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MASTER'S THESIS

EVALUATION OF PHYSICAL PROPERTIES OF RICE CULTIVARS IN NIGERIA

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Declaration

I hereby declare that I have written and presented this master thesis entitled “Evaluation of physical properties of rice cultivars in Nigeria” by myself. All the texts in this thesis are original and all the literature sources have been acknowledged and quoted in the references according to the citation rule of the faculty.

Prague, April 25, 2024

Kutelu Aderemi Bunmi, B.Sc.

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LIST OF ABBREVIATIONS

FARO - Federal Agricultural Research Oryza

IITA – International Institute For Tropical Agriculture

FMARD – Federal Ministry Of Agriculture And Rural Development

NERICA – New Rice For Africa

WARDA – West African Rice Development Association

FAO - Food and Agriculture Organization of the United Nations

FAOSTAT - Food and Agriculture Organization of United Nations (Statistic division)

GRiSP - Global Rice Science Partnership

IRRI - International Rice Research Institute

GDP – Gross Domestic Product

SNK – Student-Newman-Keuls

Abstract

Rice, *Oryza sativa,* is a cereal whose grain has been the third most important food item after wheat and maize. Several cultivars of rice are planted in different ecological zones of Nigeria. However, available information on the physical properties of the rice grains of Nigerian rice cultivars is still insufficient. This study therefore evaluated the physical properties of the grains of five Nigerian rice cultivars (FARO 37, FARO 44, FARO 52, FARO 66, and FARO 67). Paddy rice grains were obtained from the International Institute for Tropical Agriculture (IITA), Nigeria. The milling properties of paddy (raw) rice grains were evaluated after parboiling 5 kg of each rice and subsequently milling using a standard milling machine used for commercial purposes. The size and shape, morphometrics, and colour properties of the paddy rice grains, milled rice grains, and cooked rice grains were also evaluated using standard methods. The cooking properties of milled rice grains were also evaluated using standard methods. Results showed significantly higher paddy grain and milled grain length and length-to-width ratio in FARO 66 than the other cultivars. The paddy grains were extra-long in shape and slender in size while the milled grains were long in shape and slender in size. The percentage of milling recovery was highest (76%) in FARO 67. On the other hand, only FARO 37 and FARO 44 had up to 50% head milled grains. Results also showed significant variations in the physical properties of the paddy grains and milled grains of the five Nigerian rice cultivars. Cooking time of the rice significantly varied from 20.70±0.54 minutes for FARO 44 to 24.70±0.54 minutes for FARO 37. Also, cooked grain length ranged from 10.25±0.06 mm to 11.63±0.15 mm, width from 2.85±0.06 mm to 3.30±0.14mm, thickness from 2.10±0.12 mm to 2.55±0.06 mm, and elongation ratio from 1.53±0.04 to 1.66±0.04. The water uptake ratio also ranged from 3.92±0.07 in FARO 37 to 4.62±0.06 in FARO 67. Results also showed significant variations in the colour properties of the paddy grains, milled grains, and cooked grains of the five Nigerian rice varieties.

Keywords: *Oryza sativa, Oryza glaberrima*, colour, Nigerian cultivars, paddy, milling, staple food, physical properties, Nigeria.

1. Introduction

1.1. Background of the Study

Rice is a popular staple food in Nigeria, with a high consumption rate (Maureen, 2014). As a result, Nigeria is one of West Africa's largest producers and consumers of rice. Nigeria is also the world's second-largest importer of rice, trailing only China (Diagne et al. 2011). Rice is one of the most widely consumed cereals in many parts of Nigeria, ranking third only to maize and sorghum (Odenigbo, 2013). The fundamentals of its consumption are linked to its wide acceptability and ability to be processed into various forms.

Furthermore, rice production and processing generate a plethora of by-products such as starch, straw, and husk. Starch can be commercially produced industrially from rice, and the resulting starch can be used for a variety of other purposes such as laundry and cloth inhalation, pharmacy, and many others. Straw is also used as ruminant animal feed and for other domestic household needs such as mats, bags, and many others, whereas husk is used industrially to generate fuel (Shkelqim, 2010). As a result, rice and its by-products have a variety of applications. Rice is also one of the most important crops to consider in terms of human consumption, and as such, it is regarded as critical in the country's efforts to combat food insecurity (Danbaba, 2013a).

Rice cultivars and by-products differ from country to country, as does its level of acceptability. Knowledge about Nigerian rice cultivars is limited in comparison to species and cultivars from other rice-producing countries such as Thailand, China, India, and others (Azuka et al. 2017). The properties in question are not only the physical properties but also the chemical and physiochemical properties. Although all the properties are important because they influence consumption, processing, and other value-addition opportunities, the physical properties influence several aspects of rice usage and availability, including mechanization usage and design, storage and consumption, post-harvest losses, palatability, and consumer desirability. In place of the foregoing, rice production and processing serve several purposes, and as such, there is a need to evaluate, analyze, and critically ensure that all factors and properties that may affect rice consumption are managed (Danbaba 2013). As a result, there is a need to address the physical properties of rice in Nigeria.

Rice's physical properties also influence how it can be stored, processed, and even consumed. Many physical properties of rice could be considered for this study, but for Nigeria rice cultivars, the properties included length, width, thickness, equivalent diameter, volume, bulk density, sphericity, porosity, and colour. Rice is an important food crop in the agricultural sector, and Nigerian farmers rely on it directly or indirectly because it is widely consumed in the country and beyond. Scholars have studied rice production on numerous occasions, but rice export is regarded as more important in Nigeria and many African countries than the consumption of Nigerian-produced or processed rice (Adeyemi, 2016). As a result, rice consumption, availability, and evaluation have a strong relationship with its physical properties and were considered.

2. Literature Review

2.1 Rice

Rice is a seed from *Oryza sativa* which is an indigenous crop of Asians and *Oryza glaberrima* commonly known as African rice is from Africans. It is also a very important crop in the world at large as it is consumed by a larger percentage of the world. It is not only consumed where it is indigenous but also in every part of the world even as an everyday meal. Rice contains high levels of carbohydrates and consists of about 45% of calories in foods; it is next rated after classes of fats and oil foods, and it is part of the cereals and grain food class which makes it generally acceptable and easy to prepare for consumption. Rice also constitutes over 80% of calories consumed in most African countries (FAOSTAT, 2020).

Rice is an agricultural commodity that is generally accepted after sugar cane and maize. This is because maize and sugar cane are utilized for other purposes aside from consumption. However, regarding caloric and energy consumption, the most essential food crop is rice. There are many varieties and choices of use of rice depending on the interest of the consumers that could be influenced by some cultural decisions (Jeffrey, 2017).

There are other grains such as wheat and maize apart from rice, but rice is the most cultivated of them all in the world and it is cultivated on 90 million hectares annually in Nigeria even though it is locally made rice. This local production had been ongoing before the importation of rice began so it could meet up with the increasing population. This is why considering human beings; rice is the most important cereal because wheat and maize are also used as animal feeds (Custodio et al 2019).

2.2 History of Rice

Rice production and cultivation's history is long far back to several centuries ago and as such the information available could be antagonistic and sometimes complicated as evidence points to several possibilities. However, a more reliable consensus states that *Oryza sativa*; the domestication of rice was first recorded in China (Vaughan, 2008). It was this cultivation that gave birth to others from different perspectives across the world and it continues to spread across other parts of the world including America. Thus, rice has been tagged as an international staple crop with the potential to contribute to world food availability. Over 40,000 *Oryza sativa* have since been recorded. Recently, improved breeding methods, agricultural practices, and agricultural technological advancement have helped in the production of new rice types like golden rice, genetically modified for higher beta carotene content.

During the colonial period, exploration led to the discovery of *Oryza glaberrima*, a rice species, along West Africa's coast. Observation of its cultivation in the marshlands of the Upper Guinea coast intrigued travelers, sparking inquiries into its nutritional composition and adaptability. Portuguese dissemination of *Oryza glaberrima* knowledge marked an early form of outreach, elucidating its cultivation techniques and nutritional profile. This catalyzed global interest, prompting investigations into enhancing production through technological and labor interventions. Valentim Fernandes, among others, documented the agricultural potential of the region, noting its suitability for cultivating diverse crops. This acknowledgment underscored the need for advanced agricultural practices to optimize yield. Subsequent scholarly discourse emphasized rice's pivotal role in agriculture, particularly during the rainy season. Such discussions solidified rice's status as a crucial crop for ensuring food security and economic stability (Wishart, 2018).

Portuguese admiration for production technology led to its adoption of intensive rice cultivation. Authors and naturalists further documented rice cultivation, solidifying its importance as a rainy-season crop (Potera, 2007).

Presently, the cultivation of rice is practiced in all the world's continents except in Antarctica which does not support crop cultivation (Prasad et al., 2017). The report of Prasad et al. (2017) also noted the importance of rice, being a staple food for most people in the world. The rice has thus become an item of foreign exchange that most countries have used to develop their economy. Nigeria is the largest producer of rice in Africa. As of 2020, Nigeria produces 8.1718 Mt (Mwakyusa et al., 2023) and as of 2022, India, followed by Thailand, and Pakistan were the first three of the top ten rice exporting countries (Workman, 2024). On the other hand, the Middle East, Sub-Saharan, and Western Africa were the largest importers of rice (Adjao and Staatz 2015).

2.3 Botanical Characteristics of Rice

Reports have shown that the cultivated rice is of the Poaceae family, subfamily Bambusoideae, and the genus *Oryza*. Furthermore, the genus was divided into *sativa*, *officinalis*, *meyeriana,* and *ridley* complexes (Khush 2005). The *Oryza* complex includes only two cultivable species which are the *Oryza glaberrima* and *Oryza sativa* (Manful and Graham-Acquaah, 2016). The *Oryza sativa* is cultivated worldwide and known as Asian rice while *Oryza glaberrima* is only cultivated in a few areas of some African countries (Manful and Graham-Acquaah, 2016). On the other hand, the other species are wild rice which has the problem of shattering grains and, thus, is less suitable for domestication (Callaway 2014). *Japonica* and *indica* are the main subspecies of *Oryza sativa* and are domesticated in two separate regions. For example, *japonica* is domesticated in China while *indica* is domesticated in India (Gross and Zhao, 2014). Similarly, rice belonging to the subspecies *indica* is cultivated all over the tropics and subtropics while the subspecies *japonica* is restricted to the temperate zones. The characteristics of *Oryza indica* include weak stems, long grains, tall stature, high tillering capacity, poor response to high nutrient input conditions, and droopy leaves. On the other hand, the characteristics of *Oryza japonica* include round grains, erect, stiff, and short stalks, and high responsiveness to nutrient inputs. However, to improve yield and boost economy, two different japonica cultivars (IRRI 142 and IRRI 152) were developed by the International Rice Research Institute (IRRI) to be suitable for cultivation on large scale basis in the Philippines and the tropics (Kang 2010).

