., 2004; Pinstrup-Andersen *et al*., 1999). Due to rice's global importance, its small genome size, and its genetic relatedness to other major cereals, efforts were undertaken to sequence the entire genomes of the two rice subspecies, indica and japonica. The principal challenge facing global rice research and development—including the enhancement of smallholder farmers' welfare and the promotion of rural employment on a sustainable and economically viable basis—is to identify effective strategies for increasing food production to meet the demands of a rapidly growing population. This challenge is particularly pronounced in Nigeria, where constraints such as limited arable land, inadequate labour supply, scarce water resources, and insufficient access to essential agrochemical inputs collectively hinder efforts to improve rice productivity.

Rice is recognised as the most significant food crop globally, with an annual production of approximately 600 million tonnes and cultivation covering around 11% of the world's arable land. Rice provides approximately 20% of direct human calorie intake worldwide (Zeigler & Barclay, 2008). In addition, rice cultivation serves as a vital source of income for over 100 million households worldwide (International Rice Research Institute [IRRI], 2001). Rachmat *et al*. (2006) identified milling quality as a critical determinant of rice grain quality. The edible portion of the rice grain is enclosed within the glumes, necessitating their removal through milling prior to consumption. In the milling process, the husk is first removed from paddy rice using a milling device to obtain brown rice. Traditionally, rudimentary methods such as the wooden mortar and pestle, treadle mills, or water-powered mills have been employed for hulling, and these practices persist in certain regions of Asia and Africa (Li, 2003). The milling operation further involves the removal of the husk from paddy rice, followed by the elimination of the embryo and bran layers from brown rice through abrasive milling, resulting in milled rice comprising both whole and broken kernels. Total milling yield encompasses both head rice and broken rice obtained from unclean rough rice (Khush *et al*., 1979). According to IRRI (2001), the final stage of milling involves the separation of whole kernels from broken ones using appropriately designed screens tailored for long-, medium-, or short-grain rice varieties, thereby producing whole-grain rice.

Custodio *et al*. (2019) reported that broken rice grains are typically of lower market value than whole kernels, thereby reducing the potential revenue derived from rice sales. The production of high-quality milled rice therefore depends fundamentally on the use of sound paddy. According to IRRI (2001) and Rickman *et al*. (2006), good-quality paddy is characterised by uniformly mature grains of consistent size and shape, free from fissures, unfilled or partially filled kernels, and contamination by foreign materials such as stones and weed seeds. Various crop management practices significantly influence paddy quality, which in turn determines the quality of milled rice. Cracking in paddy grains, often resulting from improper drying practices or weathering stress during late harvesting and post-harvest handling, constitutes a major factor affecting rice milling quality (Mahadevappa & Nandisha, 1987).

IRRI (2001) further outlined three essential requirements for the production of high-quality milled rice: firstly, paddy should have a moisture content within the range of 10–14%; secondly, a high level of purity must be ensured; and thirdly, the rice mill should be clean, well maintained, and operated by a skilled technician. Patindol *et al*. (2008) also emphasised that grain moisture content is a key determinant of milling quality, noting that excessively high or low moisture levels lead to reduced head rice recovery.

Milling not only extends the storage life of rice but also enhances its physical characteristics to meet consumer preferences. Consequently, the primary objective of milling is to remove as much of the bran layer and germ as possible. The proportion of bran remaining on the grain surface after milling is referred to as the degree of milling (IRRI, 2001), which represents the percentage of bran removed from brown rice kernels. This parameter influences both the colour and cooking properties of rice.

Unmilled brown rice exhibits limited water absorption capacity and correspondingly reduced cooking quality (IRRI, 2001). However, its water uptake improves progressively with increasing milling intensity up to approximately a 25% degree of milling, beyond which further increases have minimal additional effect. Nutritional composition is also substantially affected by milling, as a considerable proportion of micronutrients are concentrated in the outer layers of brown rice and are consequently removed at higher milling degrees.

IRRI (2001) noted that a higher degree of milling produces rice with a whiter appearance, reflecting more extensive removal of surface layers. The degree of milling is influenced by several grain characteristics, including hardness, size, shape, surface ridge depth, and bran thickness, as well as by the efficiency of the milling system employed. It also has implications for milling recovery and consumer acceptability (Farooq *et al*., 2005). During milling, an increased degree of polishing corresponds to a greater removal of bran from the grain surface.

The main chemical qualities of rice include amylose content, gelatinisation temperature/alkali spreading value, and gel consistency. These qualities are directly related to the cooking and eating qualities of rice (Feng *et al*., 2025). Amylose represents the predominantly linear fraction of starch in non-glutinous rice varieties, whereas amylopectin constitutes the branched component of the starch matrix. The proportion of amylose plays a crucial role in determining the quality attributes of cooked milled rice (C. Li *et al*., 2023) and is negatively associated with sensory evaluation scores relating to cohesiveness, tenderness, colour, and glossiness of boiled rice. Consequently, rice varieties are commonly classified according to their amylose content into waxy types (1–2% amylose), low-amylose (8–20%), intermediate-amylose (21–25%), and high-amylose (>25%) categories (Jennings *et al*., 1979).

