STUDIES ON EFFECTS OF CHANGE IN MOISTURE CONTENT ON SOME PHYSICAL, MECHANICAL AND QUALITY PROPERTIES OF TWO PADDY RICE (*Oriza sativa* L) VARIETIES GROWN IN NIGERIA

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN AGRICULTURAL AND BIO-RESOURCES ENGINEERING

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ZARIA, NIGERIA

NOVEMBER, 2021

DECLARATION

I declare that the work in this dissertation entitled "**Studies on Effects of Change in Moisture Content on some Physical, Mechanical and Quality Properties of Two Paddy Rice (*Oriza sativa* L) Varieties Grown in Nigeria"** was carried out by me in the Department of Agricultural and Bio-Resources Engineering under the supervision of Dr. Aminu Saleh and Prof. M. L. Suleiman. The information derived from the literature has been acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma in this or any other institution

USMAN Muhammed Bello	……………………	…………………
(P17EGAB8021)	Signature	Date

CERTIFICATION

This Dissertation entitled **"Studies on Effects of Change in Moisture Content on Some Physical, Mechanical and Quality Properties of Two Paddy Rice (*Oriza sativa* L) Varieties Grown in Nigeria"** by USMAN Muhammed Bello, meets the regulations governing the award of the degree of Master of Science in Agricultural and Bio-Resources Engineering of Ahmadu Bello University, and is approved for its contribution to scientific knowledge and literal presentation.

Dr. Aminu Saleh	……………………..	……………………..
Chairman, Supervisory committee	Signature	Date
Prof. M. L. Suleiman	……………………..	………………….
Member, Supervisory committee	Signature	Date
Prof. M. Isiaka	………………….	……………………..
Head of Department	Signature	Date
Prof. S. A. Abdullahi	. ………………	……………………..
Dean, School of Postgraduate	Signature	Date

DEDICATION

This research work is dedicated to Almighty Allah, the most Beneficent and the most Merciful and to my lovely Parents.

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ABSTRACT

The aim of this study was to investigate the effects of change in moisture content on some selected physical, mechanical and quality properties of Faro 44 and Jamila varieties of paddy rice. The selected Physical properties were Bulk Density (BD), Angle of Repose (AR), Geometric Mean Diameter (GMD), Mechanical properties include Grain Hardness (GH) and Rupture Force (RF) while the Quality properties include Milling Recovery (MR) and Head Rice Ratio (HRR). The experiment was carried out at three different moisture contents levels of 16 %, 14 % and 12 %. The experiments were conducted using Completely Randomized Design (CRD) at two levels of varieties and three levels of moisture contents. Duncan multiple Range Test and Student Neuman Keuls Test were used to further the grouping and analyze the significant variables. The results shows that the range of values for the bulk density, angle of repose and geometric mean diameter are 530-573 kgm^{-3}, 31.0^0-32.0^0 and 3.618-3.786mm, respectively. It was observed that effect of variety is not significant on bulk density. However the effect of moisture content is significant at 5 % level. The effect of interaction of variables is not significant on angle of repose but is significant on the geometric mean diameter. The highest mean Bulk Density of 573kgm^{-3} was obtained from FARO 44 variety at moisture content of 16%. While the least BD (530Kgm^{-3}) was obtained from Jamila at 14 % moisture content. The highest AR (32^o) was obtained at the combination of FARO 44 and moisture content of 16% and 14% respectively. While the least AR of 30^o was obtained from Jamila Varieties at 12 % moisture content.. The highest GMD was obtained as 3.78 mm at 16% M.C. while the least GMD was obtained as 3.69 mm at 12 % M.C. It was found that the mean values of grain hardness and rupture force are 36.27-45.07N and 48.92-73.07N, respectively. It was also observed that the effect of all the variables and their interactions on GH and RF are highly significant. The highest GH was obtained as 41.16N for jamila variety and the least GH was obtained as 37.49N for Faro 44 variety. The highest RF (67.80N) was obtained from Jamila variety. While the least RF (57.69N) was obtained from FARO 44 variety. It could be seen that the range of mean values for milling recovery and head rice ratio are 70.15 – 72.87 % and 84.24 – 87.49 % respectively. It was found that the effect of variety on milling recovery is highly significant where as it is not significant on head rice ratio. The effects of interactions on the mean values of both the milling recovery and the head rice ratio are not significant. The highest value of MR (72.87%) was at the interaction of variety and moisture content of 14% which was obtained from Jamila variety. While the least MR (70.15%) was from the interaction of FARO 44 at 12% moisture content. The highest value of HRR (87.49%) was obtained from FARO 44 at 16% moisture content. While the least HRR (84.23%) was obtained in Jamila at 12% moisture content. Jamila paddy rice variety has the highest milling recovery while Faro 44 has the highest head rice ratio. All the varieties has the potentials to compete globally in terms of better rice quality considering the IRRI (2021), World potentials yield milling recovery and head rice ratio of 68-72% and the 80.55 % respectively. It can be concluded that the change in moisture content affect physical, mechanical and quality properties of the selected paddy rice varieties, and also the variety difference influences milling recovery and head rice ratio.

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ABBREVIATIONS AND SYMBOLS

ABM	Agri- business and Market Development
ABU	Ahmadu Bello University
AGRA	Alliance for Green Revolution in Africa
AR	Angle of Repose
ARI	African Rice Initiative
BD	Bulk Density
BRR	Broken Rice Ratio
CRD	Completely Randomized Design
DMRT	Duncan Multiple Range Test
FARA	Forum for Agricultural Research in Africa
FGN	Federal Government of Nigeria
FMARD	Federal Ministry of Agriculture and Rural Development
GAP	Good Agricultural Practice
GH	Grains Hardness (N)
GMD	Geometrical Mean Diameter
GIZ	German Cooperation
HRR	Head Rice Ratio
IRM	Integrated Rice Mills
JICA	Japan International Cooperation Agency
L	Length of Paddy Rice (mm)
M.C	Moisture Content (%)
MR	Milling Recovery (%)
NBS	National Bureau for Statistics
NGO	None Governmental Organizations
NIR	Near- Infrared
NIS	National Industrial Standard
NRDS	National Rice Development Strategy
PRPC	Philippine Rice Post Production Consortium
QCM	Quality Control Managers

RF	Rupture Force (N)
RIPMAPP	Rice Postharvest Processing and Marketing Pilot Project
SA	Surface Area of the Paddy Rice (mm^2)
SON	Standard Organization of Nigeria
T	Thickness of Paddy Rice (mm)
U S	United States
V	Volume of Paddy Rice (mm^3)
W	Weight of Paddy Rice (g)
WARDA	West African Rice Development Agency

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Rice (*Oryza sativa L*) stands out as constituting the basic food for large number of families and sustaining more than half of the world population (IRRI, 2021). Rice is the most important cereal crop cultivated in the world (Alizadeh, 2016).

Recently, there has been remarkable economic development in developing countries, especially in West African countries. As a result of this development, there has been a shift of population from farming areas to cities, centers of commerce and industry, accompanied by higher standard of living. It is said that today 55% of the population lives in cities, (NBS, 2018). For this reason, a change has occurred in the consumption pattern of rice, which is a staple in many countries. Specifically, more rice is now distributed as a commercial product, and people are now demanding rice of higher quality and better taste (NRDS, 2019)

In order for rice to be distributed smoothly as an appealing product both domestically and internationally, guarantee of its quality is important, as is price. Rice must receive fair inspection based on recognized public quality and packaging standards, so that the consumers can be assured that good quality rice would be supplied in sufficient quantity (RIPMAPP, 2017). Rice inspection does not involve merely classifying rice into grades and determining the price. If rice is not fully matured, or becomes damaged, in the production process, it will be impossible to improve its quality after it is harvested. About all that can be done then is to remove damaged and broken grains. A rice inspector is in a special position in which he can see the quality of the rice, point out problems in the rice growing and in drying and storage of the rice after it is harvested, and suggest improvements (Houston, 2018).

Nigeria with a population of over 200 Million people and a land area of 923,768 square kilometers has a total of over 79 Million hectares of cultivable land *(*NBS, 2008). Out of this, 4.6 Million hectares are suitable for rice cultivation (NRDS, 2019). Rice is a food security commodity in Nigeria as well as being the fourth major cereal crop after sorghum, millet and maize both in terms of output and cultivated land areas (NRDS, 2019).

Only about 57 % of the 6.7 million metric tonnes of rice consumed in Nigeria annually is locally produced leading to supply deficit of about 3 million metric tonnes (NRDS, 2019). Although there is an increase in rice production, consumption is also increasing annually. Average yearly per capita consumption was 15.8 kg in 1990 but increased to 27 kg by 2007. During this period, self-reliance decreased from 87.4% to 71% (NBS, 2018).

With increased local rice production and quality improvement, scarce foreign exchange hitherto used for rice importation can be conserved to improve infrastructure for enhanced national socio-economic growth (NRDS, 2019). Average import in 2006 amounted to 1.6 Million tonnes, costing the nation over Two hundred and fifty four billion naira. And even shoot up to over One trillion naira in 2015 (NRDS, 2019).

The major cause of this high importation is lack of good quality domestic rice. And one of the major factors is lack of knowledge of the properties which can help in the design of the effective and efficient equipment for various processing operations.

The physical and mechanical properties of rice, are very important in the design and selection of processing and storage equipment. Therefore, the determination and consideration of properties such as moisture content, bulk density, true density, angle of internal friction and static coefficient of friction of grain has an important role to play in processing of the country's Agric Produce (Mohsenin, 1980). The principal axial dimension of rice seeds areuseful in selecting sieve separators and in calculating power requirement during the rice milling process (Ghasemi, 2008). Knowing the grains bulk density, true density and porosity can be useful in sizing hopers and storage facilities, they can affect the rate of heat and mass transfer of moisture during the aeration and drying processes *(*Sarah et al, 1988). A grain bed with low porosity will have greater resistance to water vapour escape during the drying process. Which may lead to the need for higher power to drive the aeration fans (Bern *et al*, 2011). Cereal – grain kernel densities have been of interest in breakage susceptibility and hardness studies (Martic*et al*, 1987). The static coefficient of friction is used to determine the angle at which chutes must be positioned to achieve consistent flow of materials through the chute. Such information is useful in sizing motor requirements for grain transportation and handling (Ghasemi,2008). Other researchers have determined the properties of different types of grains and seeds (Liuand Pyzyblski,1996).

Rice Quality can be defined as the combined features and characteristics of a rice product or service to satisfy stated or implied needs (Kokken and PRPC, 2003). Grain quality is a combination of many factors such as smell (aroma), size, cooking characteristics, color, nutritional value and percent whole grains. It is the standard of agricultural products which gives buyers the opportunity to purchase exactly what they want to buy (U S Grains, 2016). The quality of rice is not always easy to define as it depends on the consumer and the intended end use of the grain (Kokken and PRPC, 2003*).* All consumers want the best quality product that they can afford to buy. The demand from the consumer for better quality rice has increased. Recently the trend has changed to incorporate preferred quality characteristics that increase the total economic value of rice (Alizadeh, 2006). Grain quality is not just dependent on the variety of rice, but the quality also depends on the crop production environment, harvesting, processing and milling systems (African Rice Initiative, 2009).The quality characteristics of paddy and milled rice can be considered separately (Fruichi, 2011). These properties are playing an important role in rice quality, marketing and exporting. Rice quality is a combination of physical, mechanical and chemical characteristics which are required for a specific use by a specific user.

Since grain property variation is wide, especially when considering variety difference, rice cannot be considered to have uniform properties. Moreover, the moisture content of the paddy decreases from 22 to 8% during harvesting to milling process. Differences in grain moisture content can result in a significant variation in the processing characteristics of the grain.

1.2 Statement of the Problem

Quality of grain is of great importance for human beings as it directly impacts the human health and commercial activities. Hence there is a need to measure the quality of grain and identify adulteration/non-quality elements. Grain quality can have different meaning to different people depending upon the type of grain or seed and its intended use. Several imp-ortant factors affect grain quality, including phenotypic expression, environment, drying systems, storage management practices, processing and transportation procedures (NRDS, 2019).

Nigeria has high potential to produce rice for its domestic and export purposes, but lack of good quality rice made Nigeria to import rice for over Two hundred and fifty four billion naira (#254B) in 2006 with a mark increase of over One Trillion Naira in 2015 (NRDS, 2019). These problems rendered Nigeria to spend for what is meant to fix some highly needed infrastructures. These consequences of rice importations from Thailand and other developing countries also affect negatively the employment opportunities for the Nigerian youths and women. There is strong need for Nigeria as giant of Africa with all the potential it has to stop importing rice from countries like Thailand which has less potential in terms of cultivable land and labour force.

From my interview with the rice farmers, millers, agro-dealers and rice consumers it was found that Nigerians do not like Nigerian domestic rice due to presence of stones, chaff, bad appearances, lack of uniform sizes, high percentage of broken rice, short grains, insects and pest damages, poor soaking and parboiling systems, lack of awareness, poor or lack of value addition, poor branding and packaging and stickness.

The moisture content, discoloured grain, pest damaged grains, organic and inorganic foreign matters, Admixtures and Immature/shriveled grains affects the quality of paddy (SON *et al*, 2018).

While the organic and inorganic (stones and others), colour and percentage broken, milling recovery and head rice ratio affects the quality of the milled rice (RIPMAPP, 2017))

Physical and mechanical properties are important in many problems associated with the design of machines and the analysis of the behaviour of the product during agricultural process operations such as handling, planting, harvesting, threshing, cleaning, sorting and drying. Solutions to problems in processes such as handling, cleaning, sorting and drying involve knowledge of their physical and mechanical properties (Bal and Mishra, 2016). Principal axial dimension of paddy grains are useful in selecting sieve separators and in calculating power during rice milling process. They can also be used to calculate surface areas and volume of kernels which are important during modeling of grain, drying, aeration, heating and cooling, head rice yield, etc.

Lack of data for the variables and responses to developed the technical and strategies for the achievement of good quality processed rice has necessitated that studies.

Attempts were done by many researchers in this aspect, but were not able to use Jamila Paddy rice variety and faro 44 paddy rice variety grown at this specified environment (Kura environment) for the analysis. Also others were not able to capture other properties. But this research is different from others as it captured andanalyz the physical, mechanical and quality properties at different change in moisture content of 16%, 14% and 12% respectively.

1.3 Aim and Objectives of the Study

The aim of the study was to investigate the effects of moisture content on some physical, mechanical and quality properties of two paddy rice (*oryza sativa L.*) varieties in Nigeria.

The objectives of the study are to:

i) determine the effect of moisture content on selected physical properties (bulk density, angle of repose and geometric mean diameter) of Faro 44 and Jamila paddy rice varieties.

ii) determine the effect of moisture content on selected mechanical properties (grain hardness and rupture force) of Faro 44 and Jamila paddy rice varieties.

iii) determine the effect of moisture content on selected milled rice quality (milling recovery and head rice ratio) of Faro 44 and Jamila paddy rice varieties.