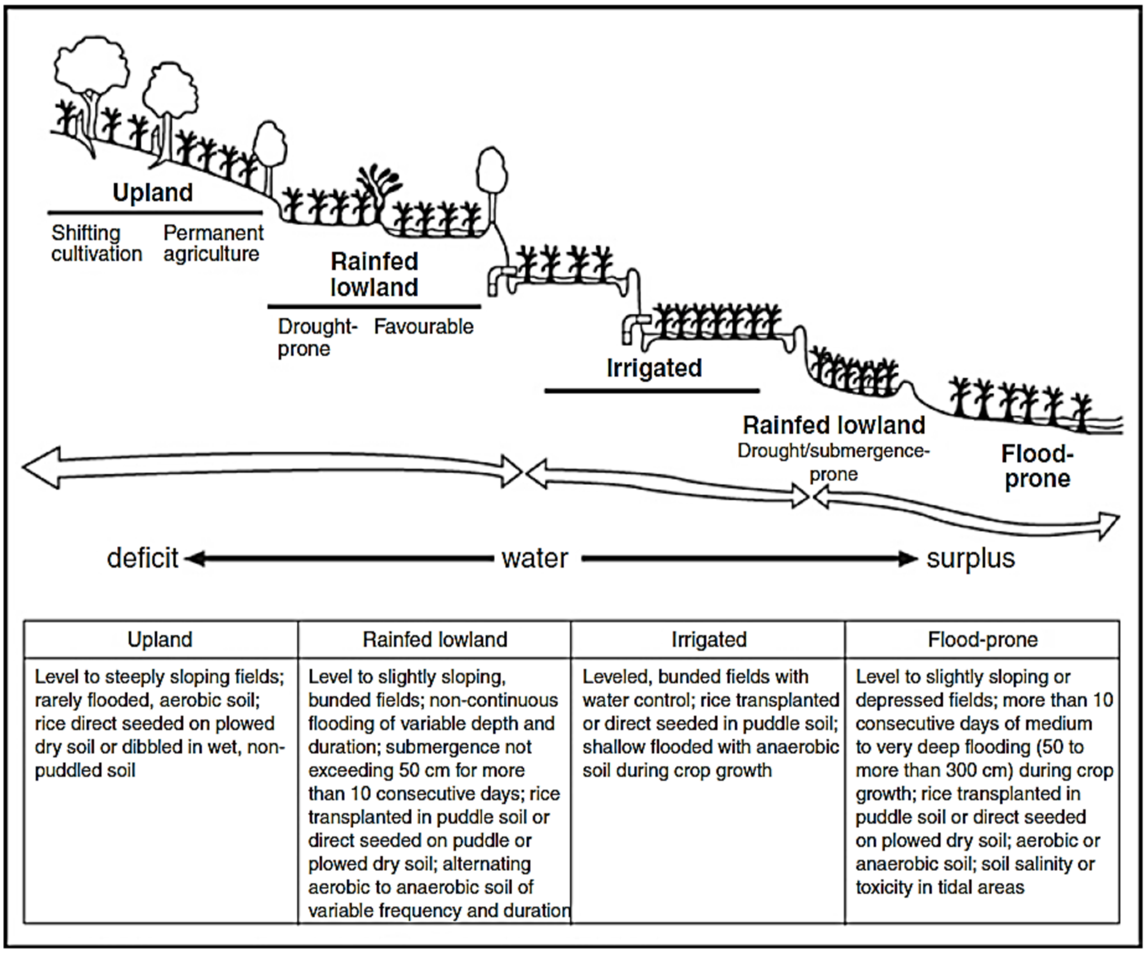
In Africa, the long-time (about 3500 years) domesticated rice is the *Oryza glaberrima* (Prasad et al., 2017). However, because of the main identified problems of this species which include lodging and shattering panicles, *Oryza sativa* was introduced about 450 years ago. This newly introduced species (*Oryza sativa*) produced higher yields than *Oryza* *glaberrima* and therefore spread fast in Africa. On the other hand, some varieties of *Oryza glaberrima* showed higher resistance to weeds, nematodes, waterlogging, drought, iron toxicity, and some major diseases and pests of African rice. Therefore, a crossbreed between *Oryza sativa* and *Oryza glaberrima* was done to produce a new rice variety called New Rice for Africa (NERICA). This rice species combined the high-yielding prospects of *Oryza sativa* with the stress-tolerant ability of *Oryza glaberrima* (Mohapatra, 2010). The distribution and habits of some of these rice species are shown in Table 1.

Table 1. The distribution and habit of rice species

SPECIES	HABIT	DISTRIBUTION
Oryza sativa	Annual, cultivated	South and Southeast Asia
Oryza nivara	Annual, wild	South and Southeast Asia
Oryza rufipogon	Perennial, wild	Tropical Asia and Australia
Oryza glaberrima	Annual, cultivated	Tropical west Africa
Oryza barthii.	Annual, wild	Saharan Africa
Oryza longistaminata.	Perennial, wild	Tropical west Africa
Oryza glumaepatula	Perennial, wild	Tropical west Africa
Oryza meridionalis	Wild	Tropical Australia
Oryza officinalis	Perennial, wild	South and Southeast Asia
Oryza minuta	Perennial, wild	The Philippines
Oryza rhizomatis	Wild	Sri Lanka
Oryza eichingeri	Wild	Tropical Africa Sri Lanka
Oryza punctata	Wild	Tropical Africa
Oryza latifolia	Wild	Central and South America
Oryza alta	Wild	Central and South America
Oryza grandiglumis	Wild	South America
Oryza australiensis	Wild	Tropical Australia
Oryza granulate	Wild	Tropical Asia
Oryza meyeriana	Wild	Southeast Asia
Oryza longiglumis	Wild	Indonesia, Papua New Guinea
Oryza ridleyi	Wild	SE Asia, Papua New Guinea
Oryza schlechteri	Wild	Papua New Guinea
Oryza brachyantha	Wild	Tropical Africa

Rice production in terms of flowering plants is also unique as it is a self-pollinating plant which makes it clear that the plant fertilizes itself. Although cross-pollination is also possible, it is very rare when the plants stand close to each other, and usually among all the agents of pollination, the wind is the major pollinating agent (GRiSP, 2013).

The species of relative importance to the world including Nigeria are *Oryza sativa* L. and *Oryza glaberrima* Steud. The rice plant is an annual crop that grows extremely well to about half meters, some exceptional varieties grow taller to about 9 meters. Some also grow with the height of flood depending on the water level of such environment. The rice plant is divided into two major parts in terms of physical look, and they are the root system and shoot system. Because the rice plant could be cultivated under different environments, the ecosystems of rice fields were categorized by the IRRI (1993) as rainfed lowland, irrigated, flood-prone, and upland ecosystems. These ecosystems are detailed in Figure 1.



Upland	Rainfed lowland	Irrigated	Flood-prone
Level to steeply sloping fields; rarely flooded, aerobic soil; rice direct seeded on plowed dry soil or dibbled in wet, non-puddled soil	Level to slightly sloping, bunded fields; non-continuous flooding of variable depth and duration; submergence not exceeding 50 cm for more than 10 consecutive days; rice transplanted in puddle soil or direct seeded on puddle or plowed dry soil; alternating aerobic to anaerobic soil of variable frequency and duration	Leveled, bunded fields with water control; rice transplanted or direct seeded in puddle soil; shallow flooded with anaerobic soil during crop growth	Level to slightly sloping or depressed fields; more than 10 consecutive days of medium to very deep flooding (50 to more than 300 cm) during crop growth; rice transplanted in puddle soil or direct seeded on plowed dry soil; aerobic or anaerobic soil; soil salinity or toxicity in tidal areas

Figure 1. The ecosystems of rice cultivation (Source: IRRI, 1993)

2.4 Rice production and consumption in Nigeria

The Federal Republic of Nigeria, generally called Nigeria is one of the most populous nations in Africa and has easy access to many natural resources. As reported by FAO (2023), the area of land available for the cultivation of crops was estimated at 70.8 million ha. Out of the various crops, rice was identified as being the most important among others. Within a year (2017 to 2018), the rate of rice production in Nigeria increased by four million metric tons. Despite this, the rate of production was still below the expected and the deficit was accommodated by the importation of rice into the country. Nigeria has adequately exploited its agricultural land mass in the production of cassava, in animal production (goat, sheep, poultry, and cattle), and in fisheries and aquaculture (FMARD and World Bank, 2020; Payne, 2000). Although, the agricultural potential of Nigeria is very high, her output in terms of agricultural production is underexploited (FAO, 2023).

According to the report of Akaeze (2010) on rice consumption within the African region, Nigeria was ranked the highest consumer per capita of rice. The study also noted that Nigeria is rated as the highest importer of rice because of its rising population and the poor quality of its locally produced rice. Similarly, most families depend on rice consumption in their everyday meals, and he further affirmed that Nigeria by far consumes rice more than every other part of West African countries.

The report of Rahji and Adewumi (2008) also noted that the economy of Nigeria is highly dependent on effective agriculture, especially through the production and accessibility of raw materials and food for the industries and consumption respectively. However, the fall in agriculture started with the discovery of crude oil in Nigeria where the channel and contribution to agricultural growth was shifted to the crude oil and led to the reduction in agricultural activities. This affected the supply of food and the demand for rice increased as it could not be met by the local production, and this gave room for people to seek more outside the country and it further led to the importation of rice (Table 2). For instance, as of 2013, the demand for local rice was about 7 million tonnes and the supply was 3.8 million tonnes. This indicates that there is a need for a rapid increase in the production of rice for the Nigerian government to meet the demand of the people until it reaches self-sufficiency and then leading to exportation. This can only be influenced by the Nigerian government and aided by policies that will favour the production of local rice before the ban on importation (Africa Research Bulletin, 2018).

Table 2. Rate of milled rice importation in Nigeria from 2010-2021

Year	Imports (MMt)	Growth rate (%)
2010	2.40	37.14
2011	3.20	33.33
2012	2.80	-12.5
2013	2.80	0
2014	2.60	-7.14
2015	2.10	-19.23
2016	2.50	19.05
2017	2.00	-20
2018	1.90	-5.0
2019	1.40	-26.32
2020	1.90	57.14
2021	2.00	11.36

Source: Index Mundi (2021); Year = Market year (the first 100% imports were recorded in 1963 at 2.00 MMt).

Terungwa and Yuguda (2014) explain that the rate of growth of Nigeria as a nation can be linked to its rate of rice production. According to the study, this is because rice production not only ensures food security but also creates employment opportunities, facilitates foreign exchange, and promotes a more concise level of development for the entire country. This generates income that can develop other sectors of the country as substantial revenue is generated from extensive rice production. The rice grain is an essential commodity and a core item that has balanced Nigeria’s economy and politics. This is because rice doubles as the main source of income for local rice farmers and as the diet of most Nigerians. It is therefore important that the policymakers in the Nigerian government pay more attention to this essential agricultural product to improve its domestic production for the local people as well as for the international market. Thus, Udo (2014) explained that various bans and restrictions placed on rice importation in Nigeria were to rice importers from such trade and shift their focus on the commercial production and enhancement of Nigerian local rice.

There is also a vast size of land made available to produce rice and set aside to meet the rising population. Out of the 5 million hectares available, less than 2 million hectares are used for the cultivation of rice in Nigeria (Nwobiala and Adesope, 2010).

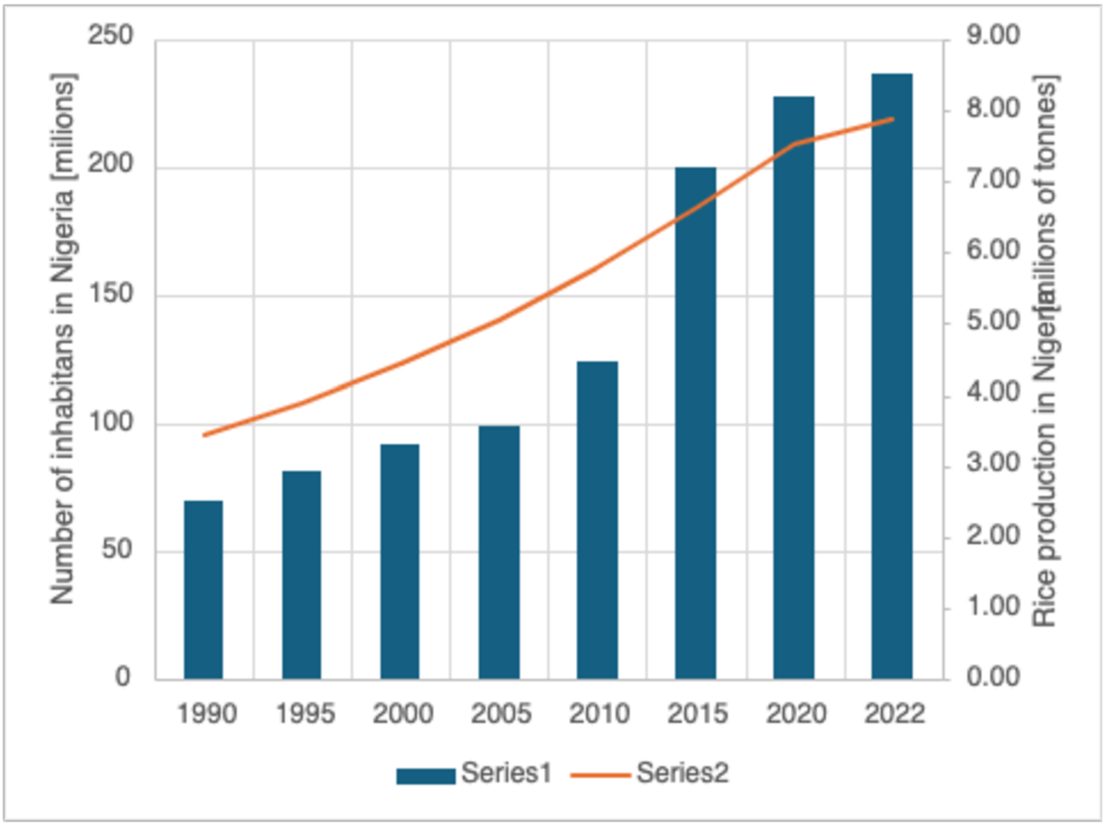
Table 3 below shows an increasing level of demand and the rate of rice consumption in Nigeria. The consumption pattern at the domestic level of rice increased from 2010 to 2023 and the increase continued gradually through the years.