Starch makes up about 90% of the dry matter content of milled rice. Starch is a polymer of glucose, and amylose consists of linearly linked glucose molecules α-1,4 D-glucopyranosyl, which are described as highly resistant to digestion, hence the term "resistant starch", and are associated with a low glycaemic index. This means that rice varieties with a greater proportion of starch in the form of amylose tend to have a lower glycaemic index. High-amylose grain cooks to a dry, less tender texture and becomes firm after cooking, whereas low-amylose varieties are moist, sticky and glossy when cooked and may split and disintegrate when overcooked. The gelatinisation temperature of endosperm starch, which serves as an important indicator of cooking quality, refers to the temperature at which rice absorbs water and starch granules undergo irreversible swelling accompanied by a loss of crystalline structure. During heating and gelatinisation, a physical barrier is formed around the starch granules, thereby limiting water uptake, expansion, and subsequent rupture (Zhang *et al*., 2024; W. Li *et al*., 2023). Gelatinisation temperature typically ranges from approximately 55 to 79 °C and is classified into three categories: low (<70 °C), intermediate (70–74 °C), and high (>74 °C) (Jennings *et al*., 1979).

In the rice breeding programme, gelatinisation temperature may be measured by the alkali digestibility test (Little *et al*., 1958). The physical cooking behaviour of rice is more strongly associated with gelatinisation temperature than with starch amylose content. Rice varieties characterised by a high gelatinisation temperature tend to become overly soft and may disintegrate when subjected to prolonged cooking. Conversely, under standard cooking conditions, such rice is more likely to remain insufficiently cooked. Varieties with higher gelatinisation temperatures generally require greater quantities of water and longer cooking durations than those with low or intermediate gelatinisation temperatures; accordingly, gelatinisation temperature is positively correlated with cooking time.

Amylose content remains the primary determinant of sensory attributes, including cohesiveness, tenderness, colour, and glossiness of cooked non-waxy rice, as assessed by taste panels. Nevertheless, notable varietal differences in gel consistency are observed even among rice types with similarly high amylose content (>25%). Rice varieties with amylose levels below 24% typically exhibit soft gel consistency (Jennings *et al*., 1979). The gel consistency test, which evaluates the firmness of cooled rice paste, is specifically designed to differentiate among high-amylose varieties and was developed as a complementary method to amylose determination within rice quality breeding programmes. This test classifies high-amylose rice into three distinct categories: very flaky rice with hard gel consistency (gel length of 40 mm or less); flaky rice with intermediate gel consistency (gel length of 41–60 mm); and soft rice characterised by soft gel consistency (gel length exceeding 61 mm).

The quality of rice protein is largely determined by the protein content of the grain. An increase in protein level, whether achieved through agronomic practices or genetic improvement, is associated with a reduction in the proportion of protein lost during milling, suggesting that the additional protein is predominantly not located within the bran fraction (Jennings *et al*., 1979). Aromatic or scented rice, although considered a relatively minor quality trait of limited overall importance, is highly valued in certain regions of Asia and commands a premium price in niche markets. At the International Rice Research Institute (IRRI), the aroma trait has recently been incorporated into improved plant types, including those with common glutinous endosperms. The inheritance of aroma is governed by one to three complementary genetic factors. However, limited information is available regarding the breeding behaviour of aroma and the extent to which environmental conditions influence its expression. A simple laboratory procedure for aroma assessment was developed at IRRI, in which 20–30 freshly harvested milled grains are placed in a test tube containing 20 mL of distilled water. The tube is then sealed and immersed in boiling water for 10 minutes (or 20 minutes in the case of brown rice). After heating, the tube is removed and allowed to cool, following which aroma is evaluated and rated as strong, intermediate, slight, or absent. A strongly scented variety is included in each set of tests to provide a reference standard (Jennings *et al*., 1979).

Research gap. Although amylose content, gel consistency and gelatinisation temperature are recognised indicators of rice cooking quality, the introduction does not establish how these attributes vary together among the sixteen genotypes evaluated in this study. A genotype-specific comparison of these indicators is therefore needed to describe the biochemical quality of the tested materials.

Study objective. This study aimed to evaluate and compare amylose content, gel consistency and alkali spreading value/gelatinisation temperature among sixteen rice genotypes obtained from Malaysia and AfricaRice, together with their recorded agronomic and yield-component traits.

2. Materials and Methods

2.1 Source of Plant Materials

The rice genotypes used in this study were obtained from Malaysia and the Africa Rice Centre in IITA, Nigeria, as shown in Table 1.

2.2 Details of Experimental Site

The experiment was conducted at the experimental field and in the Plant Science and Biotechnology laboratory, Adekunle Ajasin University, Akungba-Akoko, Nigeria. The rice varieties were cultivated in the experimental field. After harvest, the grains were dried, milled, and polished to obtain milled rice for further analysis.