1.4 Justification of the Study

The determination and study of the properties of paddy rice provide data that will help to design and construct equipment for production and processing of paddy rice. The data can be use to reduce seed damage during threshing and processing, thereby improving the efficiency of threshing and milling. The information on the properties of the paddy rice seeds will enhance the knowledge and method of handling the seeds during processing and storage. The information also can be use to improve the efficiency and effectiveness of existing equipment to meet the demand for the International competition for exports and income diversification. Thereby, to design equipment for the handling, separation, drying, storing, aeration and processing of paddy/rice grains, determine the properties of paddy rice as a function of moisture content is essential.

Good quality rice depends on good, effective and efficient machines as well as Good Agricultural Practices (GAP) and good post harvest handling (Kodama, 2013).

When the physical and mechanical properties are studied, it will enable to determine the best quality rice from the locally produced paddy rice. It can also give room to classify rice for different purposes.

The survey carried out by USAID/WARDA revealed that rice consumers in Nigeria are ready to pay for quality (SON et, al., 2018). Therefore this studies in properties and qualities of paddy/rice would provide information that can serve as a basic for intervention of government policy makers, non governmental organization (NGO) and donor agencies. Thus, developing the enterprises thereby raising the competitiveness of local rice, improving the living standard of processing population and ultimately enlarge the size of Nigeria rice economy. Improvement of good quality rice will also increases Employment opportunities and also reduce poverty. It will also reduce smuggling activities and consequently increase customs duty which can be use in fixing many important infrastructures to the Citizens.

This study would provide the necessary input/information to reduce higher percentage of post harvest losses and to improve on domestic rice production in Nigeria..

These are necessary for the design of equipment to effectively handle transport, processing and storage for the crop. Physical and engineering properties are important in many problems associated with the design of machines and the analyses of the behaviour of the product during agricultural process operations such as handling, planting, harvesting, threshing, cleaning, sorting and drying. Solutions to problems in these processes involve knowledge of their physical and engineering properties (Irta, 2002). Principal axial dimension of paddy grains are useful in selecting sieve separators and in calculating power during rice milling process. They can also be used to calculate surface areas and volume of kernels which are important during modeling of grain drying, aeration, heating and cooling, etc.

It usually takes a lot of time and money to access the Paddy Rice testing/grading equipment in the developing countries, however those equipment used were provided by Japan International Cooperation Agency (JICA) to the Nigerian government as a special grant but no patronage on the use of the equipment as complaint by JICA. Therefore these research may be use to collaborate with JICA on more technical knowhow.

1.7 Scope of the Study

The present work analyzed the effects of change in moisture content on some selected physical, mechanical and quality properties of some selected paddy rice varieties.

The scope could be summarized as follows:

i) Two selected paddy varieties were analysed at 3 different levels of moisture content.

ii) Two levels of quality properties (Milling Recovery and Head Rice Ratio) were used and three selected physical properties (Bulk Density, Angle of Repose and

Geometrical Mean Diameter), two mechanical properties (Grains Hardness and Rupture Force) and using three replications each.

CHAPTER TWO

LITERATURE REVIEW

2.1 Physical and Mechanical Properties of Rice

After harvest, agro raw materials are normally handled, transported, dried, stored and further processed into food, feed and fibre (Agu and Oluka, 2012). In some basic post harvest activities, separation processes such as sorting, grading and cleaning are involved.(Agu and Oluka, 2012).

In mechanized operations, these post harvest processes are supposed to be carried out with machines and equipments (Agu and Oluka, 2012). The engineering design and efficient operation of the post harvest processing machines and equipment require adequate knowledge of engineering properties of bio-materials to be handled (Isaac et al, 2016). Knowledge of engineering properties such as physical and mechanical properties constitute important and essential engineering data in the design of machines: storage structures; processes and controls as well as in the analysis and determination of the efficiency of machines, development of new consumer products of plants and animal origins and in the evaluation of the quality of food products (Mohsenin, 1980).

Lowland rice accounts for 50% of the total rice produced in Nigeria. In recent years, West African Development Agency (WARDA) has introduced several rice varieties, together with efficient natural resource/crop management and disease management technologies to rice farmers in Nigeria and other West and Central African countries. Typical examples are high yielding rice varieties: FARO 44 (SIPI), FARO 51 (CISADANE), FARO 52(WITA 4), FARO 57 (TOX 40043-1-2-1), and the lowland varieties of Jamila and New Rice for Africa (NERICA) that are currently being evaluated in several parts of Nigeria prior to full release.

The majority of these introduced technologies have been accepted and become widespread in some states of Nigeria.

Faro 44, which is one of the many lowland cultivars developed, is recently one of the most distributed rice varieties in the Nigerian rice sector. It is an improved local semi-dwarf cultivar of rice grown in Nigeria. It has high yielding ability, but also need much fertilizer. It also has life span of 110 to 120 days depending on the Agronomic practice applied.

Jamila Rice, which is one of the many locally grown uplands cultivars developed, is usually found in Kura Area of Kano state in Nigeria. It has less time for harvesting than Faro 44 (i.e 100 days). It however needs less fertilizer than Faro 44 (SIPI). It has high stand which usually makes it to fall down by wind. But the milled product is highly marketable than SIPI as it has very long grains and the color is highly appreciable by consumers.

YarIrga, popularly known as Dan Gote because it was initially provided by Dan Gote Group of Company. It is one of the locally grown lowland cultivars developed, is also usually found in Kura area of Kano state Nigeria. It resemble SIPI but has longer harvesting time (120-130 days) than SIPI. It also has higher milling recovery rate and longer grains than Faro 44 (SIPI).

Information on the physical and mechanical properties of agricultural products is an important tool for designing equipment for the purpose of planting, harvesting, de hulling, drying, grading, handling as well as storing (Hakan*et al*, 2014). Therefore, seed dimensions (width, thickness and length), 1000 seed mass (M_{1000}), surface area, porosity, sphericity, static coefficient of friction against different materials, repose angle, hardness, true and bulk densities are among the properties that are considered “physical” by researchers as per seed (Bande*et al.,* 2012). These variables are central in classification of seeds and in the design of machines for processing or analyzing the behaviour of the product in handling or grading

(Mohsenin, 1980). They are central because they give technical information to the designer on what are the basic “inputs” for their design.

All physical properties of seeds are dependent on the moisture content. They respond either in increasing or decreasing trend as the moisture content varies. The initial moisture content is determined by subjecting seeds to oven drying (either air or vacuum) at temperatures between $80^{o}C$ to $130^{o}C$ for 8hrs to 24hrs by ASAE Standards (S.352.3, 1994).

Using the knowledge of grains bulk density, true density and porosity can be useful in sizing hoppers and storage facilities: they can affect the rate of heat and mass transfer of moisture during the aeration and drying processes. A grain bed with low porosity will have greater resistance to water vapour escape during the drying process which may lead to the need for higher power to drive the aeration fans. Cereal-grain kernel densities have been of interest in breakage susceptibility and hardness studies (Heidarbeigi*et al*, 2009). The static coefficient of friction is used to determine the angle at which chutes must be positioned to achieve consistent flow of materials through the chute. Such information is useful in sizing motor requirements for grain transportation and handling (Ghasemi, 2008). Other researchers have determined the properties of different types of grains and seeds.

Many studies have reported on the physical, chemical and mechanical properties of wheat husks, rice husks and soft wood and their poly propylene composites (Oladunmoye*et al* 2010); rheological properties of dough and sensorial quality of bread made from a whole meal rice wheat blend with the addition of gluten (bande*et al*, 2012); and rheological properties of rice mash prepared by pressure less liberation of starch in mashing and fermentation (Lampe, 1995).

Bulk density, true density and porosity (the ratio of inter granular space to the total space occupied by the grain) can be useful in sizing grain hopper and storage facilities: They can affect the rate of heat and mass transfer of moisture during aeration and drying processes. Grain bed with low porosity will have greater resistance to water vapor escape during the drying process, which may lead to higher power to drive the aeration fans. Cereal grain kernel densities have been of interest in breakage susceptibility and hardness studies (Ghasemi, 2008).

Flow ability of agricultural grains is usually measured using the angle of repose. This is a measure of the internal friction between grains and can be useful in hopper design, since the hopper walls inclination angle should be greater than angle of repose to ensure the continuous flow of materials by gravity.

2.2 Rice Quality

Rice quality can be defined as the totality of features and characteristics of a rice that bears on its ability to satisfy stated or implied needs. The significance of measurement of grain quality has been felt since way back to a century old. Cereal grains play an imperative role in meeting the nutrient needs of the human population. Like any food, they are good to excellent sources of some nutrients and low or void other nutrients. Though tedious, but it is very important to measure the individual kernels qualitative analysis. Analysing the grain sample manually is more time consuming and complicated process, and having more chances of errors with the subjectivity of human perception. In order to achieve uniform standard quality and precision, machine based techniques are evolved (Liu *et al,* 2015), solely on its prime advantage of reproducing the same qualitative result efficiency again and again. Recent developments in the field of image processing have opened up a wide scope of its use for sample analysis tool

(Houston, 1972) characterization and identification of rice grains through digital image analysis. Various applications in image processing are recorded in the field of agriculture, biomedical engineering, food and drug industry and many others. Food application mainly caters the qualitative aspect of various food and dairy producers. Image processing techniques were developed to classify plants and background pixels in images of rice plants acquired in a field experiment.

So forth, measurement of grain quality and cereal research with commodity crop such as rice, wheat, barley, corn, maize (Ananthi, 2015) is wide research areas nowadays. Rice is one of the leading food crops of the world and is produced in all continents. Rice is comparatively high in caloric value and rice protein has a good balance of the essential amino acids, historically and now through planned breeding. Each grain type is associated with specific milling, cooking and processing characteristics. There are a number of varieties of each grain type in commercial production and new ones are continually in the process of being developed and released (Danbaba*et al*, 2020).

Techniques are evolved to measure grain samples quality based on it: samples can be classified in terms of productivity and price. Sample quality has also proven its significance in cereal breeding.

2.2.1 The Significance of rice as a commercial product

Rice is one of the three (3) major grains of the world. In Asia, where most of it is grown, it is eaten principally as a staple in order to supply nutrition and energy. However, as increasing income gives people more choice of food, people are no longer satisfied merely with nutrition and energy but demand “good taste”, and “pleasant to eat” so that the rice will serve as a means of communication. Quality becomes an important criterion for food selection (Kokken and PRPC, 2003)

2.2.2 Consumers demands on rice

Demands that consumers make concerning rice can be classified into two categories. One is securing a stable supply of an adequate amount to supply nutrition and energy; the other, from the economically affluent class of consumers, is securing good taste and high quality (Kokken and PRPC, 2003)

i) People in the low income class always want low price rice and are not able to be fussy about quality. People in this class are mainly concerned about quantity, but there is a limit to their purchasing power. When the price increases, they compensate by buying less, so the price tends to stabilize at a low level.

ii) The class of consumers with income above a certain level demands rice that will meet a complex of requirements centering on “good taste”, “safety” and “convenience”. It can be expected that these consumers will be more interested in quality than in price.

In particular, it is expected that interest in the safety of rice will increase, especially among the upper income class.

2.3 Classification of Parameters

Classification parameters vary based on consumer preferences. Grain quality depends on individual kernel features. Kernels features can be measured by either compositional analysis or structural analysis.

Compositional analysis is useful for measuring internal aspects of the kernel such as oil, moisture, protein, fatty acid and amino acid. The quantitative models are useful for measurement. For compositional analysis generally, near-infrared (NIR) technologies and chemical analysis based technologies are preferred. Some expensive and time consuming biological DNA methods are also used for the analysis of rice quality. NIR technologies are used for detection of protein, fat, starch and water in the rice (Alizadeh, 2006). The research was carried out to check sugar, fructose and glucose level in fruit using NIR technology (Bellon, 1994).Infrared and near-infrared technology for the food industry and agricultural uses: on line applications, (Ahmad *et al*, 2012). With this study structural analysis is considered for quality analysis.

The structural analysis focuses on the outer part analysis. The structural analysis covers the visualization aspect like measurement of size (length, width and height), color and glossiness (Liu *et al.*, 2015). Structural analysis is done either by manual sorting or image-based analysis. Detailed measurement of seed shape characteristics such as length and width traditionally depends on laborious techniques such as manual measurement of individual seeds. Manual analysis is done either by naked eyes or using measuring instruments (Ahmad *et al*, 2012). In the manual measurements, the quality of measurement depends on analysers experience/skills and the end results are more in numbers.

If the sample is analysed by two different analysers then there is a chance of variation in quality results. Only few attributes of quality parameter can be measured by observation of the grain sample. Broken kernel's examination can be made up to some extent with manual analysis. With this approach, only average parameters of grain sample can be measured, as it is not possible to individually identify and memorize the quality parameters of each individual kernels. For measuring the individual kernel's parameters, the image analysis techniques have proven as a very effective solution. As compared to sample analysis by visual observation, the instrument measurement has more accurate results. While measuring length or width of seed using vernier calipers or micrometer screw, if more pressure is applied; the edge of the seed gets damaged (Ramon *et al*, 2019).

Chemical analysis is also used for measuring grain quality sample. With this approach, for grain sample seeds undergo the chemical process as a part of sample preparation. After passing through a chemical process the actual parameters of the grain sample may alter. Due to this same, the same sample cannot be used again to check the repeatability of the analysis results. Non-destructive quality evaluation of food products is an important and very vital factor in food/agricultural industry (Naik*et al*, 2016). Alternative to this approach, image analysis techniques (Naik*et al*, 2016) is useful and effective solution for structural analysis.

2.4 Grain Quality

Quality can be defined as the combined features and characteristics of a product or service to satisfy stated or implied needs (Kokken and PRPC, 2003). Grain quality is a combination of many factors such as smell (aroma), size, cooking characteristics, colour, nutritional value and percentage whole grains.

It is the standard of agricultural products which gives buyers the opportunity to purchase exactly what they want (US Grains 2016). The quality of rice is not always easy to define as it depends on the consumer and the intended end use of the grain. All consumers want the best quality product that they can afford. The demand from the consumer for better quality rice has increased. Recently the trend has changed to incorporate preferred quality characteristics that increase the total economic value of rice. Grain quality is not just dependent on the variety of rice, but the quality also depends on the crop production environment, harvesting, processing and milling systems. The quality characteristics of paddy and milled rice can be considered separately. These properties are playing an important role in rice quality, Marketing and exporting. Rice quality is a combination of physical and chemical characteristics which are required for a specific use by a specific user (Philip, 2013). The Milling Recovery (MR) and the Head Rice Ratio (HRR) are very important parameters that can be used in determining quality of rice. That is because it symbolizes the actual rates of breakages which is very important in rice marketing and acceptability by consumers.

2.5 Importance of Grain Quality

Quality of grain is of great importance for human beings as it directly impacts the human health. Hence there is a great need to measure a quality of grain and identifying adulteration/non-quality elements. Grain quality can have different meaning to different people depending upon the type of grain or seed and its intended use. Several important factors affect grain quality, including phenotypic expression, environmental conditions, harvesting and handling equipment, drying systems, storage management practices and transportation procedures (Dubale, 2014).