Table 3. Milled Rice in Nigeria and Domestic Consumption from 2010-2023

Market year	Domestic consumption (MMt)	Growth rate (%)
2010	4.80	10.34
2011	5.60	16.67
2012	5.70	1.79
2013	5.80	1.75
2014	6.10	5.17
2015	6.40	4.92
2016	6.70	4.69
2017	6.75	0.75
2018	6.95	2.96
2019	7.05	1.44
2020	7.15	1.42
2021	7.35	2.8
2022	7.50	2.04
2023	7.60	1.33

Source: https://www.indexmundi.com/agriculture/?country=ng&commodity=milled-rice&graph=domestic-consumption (first consumption in 1960 had no growth rate and 100% consumption was N/A)

Nigeria currently occupies the position of the highest rice producer in West Africa, and the top-rated producer in Africa.



Source: FAOSTAT, 202

2.5 Rice Varieties

Rice farmers are expected to choose the variety or species of rice depending on environmental factors such as rainfall, sunshine, and soil conditions. Although rice survives in diverse and wild climatic conditions, the species to be selected should at least be favoured in the environment in which it is to be planted. More recently, there have been different developments and innovations of rice varieties to the environment to increase yield and meet up with the dynamic climatic conditions. Recently, a hybrid rice variety was produced by the West African Rice Development Association (WARDA) and was developed by the Africa Rice Centre which was called New Rice for Africa (NERICA). This rice is a mixed breed of both *Oryza sativa and Oryza glaberrima*. Rice varieties planted in Africa and Nigeria are mostly introduced from other parts of the world. For instance, Federal Agricultural Research Oryza rice 1 (FARO 1) was introduced from Sri Lanka because it is a lowland rice with white grains. Jones (2005) however affirmed that African rice is planted across all parts of Nigeria. The origin of the first ten earlier introduced rice varieties as reported by Maji and Fagade (2002) are shown in Table 4. The rice varieties released in Nigeria between the years 1992 and 2000 are also shown in Table 5.

Table 4. The characteristics of rice earlier released in Nigeria

FARO No.	Origin	Pedigree/Parentage	Ecology	Year of Release	Growth Duration (days)	Plant Height (cm)	Yield Potential (t/ha)
1	Guyana	BG 79	Shallow swamp	1954	135-174	105-120	3.0-5.0
2	Guyana	D 144	Shallow swamp	1957	135-115	100-115	3.0-4.5
3	Nigeria	Agbede	Upland	1958	95-120	95-100	1.5-2.5
4	India	Kavunginpoothala 12	Deepwater	1959	189-220	145-150	2.0-4.0
5	Madagascar	Makalioka 825	Shallow swamp	1960	135-154	111-115	2.0-4.5
6	F/Guinea	Indochinablank (ICB)	Deepwater	1961	176-198	156-160	2.0-3.0
7	Thailand	Maliong	Deep flooded water	1962	160-217	160-165	2.5-3.5
8	Indonesia	Mas 2401	Shallow swamp	1963	155-160	120-125	3.5-4.5
9	Malaya	Siam 29	Shallow swamp	1963	189-220	120-125	2.5-3.0
10	Kenya	Sindano	Shallow swamp (high altitude)	1963	115-162	125-130	2.5-4.5

Source: Maji and Fagade (2002)

Table 5. The rice varieties released in Nigeria between the years 1992 and 2000

FARO No.	Origin	Pedigree/Parentage	Ecology	Year of Release	Growth Duration (days)	Plant Height (cm)	Yield Potential (t/ha)
44	Taiwan	SIPI 692033 (SIPI661044/SIPI651021)	Irrigated/ shallow	1992	110-120	95-110	4.0-6.0
45	ITA, Nigeria	ITA 257 (IRAT 13/ Dorado Precose 689/TOX 490-1)	Upland	1992	90-100	90-100	2.0-3.0
46	ITA, Nigeria	ITA 150 (63-83/Multiline)	Upland	1992	100-105	80-90	2.0-3.0
47	ITA, Nigeria	ITA 117 (13A-18-3-1/TOX 7)	Upland	1992	115-120	90-110	2.0-3.0
48	ITA, Nigeria	ITA 301 (IRAT 13/ Dorado Precose 689/Padipapayak)	Upland	1992	115-120	90-110	2.0-3.5
49	ITA, Nigeria	ITA 315 (IR 43/Iguape Cateto)	Upland	1992	115-120	90-110	2.0-3.5
50	ITA, Nigeria	ITA 230 (BG 90-2*/Tetep)	Irrigated/ shallow swamp	1992	130-135	90-115	3.0-4.0
51	Indonesia	Cisadane (Pelita-1/IR/789-98-2-3/IR 2157-3)	Irrigated/	1997	130-135	100-120	3.0-4.0
52	IITA/WARDA	WITA 4 (TOX 3100- 44-1-2-3-3)	Irrigated/ shallow	2000	120 - 135	115-120	3.0-4.5

Source: Maji and Fagade (2002)

The study of Maji and Fagade (2002) described the basic characteristics of some of the rice varieties. FARO 12 was described as a tall, long-duration rice variety having narrow long leaves and suitable for rainfed swamps. They also have long grains. Also, the FARO 15 variety has broad leaves and medium-sized grains. It is suitable for medium to deep water because it can grow tall. It is a high-yielding variety. FARO 16 and FARO 17 are no longer in existence and thus not planted anymore on the farm. Also, FARO 25, FARO 39, FARO 40, and FARO 42 were not cultivated in any regions of Nigeria.

2.5.1 Characteristics of evaluated FARO cultivars

FARO 37 is a rainfed lowland rice variety. It is a member of the *Oryza sativa* species, which is typically grown in lowland and sometimes in irrigated conditions (Khush, 2004; Londo, 2006; Vaughan, 2003; Chang, 2004).

FARO 44 is a rainfed lowland rice variety, as indicated by Imolehin (1997). It is specifically suitable for irrigation under lowland rice ecosystems in Nigeria, with its adoption among smallholder farmers being influenced by factors such as age, occupation, farming experience, access to credit, and extension services. This variety has been found to have high yield potential and is well-suited for the Nigerian Niger Delta region.

Amadu and Sandi-Gahun (2023) also described the FARO 44 as an improved rice variety with high disease and pest resistance qualities and the ability to withstand flooding more than other varieties of rice.

FARO 52 was introduced to combine the two main limitations of rice production in rainfed lowland ecology. This includes iron toxicity and drought resistance. Under low input conditions, this variety has high yield and yield stability. In addition, Toungos (2016) described the FARO 52 as an improved variety with a short growth duration, the ability to respond to high fertilizer doses, and a short planting duration.

FARO 66 is a rainfed lowland rice variety, belonging to the *Oryza sativa* species, commonly cultivated in lowland, rainfed, and irrigated ecosystems. FARO 66 demonstrates 1–3 t/ha yield advantages over recurrent parents under flooding stress (Mwakyusa et al., 2023). FARO 66 can yield about 80 times higher than its parent FARO

52, which cannot survive flooding. “This makes FARO 66 a clear alternative for planting in flood-prone areas (PreventionWeb., 2017).

FARO 67 variety is a rainfed lowland rice variety. It is an annually cultivated *Oryza sativa* species, which is typically grown in lowland, rainfed, and irrigated ecosystems (Khush, 2004; Chang, 2004). This variety may have originated from a common ancestor with the AA genome, and its cultivation has been influenced by human selection and its adaptation to diverse environments (Khush, 2004).

2.6 Importance of rice

From the report of Terungwa and Yuguda (2014), it is indisputable that the importance of rice cannot be underestimated in human daily meal consumption. Thus, the report summarized some of the possible effects of rice on economic development and political development as follows:

1. **Food security.** Sufficient production of rice would increase food availability for local consumption and provide extra income through foreign exports. This would reduce the food crisis and improve food security.
2. **Employment generation.** In a bid to increase the mass rice production of rice for the nation, a lot of people would be employed and make their livelihood from it. Such employment would come along the value chain of rice production, from farming to processing, packaging, and marketing.
3. **Foreign exchange incomes.** Increased production of rice is not only beneficial to the nation in terms of local consumption, but it will also give room for excess production that could be sold out to other countries. Income from such foreign exchange would increase the country’s gross domestic product (GDP) and could be used to develop the country.

4. **General development.** Aside from solving the problem of food insecurity, unemployment, and foreign income generation, mass production of rice could help in national development. Income made from local and foreign sales of these rice could be used in infrastructural development thus, enhancing the livelihood of the citizens.

Other importance of rice as described by Toungos (2016) include:

1. Rice is important as the basic food crop for more than 60% of the world's population.
2. Rice bran oil is also used in the soap industry.
3. Rice straw is used for thatching of the roof, as cattle feed, poultry feed, and in cottage industry and as litter material.
4. Rice husk is used as a fuel source, for paper making, and as animal feed.

2.7 Rice nutritional composition and properties

Rice is a nutritional food component that contains a high energy percentage as its component includes water and starch. Rich is also limited in that it has a low content of nitrogen which makes it a non-complete food that is; it cannot be eaten alone. Rice has several uses across the world, and it is consumed by both humans and animals for diverse uses. Rice is also rich in starchy components which makes it also useful for other components such as alcoholic malts, food materials, and some other non-food materials such as porcelain, glass, and pottery. The composition of the rice determines the level of nutrients it can supply, and this can further be explained by considering husked rice for example which is about 12% rich in protein and some other times the content of the fertilizer will determine the residues left on the plant; a nitrogenous fertilizer increase amino acids content of the plant. In addition, comparing other cereals to rice, rice still has the highest nutritional content and more energy generated from it than other cereals as shown in the table below.