Table 1. The selected rice genotypes and their source

S/N	Genotype	Source
1	MRQ 76	Malaysia
2	MR 269	Malaysia
3	MRQ 74	Malaysia
4	MR 220	Malaysia
5	MR 263	Malaysia
6	MR 253	Malaysia
7	FARO 57	AfricaRice
8	FARO 44	AfricaRice
9	NL 19	AfricaRice
10	WITA 4	AfricaRice
11	BW 348-1	AfricaRice
12	NL 30	AfricaRice
13	NL 34	AfricaRice
14	IRRI 154	AfricaRice
15	NL 11	AfricaRice
16	NL 25	AfricaRice

2.3 Experimental Procedure

2.3.1 Chemical Quality Test

These quality parameters are commonly used in rice breeding, grain quality evaluation, and food science to assess cooking and eating qualities of rice. They include amylose content, translucency, chalkiness, gelatinisation temperature, alkali digestion value, and gel consistency. The categories of the quality test of the rice genotypes studied refer to the standard IBPGR descriptors for rice.

2.3.1.1 Determination of Amylose Content in Rice

Amylose in rice reacts with iodine solution to form a blue-coloured complex. The intensity of the colour is measured spectrophotometrically and compared with a standard curve. The materials included rice grains, a mortar and pestle or grinding mill, a weighing balance, volumetric flasks, pipettes, test tubes, a water bath and a spectrophotometer. The reagents are 95% ethanol, 1 N sodium hydroxide (NaOH), acetic acid solution, iodine solution, and distilled water. Samples were prepared by dehusking rice grains and grinding them into fine flour. A 100 mg sample of rice flour was weighed and placed in a test tube. The second step involved gelatinisation and dissolution: 1 mL of 95% ethanol and then 9 mL of 1 N NaOH were added. The mixture was heated in a boiling water bath for 10 minutes to gelatinise the starch, cooled, transferred to a 100 mL volumetric flask and made up to volume with distilled water. For colour development, 5 mL of starch solution was pipetted into another flask, followed by 1 mL of acetic acid and 2 mL of iodine solution; the mixture was then diluted to volume with distilled water. The colour was allowed to develop within 20 minutes. Finally, absorbance was measured at 620 nm using a spectrophotometer and compared with the standard amylose curve. The amylose-content classification scale is presented in Table 2.

Amylose content was calculated as follows:

$$\text{Amylose content} = \frac{sample\ absorbance}{Standard\ curve}\ x\ 100\%$$

Table 2. Amylose content

Scale	Percent	Class
0	< 3.0	Waxy (glutinous)
1	3.1 – 10.0	Very low
3	10.1 – 15.0	Low
5	15.1 – 20.0	Intermediate
7	20.1 – 25.0	Intermediate – high
9	25.1 - 30.0	High

2.3.1.2 Determination of Gel Consistency in Rice

Gel consistency measures the firmness of cooked rice paste after cooling. A softer gel indicates a softer cooked-rice texture. The materials required were rice flour, test tubes, a water bath, an ice bath, and a ruler. The reagents included 95% ethanol containing thymol blue and 0.2 N potassium hydroxide (KOH). The rice grains were ground into fine flour. A 100 mg sample of rice flour was weighed and placed in a test tube. A 0.2 mL volume of ethanol–thymol blue solution and 2 mL of 0.2 N KOH were added and mixed thoroughly. The mixture was heated in a boiling water bath for 8 minutes. The test tubes were covered with glass marbles to prevent evaporation, cooled at room temperature for 5 minutes and then placed in an ice bath for 20 minutes. For measurement, the tubes were placed horizontally on a flat surface for 1 hour, and gel length was measured in millimetres using a ruler. Gel-consistency categories are presented in Table 3.

Table 3. Gel Consistency

Scale	Gel length	Gel consistency type	Cooked rice texture
1	81 – 100mm	Soft	Soft
3	61 – 80mm	Soft	Soft
5	41 – 60mm	Medium	Intermediate
7	36 – 40mm	Medium-hard	Firm
9	26 – 35mm	Hard	Firm

2.3.1.3 Determination of Alkali Spreading Value (ASV) / Gelatinization Temperature (GT)

Rice grains spread and disintegrate in dilute alkali depending on gelatinisation temperature. Low-GT rice spreads more rapidly. The materials required included whole milled rice grains, petri dishes, and forceps. A 1.7% potassium hydroxide solution was used. For the determination, six whole milled rice grains were placed evenly in a Petri dish, and sufficient 1.7% potassium hydroxide (KOH) solution was added to immerse the grains completely. The Petri dishes were then covered and incubated at room temperature for 23 hours. After incubation, the extent of grain spreading and disintegration was recorded according to the IBPGR descriptors for rice classification. The classification scale is presented in Table 4.