Whole grains are rich sources of vitamins, minerals and dietary fiber all of which may have individual synergistic or additive actions that positively affect health. In addition, whole grains photochemical complement the physiochemical in fruits and vegetables when they are consumed together. So it is mandated to identify the size of the kernel in grain sample (Nestor *et al*, 2016).

Lower quality grain in daily food can cause serious diseases e.g. Kwashiorkor. Sometimes the lower quality grain is mixed with good quality grain to get a higher price. The product made from this kind of mixture can lead to poor quality foods. This kind of adulteration must be identified while the selection of the grain.

Consumer preferences (e. g. a preference for a certain smell or colour of grain) affect what people buy and so affect market prices. Therefore it requires different kind of grain analyzer which can provide analyses to satisfy the market needs (Philip, 2013).

2.6 Conventional Techniques of Rice Grains Measurement

Grain shape is evaluated with length, width and the ratio of length and width of rice grains. At present the length and width of rice grains are usually measured by an inspector using a ruler or a micrometer. For measuring quality of grain sample, examiner needs to get few seeds from sample and do the analysis. But for measuring length and width of even few seeds, by placing them in one grain tray and measure the length and width of each seed one by one is very tedious task and takes lots of time (Kodama, 2013).

Rice chalkiness is also estimated by the naked eyes of an inspector. Outcomes from different inspectors may vary at an unacceptable range. So it is a neither objective nor efficient way in evaluating rice appearance quality relying upon manual method (Danbaba*et al*, 2020)..

A new scientific era has emerged with great grain quality image processing instruments which can help in the categorization of grain samples and get attractive price from consumers for the food industry, especially in Asia. Machine vision and image processing are widely used in biological and agricultural research with the improvement of computer technology and significant reduction of the cost of hardware and software of digital imaging. Many researches applied machine vision to estimate rice appearance quality inspection. There are various food varieties like rice, wheat, potato, soya bean and maize. The rice and wheat being commodity crops are important among all the grains (Sarah *et al*, 1998).

These researches provided some new ideas and image processing methods for evaluating rice appearance quality. The effectiveness and accuracy of inspections have been improved through these methods. But some factors might affect the outcomes of inspection for rice appearance quality using machine vision and still remains unsolved. For example, the inspection environment, light source, Image processing method could result in an inconsistent and low accuracy of inspecting outcomes. With this research, new valuation system is developed for inspecting the rice appearance quality based on machine vision. With this work new sample preparation technique is introduced and colour calibration mechanism is provided to deal with different standards defined by various organizations. Web based implementation is provided to use this system globally. The developed system is non-destructive and is an alternate to human visual assessment (Ahmad *et al,* 2012).

2.7 Primary and Secondary Quality of Rice

The quality of rice consists of both the primary quality and the secondary quality (Kokken and PRPC, 2003). Primary quality consists of those items on which grain is generally inspected at a drying facility such as cracking rate, moisture content and test weight. That is to say, characteristics of the form of the rice make up its primary quality. Secondary quality consists of those characteristics related to the storage and processing of grain that are demanded by the consumer. The taste of the rice belongs to this category. In addition, characteristics which come into question in a rice milling plant, such as the ease of milling and the storability of the grain, come into secondary quality (Bellon, 1994).

It cannot necessarily be said that rice that is of good primary quality will be of good secondary quality and that rice of poor primary quality will be of poor secondary quality, but it is certainly true that there is a close connection between them (RIPMAPP, 2017).

2.8 Taste as an Example of a Quality Characteristics that is Difficult to Judge

Around the world, when one thinks of the quality of rice, if the measurement methods for cracking during drying, moisture content, scratching and bruising of skin during husking, fatty acids that change in storage and so on are determined, there is no particular problem. However, the matter is not necessarily so simple as regards taste, which is affected by all of the processing conditions to which the rice is subjected after harvesting. There is a problem in determining whether the taste is good or not. Even if a worldwide uniform testing method for taste were established, it would be difficult to determine a yardstick by which to judge whether the taste is good or not (Kokken and PRPC, 2003). The people of Japan, Korea and Egypt as those in Nigeria tend to like japonica rice with its sticky consistency. People of other countries prefer indica rice which is not so sticky (Kokken and PRPC, 2003). Even within the same country there can be differences. In China, the people of northern China, including the yellow River region, like japonica rice, while the people of southern China prefer indica rice. There are also differences by region within India. The Japanese do not like rice that has an odour, but some people like rice that has an aroma, such as the Basmati rice of India and the Jasmine rice of Thailand. People in some countries such as Bangladesh, Nigeria and Sri Lanka like parboiled rice, which is a semi-processed rice. In some countries, such as America and Brazil, there are people who regard parboiled rice as being nutritionally preferable. Thus, preferences regarding the taste of rice are not uniform world-wide, and it is difficult to use taste as a criterion in judging the quality of rice (Davies, 2010).

According to the results of tests in Japan, as shown in Figure 2.1, there is a correlation between taste and germination rate. If the germination rate is high, it means that the rice in question is really alive; the natural characteristics of that rice have not been lost. Also, the increase in fatty acid content that occurs during storage represents a change in rice quality, and can be used to evaluate the post-harvest processing used for that rice. However, since as mentioned above, there are people who prefer semi-processed rice as parboiled rice, and there are some people who prefer aged rice to fresh rice, it cannot be stated flatly that there should not be any change in the quality. This point is in fact a problem in evaluating the post-harvest processing techniques (Amin *et al*, 2004)

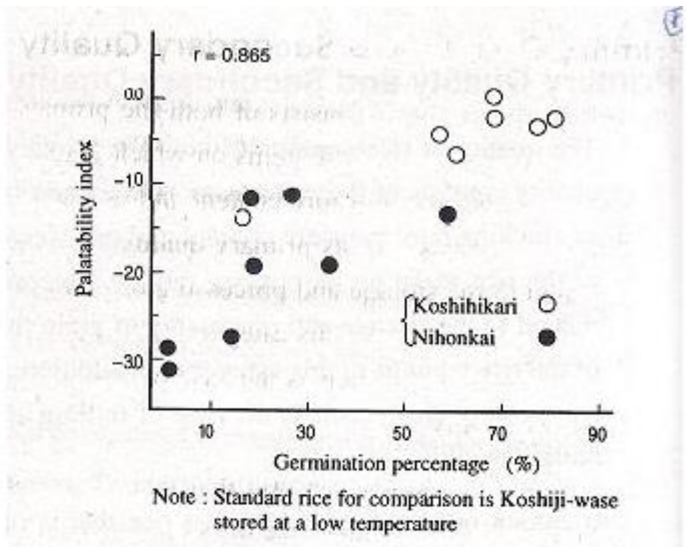


Figure 2.1: Palatability and Germination Percentageof Paddy Rice

Source: Kokken and PRPC, 2003.

2.9 Drying and Quality of Rice

When cracking occurs in brown rice, not only do more broken form in milling reducing the yield, as shown in Figure 2.2, but in addition rice with many broken seeds does not appeal to the Nigerians. Also in Malaysia, when there are many broken seeds the rice becomes sticky, which does not appeal to the local people (RIPMAPP, 2017). Even if cracked grains do not break in milling, it is possible that rice grains will crack when the rice is soaked in water for cooking, degrading the taste. Since cracking is thus highly related to the yield and quality of rice, in inspections in Japan cracked rice is classified as damaged rice (Kodama, 2013). Cracking that occurs during the drying of rice is classified as either slight cracking or severe cracking. Slight cracking is cracking that will not cause the rice to be classified as damaged under Japanese inspection standards. Severe cracking that will cause the rice to be classified as damaged, and means that at least one crack goes all the way around the grain.

When drying is severe the rice grain can become hard-shelled forming honey-comb-pattern fissures and may break into pieces and disfigured. Rice that is both slightly cracked and severely cracked together is referred to as total cracked rice (SON *et al*, 2018)

Cracking is believed to be caused by a variety of changes that occur in rice grains during drying and storage, with the principal cause being the difference in moisture content between the surface and interior of grains that develops during drying. The cracking mechanism is believed to be as follows. When grains dry, they dry from the outside in. When any object dries, it shrinks. At this time, shrinking of the surface produces a compression force that acts on the interior. However, the interior, that is to say the embryo section, is strongly resistant to the pressure and does not crack. After the drying is completed, when the rice is placed toward the surface with its low moisture content; this causes the interior to shrink somewhat while the surface swells, applying tension to the interior. The interior is weak to tension and cracks.

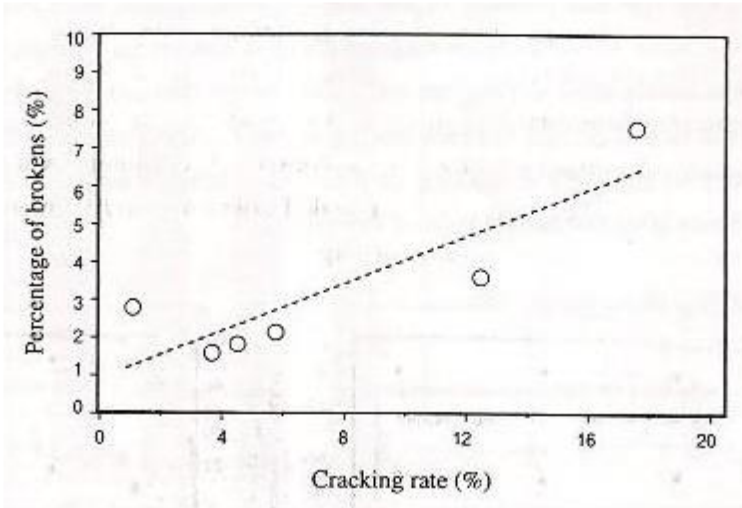


Figure 2.2: Cracking Rate of Brown Rice and Percentage of Broken Rice During Milling

Source: Kokken and PRPC, 2003.

Figure 2.3 shows the relation between storage temperature and amount of cracking. It shows that even if there is little cracking at the completion of drying, cracking rapidly increases within 10 hours more or less independent of the storage temperature, then more slowly until 24 hours after drying;

After 48 hours have elapsed there is almost no change. When cracking is measured immediately after drying, an erroneous result that cracking does not occur is obtained although the rice is certain to crack during storage. Accordingly, when measuring cracking it is necessary to store the dried rice in a sealed container and then measure the cracking 48 hours or more after the completion of drying (Kokken and PRPC, 2003)

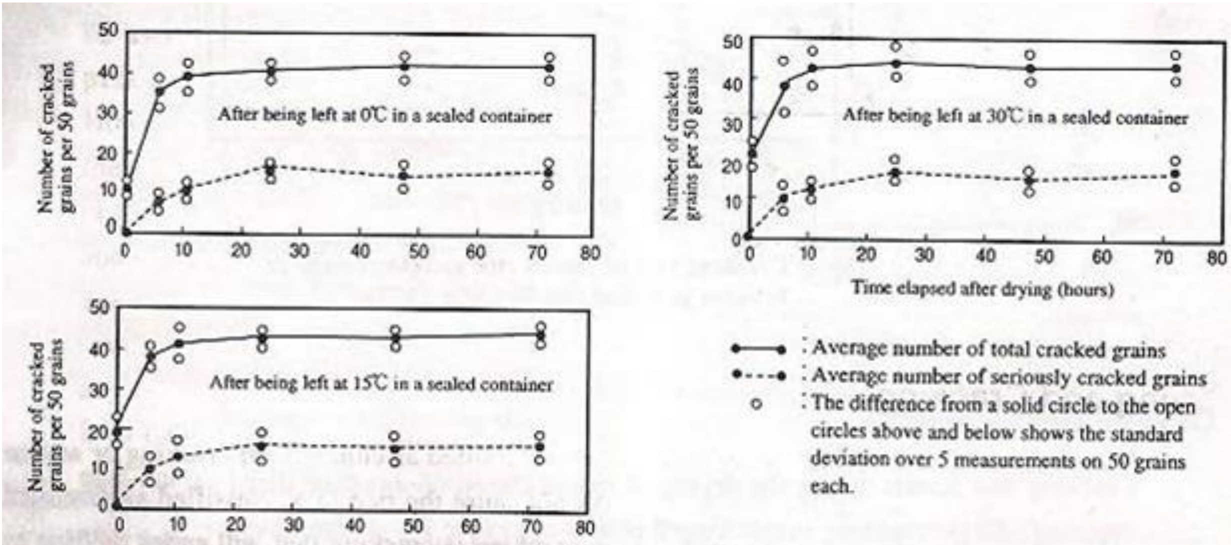


Figure 2.3: Storage Temperature after Drying and Increase of Cracked Grains.

Source: Kokken and PRPC, 2003.

2.10 Head Rice Yield

In Japan as well as in Nigeria when one speaks of change in quality due to drying the first thing that is brought into question is cracking. In many countries including Nigeria trading is done in rough rice or milled rice so it is the head rice yield that is the head rice after milling (the proportion of milled head rice obtained to the amount of rough rice, by weight) that is important. Cracked grains easily become broken in milling, so there is a relation between the two.

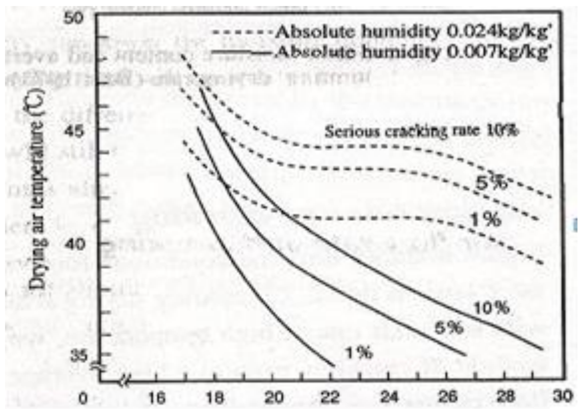
2.11 Natural Drying and Artificial Drying

Rice is dried artificially in some countries, including Japan, the United States, Malaysia, South Korea and Brazil, but worldwide natural drying is more common. However, in regions such as Southeast Asia where double cropping is done per year, harvesting is carried out during the rainy season. In such a case, artificial drying becomes necessary to reduce losses and improve quality (Kodama, 2013).

2.12 Drying Conditions and Cracking

The condition that is most highly related to the amount of cracking is the drying rate. In general, the higher the air temperature the greater the drying rate. As shown in Figure 2.4

In order to hold the amount of cracking below a certain level, the higher the initial moisture content the lower the ventilation air temperature must be held. In addition the lower the absolute humidity of air, the lower the ventilation air temperature must be held.



Initial moisture content (%)

Figure 2.4 Initial Moisture Content and Limiting Drying Air Temperature of Paddy Rice

Source: Kokken and PRPC, 2003

Figure 2.5 shows the relation between the initial moisture content and the limiting average drying rate. The limit of the average age drying rate when the increase in the cracking rate after drying is held to a certain level increases dramatically when the initial moisture content is 18 to 20% or less. This trend increases with lower absolute humidity of the drying air; this limit of the average drying rate becomes fairly large compared with the case in which the absolute humidity of the drying air is high. In addition, when the absolute humidity is low then even with an initial moisture content of 20% or higher the higher the moisture content the lower the limiting average drying rate tends to be, but when the absolute humidity is high the initial moisture content has little effect and this limit of the average drying rate is approximately constant (Kokken and PRPC, 2003).