Table 6. Nutritional composition of cooked different types of rice

Nutrients	White rice, unenriched	White rice, enriched	Brown rice, unenriched
Calories	123	123	111
Protein	2.9 grams	2.9 grams	2.6 grams
Carbs	30 grams	26 grams	23 grams
Fat	0.4 grams	0.4 grams	0.9 grams
Fiber	0.9 grams	0.9 grams	1.8 grams
Folate	1% of the RDI	20% of the RDI	1% of the RDI
Manganese	18% of the RDI	18% of the RDI	45% of the RDI
Thiamine	5% of the RDI	14% of the RDI	6% of the RDI
Selenium	13% of the RDI	13% of the RDI	14% of the RDI
Niacin	12% of the RDI	12% of the RDI	8% of the RDI
Iron	1% of the RDI	10% of the RDI	2% of the RDI
Vitamin B6	8% of the RDI	8% of the RDI	7% of the RDI
Phosphorus	6% of the RDI	6% of the RDI	8% of the RDI
Copper	4% of the RDI	4% of the RDI	5% of the RDI
Magnesium	2% of the RDI	2% of the RDI	11% of the RDI
Zinc	2% of the RDI	2% of the RDI	4% of the RDI

RDI = Recommended Dietary Intake (Source: Raman, 2023)

Enriched white rice often contains added nutrients such as iron and B vitamins, including folic acid, niacin, and thiamine. While both brown and white rice offer varying levels of vitamins and minerals, enriched white rice tends to be higher in iron and folate compared to its brown counterpart (Raman, 2023). Generally, rice is high in nutritional composition. Such essential nutrients include vitamins, especially niacin or nicotinic acid (4.7 mg), B2 or riboflavin (0.05 mg), B1 or thiamine (0.34 mg), and minerals. The world generally regards rice as important in the following basic positions: -

1. Rice is a ready-to-eat food product, and it is consumed widely by a wide number of people across the world, either as rice or rice products.

2. Rice is a significant stable crop consumed by over half of the world's population.
3. It is used as feed for livestock and further processing of many industrial materials such as mats, rope, and litter.
4. Rice waste products such as husks are used for other purposes such as paper or pulp making.
5. Rice bran has oil that is used for other refined purposes such as soap making. There should still be chapters on the physical properties of rice here.

2.7.1 Physical properties of rice

Some differences occur in the quality of rice grains. These qualities are so important that they could predict the market value and the acceptability of such rice as local food. Some of these qualities include textural quality, cooking quality, and physical appearance. However, the rate at which these qualities are valued could vary based on culture and local cuisine (Fitzgerald et al., 2009). Among the several physical parameters of rice grains, studies have identified the basic parameters used in the measurement of rice grain dimensions as grain length, thickness, and width (Oli et al., 2016; Díaz et al., 2015). Similarly, these grain dimensions vary with different rice varieties (Mir et al., 2013; Shittu et al., 2012) and were reported by Varnamkhasti et al. (2008) to be associated with the milling operations of such rice varieties.

Another importance of measuring the dimension of rice grains has been shown in the cooking properties. For example, rice grain surface area was associated with the rate of water absorption into the grain during cooking. Therefore, rice grain surface area could directly influence the energy required during the drying of grains (Zareiforoush et al., 2011) as well as cooking time (Mohapatra and Bal, 2006). Some other physical parameters studied on rice grains include solid density, width, thickness, and grain volume (Hoque et al., 2022).

2.8 Aims of the Thesis

This study aims to evaluate the physical parameters of rice cultivars grown in Nigeria. Five rice cultivars which are grown by both local and commercial farmers and sold on the market for consumption in Nigeria were used in this study. The cultivars were examined and evaluated in terms of length, width, thickness, equivalent diameter, volume, bulk density, sphericity, porosity, and colour. The goal is to compare Nigerian rice cultivars to each other and to the system on which rice standards are based by categorizing and describing their properties.

The specific objectives of this study are to:

i. Determine the shape and size of five Nigerian rice cultivars.
ii. Evaluate the physical and colour properties of five Nigerian rice cultivars.
iii. Determine the cooking time as well as other cooking properties of five Nigerian rice cultivars.

3. Methodology

3.1 Collection of paddy rice samples

Five Nigerian rice cultivars with the variety name of Federal Agricultural Research Oryza (FARO) were obtained from the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria, and used for this study. The rice cultivars are FARO 37, FARO 44, FARO 52, FARO 66, and FARO 67.

FARO 37, FARO 44, and FARO 52 are rice of Forest Transition/Derived Savannah and Humid Forest while FARO 66 and FARO 67 are Lowland rice. Six kilograms (6kg) of paddy rice were obtained for each rice cultivar. Five kilograms (5kg) were taken to the mill for the milled grain analysis. One gram (1g) which contains about 38 seeds was measured from the remaining one kilogram (1kg) and used for the physical parameters of paddy rice grains.

3.2 Preparation of rice samples

This study made use of clean and disease-free rice grains. The paddy rice was carefully observed to remove unwanted materials such as dirt, straw, other plant parts, and stones. The paddy rice samples were stored in sealed airtight polythene bags before usage.

3.3 Parboiling of Kernel rice

The method of Danbaba et al. (2011) was adopted and used in this study for the parboiling of the five rice cultivars with little modifications. Five kilograms (5kg) of cleaned rice samples were placed in a labelled cloth bag and placed into boiling water in a heated vessel with a lid. The samples were stirred till the final temperature of the water was about 75±2 ^{o}C. This was then left to soak overnight. After eighteen hours (18 hours), water was drained and the steeped paddy was steamed locally fabricated laboratory parboiling vessel at the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. The steaming was observed until the paddy hull began to open. Thereafter, the steamed rice was spread out and dried in a solar dryer to about 10% moisture content.

3.4 Milling of rice grains

The parboiled rice grains for each cultivar were weighed and milled using a Small Rice Milling Machine (FN150, 150 – 200 kg/h) at the milling section of the Rice Research Unit of the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria.

3.4.1 Milling Recovery (MR)

Percentage milling recovery was calculated as follows:

$$\text{Milling recovery (\%)} = \frac{\text{Milled rice weight (g)}}{\text{Paddy weight used (g)}}\ x\ 100$$

3.4.2 Broken Milled Rice

The percentage of Broken milled rice was calculated as follows:

$$\text{Broken milled rice (\%)} = \frac{\text{Weight of broken milled rice (g)}}{\text{Total weight of milled rice (g)}}\ x\ 100$$

3.5 Physical Analysis of the rice grains

3.5.1 Length, Width, and Thickness

The grain length, grain width, and grain thickness of the rice samples (paddy rice, milled rice, and cooked rice) were carefully measured in millimetres (mm) with a digital Veneer Calliper with a 0.01 mm accuracy as described by Hoque et al. (2022). Twenty (20) rice grains were randomly selected for the length, width, and thickness measurements. The rice grains were classified into shape and size using the parameters of length, width, and thickness.

Paddy rice grains: The paddy rice grains were classified into shape and size based on the description of IRRI (2017).

Mean length classification:

- extra-long: greater than 7.5 mm
- long: within 6.61 mm – 7.50 mm
- medium: within 5.51 mm – 6.60 mm
- short: 5.50 mm and below

The length-to-width ratio classification:

- slender: a length-to-width ratio greater than 3.0
- medium: a length-to-width ratio 2.1 – 3.0
- bold: a length-to-width ratio 1.1 – 2.0
- round: a length-to-width ratio 1.0

Milled rice grains: The milled rice grains were classified into shape and size based on the description of Dipti et al. (2003). Grains were classified as:

- long: a mean length greater than 6.0 mm
- medium: those within 5.0 mm – 6.0 mm
- short: those less than 5.50 mm

Also, the length-to-width ratio was used to classify the size of the paddy rice grains:

- slender: a length-to-width ratio greater than 3.0
- bold: a length-to-width ratio 2.0 – 2.9
- round: a length-to-width ratio less than 2.0

$$\text{Length} - \text{to} - \text{width ratio } = \frac{\text{Length of rice grains (mm)}}{\text{Width of rice grains (mm)}}$$

3.5.2 Grain Diameter

The equivalent diameter, geometric mean diameter, and arithmetic mean diameter of the rice grains were calculated with the formula used by Mohsenins (1986):

$$Equivalent\ diameter = \left(L\frac{(W+T)^2}{4}\right)^{1/3}$$

$$Arithmetic\ mean\ diameter = \frac{L+W+T}{3}$$

$$Geometric\ mean\ diameter = (L\ x\ W\ x\ T)^{1/3}$$

Length (L), Width (W), and Thickness (T)

3.5.3. Grain sphericity

The formula of Mohsenins (1986) was also used in the calculation of grain sphericity.

$$Grain\ sphericity = \left(\frac{(L\ x\ W\ x\ T)^{1/3}}{L}\right)$$

Length (L), Width (W), and Thickness (T)

3.5.4 Grain aspect ratio

Calculation of the aspect ratio was done using the following formula (Mohsenins, 1986):

$$Grain\ aspect\ ratio = \frac{Grain\ lenght}{Grain\ width}$$

3.5.5. Grain surface area

Calculation of rice grains' surface area was done using the following formula (Jain and Bal, 1997).

$$Surface\ area = \frac{\pi B(L)^2}{(2L-B)}$$

Where $B = \sqrt{Width\ x\ Thickness}$

3.5.6 Grain volume

The grain volume was also calculated as follows (Jain and Bal, 1997):

$$Grain\ volume = \frac{1}{4}\ x\ [\left(\frac{\pi}{6}\right) x\ L\ x\ (W + T)^2]$$

Length (L), Width (W), and Thickness (T)

3.5.7 Grain bulk density

The formula described by Fraser et al. (1978) was used in the calculation of grain bulk density in g/cm^3. Rice grains were added to 100 ml mark in a 200 ml capacity beaker. The mass of these rice grains was weighed using an electronic digital balance. The process was repeated thrice.

$$Grain\ bulk\ density = \frac{Mass\ of\ rice\ grains}{Volume\ occupied\ in\ cm^3}$$

3.5.8 Grain solid density

The method used by Hoque et al. (2022) was adopted and used for the determination of grain solid density. A 100 ml capacity beaker was filled with 50 ml of distilled water. Three grams (3g) of rice grains were then added and the volume of water displaced was recorded. This was also in triplicates. Grain solid density was calculated as:

$$Grain\ solid\ density = \frac{Mass\ of\ rice\ grains}{Volume\ displaced\ in\ cm^3}$$

3.5.9 Grain porosity

Grain porosity was calculated as suggested by Jain and Bal (1997). Therefore, the calculation of grain porosity was done using the grain solid density and bulk density as follows:

$$Grain\ porosity = 100\ x\ \left(1 - \frac{Grain\ bulk\ density}{Grain\ solid\ density}\right)$$

3.6 Colour properties of grains

A CHROMA METER Colorimeter (CR – 410) was used to measure the colour properties of the paddy rice grains, milled rice grains, and cooked rice grains. Colorimeter produced the colour properties as the degree of lightness or whiteness (L*), degree of redness (A*), and degree of yellowness (B*).

3.7 Cooking properties of grains

The method used by Oko et al. (2012) was used with slight modification in the determination of the cooking properties of the rice grains.

3.7.1 Cooking time

Milled rice grains (10 g) were boiled in 100 ml distilled water. A few grains were removed at intervals during the cooking period and pressed between two glass plates. Cooking time was taken as the time when 90% or more of the rice grains had lost their white core.

3.7.2 Elongation ratio

Twenty grains of milled rice were randomly picked, and the length was measured before cooking. After cooking, twenty cooked rice grains were also selected randomly for length measurement. The grain elongation ratio was thus calculated as:

$$Elongation\ ratio = \frac{\text{Average cooked rice length (mm)}}{\text{Average uncooked rice length (mm)}}$$

3.7.3 Length/Breadth Ratio

The length and breadth of randomly picked twenty (20) cooked rice grains were measured with a digital veneer calliper. The length/breadth ratio of the cooked rice was calculated as:

$$Length/Breadth\ ratio = \frac{\text{Cooked rice length (mm)}}{\text{Cooked rice breadth (mm)}}$$

3.7.4 Water Uptake Ratio

The calculation of the water uptake ratio was done as follows:

$$Water\ uptake\ ratio = \frac{\text{Cooked rice weight}}{\text{Uncooked rice weight}}$$

3.8 Methods of data analysis

IBM SPSS statistical software version 21.0 (IBM Corp, 2012) was used to analyze the data generated from this study. Analysis of Variance was used to compare all mean parameters of the rice grains between the five Nigerian rice cultivars. The post hoc test used for the separation of the mean was the Student-Newman-Keuls (SNK) at a probability value of 0.05. Pearson correlation was also used to evaluate the relationship between rice milling properties and rice cooking properties and the relationship between milled rice size parameters and rice cooking properties.