Table 4. Gelatinization temperature / Alkali digestion value

Scale	Description	Alkali digestion	Gelatinization temperature
1	Not affected but chalky	Low	High
2	Swollen		
3	Swollen with collar incomplete and narrow	Low-intermediate	High-intermediate
4	Swollen with collar complete and wide	Intermediate	Intermediate
5	Split or segmented with collar complete and wide		
6	Dispersed, merging with collar	High	Low
7	Completely dispersed and clear		

2.4 Statistical Analysis

The data collected from the field were subjected to analysis of variance (ANOVA) using SPSS version 20 to determine significant differences among the traits measured. One-way analysis of variance was utilised to evaluate differences among multiple means, followed by Duncan's multiple range test for post hoc comparisons ($p < 0.05$).

3. Results

3.1 Analysis of Variance and Coefficient of Variation

The mean squares and coefficients of variation (CVs) from the analysis of variance (ANOVA) for fourteen agronomic and yield component traits of sixteen lowland rice genotypes evaluated in Akungba during the 2014 rainy season are presented in Table 5. The analysis of variance was highly significant ($P < 0.001$) for all fourteen traits evaluated in Akungba Akoko in the second season. The effect of replication was also highly significant except for grain length and grain width, which were not significantly different. The grand mean values were as follows: plant height (114.5cm), number of tillers (18.4), effective tillers (16.4), flag leaf length (28.3cm), panicle length (24.9cm), panicle weight (4.5g), number of grains per panicle (152.2), number of spikelets (12.6), thousand-grain weight (24.9g), grain length (0.9), grain width (0.3), number of days to heading/panicle initiation (87.5), number of days to maturity (117.5) and grain yield per hill (47.3g). The coefficients of variation were generally moderate, with the lowest values for days to panicle initiation and days to maturity (1.0%) and the highest value for tillers per hill (22.7%).

3.2 Mean Performance of the Rice Genotypes

The mean performance of sixteen rice genotypes for fourteen agronomic and yield-component traits evaluated in Akungba Akoko during the 2014 rainy season is presented in Table 6. All the traits varied from one another, and their mean values differed significantly ($P= 0.05$) using Duncan's multiple range test (DMRT). MR 263 had the lowest plant height (78.1 cm), while BW 348-1 had the highest (150.8 cm). Number of tillers per hill ranged from (13.7) in NL-19 to (34.3) in MRQ 74. The number of effective

tillers per hill ranged from 12.3 in NL-19 to 25.3 tillers in MRQ 74. Flag leaf length was lowest in MR 263 (20.1 cm) and highest in WITA 4 (39.2 cm). Panicle length had the least mean value of (22.1cm) in MRQ 76 and the highest (30.4cm) in NL-19. Panicle weight had the least mean weight (2.7g) in MRQ 76 and the highest (6.8g) in NL-19. The number of grains per panicle was counted, and the least number of grains (113.3) was observed in NL 11, and the highest (261.7) in Faro 57. The fewest spikelets per panicle were observed in NL 11 (8.0), and the most (16.0) in NL-19 and Faro 57. The lowest mean one thousand grain weight was recorded in MRQ 76 (20.1g), and the highest (31.3g) in BW 348-1. The lowest grain length and width (0.8 cm and 0.2 cm) were observed in NL 11, while MR 220 had the highest grain length (1.0 cm); five of the six exotic genotypes had the highest mean grain width (0.4 cm). Number of days to heading or panicle initiation ranged from (68.3) days in MRQ 76 to (100) days in WITA 4 and NL 30. Number of days to maturity among the genotypes ranged from (98.3) days in MRQ 76 to (130) days in WITA 4 and NL 30. Grain yield per hill ranged from 14.0 g in MRQ 76 to 87.2 g in BW 348-1.

3.3 Chemical Qualities of Rice

3.3.1 Standard Amylose Curve

Fig. 1 shows the standard amylose curve for 0.4 g of pure potato starch at different concentrations (1, 2, 3, 4 and 5), and absorbance was measured at 620 nm using a spectrophotometer. The standard was compared with the absorbance of different rice samples at 620 nm to determine the percentage of AC for the different rice genotypes studied. The absorbance values were plotted along the abscissa axis, while different concentrations were plotted along the ordinate axis. A straight-line graph was produced over an absorbance range of 0.04 to 0.16 with the equation Y=0.0077X + 0.0082, and the reported R2 value was 0.9906.

3.3.2 Amylose Contents of Rice

The amylose content (AC) for the rice genotypes studied is presented in Table 7a. AC ranged from 9.3% to 21.0%. The highest amylose content (21.0%) was recorded in NL 19, which was followed by BW 348-1 (20.7%), while the lowest AC was obtained in MRQ 74 (9.3%) followed by WITA 4 (9.4%). The other genotypes fell into the low-amylose category based on the classification in Table 7b.