In drying of a thick layer, when the initial moisture content is 24 or higher there is danger that cracking will become greater than in the case of a thin layer. It can also be seen from Figure 2.6 that when the initial moisture content is low then the drying air temperature can be made higher. The air temperature for drying that will not reduce the germination rate of grains is about 40^{o}C.

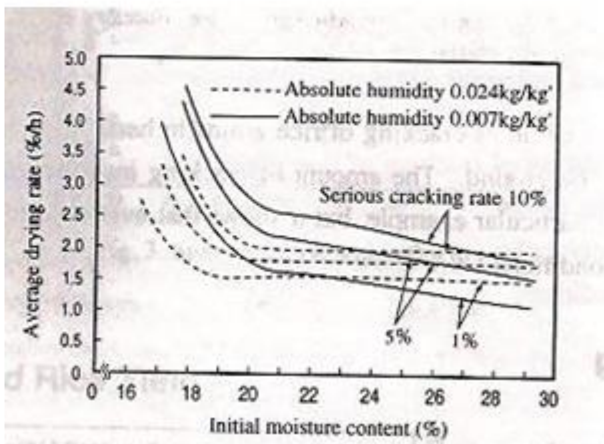


Figure 2.5: Initial Moisture Content and Average Limiting Drying Rate of Paddy Rice

Source: Kokken and PRPC, 2003

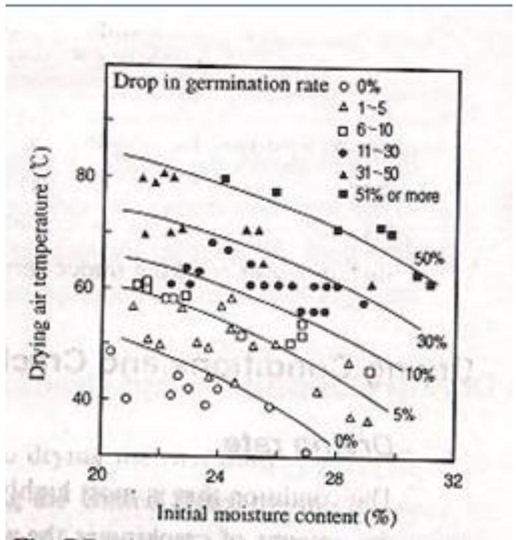


Figure 2.6: Drying Conditions in a Circulating Batch and Germination Rate.

Source: Kokken and PRPC, 2003

2.13 Quality of Rice and Skill of Paddy/Rice Quality Test

When talking about the quality of rice and the characteristics of parboiled and un-parboiled rice, it should be understood how they are quantified and measured. Methods for measuring Paddy quality and parboiled and un-parboiled rice characteristics through the use of standard test instruments are introduced in this research, and a practice test measurement is performed. In general, the quality and characteristics of rice are expressed in terms of moisture content (%), milling recovery (%), head rice recovery (%), head rice ratio (%), broken rice ratio (%), damaged grain, foreign matter, the ratio of discoloured grain (%), whiteness (%), and grain hardness (kgf or N) (Furuichi, 2011).

2.13.1 Definition and calculation of parameters

2.13.2 Moisture content (%, w.b.)

Moisture content is the proportion of water mass contained in grains to the total mass of the grains. It was found that for most of the Nigerian local varieties a good processing outcome is at the moisture content range of 12% to 14%. It is expressed as a percentage of the wet weight (wet base); therefore, the units are sometimes written as '% w.b.(Furuichi, 2011)

Moisture content (%, w.b) = $\frac{\text{weight of grain} - \text{weight of dry matter in grain}}{\text{weight of grain}}$ x 100 (%) (2.1)

2.13.3 Milling recovery (%)

Milling recovery is the proportion of the weight of milled rice to the weight of paddy rice, written as a percentage. (Furuichi, 2011)

Milling Recovery = $\frac{\text{Weight of milled rice}}{\text{Weight of paddy}}$ x 100 (%) (2.2)

2.13.4 Head rice recovery (%)

Head rice is a rice grain that is longer than 3/4 of the total length of a whole grain, as shown in Figure 2.7. Head rice recovery is the proportion of head rice weight to weight of paddy, as a percentage (%)

Head Rice Recovery = (Weight of head rice/Weight of paddy) x 100 (%) (Furichi, 2011) (2.3)

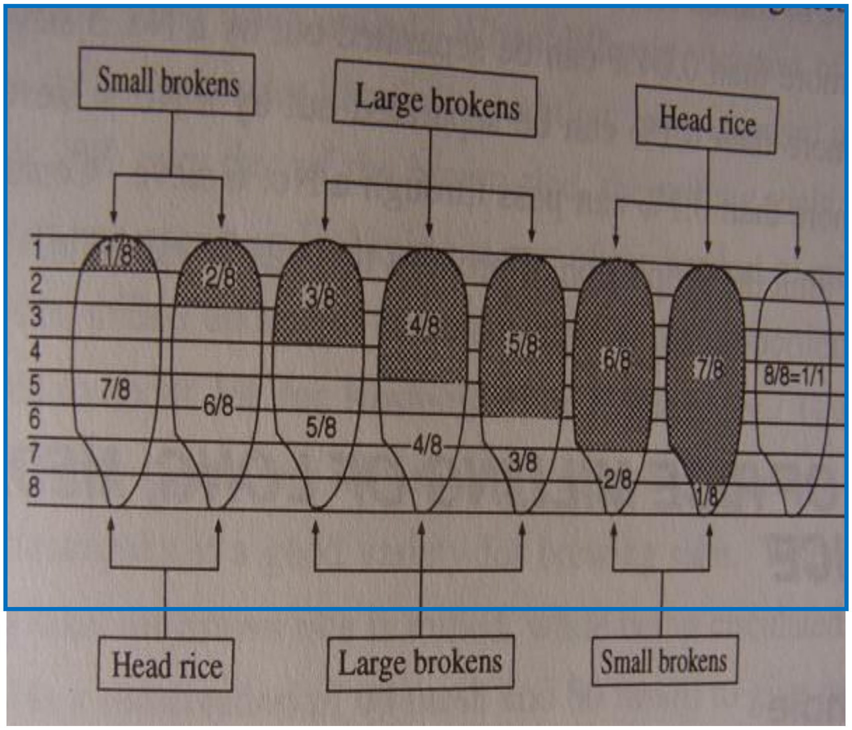


Figure 2.7 Head and Broken Rice (Kokken and PRPG, 2003)

2.13.5 Head rice ratio (%)

The head rice ratio is the proportion of head rice weight to the weight of milled rice. Head rice yield which is the mass percentage of paddy that remains as head rice. Head rice is ¾ or more of the whole milled kernels separated from the total milled rice (Alizadeh, 2006)

Head Rice Ratio = $\frac{Weight\ of\ Head\ Rice}{Weight\ of\ Milled\ Rice}$ x 100 (%) (Furuichi, 2011) (2.4)

2.13.6 Broken rice ratio (%)

Broken rice is a piece of milled rice grain whose length is less than 3/4 of the total length of a whole grain, as shown in Figure 2.7. The broken rice ratio is the proportion of broken rice weight to milled rice weight.(Furuichi, 2011)

Broken Rice Ratio = $\frac{Weight\ of\ broken\ rice}{weight\ of\ milled\ rice}$ x 100 (%) (2.5)

2.13.7 Damaged grain, foreign matter, and discolored grain ratio (%)

Damaged grain is grain that has been damaged by insects or disease, resulting in low starch content. Damaged grain is sometimes discolored. Foreign matter is any material that is not rice grains, including stones, chaff, sand, and metal. (Furuichi, 2011)

$$\text{Damaged and others} = \frac{\text{Wt. Damaged grain,foreign matter \& discoloured grain}}{\text{weight of milled rice}} \text{x100} \qquad (2.6)$$

2.13.8 Whiteness (%)

Whiteness is the degree of whiteness of milled rice, with 100% indicating a pure white color. The color of milled rice is compared with a standard white color (100%) using a special instrument called a whiteness tester.

2.13.9 Grain hardness (N)

Grain hardness is the amount of force required to cause a crack inside brown rice, when applied vertically to the belly part of a grain. It is also called 'yielding point' and is expressed in 'kgf' or 'N (newton)'. 1 kgf = 9.8 N

2.13.10 Grain rupture force (N)

Rupture-Force is the force that is required to produce a major break/rupture in a sample. It is related to burst force which is the force to come a part suddenly and violently in to pieces. Developed seed coat cracks at lower levels of force when it was loaded with the hilum horizontal. The interaction effects of the grain variety and loading rate showed that the grain rupture force decreased from 79.6 to 73.6 of N and 67.68 to 55.01N at loading rates of 5 and 10mm/min, respectively for Alikazemi and Hashemisvarieties. Mohsenin*et al* (1980) found that the rate of deformation affected the maximum force that could be exerted by a steel punger on applied force.

2.14 Paddy Rough (Rice) Specification

In addition to achieving self-sufficiency in rice production the production of good quality rice is very important. In order to achieve this, the Standard Organization of Nigeria (SON) developed the paddy (Rough) Rice Specification for stakeholders, such as farmers, millers and traders for the determination of paddy rice quality.

Another objective for the development of the specification was for the harmonization of existing paddy rice testing methods utilized by various integrated rice mills.

Rough rice may be graded into three grades on the basis of the tolerable limits established by the SON, (Kodama, 2013)

2.14.1 Paddy quality/work flow documentation

Paddy quality can be checked using the methods described in the paddy grading and paddy quality manuals established by Federal Ministry of Agriculture and Rural Development (FMARD) in collaboration with Japan International Cooperation Agency (JICA) and Standard Organization of Nigeria (SON). (Kodama, 2013)

Since paddy grading can be conducted only in the grading laboratories of mills with a set of equipment, the paddy checking method was developed for farmers, extension agents and buying agents to check their paddy with a set of less expensive equipment so that they can verify the grade prescribed by mills. Farmers can also conduct the simple checking for finding out what they have to do. In order to improve their cultivation and /or post-harvest activities.Kodama, 2013).

2.14.2 Paddy rice grading standard

Federal Government of Nigeria is desirous to achieve its goal of self-sufficiency in rice production and these replace imported rice with locally produced rice by 2018. Mills need sufficient amount of quality paddy for processing. In addition to obtaining enough amount of paddy the quality of domestic rice needs to be improved, and since the quality of paddy is critical and panacea to obtaining better milled rice some initiatives for the improvement of quality of paddy are currently on going. The drafting of Nigerian Industrial standards (NIS) on paddy grading by the Standards Organization of Nigeria (SON) is among these initiatives. The challenge before now was that most stakeholders were not aware of the draft NIS on paddy grading, therefore all the integrated rice mills (IRM) in the country graded their paddy differently using parameters and thresholds based on their individual convenience and experience which were however contradictory to the draft NIS and made trading in paddy difficult. In order to solve this problem, the Federal Government of Nigeria represented by the Federal Ministry of Agriculture and Rural Development (FMARD) in collaboration with Japan International Cooperation Agency (JICA) has conducted several activities on paddy grading standard (SON *et. al*, 2018)

In order to discuss possible revision on draft NIS of paddy grading and harmonization of the IRMS grading standards with the NIS, a technical meeting was held at Abuja in 2016 with selected Quality Control Managers (QCM) of IRMS. After a brain storming session, comments on draft NIS were consolidated and all the QCMS agreed to harmonized their standards with that of NIS.

Recently the Federal Government of Nigeria (FGN) was planning to replace imported rice with locally produced rice. In order to achieve this goal, locally produced rice must be able to compete favorably with foreign rice.

The FMARD in collaboration with JICA and German Cooperation (GIZ) had made a lot on analyses of Nigerian paddy across many locations in the country using the harmonized SON Standard. Among the major experiments carried out are the Analysis of 270 samples by the GIZ and the results were as discuss below:

2.14.3 Analyses on the results of paddy grading of 270 samples from GIZ

The team of Agribusiness, Processing and Market Development Department (ABM) of Federal Ministry of Agriculture and Rural Development (FMARD), and Japan International Cooperation Agency (JICA) received 270 samples from 4 states of Nigeria. The team used Paddy Grading Methods jointly developed by ABM and JICA and endorsed by Standard Organization of Nigeria (SON). Grading was done based on the characteristics and thresholds of Paddy Grading Standard. In addition, percentages of red rice, winnowed paddy and sieved paddy were recorded and graded. Since most of the samples were “out of grade” according to SON standard, Grade 4 was created for this grading activity. The characteristics and thresholds are attached as Appendix B.

2.15 Works on Determination of Physical, Mechanical and Quality Properties of Paddy Rice

Mamudu (2016), in his research on Physical and processing characteristics of some popular rice varieties in Nigeria determined the physical and processing qualities of nine (9) popular rice varieties cultivated in Nigeria as a strategy for developing sustainable rice processing technology. Physical properties and milling attributes including paddy length (L), Width (W), Thickness (T), Mass (M1000), Surface area (SA), Aspect Ratio (AR), Sphericity (SC) and Volume (V) and percentage head rice, Broken grains, milling degree and Milling recovery were measured at moisture content of 12.86% dry weight basis and the following results were obtained: the average L, W, L/W ratio T and M1000 were 9.46mm, 2.57mm, 3.70, 2.25mm and 31.77g respectively, while calculated physical properties, GMD, V, SC, AR and SA were 3.78mm, 28.89cm3, 40.05%, 26.67% and 44.86cm3 respectively. The mean milling characteristics significantly (P = 0.05) varied in terms of hull, head rice recovery, percentage broken fraction, milling degree and milling recovery as 19.18%, 69.97%, 15.45%, 2.65% and 79.06% respectively. These characteristics are primarily considered when developing rice processing machinery and processes, while hierarchical analyses indicate close similarity between the varieties in terms of their milling yield.

Zubairu*et al* (2014), in their research on the Determination of some physical properties of common Malaysia rice MR219 seeds measured at different moisture contents and found that the bulk density increase at various levels; at 14.26% it was 517.70kg/m^3 and a significant increase was observed when the moisture content increased to 22.50% with bulk density value of 543.544kg/m^3. Similar findings were reported by Reddy and Charkraverty, 2004 with increasing values from 522 to 566kg/m^3 on raw paddy when the moisture content was increased from 7.19 to 28.28% dry basis. It was also reported an increase in bulk density from 454.8 to 537.6kg/m^3 when subjected to moisture changes of 6 to 18.13% by Bern *et al,* 2011 on dried pomegranate.