4. Results

The rice cultivars which were collected on Monday morning November 6th 2023, were clean and disease-free rice grains. The paddy rice and the milled counterpart were carefully observed, and they were devoid of any physical or chemical damage.

4.1 Shape and size of Nigerian rice cultivars

4.1.1 Shape and size of paddy rice grains

The parameters used for the determination of the shape and size of the studied paddy rice grains of Nigerian rice cultivars are shown in Table 7. These parameters are the length of paddy rice and the length-to-width ratio of the paddy rice grain. The length and length-to-width ratio as well as the shape and size of the rice were compared between the five Nigerian rice varieties.

Mean rice grain length was the highest in FARO 66. This was not significantly different from the length of RARO 67. However, the lengths of FARO 66 and FARO 67 rice grains were significantly higher than those of the other three rice varieties. Lengths of FARO 37, FARO44, and FARO 52 were not significantly different. The length-to-width ratio of the rice grains also followed similar patterns as the length of rice grains. Results also showed that the rice grains of all the Nigerian rice cultivars evaluated were extra-long in shape and slender in size.

Table 7. Comparison of the length and length-to-width ratio of five Nigerian rice varieties

	Length (mm)	Shape	Length/width ratio	Size
FARO 37	9.32±0.40^{b}	Extra long	3.81±0.27^{b}	Slender
FARO 44	9.32±0.40^{b}	Extra long	3.71±0.15^{b}	Slender
FARO 52	9.16±0.41^{b}	Extra long	3.68±0.21^{b}	Slender
FARO 66	9.88±0.36^{a}	Extra long	4.00±0.27^{a}	Slender
FARO 67	9.74±0.43^{a}	Extra long	3.97±0.25^{a}	Slender

^{abc}Mean (±Standard deviation) with similar superscripts in the same column are not significantly different ($p > 0.05$); FARO = Federal Agricultural Research Oryza

4.1.2 Shape and size of milled rice grains

Table 8 also shows the parameters used for the determination of the shape and size of the studied milled rice grains of Nigerian rice cultivars. Significant variations were observed in the length and length-to-width ratio of the milled rice grains of the five studied Nigerian cultivars. However, the shape of the grains of all the rice cultivars was classified as long while the size was classified as slender.

Table 8. Shape and size of milled rice grains of five Nigerian rice cultivars

	Length (mm)	Shape	Length/width ratio	Size
FARO 37	6.83±0.21^{b}	Long	3.35±0.16^{b}	Slender
FARO 44	6.47±0.34^{c}	Long	3.06±0.24^{c}	Slender
FARO 52	6.76±0.24^{b}	Long	3.16±0.17^{c}	Slender
FARO 66	7.19±0.30^{a}	Long	3.46±0.14^{a}	Slender
FARO 67	6.78±0.26^{b}	Long	3.30±0.19^{b}	Slender

^{abc}Mean (±Standard deviation) with similar superscripts in the same column are not significantly different ($p > 0.05$); FARO = Federal Agricultural Research Oryza

4.2 Milling properties of Nigerian rice cultivars

Figure 2 represents the percentage milling recovery of the five Nigerian rice cultivars studied. On the other hand, the percentage of broken, and head-milled rice of the five rice cultivars is shown in Figure 3. Percentage milling recovery was highest (76%) for FARO 67 (Figure 2). However, the percentage milling recovery recorded for FARO 67, FARO37, and FARO 44 were not significantly different. On the other hand, the percentage of milling recovery was significantly lowest in FARO 52.

Percentage broken milled rice followed an opposite trend with the percentage head milled rice of five Nigerian rice cultivars (Figure 3). The percentage of broken milled grains was significantly higher in FARO 52, FARO 66, and FARO 67. On the other hand, broken milled grains and head milled grains were equal in FARO 44 while FARO 37 had higher head milled grains than broken milled grains.

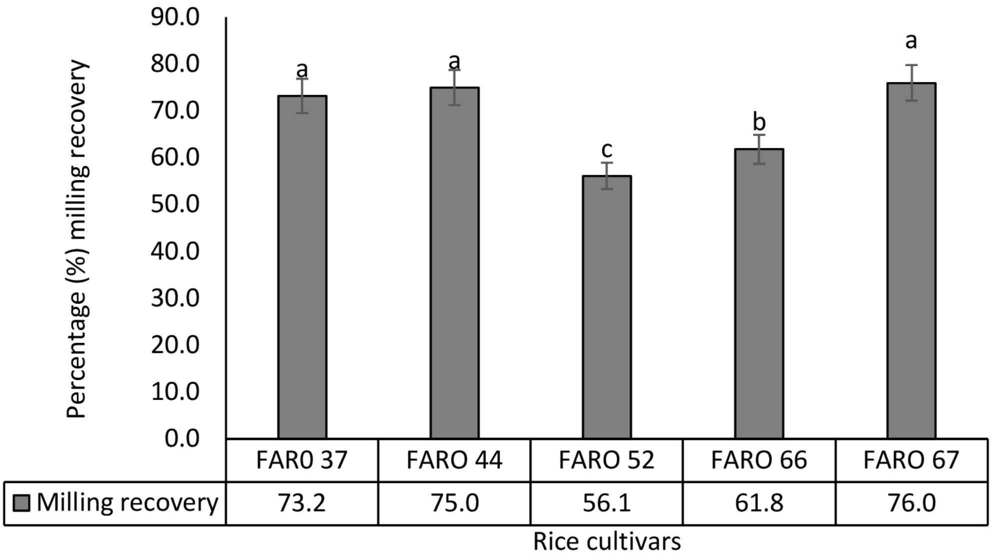
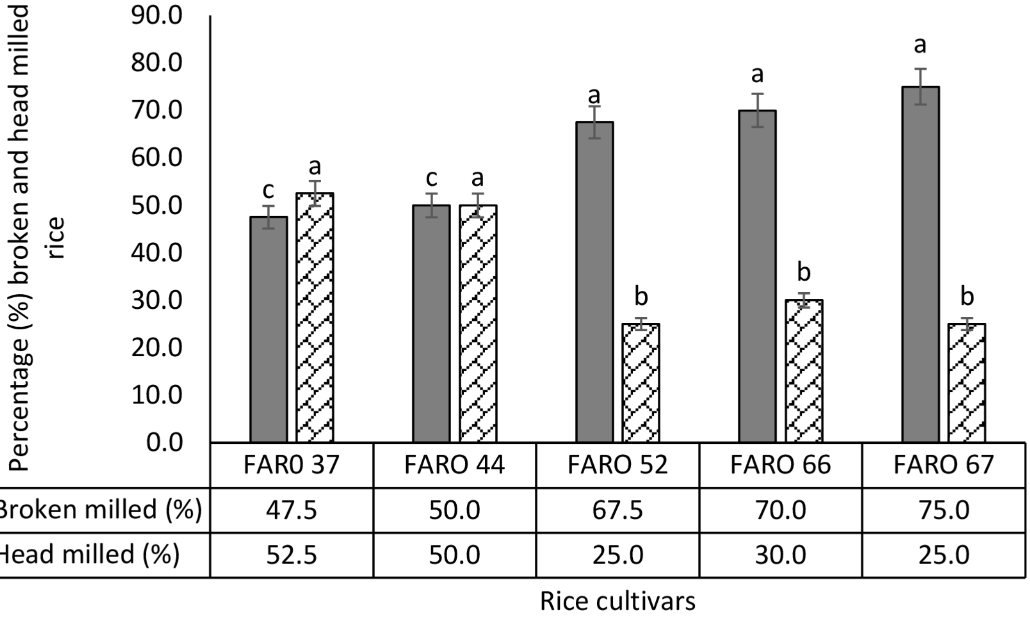


Figure 2. Percentage milling recovery of five Nigerian rice cultivars; Error bar represents standard deviation; Bars (mean) with similar alphabets are not significantly different ($p > 0.05$)



	FAR0 37	FARO 44	FARO 52	FARO 66	FARO 67
■ Broken milled (%)	47.5	50.0	67.5	70.0	75.0
▨ Head milled (%)	52.5	50.0	25.0	30.0	25.0

Figure 3. Percentage broken and head milled rice of five Nigerian rice cultivars; Error bar represents standard deviation; Bars (mean) with similar alphabets are not significantly different ($p > 0.05$)

4.3 Physical properties of the rice cultivars

4.3.1 Physical properties of paddy rice grains

The physical properties of paddy grains of five Nigerian rice cultivars are shown in Table 9. Grain length was significantly higher in FARO 66 and FARO 67 than in the other rice cultivars. There was however no significant difference in the grain length of FARO 37, FARO 44, and FARO 52. The paddy length of the rice grain ranged from 9.16±0.41 mm in FARO 52 to 9.88±0.36 mm in FARO 66.

The paddy length-to-width ratio, grain aspect ratio, and grain arithmetic diameter followed a similar pattern as the grain length. These were significantly higher in FARO 66 and FARO 67 than in the other rice cultivars. No significant difference was however recorded in the paddy length-to-width ratio, grain aspect ratio, and grain arithmetic diameter of FARO 37, FARO 44, and FARO 52. The paddy length-to-width ratio ranged from 3.68±0.21 mm to 4.00±0.27 mm while the grain aspect ratio ranged from 3.68±0.21 mm to 4.00±0.27 mm, and grain arithmetic diameter ranged from 4.54±0.15 mm to 4.77±0.13 mm among the five rice cultivars.

The surface area of the paddy grains was significantly highest in FARO 66 (44.10±2.44 mm^2). The surface area recorded in the other four rice cultivars was not significantly different. Similarly, grain porosity was significantly highest in FARO 37 (41.92±7.46 %). Grain porosity was lowest in FARO 44 (17.99±6.81%). On the other hand, FARO 37 Significantly had the lowest bulk density (0.77±0.01 g/cm^3). The bulk density recorded in the other four rice cultivars was however higher and not significantly different from each other. Bulk density was highest in FARO 67 (0.89±0.01 g/cm^3).

Solid density recorded in FARO 37, FARO 66, and FARO 67 were not significantly different. These were significantly higher than those of FARO 44 and FARO 52. However, the solid density of the five rice cultivars ranged from 1.05±0.10 g/cm^3 to 1.35±0.17 g/cm^3. On the other hand, the width (2.46±0.11 mm to 2.52±0.13 mm), thickness (1.90±0.09 mm to 1.97±0.08 mm), sphericity (0.37±0.01 to 0.39±0.01), equivalent diameter (6.71±0.40 mm to 6.98±0.30 mm), grain volume (23.62±2.71 mm^3 to 25.56±2.17 mm^3) and grain geometric diameter (3.54±0.12 mm to 3.64±0.10 mm) were not significantly different between the rice cultivars.