3.3.3 Gel Consistency Test on Sixteen Rice Genotypes

The gel consistency test conducted on sixteen rice genotypes is presented in Table 8. Two of the sixteen rice genotypes, MR 269 and FARO 44, were described as having soft gels with lengths of 61–80 mm. The remaining fourteen genotypes were described as having medium-hard to hard gels, with gel-length classes of 41–60 mm, 36–40 mm and 26–35 mm, respectively. Genotypes with soft GC are associated with rice that tends to be sticky (glutinous) after cooking, whereas those with hard GC are associated with very flaky, firmer cooked rice; this characteristic is particularly evident in high-amylose rice, which tends to be less sticky. These are shown in Plates 1 and 2, respectively.

3.3.4 Gelatinization Temperature and Alkali Spreading Value

The alkali spreading value and gelatinisation temperature of the rice genotypes studied are presented in Table 9. The following genotypes had low ASV: MRQ 76, MR 269, NL 19, NERICA L 25, NERICA L 11, BW 348-1, FARO 44, FARO 57, IRRI 154, and NERICA L 34, with corresponding high gelatinisation temperatures. These genotypes require more water and time to cook than those with low or intermediate gelatinisation temperatures. WITA 4, NL 30, and MRQ 74 had high ASV but low gelatinisation temperature, while MR 220 and MR 253 are intermediate, and MR 263 had low-intermediate ASV. These are shown in Plate 3.

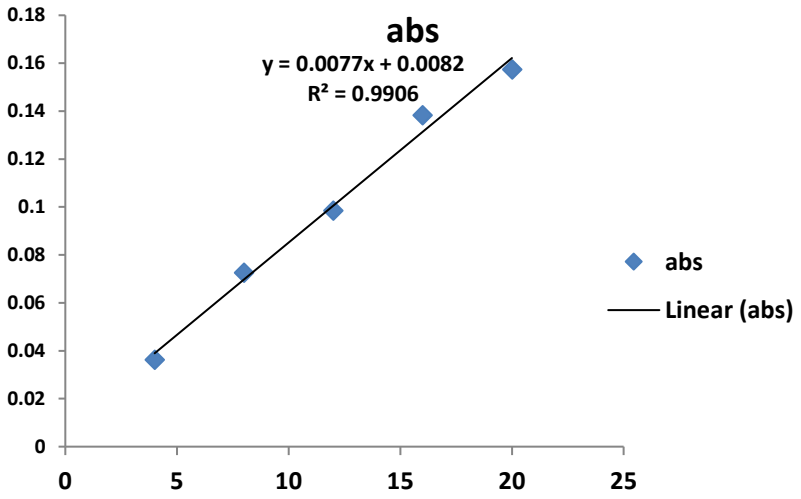


Fig. 1. Amylose Standard curve of 0.4g potato starch at different concentrations and absorbance taken at 620nm using a spectrophotometer

Table 5. Analysis of variance and coefficient of variation for fourteen traits of lowland rice evaluated

SV	DF	PLTHT	NT	ETP	FLL	PANL	PANWT	NGP	NSPKP	TGW	GL	GWD	NDPI	NDTM	YHD
Gen.	15	1877.1**	61.4**	24.5**	98.9**	17.2**	5.5**	5295.1**	16.3**	39.1**	0.003	0.01	216.6**	216.6**	1135.7**
Rep	2	26.1**	37.3**	17.8**	2.2**	0.3**	0.1**	3.1**	0.3**	3.7**	0.00	0.01	0.3**	0.3**	23.5**
Error	30	44.4	17.5	7.3	3.2	0.7	0.3	353.9	0.5	3.1	0.01	0.001	0.7	0.7	69.2
CV(%)		5.8	22.7	16.5	6.3	3.4	12.2	12.4	5.6	7.3	11.1	10.5	1.0	1.0	17.6
G$\bar{x}$		114.5	18.4	16.4	28.3	24.9	4.5	152.2	12.6	24.9	0.9	0.3	87.5	117.5	47.3

**, ** significant at P = 0.05 and 0.01 respectively.*

Note: PLTHT=plant height(cm), NT= No of tillers per hill, ETP= Effective tillers per hill, FLL(cm)= Flag leaf length, PANL (cm)= Panicle length, PANWT (g) = Panicle weight, NGP = No of grains per panicle, NSPKP = No of spikelet per panicle, TGW (g) = Thousand grain weight, GL(cm) = Grain length, GWD = Grain width (cm), NDPI = No of days to panicle initiation, NDTM = No of days to maturity, YHD(g) = Yield per hill