Also According to Ago, (2012) in his research on “Selected physical and Mechanical Properties of NERICA Paddy”.determinedf the physical and mechanical properties of

NERICA paddy, FARO's 44 (SIPI). 51 (Isadanc), 52 (WITA 40) and 57 (TOX4004-43-1-2-1) at different moisture contents were carried out. The paddy rice was studied under un-parboiled and parboiled states. The results indicate that the size ranges were 3.88mm to 5.14mm for FARO 51; 3.91mm to 4.98mm for FARO57; 3.62mm to 4.61mm for FARO 52 and 3.10mm to 4.82mm fo FARO 44. This explains that no single sample of NERICA paddy can effectively represent the size of the other samples. In mechanical properties, results indicate that FARO 51 had highest values of rupture force, 42.00N at 13% moisture content in longitudinal loading position and FARO 52 had lowest values of rupture force, 23.10N at 13% moisture content for un-parboiled samples in lateral loading position. FARO 51 had highest values of rupture force, 39.50N at 13% moisture content in longitudinal loading position and FARO 52 recorded lowest rupture force, 15.80N at 15% moisture content for parboiled samples in lateral loading position. It implies that force beyond these points at this moisture contents may cause damaged to the NERICA Paddy.

Naik*et al*, (2016) also studied the Physical Properties and Milling Characteristics of Rice (Oryza sativa L), In their research They found that the physical properties of grains are necessary for effective design of processing and storage machinery. Various physical properties of paddy, brown rice and head rice were determined for Hamsa variety of rice at 9.61% wet basis (W.b) and the milling characteristics of rice were found at 8, 10 and 12% (w.b) moisture content (m.c) of brown rice, Geometric mean diameter, sphericity, test weight, true density, porosity and angle of repose for paddy were 3.54mm, 0.39, 22.09g, 1166kgm-3, 48.19% and 31.44^{o} respectively. The corresponding values 2.88mm, 0.46, 19.31g, 1510kgm-3, 38.90% and 30.22^{o} were for brown rice and 2.86mm, 0.47, 17.32g, 1430kgm-3, 44.43% and 30.16^{o} for head rice, respectively. For this variety, the maximum degree of polishing of

15.08% was obtained at 8% m.c of brown rice polishing for 60_s maximum head rice yield of 89.05% was obtained at 8% m.c. of brown rice for polishing time of 15_s. The head rice decreases and broken content increases with the increase in m.c and polishing time.

Mir *et al.* (2012) conducted a research on "Evaluation of Physical properties of rice cultivars grown in temperate region in India. Seven rice cultivars namely, jehlum, K-332, Koshar, pusa-3, SKAU-345, SKAU-382 and SR-1 grown in temperate region of India. Results revealed that the hardness significantly varied from 131N to 73.99 with the highest hardness found in the brown rice of jehlum cultivar. An this may be due to variety difference.

The summary for the research gaps observes can be seen in the Table 2.1

Table 2.1 Summary for Research Gap Observes in a Tabular Form

S/NO	AUTHOR	WORK	ACHIEVEMENT	RESEARCH GAP	POSSIBLE SOLUTION
01	Agu and Oluka (2012)	Worked on Selected physical and mechanical properties of NERICA Paddy.	Achieved to some extend on the general knowledge of physical and mechanical properties of NERICA	Has not specifically address the other paddy rice varieties in detail	Need to apply that general knowledge to address other paddy rice in detail. Especially, Jamila and Faro 44 varieties.
02	SON *et. al.*, (2018)	Paddy Grading using laboratory Equipment	Was able to harmonize the grading systems used by millers in Nigeria and produced an accepted, effective standard grading manual	Not able to produce the grading standards on milled par-boiled rice	Need to develop the grading standard on parboiled and un-parboiled Rice
03	Zubairu, *et*	Determination	Identified that the	Was not able	Need to

	al (2014)	of some physical properties of common Malaysia Rice MR219 Seeds	Bulk density of MR219 Rice seed increases with an increase in moisture content	to address other physical, mechanical and quality properties.	address other physical, mechanical and quality properties.
04	Mamudu (2016)	Physical and processing characteristics of some popular rice varieties in Nigeria	Determined the physical and processing qualities of 9 popular rice varieties cultivated in Nigeria	Not able to include other varieties at different change in moisture content	There is need to vary the moisture content as well as using other popular varieties such as Jamila.
05	Naik et al (2016)	Physical properties and milling characteristics of rice	Found that the physical properties of grains are necessary for effective design of processing and storage machinery	Did not address mechanical and quality properties	Need to address other physical, mechanical and quality properties.

2.16 Deduction from the Literature Review

I) The physical and mechanical properties capture other varieties at other locations not the exact varieties use in this Research

II) Other Researchers captured only the Mechanical, Chemical and Physical Properties of paddy rice only, while this research captured the Quality Properties

III) Other researchers determined the Physical and Mechanical Properties of Millet, Sorghum, Maize and Wheat only in the same location and using the same method but did not address the paddy rice

IV) From the review literature it can be concluded that their will be available data to design effective and efficient machines to improve the quality of the selected local varieties

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials Used

The materials used were two varieties of FARO 44 and Jamila. They were chosen because of their high yield, good appearances and popularity. The moisture contents of 12 % was chosen because of being closer to the storage moisture content of 12 %, RIPMAPP, (2017). While the 14 % and 16 % moisture content were choosing because of their closeness to the good milling moisture content of 13.5 %, Kadama (2013).

3.1.1 Material Preparation

The two commonly and high yielding available varieties of paddy rice: Faro 44 (SIPI) and Jamila rice were obtained from Kura market of Kano state, Nigeria. The sample size of 15 kg of each variety were thoroughly cleaned (manually by winnowing and hand sorting) to remove foreign materials such as dirt's, stones, dust and un-removed chaffs, dried gradually conventionally and then stored in containers at room temperatures (25^0C), to allow uniformity of moisture sample distribution. The size and principal axes of the grain (minor, intermediate and major) in each group were determined using a dial screw gauge at different moisture contents. The weight of the grains were also determined using a weighing scale. The moisture content was varied by gradually drying the samples conventionally from the moisture content at the point of harvest from the farm which was 21.6 % and 20.5% moisture content for Jamila and Faro 44 respectively, to 16, 14 and 12 % for each of the two selected samples.

3.2 Equipment Used

The equipment that were used includes Moisture meter (Model SS7 SATAKE, Japan), Grain hardness tester (Model FUJUWARA SEISAKUSHO, Japan), Test husker ((Model SS7, SATAKE, Japan), Test mill (Model SS7, SATAKE Japan), Test length grader (Model SS7 SATAKE, Japan), micro meter screw gauge, weighing scale, all with a sensitivity of 0.01, Trays/plates, Containers, protractor, beaker and ovum. The specifications of the equipment that was used and what they were used for is as follows:

3.2.1 Moisture Meter

Moisture meter measures the moisture content of samples. The two varieties were measured three times at three different moisture content using three replications. The meter that was used in the research is Model SS 7 (SATAKE, Japan) as shown in plate 3.1, and it was used to measure moisture content from paddy, brown rice, milled rice, and other cereals. The measurement range for paddy according to the equipment designer is 8.7–40.0 % and that for milled rice is 9.8–20.0 %. When measuring, samples should not be touched directly by hands or fingers as this may affect the reading.

The procedure for measuring moisture content is by collecting a small sample of paddy of 3 g. The sample is collected into the moisture meter. The sample was crushed in the moisture meter. Then the average moisture content was read from the digital screen of the moisture meter calibrated as % moisture content.

Plate: 3.1 Paddy Rice Moisture Meter.

3.2.2 Grain hardness tester

A grain hardness tester was used to measure the hardness of a single grain of brown rice (de-husked rice). The measurement tool used was Grain Hardness Tester (FUJUWARA SEISAKUSHO, Japan) as shown in Plate 3.2. It can measure up to 196.0 N or 20.0 kgf.

Ten (10) grains of brown rice, is the optimum number of sample grains for the measurement of grain hardness (Kodama, 2011).

After measurement, the average hardness was calculated. The procedure used for the measurement is that the husks are removed from the grains by hand to obtain a brown rice. Then the de-husked one grain of brown rice is placed on the center of a small round measurement table and vertical force is applied through rotating the rod handle. The force on the grain is increased by rotating the rod handle. A red needle indicates the amount of force applied to the grain. At the moment when a small cracking sound is generated inside the grain, the force is read in kgf (kilogram force) or N (Newton). It is important to listen carefully for the cracking sound so that the measurement can be read at the appropriate time.

In addition this same equipment was used to measure the rupture force. And that was obtained when the grain ruptured at a specific force that was read from the equipment using the same procedure as in the grain hardness test. The difference is that for grains hardness reading is taking at the point of small crack sound while for the rupture force the reading was taking at the point of complete rupture.

Plate 3.2: Rice Grain Hardness Tester.

3.2.3 Paddy Test de-husker

A test husker was used to remove husks from the raw paddy to produce brown rice. The machine model used was Test Husker (Model SS7 SATAKE, Japan) as shown on Plate 3.3. This machine uses two rotating rubber rolls with different peripheral speeds to peel the husk off from paddy that was introduced. The initial clearance between the two (2) rolls was between 1/3 and 2/3 of the thickness of the brown rice. The test de husker also blows the separated husk from the brown rice and the husk was collected in a small tank through a cyclone. Brown rice was eventually collected in a transparent box. The weight of the raw paddy sample for de husking was 250 g.

Plate 3.3: Paddy Test Husker Machine.

3.2.4 paddy rice test milling machine

After husking, brown rice was milled using a test mill (Model SS7, SATAKE, Japan) as shown in Plate 3.4. In the test mill, there was a grinding stone in a milling chamber. Brown rice was introduced into the milling chamber, and the rotating grinder scratches the pericarp and embryo of the brown rice to produce milled rice. The milling time was adjustable: 1 min, 2 min, and 3 min, etc. Changes in milling time increase or decrease milling recovery, head rice ratio, and broken rice ratio. Therefore, trial milling was performed in order to determine the optimal milling time. The time used for milling in this particular research was 2 min for all samples. After milling, a slit in the milling chamber was opened, and the milled rice was collected in a transparent plastic box. The bran was collected in two transparent boxes on either side of the milled-rice collection box. (The out putquantities depends on the variety, post harvest handling, crops production environment etc).

Plate 3.4: Rice Test Milling Machine

3.2.5 Paddy rice test grading machine

Milled rice was separated into head rice and broken rice using a test length grader (Model SS7, SATAKE, Japan), as shown in Plate 3.5. Milled rice was introduced into an indented cylinder. As the cylinder rotates, broken rice was picked up by the indentations and raised to a certain point before it was dropped into a trough. While broken rice was caught in the trough, head rice remains in the indented cylinder. This operation was normally continued for 3 min before collecting the graded samples. (However the operation time can be changed by adjusting the built-in timer). The time selected for this particular operation was 3 minutes for each specimen.

Plate 3.5: Rice Test Grading Machine.

3.2.6 Dial thickness guage

Dial Thickness Guage is an instrument use to measure the length, width and the breadth of the grains. It is manufactured by E-Zoon tools, Japan. It has an accuracy of 0.001mm. It was used in taking the measurement of the paddy length, width and thickness of all samples. The procedure is that one paddy grain will be put in between the jaw of the instrument and tight gradually. The reading will be read from the digital screen for the length, width and thickness

3.3 Methods

The parameters measured in this study were Physical Properties (bulk density, angle of repose and geometrical mean diameter), Mechanical Properties (grain hardness and rupture force) and Quality Properties (milling recovery and head rice ratio). The rice paddy varieties used were FARO 44 (SIPI) and JAMILA Rice.

The experiments on the analysis of paddy/rice Quality and mechanical properties was carried out in the Quality Control Laboratory of the Department of Agribusiness, Processing and

Market Development, Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria. While the experiment on the analysis of physical Properties was carried out in the processing Laboratory located at the Department of Agricultural and Bio Resources Engineering, Ahmadu Bello University, Zaria, Nigeria. The samples of paddy/rice varieties was cultivated (using Good Agricultural Practice-GAP), harvested in the 2nd week of July, 2020 and obtained from Kura area of Kano state, Nigeria at the Farm moisture content of 20.5 % and 21.6 % for FARO 44 (SIPI) and JAMILA Rice, respectively. The samples were dried conventionally and data was obtained at the moisture contents of 16 %, 14 % and 12 % wet basis, for the Faro 44 and Jamila varieties respectively.

Expected milling output was determined at the laboratory by taking the weight of a thousand grains of milled head rice and the corresponding weight of a thousand grains of paddy and then expressing the weight of milled head rice as a percentage of the weight of the paddy. Any short fall in actual milling output would be considered as the milling loss due to breakage of grain.

The values of the following parameters were determined: Physical Properties (Bulk Density, Angle of Repose, Geometrical Mean Diameter), Mechanical Properties (Grains Hardness and Rupture Force), Quality Properties (milling recovery and head rice ratio) for the two paddy rice varieties at the moisture content of 16, 14 and 12 % respectively.

3.3.1 Physical properties of paddy rice

Physical properties of paddy rice are the characteristics of paddy rice that can be observed and measured without any change to chemical identity of the paddy rice sample. Some of the physical properties that were used are bulk density, angle of repose and geometric mean diameter. The details is as shown below

a. Bulk density of paddy rice

Bulk density of the paddy/rice was determined by weighing the paddy/rice parked in a container of known volume. The paddy/rice was densely parked by gently tapping the container to allow the settling of grains in the container (Oladunmoye, 2010). The volume of the container was estimated by filling the container with water and the water was then poured out into a calibrated measuring cylinder and the volume was then recorded. And the following expression was used in determining the bulk density of the paddy/rice varieties. (Oladunmoye, 2010):

$$\text{Bulk density} = \frac{Mass\ \ of\ Paddy\ packed}{Known\ volume} \qquad (3.1)$$

b. Angle of repose

In determining the angle of repose of the paddy, they paddy were piled on plywood, placed on a table in a conical form and then the plywood was tilted until the paddy began to slide (flow) freely, the angle the plywood makes with the table as at the time of free flow was taken as the angle of repose of the paddy (Mohsenin, 1980). This experiment was repeated five times for the selected varieties of the paddy/rice at different moisture contents to ascertain the mean angle of repose of the material.

c. Geometric Mean Diameter

The grain dimensions of the selected varieties such as length, width and thickness were determined using a micro meter screw gauge. A micro meter screw gauge having at least resolution count of 0.001cm (made) was used carefully to determine the dimensions of the Length, width and thickness. The geometric mean diameter, D_g of the grain was calculated using the following relationship as described by Mohsenin (1980):

$$Dg = (LBT)^{1/3} \qquad (3.7)$$

Where, L, B and T are the length, width and thickness of the Kernel respectively. Samples of 100 randomly selected whole kernels of each of the varieties were used to determine the grain dimensions.

3.3.2 Mechanical properties of paddy rice

Mechanical properties of paddy rice are defined as those properties of paddy that influence the paddy rice's reaction to applied loads. The mechanical properties investigated in the research were:

a. Grain hardness (kgf or N)

Grain hardness is the amount of force required to cause a crack inside brown rice, when applied vertically to the belly part of a grain. It is also called 'yielding point' and is expressed in 'kgf' or 'N (newton)'. 1 kgf = 9.8 N

b. Grain rupture force (Kgf or N)

Rupture-Force can be related to the firmness and brittleness of a product/grain. It is the force that is required to produce a major break/rupture in a sample. It is related to burst force which is the force to come a part suddenly and violently in to pieces. Developed seed coat cracks at lower levels of force when it was loaded with the hilum horizontal.