Table 9. Physical properties of paddy grains of five Nigerian rice cultivars

	FAR0 37	**FARO 44**	**FARO 52**	**FARO 66**	**FARO 67**
Length (mm)	9.32 ± 0.40^{b}	9.32 ± 0.40^{b}	9.16 ± 0.41^{b}	9.88 ± 0.36^{a}	9.74 ± 0.43^{a}
Width (mm)	2.46 ± 0.16^{a}	2.52 ± 0.13^{a}	2.49 ± 0.10^{a}	2.48 ± 0.13^{a}	2.46 ± 0.11^{a}
Thickness (mm)	1.94 ± 0.10^{a}	1.90 ± 0.09^{a}	1.97 ± 0.08^{a}	1.97 ± 0.08^{a}	1.93 ± 0.06^{a}
Paddy length/width ratio	3.81 ± 0.27^{b}	3.71 ± 0.15^{b}	3.68 ± 0.21^{b}	4.00 ± 0.27^{a}	3.97 ± 0.25^{a}
Sphericity	0.38 ± 0.02^{a}	0.38 ± 0.01^{a}	0.39 ± 0.01^{a}	0.37 ± 0.01^{a}	0.37 ± 0.01^{a}
Equivalent diameter (mm)	6.71 ± 0.40^{a}	6.73 ± 0.34^{a}	6.75 ± 0.27^{a}	6.98 ± 0.30^{a}	6.85 ± 0.24^{a}
Aspect ratio	3.81 ± 0.27^{b}	3.71 ± 0.15^{b}	3.68 ± 0.21^{b}	4.00 ± 0.27^{a}	3.97 ± 0.25^{a}
Surface area (mm^2)	41.71 ± 3.15^{b}	41.71 ± 2.77^{b}	42.02 ± 2.26^{b}	44.10 ± 2.44^{a}	42.91 ± 2.00^{b}
Grain volume (mm^3)	23.62 ± 2.71^{a}	23.77 ± 2.42^{a}	23.87 ± 1.94^{a}	25.56 ± 2.17^{a}	24.58 ± 1.72^{a}
Arithmetic diameter (mm)	4.57 ± 0.16^{b}	4.58 ± 0.17^{b}	4.54 ± 0.15^{b}	4.77 ± 0.13^{a}	4.71 ± 0.15^{a}
Geometric diameter (mm)	3.54 ± 0.14^{a}	3.54 ± 0.12^{a}	3.55 ± 0.10^{a}	3.64 ± 0.10^{a}	3.59 ± 0.08^{a}
Bulk density (g/cm^3)	0.77 ± 0.01^{b}	0.86 ± 0.01^{a}	0.85 ± 0.01^{a}	0.87 ± 0.01^{a}	0.89 ± 0.01^{a}
Solid density (g/cm^3)	1.35 ± 0.17^{a}	1.05 ± 0.10^{b}	1.05 ± 0.10^{b}	1.30 ± 0.24^{a}	1.21 ± 0.03^{a}
Porosity (%)	41.92 ± 7.46^{a}	17.99 ± 6.81^{c}	18.90 ± 7.49^{c}	30.89 ± 13.80^{b}	26.22 ± 1.08^{b}

^{abc}Mean (±Standard deviation) with similar superscripts in the same row are not significantly different ($p > 0.05$); FARO = Federal Agricultural Research Oryza; Arithmetic diameter = Arithmetic mean diameter; Geometric diameter = Geometric mean diameter

4.3.2 Physical properties of milled rice grains

There was no significant variation in the milled rice grain mean width, thickness, and bulk density of the five studied Nigerian rice cultivars (Table 10). However, the mean rice grain width ranged from 2.05±0.09 mm to 2.12±0.16 mm, thickness from 1.66±0.06 mm to 1.76±0.05 mm, and bulk density from 0.59±0.01 g/cm^3 to 0.60±0.00 g/cm^3. On the other hand, FARO 66 had significantly highest mean rice length (7.19±0.30 mm) and mean milled length to width ratio (3.46±0.14 mm). However, FARO 44 had the lowest mean rice length (6.47±0.34 mm) and mean milled length-to-width ratio (3.06±0.24 mm).

The mean milled grain sphericity recorded in FARO 44 (0.44±0.02) and FARO 52 (0.44±0.01) were not significantly different. These were however significantly higher than those of the other rice cultivars. Sphericity was lowest (0.41±0.01) in FARO 66. Similarly, the equivalent diameter, surface area, grain volume, and geometric diameter were highest in FARO 66. The values of equivalent diameter, surface area, grain volume, and geometric diameter recorded in FARO 66 were not significantly different from those of FARO 52. These were however higher than those recorded in the other rice cultivars.

The grain aspect ratio recorded for FARO 44 and FARO 52 were like each other. These were however significantly lower than those of the other rice cultivars. The grain aspect ratio was highest in FARO 66 (3.46±0.14) and lowest in FARO 44 (3.06±0.24). On the other hand, FARO 44 had significantly higher solid density (1.21±0.03 g/cm^3) and porosity (51.57±1.23 %) than those of the other rice cultivars. These were the lowest in FARO 66.

Table 10. Physical properties of milled grains of five Nigerian rice cultivars

	FAR0 37	FARO 44	FARO 52	FARO 66	FARO 67
Length (mm)	6.83 ± 0.21^{b}	6.47 ± 0.34^{c}	6.76 ± 0.24^{b}	7.19 ± 0.30^{a}	6.78 ± 0.26^{b}
Width (mm)	2.05 ± 0.09^{a}	2.12 ± 0.16^{a}	2.15 ± 0.08^{a}	2.08 ± 0.07^{a}	2.06 ± 0.10^{a}
Thickness (mm)	1.70 ± 0.06^{a}	1.69 ± 0.06^{a}	1.76 ± 0.05^{a}	1.73 ± 0.07^{a}	1.66 ± 0.06^{a}
Milled length/width ratio	3.35 ± 0.16^{b}	3.06 ± 0.24^{c}	3.16 ± 0.17^{c}	3.46 ± 0.14^{a}	3.30 ± 0.19^{b}
Sphericity	0.42 ± 0.01^{b}	0.44 ± 0.02^{a}	0.44 ± 0.01^{a}	0.41 ± 0.01^{b}	0.42 ± 0.01^{b}
Equivalent diameter (mm)	4.89 ± 0.21^{b}	4.84 ± 0.32^{b}	5.08 ± 0.13^{a}	5.11 ± 0.22^{a}	4.83 ± 0.23^{b}
Aspect ratio	3.35 ± 0.16^{a}	3.06 ± 0.24^{b}	3.16 ± 0.17^{b}	3.46 ± 0.14^{a}	3.30 ± 0.19^{a}
Surface area (mm^{2})	27.46 ± 1.54^{b}	27.20 ± 2.39^{b}	28.94 ± 0.99^{a}	29.10 ± 1.64^{a}	27.02 ± 1.74^{b}
Grain volume (mm^{3})	12.52 ± 1.07^{b}	12.33 ± 1.65^{b}	13.49 ± 0.69^{a}	13.68 ± 1.14^{a}	12.26 ± 1.18^{b}
Arithmetic diameter (mm)	3.52 ± 0.09^{b}	3.43 ± 0.15^{c}	3.56 ± 0.08^{b}	3.67 ± 0.12^{a}	3.50 ± 0.11^{b}
Geometric diameter (mm)	2.87 ± 0.08^{b}	2.85 ± 0.12^{b}	2.94 ± 0.05^{a}	2.96 ± 0.08^{a}	2.85 ± 0.09^{b}
Bulk density (g/cm^{3})	0.59 ± 0.01^{a}	0.59 ± 0.01^{a}	0.59 ± 0.00^{a}	0.59 ± 0.01^{a}	0.60 ± 0.00^{a}
Solid density (g/cm^{3})	0.83 ± 0.06^{b}	1.21 ± 0.03^{a}	0.83 ± 0.06^{b}	0.83 ± 0.06^{b}	0.81 ± 0.06^{b}
Porosity (%)	29.14 ± 4.08^{b}	51.57 ± 1.23^{a}	28.42 ± 4.73^{b}	29.15 ± 5.82^{b}	25.30 ± 5.91^{b}

^{abc}Mean (±Standard deviation) with similar superscripts in the same row are not significantly different ($p > 0.05$); FARO = Federal Agricultural Research Oryza; Arithmetic diameter = Arithmetic mean diameter; Geometric diameter = Geometric mean diameter

4.4 Colour properties of the rice cultivars

4.4.1 Colour properties of paddy rice

The degree of lightness/whiteness of paddy grains of the five Nigerian rice cultivars is shown in Table 11. The degree of lightness/whiteness recorded for FARO 52 was significantly higher than those of the other rice cultivars. However, the degree of lightness/whiteness recorded in the other four rice cultivars was not significantly different from each other.

On the other hand, the degree of redness and yellowness recorded in the five rice cultivars followed a similar pattern. These were significantly lowest in FARO 37. The degree of redness and yellowness recorded in the other rice cultivars were not significantly different.

Table 11. Colour properties of paddy rice grains of five Nigerian rice cultivars

	Whiteness (L*)	Redness (A*)	Yellowness (B*)
FAR0 37	36.56±0.18^{b}	5.48±0.01^{b}	13.58±0.07^{b}
FARO 44	37.67±0.01^{b}	6.22±0.01^{a}	17.45±0.01^{a}
FARO 52	39.17±7.09^{a}	5.90±0.05^{a}	16.53±2.14^{a}
FARO 66	37.17±0.16^{b}	6.88±0.03^{a}	18.04±0.11^{a}
FARO 67	36.46±0.08^{b}	6.35±0.07^{a}	17.83±0.03^{a}

^{abc}Mean (±Standard deviation) with similar superscripts in the same column are not significantly different ($p > 0.05$); FARO = Federal Agricultural Research Oryza; Whiteness = Lightness/brightness

4.4.2 Colour properties of milled rice

Significant variation was also observed in the degree of lightness/whiteness, degree of redness, and degree of yellowness of milled grains of the five Nigerian rice cultivars (Table 12). The degree of lightness/whiteness was highest in FARO 67 and lowest in FARO 44. Also, the degree of redness was highest in FARO 66 and lowest in FARO 44. Similarly, Faro 66 had the highest degree of yellowness. The degree of yellowness was however lowest in FARO 52.

Table 12. Colour properties of milled rice grains of five Nigerian rice cultivars

	Whiteness (L*)	Redness (A*)	Yellowness (B*)
FAR0 37	45.48±0.09^{c}	3.44±0.06^{b}	9.94±0.01^{c}
FARO 44	44.74±0.14^{d}	3.24±0.01^{c}	10.52±0.03^{b}
FARO 52	46.96±0.08^{b}	3.37±0.01^{b}	9.51±0.01^{c}
FARO 66	46.57±0.07^{b}	3.66±0.04^{a}	12.57±0.01^{a}
FARO 67	48.53±0.01^{a}	3.58±0.01^{a}	10.78±0.01^{b}

^{abc}Mean (±Standard deviation) with similar superscripts in the same column are not significantly different ($p > 0.05$); FARO = Federal Agricultural Research Oryza; Whiteness = Lightness/brightness

4.5 Cooking properties of the rice cultivars

4.5.1 Cooking time

The cooking time of the five Nigerian rice cultivars is represented in Figure 4. Results showed that the cooking time significantly varied between the rice varieties. This variation ranged from 20.70±0.54 minutes for FARO 44 to 24.70±0.54 minutes for FARO 37.

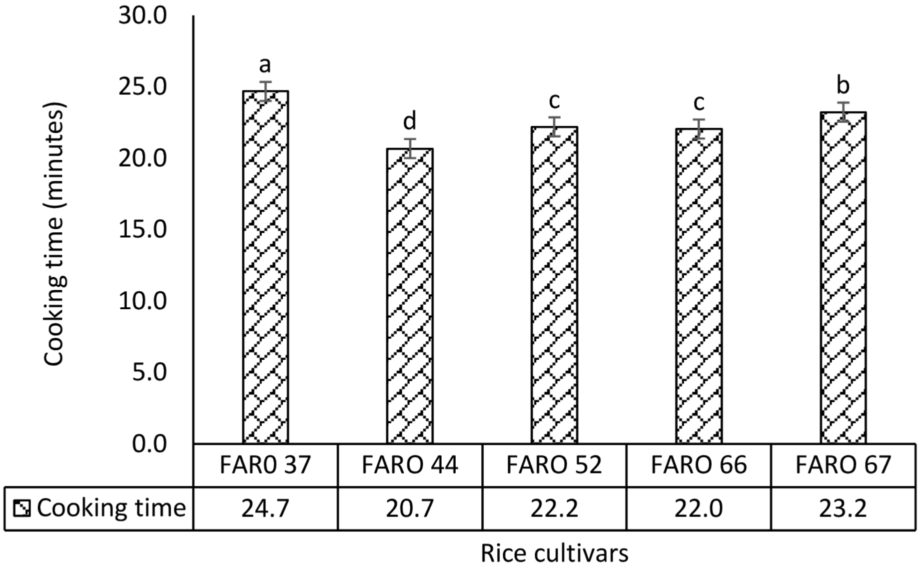


Figure 4. Cooking time of five Nigerian rice cultivars; Error bar represents standard deviation; Bars (mean) with similar alphabets are not significantly different ($p > 0.05$)

4.5.2 Other cooking properties

Table 13 shows the cooking properties (length, width, thickness, elongation ratio, length-to-breath ratio, and water uptake ratio) of the five Nigerian rice cultivars. The result shows that FARO 66 had significantly higher cooked rice length (11.63±0.15 mm) than the other rice cultivars. However, the cooked rice length recorded in the other four rice cultivars was not significantly different.