Table 6. Mean performance of sixteen lowland rice genotypes

Genotypes	PLHT	NOT	ETP	FLL	PANL	PAWT	NGP	NSPK	TGW	GL	GW	NDPI	NDM	GYD
MRQ 76	85.0^{ab}	16.3^{a}	14.7^{ab}	25.0^{bc}	22.1^{a}	2.7^{a}	121.3^{ab}	11.7^{c}	20.1^{a}	0.9^{b}	0.4^{c}	68.3^{a}	98.3^{a}	14.0^{a}
MR 269	81.5^{ab}	17.7^{a}	14.0^{ab}	25.7^{bc}	23.2^{ab}	2.8^{ab}	126.7^{ab}	11.3^{c}	24.9^{b}	0.9^{b}	0.4^{c}	82.0^{d}	112.0^{d}	24.9^{ab}
MRQ 74	89.0^{ab}	34.3^{b}	25.3^{c}	26.1^{bcd}	23.9^{bc}	3.0^{abc}	129.7^{ab}	12.3^{cd}	20.2^{a}	0.9^{b}	0.4^{c}	75.3^{b}	105.3^{b}	42.1^{cde}
MR 220	93.1^{b}	18.7^{a}	15.7^{ab}	29.1^{d}	23.6^{abc}	3.9^{cd}	150.3^{bc}	13.0^{de}	24.5^{b}	1.0^{c}	0.3^{b}	79.0^{c}	109.0^{c}	33.1^{bcd}
MR 263	78.1^{a}	17.3^{a}	16.3^{ab}	20.1^{a}	25.1^{cd}	4.4^{d}	204.0^{de}	13.7^{e}	20.2^{a}	0.9^{b}	0.4^{c}	89.3^{g}	119.3^{g}	43.6^{cde}
MR 253	84.9^{ab}	19.3^{a}	17.0^{ab}	20.4^{a}	22.3^{a}	4.0^{cd}	175.0^{cd}	13.7^{e}	20.3^{a}	0.9^{b}	0.4^{c}	86.7^{f}	116.7^{f}	62.8^{fg}
Faro 57	125.6^{c}	15.7^{a}	14.3^{ab}	36.4^{ef}	25.6^{de}	6.6^{g}	261.7^{f}	16.0^{f}	25.5^{bc}	0.9^{b}	0.3^{b}	89.7^{g}	119.7^{g}	47.8^{def}
Faro 44	122.0^{c}	15.3^{a}	14.0^{ab}	37.2^{ef}	27.7^{f}	4.0^{cd}	152.0^{bc}	14.0^{e}	25.9^{bc}	0.9^{b}	0.3^{b}	85.0^{e}	115.0^{e}	31.1^{bc}
NL 19	145.9^{d}	13.7^{a}	12.3^{a}	35.4^{e}	30.4^{g}	6.8^{g}	217.3^{e}	16.0^{f}	28.6^{cde}	0.9^{b}	0.3^{b}	95.0^{h}	125.0^{h}	40.9^{cde}
WITA 4	124.8^{c}	18.0^{a}	16.7^{ab}	39.2^{f}	27.1^{ef}	4.2^{d}	200.7^{de}	15.3^{f}	20.6^{a}	0.9^{b}	0.3^{b}	100.0^{i}	130.0^{i}	24.1^{ab}
BW 348-1	150.8^{d}	17.0^{a}	16.7^{ab}	28.3^{cd}	27.9^{f}	6.6^{g}	183.3^{cd}	14.0^{e}	31.3^{e}	0.9^{b}	0.3^{b}	95.0^{h}	125.0^{h}	87.2^{h}
NL 30	127.8^{c}	20.0^{a}	18.3^{b}	27.5^{bc}	26.1^{de}	5.4^{ef}	138.0^{ab}	10.0^{b}	26.4^{bcd}	0.9^{b}	0.3^{b}	100.0^{i}	130.0^{i}	56.2^{ef}
NL 34	126.8^{c}	18.0^{a}	16.7^{ab}	27.2^{bcd}	22.6^{ab}	5.9^{fg}	135.3^{ab}	10.0^{b}	26.0^{bc}	0.9^{b}	0.3^{b}	90.0^{g}	120.0^{g}	61.7^{fg}
IRRI 154	125.0^{c}	17.0^{a}	15.3^{ab}	27.6^{bcd}	23.1^{ab}	4.5^{de}	138.0^{ab}	12.0^{cd}	29.4^{de}	0.9^{b}	0.3^{b}	85.0^{e}	115.0^{e}	72.1^{g}
NL 11	125.5^{c}	18.3^{a}	17.3^{ab}	24.6^{b}	23.2^{ab}	3.7^{bcd}	113.3^{a}	8.0^{a}	26.2^{bcd}	0.8^{a}	0.2^{a}	90.0^{g}	120.0^{g}	51.7^{ef}
NL 25	146.4^{d}	18.3^{a}	17.0^{ab}	25.4^{bc}	24.0^{bc}	3.6^{abcd}	127.3^{ab}	10.0^{b}	27.5^{bcd}	0.9^{b}	0.3^{b}	90.0^{g}	120.0^{g}	62.7^{fg}

Note: Means with the same alphabet in the same column are not significantly different by DMRT (P=0.05)

PLTHT=plant height(cm), NT= No of tillers per hill, ETP= Effective tillers per hill, FLL(cm)= Flag leaf length, PANL (cm)= Panicle length, PANWT (g) = Panicle weight, NGP = No of grains per panicle, NSPKP = No of spikelet per panicle, TGW (g) = Thousand grain weight, GL(cm) = Grain length, GWD = Grain width (cm), NDPI = No of days to panicle initiation, NDTM = No of days to maturity, YHD(g) = Yield per hill