3.3.3 Quality properties of paddy rice

Is defined as the totality of features and characteristics of a rice that bears on its ability to satisfy stated or implied needs. The format used in recording the data to calculate the quality properties is as shown in Table 3.1.The quality properties selected and investigated in this research are:

a. Milling recovery (%)

Milling recovery is the proportion of the weight of milled rice to the weight of paddy rice, written as a percentage, as given by Fruichi (2011)

$$\text{Milling Recovery} = \frac{Weight\ of\ milled\ rice}{Weight\ of\ paddy} \text{ x } 100\ (\%) \qquad (3.3)$$

b. Head rice ratio (%)

The head rice ratio is the proportion of head rice weight to the weight of milled rice. Head rice yield which is the mass percentage of paddy that remains as head rice. Head rice is ¾ or more of the whole milled kernels separated from the total milled rice (U S Grains, 2016)

$$\text{Head Rice Ratio} = \frac{Weight\ of\ Head\ Rice}{Weight\ of\ Milled\ Rice} \text{ x } 100\ (\%) \qquad (3.4)$$

Table 3.1 A format used in data recording and calculations for paddy quality, physical and mechanical analysis

<table>
<tr><td colspan="7">Milling Report</td></tr>
<tr><td colspan="7">Recorder:</td></tr>
<tr><td colspan="3">Sample No.:</td><td colspan="4">Date:</td></tr>
<tr><td colspan="3">Variety:</td><td colspan="4">Origin:</td></tr>
<tr><td colspan="7">Parboiled or non-parboiled:</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="2">Moisture content</td><td colspan="2">1</td><td colspan="2">2</td><td>3</td><td>Average (%)</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td></td><td></td></tr>
<tr><td>Grain hardness (N)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>Average (N)</td></tr>
<tr><td>Rupture Force (N)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7"></td></tr>
<tr><td>Weight of paddy (g)</td><td colspan="2"></td><td colspan="3">Weight of milled rice (g)</td><td></td></tr>
<tr><td>Weight of head rice (g)</td><td colspan="2"></td><td colspan="3">Weight of broken rice (g)</td><td></td></tr>
<tr><td>Milling recovery (%)</td><td colspan="6">Bulk Density (mm)</td></tr>
<tr><td>Head rice recovery (%)</td><td colspan="6">Angle of Repose (Degrees)</td></tr>
<tr><td>Head rice ratio (%)</td><td colspan="6">Geom. Mean Dia. (mm)</td></tr>
<tr><td>Broken rice ratio (%)</td><td colspan="6">Rupture Force (N)</td></tr>
</table>

Source: (RIPMAPP, 2014)

3.4 Experimental Design

The experiments were conducted using Completely Randomized Design (CRD) at two (2) levels of (Varieties), and three (3) levels of (Moisture contents). Duncan Multiple Range Test (DMRT) was used to further analyze the significant variables. The CRD was used because the experiment was carried out in the Laboratory not in the field.

3.5 Experimental Layout

The experiment layout that was used to carry out the analysis was given on Tables 3.2:

Tables 3.2: The experimental layout

Replicate I

V1M1	V2MI
V1M2	V2M2
V1M3	V2M3

Replicate II

V1M1	V2MI
V1M2	V2M2
V1M3	V2M3

Replicate III

V1M1	V2MI
V1M2	V2M2
V1M3	V2M3

Where:

Where V1 = Faro 44 variety, V2 = Jamila paddy rice variety

M1 = 12 % moisture content, M3 = 14 % moisture content, M3 = 16 % moisture content

The ANOVA for CRD table is presented as below:

Table 3.3 Anova Table for Factorial Experiment in Completely Randomized Design (CRD)

Source	DF
Moisture, m	m-1 = 2
Variety, v	v-1 = 1
M x v	(m-1) (v-1) = 2
Error	M v (r-1) = 12
Total	rmv – 1 = 17

3.7 Appendix

Appendix A, B, C, D and E shows the results of the 270 samples analyzed using SON Grading Standard, The Rough data for the Research, the Duncan Multiple Test Analysis using a soft wire, SNT (Student Newman Kauls Test) Test and Secondary and primary drying as well as the quality testing equipment and operation process respectively.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Description of the Project

The results of the study are presented and discussed under the following sub headings:

i. Effects of change in moisture content on physical properties of Faro 44 and Jamila paddy rice varieties.

ii. Effects of change in moisture content on mechanical properties of Faro 44 and Jamila paddy rice varieties.

iii. Effects of change in moisture content on quality properties of Faro 44 and Jamila paddy rice varieties.

4.2. Effects of Change in Moisture Content on Physical Properties of Faro 44 and Jamila Paddy Rice Varieties.

Details of the results are presented in appendix B. Table 4.1 presents the mean values of the physical properties obtained at different moisture contents for the two paddy rice varieties. It could be seen that the range of values for the bulk density, angle of repose and geometric mean diameter are 530-573 kgm^{-3}, 31.0 – 32.0 and 3.618-3.786 respectively. These values are similar to the results obtained by Zubairu*et al*.(2014) and Mamudu (2016).

Table 4.1: Mean Values of Physical Properties of Varieties of Paddy Rice at Different Moisture Contents

Variety	M	BD	AR	GMD
	12	533	31	3.618
Faro 44	14	544	32	3.784
	16	573	32	3.674
	12	530	30	3.768
Jamila	14	531	30.3	3.786
	16	539	31	3.740

M: Moisture content, % (w. b.).

BD: Bulk density, kgm^{-3}.

AR: Angle of repose, ^{0}.

GMD: Geometric mean diameter, mm.

The effects of moisture content and varietal response on bulk density, angle of repose and geometric mean diameter of the selected paddy rice varieties are presented in Table 4.2. It was observed that the effect of variety is not significant on bulk density. However the effect of moisture content is significant at 5 % level. The effect of these two factor interaction is not significant on bulk density. It was also observed that the effects of variety and moisture content on both angle of repose and geometric mean diameter are significant. The effect of the interaction of variables is not significant on the angle of repose but it is significant on the geometric mean diameter.

Table 4.2: Effects of Moisture Content on Physical Properties of Faro 44 and Jamila Varieties of Paddy Rice.

Source	BD	AR	GMD
Variety, V	4.68 NS	17.29**	1239.56**
Moisture content, M	3.45 *	4.00*	780.41**
V x M interaction	0.00035 NS	0.57NS	434.27**

NS: Not significant

*: significant

**: Highly significant

4.2.1 Effects of change in moisture content on bulk density of faro 44 and jamila paddy rice varieties.

The implication deduced from the above findings is that the highest mean bulk density of 573 kgm^{-3}irrespective of paddy rice variety should be taken into consideration in sizing hoppers and storage facilities for the selected varieties. This would serve to prevent failure of the facility due to higher pressure as a result of higher bulk density.

Further analysis using the Duncan multiple range test, DMRT, as presented in Table 4.3, shows that the mean values of bulk density at 16 % and 14 % moisture content are statistically similar and significantly higher than those at 12 %. The bulk density increases with increase in moisture content. This agrees with findings of Zubairu*et al*. (2014), where it was found out that an increase in moisture content from 14.26 – 22.5 % increased the bulk density from 517.70 – 543.54 kgm^{-3}. Similar findings were reported by Raddy and Chakraverty (2004) where it was stated that the values of bulk density increased from 522 to 586 kgm^{-3} when the moisture content was increased from 7.19 to 28.28 % (d.b.). It was also reported that an increase in bulk density from 454.8- 537.6 kgm^{-3} was observed when dried pomegranate was subjected to moisture changes from 6.0 to 18.13 % (Amir *et al.*, 2012).

Table 4.3: DMRT Grouping for the Effect of Moisture Content on Bulk Density for the Selected Varieties of Paddy Rice.

M, %	BD, kgm^{-3}
16	559a
14	538a,b
12	532b

4.2.2 Effects of change in moisture content on angle of repose for faro 44 and jamila paddy rice varieties

The implication deduced from Tables 4.1 and 4.2 above is that the angle of repose for a hopper facility should not be less than 32^0 in order to achieve consistent flow of the Faro 44 and Jamila paddy rice varieties.

Further analysis using the Duncan multiple range test, DMRT, as presented in Table 4.4, shows that Faro 44 paddy variety has significantly higher mean values of angle of repose than Jamila. The mean values of angle of repose at moisture contents of 16 % and 14 % are statistically similar and significantly higher than those values at 12 %. The angle of repose is higher at higher moisture contents. This is in conformity with the values of, 30.16^0, 30.22^0 and 31.44^0 for paddy, brown rice and head rice at the moisture content of 8, 10 and 12 % respectively obtained by Naik*et al.* (2016).

Table 4.4: DMRT Grouping for the Effect of Moisture Content on Angle of Repose for Faro 44 and Jamila Paddy Rice Varieties.

Variety, V	Angle of repose, AR, degree
Faro 44	31.67a
Jamila	30.46b
Moisture content, M, %	
16	31.500a
14	31.167a,b
12	30.500b

4.2.3 Effects of change in moisture content on geometric mean diameter for faro 44 and jamila paddy rice varieties

The implications of Tables 4.1 and 4.2 above is that the mean values of geometric mean diameter for sieve separators for Jamila and Faro 44 paddy varieties should be sized between 3.69 – 3.78 mm.

Further analysis using the Duncan multiple range test, DMRT, as presented in Table 4.5, shows that Jamila paddy variety has significantly higher mean values of geometric mean diameterthan Faro 44 at the same moisture content. For a particular variety, the highest mean value of geometric mean diameter is obtained at 14 % and the lowest at 12 %. SNK Tests for the V x M interactions effect on geometric mean diameter show that the combination Jamila at 14% moisture content gives the highest GMD. Faro 44 at moisture content 12% gives the lowest mean value of GMD.

Table 4.5: DMRT Grouping and SNK Test for the Effect of Moisture Content on Geometric Mean Diameterfor Faro 44 and Jamila Paddy Rice Varieties.

Variety, V	Geometric mean diameter, mm
Jamila	3.764a
Faro 44	3.692b
Moisture content, M, %	
16	3.707b
14	3.785a
12	3.693c
Vx M interactions	
V1M1	3.674 d
V1M2	3.784 b
V1M3	3.618 f
V2M1	3.740 c
V2M2	3.786 a
V2M3	3.768 e

4.3. Effects of Change in Moisture Content on Mechanical Properties of Faro 44 and Jamila Varieties of Paddy Rice.

Details of the results are presented in appendix B. Table 4.6 presents the mean values of the mechanical properties obtained at different moisture contents for the two paddy rice varieties. It could be seen that the range of mean values for grain hardness and rupture force are 36.27 –

45.07 N and 48.92 – 73.07 N, respectively. These values are similar to the results obtained by Mamudu (2016) and Agu (2012).

Table 4.6: Mean Values of Mechanical Properties of Varieties of Paddy Rice at Different Moisture Contents

Variety	M	GH	RF
	16	36.27	48.92
Faro 44	14	49.00	64.68
	12	38.10	59.46
	16	41.53	62.72
Jamila	14	45.07	73.07
	12	36.88	67.60

M: Moisture content, % (w. b.).

GH: Grain hardness, N

RF: Rupture force, N

The effects of moisture content and varietal response on grain hardness and rupture force of the selected paddy rice varieties are presented in Table 4.7. It was observed that the effect of all the variables and their interactions are highly significant.

Table 4.7: Effects of Moisture Content on Mechanical Properties of Faro 44 and Jamila Varieties of Paddy Rice.

Source	GH	RF
Variety, V	∞**	∞**
Moisture content, M	∞**	∞**
V x M interaction	∞**	∞**

**: Highly significant

4.3.1 Effects of change in moisture content on grain hardness of faro 44 and jamila paddy rice varieties.

Further analysis using the Duncan multiple range test, DMRT, as presented in Table 4.8, shows that Jamila paddy variety has significantly higher mean values of grain hardness than Faro 44 at the same moisture content. Jamila variety can resist higher speed during the dehusking and milling operations . Also, for a particular variety the mean values for grain hardness are significantly highest at the moisture content of 14 %. SNK Tests for the V x M interactions effect on grain hardness show that the combination Faro 44 at 14% moisture content has the highest mean value of GH and the combination of Faro 44 at 12% has the lowest mean values of GH.

Table 4.8: DMRT Grouping and SNK Test for the Effect of Moisture Content on Grain Hardnessfor Faro 44 and Jamila Paddy Rice Varieties.

Variety, V	Grain hardness, N
Jamila	41.16a
Faro 44	41.12b
Moisture content, M, %	
16	38.70b
14	47.04a
12	37.49c
Vx M interactions	
V1M1	36.27 f
V1M2	49.00 a
V1M3	38.10 d
V2M1	41.53 c
V2M2	45.07 b
V2M3	36.87 d

4.3.2 Effects of change in moisture content on rupture force of faro 44 and jamila paddy rice varieties.

Further analysis using the Duncan multiple range test, DMRT, as presented in Table 4.9, shows that Jamila paddy variety has significantly higher mean values of rupture force than Faro 44 at the same moisture content. Also for a particular variety the mean values for grain hardness are significantly highest at the moisture content of 14 %. SNK Tests for the V x M interactions effect on grain hardness show that the combination Jamila at 14% moisture content has the highest mean values of RF and Faro 44 at 12% moisture content has the least mean value of RF.

Table 4.9: DMRT Grouping and SNK Test for the Effect of Moisture Content on Rupture Forcefor Faro 44 and Jamila Paddy Rice Varieties.

Variety, V	Rupture force, N
Jamila	67.80a
Faro 44	57.69b
Moisture content, M, %	
16	65.82b
14	68.88a
12	63.53c
Vx M interactions	
V1M1	48.92 f
V1M2	64.68 c
V1M3	59.46 d
V2M1	52.72 e
V2M2	73.07 a
V2M3	67.60 b

4.4. Effects of Change in Moisture Content on Quality Properties of Faro 44 and Jamila Varieties of Paddy Rice.

Details of the results are presented in appendix B. Table 4.10 presents the mean values of the quality properties obtained at different moisture contents for the two paddy rice varieties. It could be seen that the range of mean values for milling recovery and head rice ratio are 70.15 – 72.89 % and 84.23 – 87.49 %, respectively. These values are similar to the results obtained by Mamudu (2016).

Table 4.10: Mean Values of Quality Properties of Varieties of Paddy Rice at Different Moisture Contents

Variety	M	MR	HRR
	16	70.89	87.49
Faro 44	14	70.92	87.16
	12	70.15	85.66
	16	72.76	85.10
Jamila	14	72.87	86.92
	12	70.93	84.23

M: Moisture content, % (w. b.).

MR: Milling recovery, %

HRR: Head rice ratio, %

The effects of moisture content and varietal response on milling recovery and head rice ratio of the selected paddy rice varieties are presented in Table 4.11. It was observed that the effect of variety on milling recovery is highly significant whereas it is not significant on head rice ratio. The effect of moisture content is significant at 5 % level for both mean value of milling recovery and head rice ratio. The effects of interactions on the mean values of both the milling recovery and the head rice ratio are not significant.

Table 4.11: Effects of Moisture Content on Quality Properties of Faro 44 and Jamila Varieties of Paddy Rice.