Cooked rice width recorded for FARO 37, FARO 44, and FARO 66 were also significantly similar. These were however significantly higher than those recorded for FARO 52 and FARO 67. On the other hand, cooked rice thickness was significantly lower in FARO 37 than in the other rice cultivars. However, the thickness of the other cooked rice grains was not significantly different from each other.

The elongation ratios recorded for FARO 44 and FARO 66 were also significantly similar. These were significantly higher than those of the other three rice cultivars. Similarly, the length-to-breadth ratio recorded in FARO 52, FARO 66, and FARO 67 were significantly similar. These were significantly higher than those of FARO 37 and FARO 44. The result also showed a significantly higher water uptake ratio (4.62±0.06) in FARO 67. Water uptake ratio also was however lowest (3.92±0.07) in FARO 37.

Table 13. Cooking properties of milled grains of five Nigerian rice cultivars

	FAR0 37	**FARO 44**	**FARO 52**	**FARO 66**	**FARO 67**
Length (mm)	10.73 ± 0.21^{b}	10.40 ± 0.12^{b}	10.40 ± 0.38^{b}	11.63 ± 0.15^{a}	10.25 ± 0.06^{b}
Width (mm)	3.18 ± 0.05^{a}	3.30 ± 0.14^{a}	2.95 ± 0.17^{b}	3.20 ± 0.08^{a}	2.85 ± 0.06^{b}
Thickness (mm)	2.10 ± 0.12^{b}	2.48 ± 0.15^{a}	2.53 ± 0.05^{a}	2.43 ± 0.10^{a}	2.55 ± 0.06^{a}
Elongation ratio	1.54 ± 0.03^{b}	1.63 ± 0.07^{a}	1.53 ± 0.05^{b}	1.66 ± 0.04^{a}	1.55 ± 0.02^{b}
L/B ratio	3.38 ± 0.05^{b}	3.16 ± 0.11^{c}	3.53 ± 0.11^{a}	3.64 ± 0.13^{a}	3.60 ± 0.05^{a}
Water uptake ratio	3.92 ± 0.07^{d}	4.13 ± 0.06^{c}	4.19 ± 0.08^{c}	4.34 ± 0.05^{b}	4.62 ± 0.06^{a}

^{abc}Mean (±Standard deviation) with similar superscripts in the same row are not significantly different ($p > 0.05$); FARO = Federal Agricultural Research Oryza

4.6 Relationship between milled rice and cooked rice properties

4.6.1 Rice milling properties and rice cooking properties

The Pearson correlation values of the relationship between rice milling properties and rice cooking properties of the five Nigerian rice cultivars are shown in Table 14. Broken milled rice showed a significantly positive correlation with grain bulk density, cooked grain thickness, and water uptake ratio. However, a significantly negative correlation was recorded between broken milled rice and cooked grain width.

On the other hand, it was observed that head-milled rice showed a significantly negative correlation with grain bulk density, cooked grain thickness, and water uptake ratio. A significantly positive correlation was recorded between head-milled rice and cooked grain width. Grain bulk density also showed a significantly negative correlation with grain porosity and grain cooking time and a significantly positive correlation with cooked grain thickness and water uptake ratio.

However, grain solid density showed a significantly positive correlation with grain porosity and grain cooking time. Grain porosity also showed a significantly positive correlation with grain cooking time. Significant negative correlation was however recorded between grain porosity and cooked grain thickness.

Table 14. Correlation (Pearson) between rice milling properties and rice cooking properties

	Broken milled	Head milled	Bulk density	Solid density	Porosity	Cook Time	Cook Length	Cook Width	Cook Thickness	Elongation ratio	Water uptake ratio
Broken milled	1										
Head milled	-0.853**	1									
Bulk density	0.683**	-0.650**	1								
Solid density	-0.120	0.113	-0.219	1							
Porosity	-0.284	0.253	-0.461*	0.957**	1						
Cook Time	-0.068	0.138	-0.532*	0.508*	0.631**	1					
Cook Length	-0.001	-0.017	-0.038	0.396	0.347	-0.058	1				
Cook Width	-0.561*	0.528*	-0.344	0.222	0.270	-0.340	0.481*	1			
Cook Thickness	0.537*	-0.618**	0.759**	-0.336	-0.491*	-0.608**	-0.160	-0.235	1		
Elongation ratio	-0.160	0.038	0.262	-0.043	-0.112	-0.547*	0.586**	0.566**	0.137	1	
Water uptake ratio	0.758**	-0.674**	0.868**	-0.039	-0.234	-0.142	-0.086	-0.566**	0.633**	0.031	1

*Correlation significant at $p < 0.05$; ** Correlation significant at $p < 0.01$; Values represents Pearson correlation value

4.4.3 Colour properties of cooked rice

The colour properties of cooked rice rains also showed significant variations between the five Nigerian rice cultivars (Table 15). The degree of lightness/whiteness was highest in FARO 44. The degree of lightness/whiteness recorded in the other rice cultivars was not significantly different. On the other hand, the degree of redness and degree of yellowness were significantly highest in FARO 67.

Table 15. Colour properties of cooked rice grains of five Nigerian rice cultivars

	Whiteness (L*)	Redness (A*)	Yellowness (B*)
FAR0 37	48.71±0.23^{b}	2.34±0.01^{b}	6.69±0.04^{b}
FARO 44	50.54±0.38^{a}	2.00±0.01^{c}	6.63±0.06^{b}
FARO 52	48.78±0.08^{b}	2.44±0.01^{b}	6.38±0.01^{b}
FARO 66	48.19±0.14^{b}	3.15±0.01^{a}	7.84±0.04^{a}
FARO 67	47.06±0.18^{b}	2.70±0.01^{b}	7.19±0.04^{b}

^{abc}Mean (±Standard deviation) with similar superscripts in the same column are not significantly different ($p > 0.05$); FARO = Federal Agricultural Research Oryza; Whiteness = Lightness/brightness

4.6.2 Milled rice size parameters and rice cooking properties

Table 16 shows the Pearson correlation values of the relationship between milled rice size parameters and rice cooking properties of the five Nigerian rice cultivars. Rice grain thickness showed a significantly positive correlation with grain length and grain width. This correlation was however weak. On the other hand, the correlation between the milled rice grain length and cooking properties (cooking time, cooked grain length, cooked grain width, cooked grain thickness, elongation ratio, and water uptake ratio) was not significant. However, a significantly positive correlation ($r = 0.430$, $p < 0.05$) was recorded between milled grain width and cooked rice thickness.

Table 16. Correlation (Pearson) between milled rice size parameters and rice cooking properties

	Length	Width	Thickness	Cook Time	Cook Length	Cook Width	Cook Thickness	Elongation ratio	Water uptake ratio
Length	1								
Width	0.037	1							
Thickness	0.281*	0.424*	1						
Cook Time	-0.031	-0.354	-0.160	1					
Cook Length	-0.107	-0.401	-0.163	-0.058	1				
Cook Width	-0.151	-0.072	-0.090	-0.340	0.481*	1			
Cook Thickness	0.096	0.430*	0.144	-0.608**	-0.160	-0.235	1		
Elongation ratio	-0.068	0.060	0.067	-0.547*	0.586**	0.566**	0.137	1	
Water uptake ratio	0.144	0.091	0.174	-0.142	-0.086	-0.566**	0.633**	0.031	1

*Correlation significant at $p < 0.05$; ** Correlation significant at $p < 0.01$; Values represents Pearson correlation value

5. Discussion

5.1 Shape and size of Nigerian rice cultivars

5.1.1 Shape and size of paddy rice grains

This study revealed significant variation in the length of paddy rice grains of the five studied Nigerian cultivars. The length ranged from 9.16±0.41 mm in FARO 52 to 9.88±0.36 mm in FARO 66. This finding is like that of Hoque et al. (2022) which also recorded significant variation in the length of rice grains of Boro rice varieties. The length of rice grain recorded in this study is lower than those of BRRIdhan50 and BRRIdhan63 and greater than those of BRRIdhan74, BRRIdhan88, BRRIdhan89, BRRIdhan,96, and BRRIdhan100 reported by Hoque et al. (2022). This is an indication that the Nigerian rice cultivars have appreciable grain length and are comparable to other improved rice cultivars around the world. Similarly, the shape of the paddy rice grains of all the five studied Nigerian cultivars is extra-long while the size is slender. This classification is also in agreement with the submission of IRRI (2017). Also, the similar shape and size of the rice is an indication that the rice cultivars originated from a similar glutinous rice type (Zainal and Shamsudin, 2021).

5.1.2 Shape and size of milled rice grains

The length of milled rice grains from this study ranged from 6.47±0.34 mm in FARO 44 to 7.19±0.30 mm in FARO 66. Also, the length-to-width ratio of the rice grains was greater than 3.0. A previous report by IRRI (1980) had earlier explained that the milled rice grain length-to-breadth ratio could be described as slender if greater than 3 (> 3). The shape of the milled rice grains was therefore classified as long while the size was slender. Similar shape and size of the milled rice grains could be an indication that the rice cultivars are of similar glutinous rice type origin (Zainal and Shamsudin, 2021). The mean grain length and length-to-width ratio of the milled rice grains of the five Nigerian rice cultivars recorded in this present study are like those reported by Zainal and Shamsudin (2021). According to Alaka et al. (2011), longer rice grains improve marketability and market price of rice. Thus, Nigerian rice cultivars have good potential for high market price and marketability.

5.2 Milling properties of Nigerian rice cultivars

The percentage of milling recovery ranged from 56.1% in FARO 52 to 76% in FARO 67. This percentage of milling recovery compares with those reported by Dambaba et al. (2013) for different rice cultivars. The study also affirmed that the milling quality of rice is highly essential in the selection of rice cultivars. Therefore, Webb (1972) had long ago affirmed that this milling recovery is a factor in the determination of commercially successful variety. However, in their report, Biswas et al. (1992) reported that modern rice has about 69% to 73% milling recovery. Dipti et al. (2003) therefore submitted that a milling recovery which is less than 67% is unacceptable. From this present study, FARO 37, FARO 44, and FARO 67 had milling recovery ranging from 73.2% to 76%. Based on the classification of Webb (1972) and Biswas et al. (1992), these rice cultivars are commercially successful and could be classified as modern rice.

On the other hand, the percentage of head-milled grains was low for the five Nigerian rice cultivars evaluated in this study in comparison with the previous study by Dambaba et al. (2013) on different rice cultivars. Only FARO 37 and FARO 44 had up to 50% head milled grains. Others ranged from 25% to 30%. Dambaba et al. (2013) described head-milled rice as the level of whole grains found in the milled rice. The lower-head milled rice grains recorded in this study could be attributed to the drying temperature and level of dryness (Webb, 1972). However, more attention should be placed on the drying of these rice cultivars to achieve a higher percentage of head-milled rice grains during milling processes.

5.3 Physical properties of the rice cultivars

5.3.1 Physical properties of paddy rice grains

This study has shown significant variations in some physical properties of the paddy grains of the five Nigerian rice cultivars. Other studies have also shown that different levels of variations may exist in the grain dimension and physical properties of different varieties of rice (Mir et al., 2013; Shittu et al., 2012). Similarly, the importance of measuring grain dimensions was associated with the efficiency of rice milling operations (Varnamkhasti et al., 2008). Therefore, several authors have affirmed that grain length, thickness, and width are the basic parameters in the measurement of rice grain dimensions (Oli et al., 2016; Díaz et al., 2015).