Table 7a. Rice genotypes showing absorbance and amylose contents

Samples		ABS	% AC
R1	MRQ 74	0.0796	9.3
R2	MR 220	0.12	14.5
R3	NL 34	0.1432	17.5
R4	NL25	0.1388	17.0
R5	FARO 44	0.1204	14.6
R6	MRQ 76	0.1032	12.3
R7	WITA 4	0.0808	9.4
R8	MR 253	0.0908	10.7
R9	IRRI 154	0.1216	14.7
R10	NL 19	0.17	21.0
R11	MR 263	0.092	10.9
R12	NL 30	0.1096	13.2
R13	NL 11	0.1548	19.0
R14	BW 348-1	0.1676	20.7
R15	FARO 57	0.1168	14.1
R16	MR 269	0.0876	10.3

Table 7b. Category of amylose classification

Category	AC (%)
Waxy	1 to 2
Very Low Amylose	2 to 9
Low	10 to 20
Intermediate	20 to 25
High	25 to 30

Table 8. Gel Consistency test on sixteen rice genotypes

Genotypes	Length of Gel (mm)	Category
MRQ 76	61 – 80	Soft
WITA 4	61 – 80	Soft
NL 30	61 – 80	Soft
MR 220	61 – 80	Soft
MR 269	61 – 80	Soft
NL 19	61 – 80	Soft
MR 263	61 – 80	Soft
NERICA L 25	61 – 80	Soft
NERICA L 11	61 – 80	Soft
BW 348-1	61 – 80	Soft
MR 253	61 – 80	Soft
MRQ 74	61 – 80	Soft
IRRI 154	61 – 80	Soft
FARO 44	61 – 80	Soft
FARO 57	61 – 80	Soft
NL 34	61 – 80	Soft



Plate 1. Pictures of ten rice samples showing the length of gel in solution containing thymol blue



Plate 2. Pictures of six rice samples showing the length of gel in solution containing thymol blue

Table 9. Alkali spreading value and Gelatinization temperature of sixteen rice genotypes

Genotypes	ASV(KOH)	GT (^{0}C)
MRQ 76	Low	>74
WITA 4	High	<70
NL 30	High	<70
MR 220	Intermediate	70 – 74
MR 269	Low	>74
NL 19	Low	>74
MR 263	Low-Intermediate	High-Intermediate
NERICA L 25	Low	>74
NERICA L 11	Low	>74
BW 348-1	Low	>74
MR 253	Intermediate	70 – 74
MRQ 74	High	<70
FARO 44	Low	>74
FARO 57	Low	>74
IRRI 154	Low	>74
NL 34	Low	>74

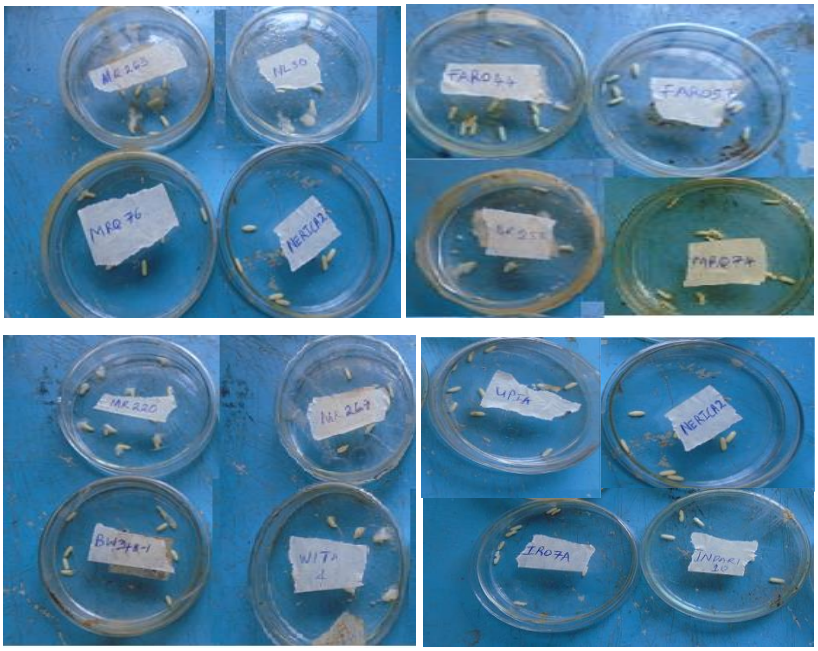


Plate 3. Reactions of rice grains in a solution cotaining 0.2N KOH for the ASV test