Source	MR	HRR
Variety, V	12.94 **	4.55 NS
Moisture content, M	4.27*	3.79*
V x M interaction	0.75 NS	0.97NS

NS: Not significant

*: Significant

**: Highly significant

4.4.1 Effects of change in moisture content on milling recovery of faro 44 and jamila paddy rice varieties.

Further analysis using the Duncan multiple range test, DMRT, as presented in Table 4.12, shows that Jamila paddy variety has significantly higher mean values of milling recovery than Faro 44 at the same moisture content.. Also, for a particular variety the mean values for milling recovery at the moisture content of 16 and 14 % are statistically at far but significantly higher than those at the moisture content of 12 %. According to IRRI (2021), the average World potential yields milling recovery is 68-72 % at 13 % moisture content. Therefore Jamila paddy rice having a mean value of 72.87 % milling recovery at 14 % moisture and 72.76 % at 16 % moisture content has potential to compete globally in terms of better rice quality.

Table 4.12: DMRT Grouping for the Effect of Moisture Content on Milling Recoveryfor Faro 44 and Jamila Paddy Rice Varieties.

.Variety	MR, %
Jamila	72.19a
Faro 44	70.66b
Moisture content, %	
16	71.83a
14	71.90a
12	70.54b

4.3.2 Effects of change in moisture content on head rice ratio of faro 44 and jamila paddy rice varieties.

Further analysis using the Duncan multiple range test, DMRT, as presented in Table 4.13, shows that for either of the varieties, the mean values for head rice ratioat the moisture content of 16 and 14 % are statistically at far but significantly higher than those at the moisture content of 12 %. According to IRRI (2021), the world average potential yields head rice ratio is about 80.55 % (IRRI, 2021). Therefore Faro 44 having the head rice ratio of 87.49% at 16% moisture content and 87.16% at 14% moisture content is above the potential yields average and therefore has a strong potentials to compete Internationally in terms of quality.

Table 4.13: DMRT Grouping for the Effect of Moisture Content on Head Rice Ratiofor Selected Paddy Rice Varieties.

Moisture content, %	HR, %
16	86.29a, b
14	87.04a
12	84.95b

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The research titled "Studies on the Effects of Change in Moisture Content on some Physical, Mechanical and Quality Properties of Two Paddy Rice (*Oryza sativa L*) Varieties in Nigeria"was carried out in the Department of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Zaria, Nigeria. The study investigated the quality as well as some physical and mechanical properties of the two commonly grown varieties of rice in relation to change in moisture content. The two varieties used were *FARO 44 (SIPI)* and *JAMILA.* The parameters measured were bulk density, angle of repose, geometrical mean diameter, grain hardness, rupture force, milling recovery and head rice ratio. Using the CRD, DMRT and SNK Tests, the results show that there is a relationship between the physical, mechanical and moisture contents on quality of the milled paddy rice. It could be summarized that Jamila variety has highest milling recovery of 72.87% at 14% moisture content while Faro 44 has the highest head rice ratio of 87.49% at 16% moisture content. It was also observed that the physical properties value increases with increase in moisture content. It was also observed that Jamila variety has the highest grain hardness as well as highest rupture force. Also noted was the increase in grain hardness is proportional to the increase in rupture force. And all these findings are very useful in the design and fabrication of effective processing machines for the deliverance of good processed rice products.

5.2 Conclusion

After a successful investigation carried out on the physical, mechanical and quality properties at different moisture levels of 16 %, 14 % and 12 %, the following conclusions were drawn at various level of interactions:

i) The values of physical properties (Bulk Density, Angle of Repose and Geometric Mean Diameter) increases with increases in moisture content for all of the varieties.

ii) Jamila Variety has higher milling recovery of 72.87% at 14% moisture content and 72.76% at 16% moisture content while Faro 44 has higher Head Rice Ratio of 87.49% at 16% moisture content and 87.16% at 14% moisture content.

iii) The higher the grain hardness the higher the rupture force ie increase in grain hardness is proportional to increase in rupture force.

iv) That the thermal stresses, high rates of moisture desorption and moisture reabsorption increases fissuring/cracks and consequently reduces milling recovery and the head rice ratio.

5.3 Recommendations

i) Jamila variety is recommended to those who prefer rice with high milling recovery while Faro 44 is recommended to those who prefer rice with high head rice ratio.

ii) The research results should be shared among the Rice millers, parboilers, dryers, farmers, agro-dealers and other stakeholders so as to improve the quality of the domestic paddy rice.

iii) There is need to carry out the same experiment using par-boiled paddy to see what percentage will be obtain as the milling recovery and head rice ratio for Faro 44 and Jamila varieties.

iv) There is need to carry out a similar experiment to include other physical properties (such as True Density, porosity etc) mechanical properties (such as angle of internal friction) chemical properties (such as protein, carbohydrate etc) and Quality properties (such as Head Rice Recovery, Broken Rice Ratio etc) as well as other local varieties (such as Faro 45 to Faro 61)

v) It could also be recommended for Government policies on Zero Reject Export Initiatives, that is for the exportation of paddy rice to other countries and for the use by other Non-Governmental Organizations.

vi) The result should also be recommended to Agricultural machinery fabricators.

5.4 Contribution to Knowledge

From the research the following knowledge was obtained:

i) That the values of physical properties (Bulk Density, Angle of Repose and Geometric Mean Diameter) increases with increase in moisture content

ii) That Jamila Variety has higher milling recovery of 72.19 % at 16 % moisture content while Faro 44 has higher Head Rice Ratio of 87.49 % at 14 % moisture content.

iii) That the product having high milling recovery does not guarantee it to have high head rice ratio

iv) That the Design/fabricating processing machine without considering physical, mechanical and quality properties reduces the efficiency and effectiveness of the machine.

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APPENDIX A

TABLE 2.1 Number of Samples in each grade according to SON Grading Standard for the 270 Samples analysis carried out.

<table>
<tr><th>S/No</th><th colspan="2">Characteristics</th><th>Grade 1</th><th>Grade 2</th><th>Grade 3</th><th>Grade 4</th><th>Out of Grade</th></tr>
<tr><td rowspan="2">1</td><td colspan="2" rowspan="2">Purity, %m/m (weight basis.)
(100 %– (2+3+4+6))</td><td colspan="4">Minimum Limits</td><td></td></tr>
<tr><td></td><td>4</td><td></td><td>92</td><td>174</td></tr>
<tr><td colspan="3"></td><td colspan="3">Maximum Limits</td><td></td><td></td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Foreign matter, % m/m</td><td>Organic *(empty shell + other organic.)*
[(III/II) x 100 %]</td><td></td><td>6</td><td>12</td><td>92</td><td>160</td></tr>
<tr><td>Inorganic
[(IV/II) x 100 %]</td><td>266</td><td></td><td>4</td><td></td><td></td></tr>
<tr><td>3</td><td colspan="2">Pest damaged grains, % m/m, max
[(VII/V) x 100 %]</td><td>177</td><td>22</td><td>15</td><td>23</td><td>33</td></tr>
<tr><td>4</td><td colspan="2">Discoloured grains, % m/m, max*[(VIII/V) x 100 %]*</td><td>180</td><td>54</td><td>22</td><td>13</td><td>1</td></tr>
<tr><td>5
(11)</td><td colspan="2">Moisture, % m/m, max*[I]*</td><td>25</td><td></td><td></td><td></td><td>234</td></tr>
<tr><td>6</td><td colspan="2">Immature/shrivelled grains, % m/m
(thinner grain (less than 1.6 mm))
[(VI/V) x 100 %]</td><td></td><td>51</td><td>65</td><td>134</td><td>20</td></tr>
<tr><td>7</td><td colspan="2">Winnowed paddy</td><td>49</td><td>38</td><td>42</td><td>85</td><td>56</td></tr>
<tr><td>8</td><td colspan="2">Sieved paddy</td><td>37</td><td>39</td><td>35</td><td>136</td><td>23</td></tr>
<tr><td>9</td><td colspan="2">Red Rice</td><td>125</td><td>49</td><td>51</td><td>32</td><td>13</td></tr>
<tr><td>(11)</td><td colspan="2">Final Grades</td><td></td><td></td><td></td><td>17</td><td>242</td></tr>
</table>

APPENDIX B

Raw Data Obtained from the Experiment carried out

Where:

1) B.D (Bulk Density), A.R (Angle of repose) and G. M. D (Geometrical Mean Diameter) are the Measured physical properties
2) G. H (Grains Hardness) and R. F (Rupture Forces) are the measured mechanical properties
3) M. R (Milling Recovery) and H.R.R (Head Rice Ratio) are the measured quality properties
4) M. C (Moisture Content) are the moisture contents at each experiment

Replication one:

FARO 44	JAMILA
AT M. C = 16 B. D =0.546g/mm A. R = 32^o G. M. D = 3.673mm G. H = 36.27N R. F = 48.92N M. R = 71.25% H. R. R = 87.63%	AT M. C = 16% B. D = 0.536g/mm A. R = 31 G. M. D = 3.737mm G. H = 41.53N R. F = 62.72N M. R = 73.58% H. R. R = 83.85%
AT M. C = 14% B. D = 0.5315 A. R = 32^o	AT M. C = 14% B. D = 0.510g/mm A. R = 31^o

G. D = 3.784mm G. H = 49N R. F = 64.68N M. R = 70.76% H. R. R =88.19%	G. D = 3.780 G. H = 45.07N R. F = 73.07N M. R = 72.65% H. R. R = 86.80%
AT M. C = 12% B. D = 0.5200 A. R = 31^{o} G. D = 3..618 G. H = 38.1N R. F = 59.46N M. R = 70.12% H. R. R = 84.24%	AT M. C = 12% B. D = 0.5301 A. R = 30^{o} G. D = 3.767 G. H = 36.88N R. F = 67.6N M. R = 69.34% H. R. R = 81.77%

Replication two:

AT M. C = 16 B. D =0.586g/mm A. R = 32^{o} G. D = 3.674 G. H = 36.27N R. F = 48.92N M. R = 70.83% H. R. R = 87.58%	AT M. C = 16% B. D = 0.5256g/mm A. R = 31^{o} G. D = 3.737 G. H = 41.53N R. F = 62.72N M. R = 72.78% H. R. R = 84.51%

AT M. C = 14% B. D = 0.5615 A. R = 32^o G. D = 3.785 G. H = 49N R. F = 64.68N M. R = 71.12% H. R. R =86.73%	AT M. C = 14% B. D = 0.5310g/mm A. R = 31^o G. D = 3.781 G. H = 45.07N R. F = 73.07N M. R = 73.09% H. R. R = 87.33%
AT M. C = 12% B. D = 0.5500 A. R = 31^o G. D = 3.617 G. H = 38.1N R. F = 59.46N M. R = 70.56% H. R. R = 86.56%	AT M. C = 12% B. D = 0.5301 A. R = 29^o G. D = 3.768 G. H = 36.88N R. F = 67.6N M. R = 70.34% H. R. R = 84.46%

ReplicationThree:

FARO 44	JAMILA
AT M. C = 16 B. D =0.586g/mm A. R = 32^{o} G. D = 3.674 G. H = 36.27N R. F = 48.92N M. R = 70.60% H. R. R = 87.26%	AT M. C = 16% B. D = 0.556g/mm A. R = 31^{o} G. D = 3.745 G. H = 41.53N R. F = 62.72N M. R = 71.91% H. R. R = 86.96%
AT M. C = 14% B. D = 0.5415 A. R = 32^{o} G. D = 3.783 G. H = 49N R. F = 64.68N M. R = 70.89% H. R. R =86.56%	AT M. C = 14% B. D = 0.5510g/mm A. R = 29^{o} G. D = 3.797 G. H = 45.07N R. F = 73.07N M. R = 72.86% H. R. R = 86.65%
AT M. C = 12% B. D = 0.5300 A. R = 31^{o} G. D = 3.618 G. H = 38.1N R. F = 59.46N M. R = 69.78% H. R. R = 86.17%	AT M. C = 12% B. D = 0.5301 A. R = 31^{o} G. D = 3.768 G. H = 36.88N R. F = 67.6N M. R = 73.12% H. R. R = 86.47%

APPENDIX C

Results Obtained using a Statistical Analysis Soft ware (SAS) System

Duncan Multiple Test Analysis using a Soft Wire:

The SAS System 10:10 Thursday, December 3, 2020 1

The GLM Procedure

Class Level Information

Class	Levels	Values
VAR	2	FARO44 JAMILA
MOIST	3	12 14 16

Number of Observations Read	18
Number of Observations Used	18

The SAS System 10:10 Thursday, December 3, 2020 2

The GLM Procedure

Dependent Variable: BD BD

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	0.00390371	0.00078074	2.82	0.0653
Error	12	0.00331811	0.00027651		
Corrected Total	17	0.00722182			

R-Square	CoeffVar	Root MSE	BD Mean
0.540544	3.069132	0.016629	0.541800

Source	DF	Type I SS	Mean Square	F Value	Pr> F
VAR	1	0.00129371	0.00129371	4.68	0.0514
MOIST	2	0.00190696	0.00095348	3.45	0.0656
VAR*MOIST	2	0.00070304	0.00035152	1.27	0.3157

Source	DF	Type III SS	Mean Square	F Value	Pr> F
VAR	1	0.00129371	0.00129371	4.68	0.0514
MOIST	2	0.00190696	0.00095348	3.45	0.0656
VAR*MOIST	2	0.00070304	0.00035152	1.27	0.3157

The SAS System 10:10 Thursday, December 3, 2020 3

The GLM Procedure

Dependent Variable: AR AR

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	10.27777778	2.05555556	5.29	0.0085
Error	12	4.66666667	0.38888889		
Corrected Total	17	14.94444444			

R-Square	CoeffVar	Root MSE	AR Mean
0.687732	2.008045	0.623610	31.05556

Source	DF	Type I SS	Mean Square	F Value	Pr> F
VAR	1	6.72222222	6.72222222	17.29	0.0013
MOIST	2	3.11111111	1.55555556	4.00	0.0467
VAR*MOIST	2	0.44444444	0.22222222	0.57	0.5794

Source	DF	Type III SS	Mean Square	F Value	Pr> F
VAR	1	6.72222222	6.72222222	17.29	0.0013
MOIST	2	3.11111111	1.55555556	4.00	0.0467
VAR*MOIST	2	0.44444444	0.22222222	0.57	0.5794

The SAS System 10:10 Thursday, December 3, 2020 4

The GLM Procedure

Dependent Variable: GMD GMD

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	0.07011717	0.01402343	733.78	<.0001
Error	12	0.00022933	0.00001911		
Corrected Total	17	0.07034650			

R-Square	CoeffVar	Root MSE	GMD Mean
0.996740	0.117259	0.004372	3.728167

Source	DF	Type I SS	Mean Square	F Value	Pr> F
VAR	1	0.02368939	0.02368939	1239.56	<.0001
MOIST	2	0.02982900	0.01491450	780.41	<.0001
VAR*MOIST	2	0.01659878	0.00829939	434.27	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr> F
VAR	1	0.02368939	0.02368939	1239.56	<.0001
MOIST	2	0.02982900	0.01491450	780.41	<.0001
VAR*MOIST	2	0.01659878	0.00829939	434.27	<.0001