In this study, the paddy grain aspect ratio of Nigerian rice cultivars ranged from 3.68±0.21 to 4.00±0.27. The range of aspect ratio recorded for Nigerian rice cultivars was higher than those earlier recorded by Hoque et al. (2022) [0.16 – 0.31], those recorded by Mir et al. (2013) [0.19 – 0.43], and those recorded by Varnamkhasti et al. (2008) [0.24 – 0.28] for different rice cultivars. On the other hand, the equivalent diameter (6.71±0.40 mm – 6.98±0.30 mm) recorded for Nigerian rice cultivars in this study is greater than those reported for improved rice varieties by Hoque et al. (2022) [2.97 – 3.75 mm] and Mir et al. (2013) [3.60 – 3.79].

The surface area of Nigerian rice cultivars (41.71±3.15 to 44.10±2.44) was like those recorded by Hoque et al. (2022) for different improved rice varieties. Previous studies have associated the importance of rice grain’s surface area with the rate of water diffusion into rice grain when cooking. Thus, grain surface area could lead to variation in cooking time, with higher surface area reducing cooking time (Julianos, 1993; Mohapatra and Bal, 2006). Similarly, Zareiforoush et al. (2011) also affirmed that grain surface area also affects the energy requirement during drying by reducing the drying time. The grain surface area recorded in this study for Nigerian rice cultivars was higher than those recorded by Varnamkhasti et al. (2008).

On the other hand, grain porosity recorded in Nigerian rice cultivars (18.90±7.49% to 41.92±7.46%) was lower than those recorded by Varnamkhasti et al. (2008) [22.95% to 62.98%]. Mir et al. (2013) also recorded variations in the porosity of some rice varieties. The report has shown that low rice grain porosity could reduce the drying rate of the rice in comparison with those with higher porosity, especially under convective drying. Hence, there is a need to improve the porosity of these rice cultivars.

Also, other physical parameters of the Nigerian rice cultivars such as solid density (1.05±0.10 g/cm^3 to 1.35±0.17 g/cm^3), width (2.46±0.11 mm – 2.52±0.13 mm), thickness (1.90±0.09 mm – 1.97±0.08 mm), and grain volume (23.62±2.71 mm^3 – 25.56±2.17 mm^3) were like those recorded by Hoque et al. (2022) for improved rice varieties.

5.3.2 Physical properties of milled rice grains

The mean rice grain length (6.47±0.34 mm to 7.19±0.30 mm), length-to-width ratio (3.06±0.24 to 3.35±0.16), and sphericity (0.44±0.02 to 0.41±0.01) recorded in for the milled grains of the five Nigerian rice cultivars were similar to those recorded by Zainal and Shamsudin (2021) for some local and commercial Thai rice cultivars and those of Alaka et al. (2011) for some rice varieties in Nigeria. FARO 66 had the highest grain length more than the other four Nigerian rice cultivars evaluated. The report of Alaka et al. (2011) emphasized that longer rice grains improved the marketability and market price of rice.

Thus, this study suggests that FARO 66 would attract more funds to the farmers and vendors from its market price.

On the other hand, milled grain width, thickness, surface area, and grain volume recorded for the five Nigerian rice cultivars were higher than those reported by Zainal and Shamsudin (2021) for some local and commercial Thai rice cultivars. The difference observed may be in the variety of rice, planting locality as well as the moisture content of the rice grain. This implies that the grains of rice of the five Nigerian cultivars are bigger. Previous studies have also explained the significance of grain volume and surface area on the rate of drying and drying time of rice grains. For instance, heat transfer is better when the volume and surface area are relatively smaller, thus water diffuses out of the grain easier and faster (Varnamkhasti et al. 2008). However, the larger rice grains of the Nigerian rice cultivars may not be a problem as Nigeria is in a tropical region where most of the dryers used for drying rice grains are solar dryers. A cheap and effective drying method used for drying rice in Nigeria could make the grains of the five Nigerian rice cultivars compete better than their counterpart in the international scene in terms of grain size. Similarly, Azuka et al. (2021) also affirmed that higher grain volume is of great benefit to the rice seller because its storage space will be occupied by the rice grains.

However, levels of grain porosity recorded in this study were less in the five Nigerian rice cultivars than those obtained by Zainal and Shamsudin (2021) for some local and commercial Thai rice cultivars. Differences in grain porosity have earlier been associated with intrinsic characteristics of the rice cultivars and grain drying time (Varnamkhasti et al. 2008). Thus, grains with higher porosity will dry at a slower rate when compared with those with higher porosity. On the other hand, the porosity recorded in this study was like that of Farahmandfar et al. (2009) and Nadvornikova et al. (2018). Also, the bulk density of Nigerian rice cultivars used in this study compares well with those reported by Correa et al. (2007) and Ghasemi et al. (2008).

5.4 Colour properties of the rice cultivars

There was only a slight variation recorded in the colour properties of the paddy grains, milled grains, and cooked grains of the five Nigerian rice cultivars. Andriani et al. (2020) explained that colour is an important characteristic of food products. Such importance was attributed to colour because it provides the first attraction to the product before knowing the taste and nutritional values are identified. This study therefore affirms that either of the five cultivars could be selected for use either cooked or uncooked when judging from the colour perspective.

The degree of lightness recorded in the milled rice in this study also compares well with those recorded for parboiled milled rice by Azuka et al. (2021). Thus, rice grains of Nigerian cultivars also have an off-white appearance. The degree of yellowness recorded in the five Nigeria rice cultivars is positive and compares with those of Azuka et al. (2021). This light yellow or creamy colour appearance recorded in the milled grains of the five Nigerian rice cultivars was earlier described by Semple et al. (1992) as the quality of rice grain with premium quality.

5.5 Cooking properties of the rice cultivars

5.5.1 Cooking time

Results showed that the cooking time significantly varied between the rice varieties. This variation ranged from 20.70±0.54 minutes for FARO 44 to 24.70±0.54 minutes for FARO 37. This cooking time is slightly higher than those Yadav et al. (2007) recorded for different Indian rice cultivars. On the other hand, the cooking time recorded in the five

Nigerian rice cultivars compares well with the optimum cooking time recorded by Oko et al. (2012) for different varieties of newly introduced rice in Enugu state Nigeria.

5.5.2 Cooking properties

Length ranged from 10.25±0.06 mm to 11.63±0.15 mm, width from 2.85±0.06 mm to 3.30±0.14mm, thickness from 2.10±0.12 mm to 2.55±0.06 mm, and elongation ratio from 1.66±0.04 to 1.66±0.04. The water uptake ratio also ranged from 3.92±0.07 in FARO 37 to 4.62±0.06 in FARO 67. The elongation ratio recorded for the five Nigerian rice cultivars of this study agrees with the submission of Oko et al. (2012). Similarly, the elongation ratio recorded for Nigerian rice cultivars in this study is also like that of Indian rice cultivars reported by Yadav et al. (2007).

6. Conclusions

This study has evaluated the physical properties of the grains of five Nigerian rice cultivars (FARO 37, FARO 44, FARO 52, FARO 66, and FARO 67), planted and produced for the market in Nigeria. The study has established that the paddy grains of these rice cultivars were extra-long in shape and slender in size while the milled grains were long in shape and slender in size. Also, comparing the milling recovery percentage of Nigerian rice grains used in this study with standard classifications, the rice cultivars are commercially successful and could be classified as modern rice. This study also affirms that the five Nigerian rice cultivars showed significant variations in physical properties, colour properties, and cooking properties. Thus, Nigerian rice cultivars can also be compared with standard international rice cultivars. More attention is therefore recommended in the aspect of efficient milling to obtain a greater percentage of head-milled rice grains.

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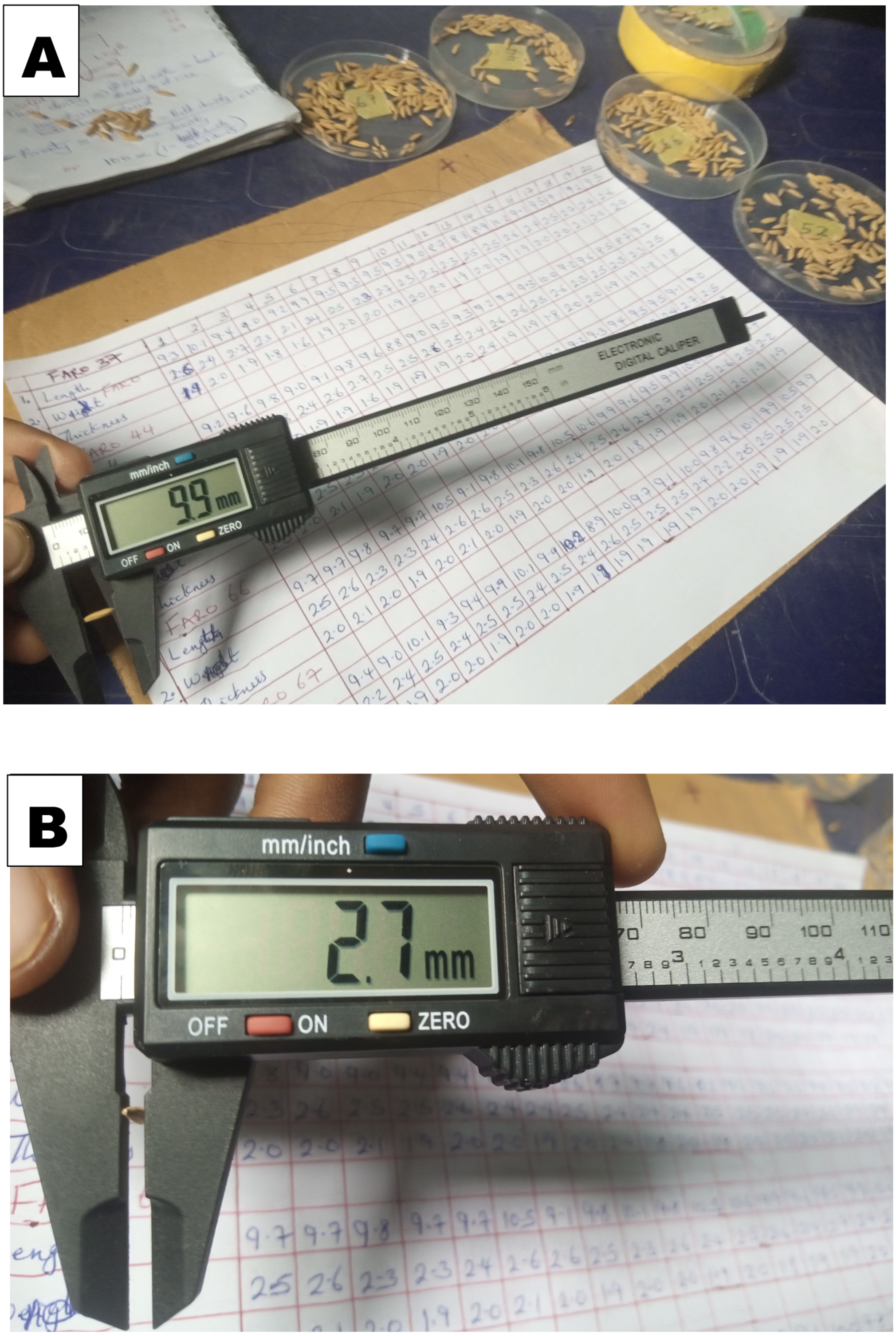
8. List of Appendices

9. Appendices

Appendix 1. Assessing some of the studied rice cultivars at market point of sale.

Appendix 2. Packaged samples of the studied rice cultivars at the warehouse.

Appendix 3. Sample analysis in the laboratory.



Appendix 4. Some pictures of morphometric analysis of the rice grains; A = Grain length, B = Grain width.

Appendix 5. Chroma Meter (CR-410) colorimeter used for grain colour analysis.