4. Discussion

The visual appearance of milled rice is of considerable importance to consumers and, consequently, to millers, rendering it a key consideration in breeding programmes. Consumers generally favour rice with a translucent endosperm and are willing to pay higher prices for such grains, despite the fact that endosperm opacity is lost during cooking and has no effect on eating quality. In this study, amylose content has a major influence on the characteristics of cooked milled rice. It is negatively correlated with taste-panel scores for cohesiveness, tenderness, colour and glossiness of boiled rice (Jennings *et al*., 1979). Rice varieties are classified according to their amylose content into waxy types (1–2% amylose), low-amylose types (8–20%), intermediate-amylose types (21–25%), and high-amylose types (greater than 25%). The rice genotypes utilised in the present study belong to the low-to-intermediate amylose category. Typically, low-amylose rice becomes moist, sticky, and glossy upon cooking, and tends to split and disintegrate when overcooked. In contrast, high-amylose rice cooks to a dry and fluffy texture but becomes firm on cooling. Intermediate amylose content is generally preferred in major consuming regions such as Nigeria, likely because it maintains a softer texture after cooling. Earlier studies of rice crosses have likewise examined associations among yield components (Bapu & Soundarapandian, 1992).

The highest amylose content (21.0%) was recorded in NL 19, followed by BW 348-1 (20.7%); these values were comparable to the intermediate apparent amylose content (AAC) of 21.2% reported for IR64, a high-quality inbred line developed by IRRI (Pang *et al*., 2016). Although the genetic control of amylose content is not yet fully elucidated, high- and low-amylose phenotypes appear to be primarily governed by a single major gene. Heterozygous individuals typically exhibit intermediate amylose levels; however, this intermediate state cannot be stably maintained. Where an intermediate amylose content is desired, at least one parent must possess an intermediate phenotype. Amylose content is also partially influenced by environmental conditions through mechanisms that remain largely unclear, although elevated temperatures during grain-filling have been shown to reduce amylose concentration (Jennings *et al*., 1979). In addition, varietal variation in gel consistency is observed even among cultivars with similarly high amylose content (greater than 25%). Rice varieties with amylose content below 24% generally exhibit a soft gel consistency; consequently, the gel consistency test evaluates the firmness of cooked rice paste and is primarily used to distinguish among high-amylose genotypes.

In this study, NERICA L 19 and BW 348-1 had intermediate amylose contents; MRQ 74 and WITA 4 had very low amylose contents, whereas the remaining genotypes had low amylose contents. The corresponding gel-consistency test grouped these genotypes according to their gel-length classes. Gelatinisation temperature and alkali spreading value were partly associated with the amylose content of starch, and were considered important determinants of cooking behaviour. This limited association is important because, in certain cases, it allows breeders to use the simple gelatinisation temperature test to estimate the amylose content, which is considerably more difficult to measure directly. In this study, three out of the sixteen genotypes examined had high alkali spreading value with low gelatinisation temperature; these genotypes were WITA 4, NL 30 and MRQ 74, whereas the others with intermediate to high gelatinisation temperature become excessively soft and tend to disintegrate when overcooked. Therefore, the three genotypes identified to possess low gelatinisation temperature would be preferred by consumers for their good cooking and eating quality. It should be noted that the combinations of the three traits relevant to rice cooking and eating quality observed in this study represented a small fraction of the possible combinations that could be achieved among the traits, i.e., AC, GC, and ASV/GT. Similar observations were reported by Tan *et al*. (1999).

5. Conclusion

The evaluation of sixteen rice genotypes demonstrated variation in amylose content and alkali spreading behaviour, two biochemical characteristics associated with the cooking properties of rice. Amylose content ranged from 9.3% in MRQ 74 to 21.0% in NL 19, with BW 348-1 recording 20.7%. According to the tabulated gel-consistency classifications, all sixteen genotypes belonged to the soft category, corresponding to a gel-length interval of 61–80 mm. The alkali spreading test differentiated ten genotypes with low ASV and high gelatinisation temperature from three genotypes—WITA 4, NL 30 and MRQ 74—with high ASV and low gelatinisation temperature. MR 220 and MR 253 were assigned intermediate values, while MR 263 was classified as low-intermediate for ASV. These findings indicate that the genotypes differ in characteristics relevant to laboratory-based rice-quality assessment. The identified biochemical profiles may assist in selecting material for further evaluation, but they do not by themselves establish consumer preference or cooking performance under all conditions. Direct cooking assessments and sensory evaluation would be useful before drawing broader conclusions about acceptance or suitability for breeding.

6. Limitations

This assessment included sixteen genotypes cultivated at one experimental location during the reported 2014 rainy season, which limits inference about performance across environments. Gel consistency was presented as categorical ranges rather than genotype-specific measured lengths, restricting comparisons within the soft class. The biochemical evaluation used amylose content, gel consistency and alkali spreading classifications rather than direct consumer sensory testing. The results should therefore be interpreted as a characterisation of the evaluated material, without assuming consistent cooking performance or consumer acceptance in other settings.

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Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. ChatGPT, Claude and Perplexity were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Author has declared that he/she has no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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