The SAS System 10:10 Thursday, December 3, 2020 5

The GLM Procedure

Dependent Variable: GH GH

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	385.4480500	77.0896100	Infty	<.0001
Error	12	0.0000000	0.0000000		
Corrected Total	17	385.4480500			

R-Square	CoeffVar	Root MSE	GH Mean
1.000000	0	0	41.14167

Source	DF	Type I SS	Mean Square	F Value	Pr> F
VAR	1	0.0060500	0.0060500	Infty	<.0001
MOIST	2	318.5467000	159.2733500	Infty	<.0001
VAR*MOIST	2	66.8953000	33.4476500	Infty	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr> F
VAR	1	0.0060500	0.0060500	Infty	<.0001
MOIST	2	318.5467000	159.2733500	Infty	<.0001
VAR*MOIST	2	66.8953000	33.4476500	Infty	<.0001

The SAS System 10:10 Thursday, December 3, 2020 6

The GLM Procedure

Dependent Variable: RF RF

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	1007.529850	201.505970	Infty	<.0001
Error	12	0.000000	0.000000		
Corrected Total	17	1007.529850			

R-Square	CoeffVar	Root MSE	RF Mean
1.000000	0	0	62.74167

Source	DF	Type I SS	Mean Square	F Value	Pr> F
VAR	1	459.9544500	459.9544500	Infty	<.0001
MOIST	2	516.8923000	258.4461500	Infty	<.0001
VAR*MOIST	2	30.6831000	15.3415500	Infty	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr> F
VAR	1	459.9544500	459.9544500	Infty	<.0001
MOIST	2	516.8923000	258.4461500	Infty	<.0001
VAR*MOIST	2	30.6831000	15.3415500	Infty	<.0001

The GLM Procedure

Dependent Variable: MR MR

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	18.73457778	3.74691556	4.61	0.0140
Error	12	9.75400000	0.81283333		
Corrected Total	17	28.48857778			

R-Square	CoeffVar	Root MSE	MR Mean
0.657617	1.262334	0.901573	71.42111

Source	DF	Type I SS	Mean Square	F Value	Pr> F
VAR	1	10.51875556	10.51875556	12.94	0.0037
MOIST	2	6.94914444	3.47457222	4.27	0.0397
VAR*MOIST	2	1.26667778	0.63333889	0.78	0.4807

Source	DF	Type III SS	Mean Square	F Value	Pr> F
VAR	1	10.51875556	10.51875556	12.94	0.0037
MOIST	2	6.94914444	3.47457222	4.27	0.0397
VAR*MOIST	2	1.26667778	0.63333889	0.78	0.4807

The SAS System 10:10 Thursday, December 3, 2020 8

The GLM Procedure

Dependent Variable: HRR HRR

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	25.21997778	5.04399556	2.81	0.0660
Error	12	21.52026667	1.79335556		
Corrected Total	17	46.74024444			

R-Square	CoeffVar	Root MSE	HRR Mean
0.539577	1.555437	1.339162	86.09556

Source	DF	Type I SS	Mean Square	F Value	Pr> F
VAR	1	8.16080000	8.16080000	4.55	0.0542
MOIST	2	13.57907778	6.78953889	3.79	0.0531
VAR*MOIST	2	3.48010000	1.74005000	0.97	0.4068

Source	DF	Type III SS	Mean Square	F Value	Pr> F
VAR	1	8.16080000	8.16080000	4.55	0.0542
MOIST	2	13.57907778	6.78953889	3.79	0.0531
VAR*MOIST	2	3.48010000	1.74005000	0.97	0.4068

The SAS System 10:10 Thursday, December 3, 2020 9

The GLM Procedure

Duncan's Multiple Range Test for BD

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.000277

Number of Means	2
Critical Range	.01708

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	VAR
A	0.550278	9	FARO44
A			
A	0.533322	9	JAMILA

The SAS System 10:10 Thursday, December 3, 2020 10

The GLM Procedure

Duncan's Multiple Range Test for AR

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.388889

Number of Means	2
Critical Range	.6405

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	VAR
A	31.6667	9	FARO44
B	30.4444	9	JAMILA

The SAS System 10:10 Thursday, December 3, 2020 11

The GLM Procedure

Duncan's Multiple Range Test for GD

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.000019

Number of Means	2
Critical Range	.004490

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	VAR
A	3.764444	9	JAMILA
B	3.691889	9	FARO44

The SAS System 10:10 Thursday, December 3, 2020 12

The GLM Procedure

Duncan's Multiple Range Test for GH

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0

Number of Means	2
Critical Range	0

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	VAR
A	41.16	9	JAMILA
B	41.12	9	FARO44

The SAS System 10:10 Thursday, December 3, 2020 13

The GLM Procedure

Duncan's Multiple Range Test for RF

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0

Number of Means	2
Critical Range	0

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	VAR
A	67.80	9	JAMILA
B	57.69	9	FARO44

The SAS System 10:10 Thursday, December 3, 2020 14

The GLM Procedure

Duncan's Multiple Range Test for MR

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.812833

Number of Means	2
Critical Range	.9260

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	VAR
A	72.1856	9	JAMILA
B	70.6567	9	FARO44

The SAS System 10:10 Thursday, December 3, 2020 15

The GLM Procedure

Duncan's Multiple Range Test for HRR

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	1.793356

Number of Means	2
Critical Range	1.375

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	VAR
A	86.7689	9	FARO44
A			
A	85.4222	9	JAMILA

The SAS System 10:10 Thursday, December 3, 2020 16

The GLM Procedure

Duncan's Multiple Range Test for BD

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.000277

Number of Means	2	3
Critical Range	.02092	.02189

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	MOIST
	A	0.555933	6	16
	A			
B	A	0.537750	6	14
B				
B		0.531717	6	12

The SAS System 10:10 Thursday, December 3, 2020 17

The GLM Procedure

Duncan's Multiple Range Test for AR

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.388889

Number of Means	2	3
Critical Range	.7845	.8211

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	MOIST
	A	31.5000	6	16
	A			
B	A	31.1667	6	14
B				
B		30.5000	6	12

The SAS System 10:10 Thursday, December 3, 2020 18

The GLM Procedure

Duncan's Multiple Range Test for GD

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.000019

Number of Means	2	3
Critical Range	.005499	.005756

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	MOIST
A	3.785167	6	14
B	3.706667	6	16
C	3.692667	6	12

The SAS System 10:10 Thursday, December 3, 2020 19

The GLM Procedure

Duncan's Multiple Range Test for GH

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0

Number of Means	2	3
Critical Range	0	0

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	MOIST
A	47.04	6	14
B	38.90	6	16
C	37.49	6	12

The SAS System 10:10 Thursday, December 3, 2020 20

The GLM Procedure

Duncan's Multiple Range Test for RF

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0

Number of Means	2	3
Critical Range	0	0

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	MOIST
A	68.88	6	14
B	63.53	6	12
C	55.82	6	16

The SAS System 10:10 Thursday, December 3, 2020 21

The GLM Procedure

Duncan's Multiple Range Test for MR

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	0.812833

Number of Means	2	3
Critical Range	1.134	1.187

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	MOIST
A	71.8950	6	14
A			
A	71.8250	6	16
B	70.5433	6	12

The SAS System 10:10 Thursday, December 3, 2020 22

The GLM Procedure

Duncan's Multiple Range Test for HRR

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	12
Error Mean Square	1.793356

Number of Means	2	3
Critical Range	1.685	1.763

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	MOIST
	A	87.0433	6	14
	A			
B	A	86.2983	6	16
B				
B		84.9450	6	12

The GLM Procedure

Level of VAR	Level of MOIST	N	BD Mean	BD StdDev	AR Mean	AR StdDev
FARO44	12	3	0.53333333	0.01527525	31.0000000	0.00000000
FARO44	14	3	0.54483333	0.01527525	32.0000000	0.00000000
FARO44	16	3	0.57266667	0.02309401	32.0000000	0.00000000
JAMILA	12	3	0.53010000	0.00000000	30.0000000	1.00000000
JAMILA	14	3	0.53066667	0.02050203	30.3333333	1.15470054
JAMILA	16	3	0.53920000	0.01545057	31.0000000	0.00000000

Level of VAR	Level of MOIST	N	GD Mean	GD StdDev	GH Mean	GH StdDev
FARO44	12	3	3.61766667	0.00057735	38.1000000	2.052162E-15
FARO44	14	3	3.78433333	0.00115470	49.0000000	0.000000E+00
FARO44	16	3	3.67366667	0.00057735	36.2700000	2.052162E-15
JAMILA	12	3	3.76766667	0.00057735	36.8800000	2.052162E-15
JAMILA	14	3	3.78600000	0.00953939	45.0700000	2.052162E-15
JAMILA	16	3	3.73966667	0.00461880	41.5300000	0.000000E+00

Level of VAR	Level of MOIST	N	RF Mean	RF StdDev	MR Mean	MR StdDev
FARO44	12	3	59.4600000	2.052162E-15	70.1533333	0.39106692
FARO44	14	3	64.6800000	0.000000E+00	70.9233333	0.18230012
FARO44	16	3	48.9200000	4.101319E-15	70.8933333	0.32959571
JAMILA	12	3	67.6000000	0.000000E+00	70.9333333	1.95860495
JAMILA	14	3	73.0700000	0.000000E+00	72.8666667	0.22007574
JAMILA	16	3	62.7200000	0.000000E+00	72.7566667	0.83524448

Level of VAR	Level of MOIST	N	HRR Mean	HRR StdDev
FARO44	12	3	85.6566667	1.24226943
FARO44	14	3	87.1600000	0.89604687
FARO44	16	3	87.4900000	0.20074860
JAMILA	12	3	84.2333333	2.35818433
JAMILA	14	3	86.9266667	0.35725808
JAMILA	16	3	85.1066667	1.63860713

The GLM Procedure
Least Squares Means

VAR	BD LSMEAN	Standard Error	Pr> |t|
FARO44	0.55027778	0.00554285	<.0001
JAMILA	0.53332222	0.00554285	<.0001

VAR	AR LSMEAN	Standard Error	Pr> |t|
FARO44	31.6666667	0.2078699	<.0001
JAMILA	30.4444444	0.2078699	<.0001

VAR	GD LSMEAN	Standard Error	Pr> |t|
FARO44	3.69188889	0.00145721	<.0001
JAMILA	3.76444444	0.00145721	<.0001

VAR	GH LSMEAN	Standard Error	Pr> |t|
FARO44	41.1233333	0.0000000	.
JAMILA	41.1600000	0.0000000	.

VAR	RF LSMEAN	Standard Error	Pr> |t|
FARO44	57.6866667	0.0000000	.
JAMILA	67.7966667	0.0000000	.

VAR	MR LSMEAN	Standard Error	Pr> |t|
FARO44	70.6566667	0.3005242	<.0001
JAMILA	72.1855556	0.3005242	<.0001

VAR	HRR LSMEAN	Standard Error	Pr> |t|
FARO44	86.7688889	0.4463874	<.0001
JAMILA	85.4222222	0.4463874	<.0001

The GLM Procedure
Least Squares Means

MOIST	BD LSMEAN	Standard Error	Pr> |t|
12	0.53171667	0.00678858	<.0001
14	0.53775000	0.00678858	<.0001
16	0.55593333	0.00678858	<.0001

MOIST	AR LSMEAN	Standard Error	Pr> |t|
12	30.5000000	0.2545875	<.0001
14	31.1666667	0.2545875	<.0001
16	31.5000000	0.2545875	<.0001

MOIST	GD LSMEAN	Standard Error	Pr> |t|
12	3.69266667	0.00178471	<.0001
14	3.78516667	0.00178471	<.0001
16	3.70666667	0.00178471	<.0001

MOIST	GH LSMEAN	Standard Error	Pr> |t|
12	37.4900000	0.0000000	.
14	47.0350000	0.0000000	.
16	38.9000000	0.0000000	.

MOIST	RF LSMEAN	Standard Error	Pr> |t|
12	63.5300000	0.0000000	.
14	68.8750000	0.0000000	.
16	55.8200000	0.0000000	.

MOIST	MR LSMEAN	Standard Error	Pr> |t|
12	70.5433333	0.3680655	<.0001
14	71.8950000	0.3680655	<.0001
16	71.8250000	0.3680655	<.0001

The GLM Procedure
Least Squares Means

MOIST	HRR LSMEAN	Standard Error	Pr> |t|
12	84.9450000	0.5467107	<.0001
14	87.0433333	0.5467107	<.0001
16	86.2983333	0.5467107	<.0001

VAR	MOIST	BD LSMEAN	Standard Error	Pr> |t|
FARO44	12	0.53333333	0.00960050	<.0001
FARO44	14	0.54483333	0.00960050	<.0001
FARO44	16	0.57266667	0.00960050	<.0001
JAMILA	12	0.53010000	0.00960050	<.0001
JAMILA	14	0.53066667	0.00960050	<.0001
JAMILA	16	0.53920000	0.00960050	<.0001

VAR	MOIST	AR LSMEAN	Standard Error	Pr> |t|
FARO44	12	31.0000000	0.3600411	<.0001
FARO44	14	32.0000000	0.3600411	<.0001
FARO44	16	32.0000000	0.3600411	<.0001
JAMILA	12	30.0000000	0.3600411	<.0001
JAMILA	14	30.3333333	0.3600411	<.0001
JAMILA	16	31.0000000	0.3600411	<.0001

VAR	MOIST	GD LSMEAN	Standard Error	Pr> |t|
FARO44	12	3.61766667	0.00252396	<.0001
FARO44	14	3.78433333	0.00252396	<.0001
FARO44	16	3.67366667	0.00252396	<.0001
JAMILA	12	3.76766667	0.00252396	<.0001
JAMILA	14	3.78600000	0.00252396	<.0001
JAMILA	16	3.73966667	0.00252396	<.0001

VAR	MOIST	GH LSMEAN	Standard Error	Pr> |t|
FARO44	12	38.1000000	0.0000000	.
FARO44	14	49.0000000	0.0000000	.
FARO44	16	36.2700000	0.0000000	.
JAMILA	12	36.8800000	0.0000000	.
JAMILA	14	45.0700000	0.0000000	.
JAMILA	16	41.5300000	0.0000000	.

The GLM Procedure
Least Squares Means

VAR	MOIST	RF LSMEAN	Standard Error	Pr> |t|
FARO44	12	59.4600000	0.0000000	.
FARO44	14	64.6800000	0.0000000	.
FARO44	16	48.9200000	0.0000000	.
JAMILA	12	67.6000000	0.0000000	.
JAMILA	14	73.0700000	0.0000000	.
JAMILA	16	62.7200000	0.0000000	.

VAR	MOIST	MR LSMEAN	Standard Error	Pr> |t|
FARO44	12	70.1533333	0.5205232	<.0001
FARO44	14	70.9233333	0.5205232	<.0001
FARO44	16	70.8933333	0.5205232	<.0001
JAMILA	12	70.9333333	0.5205232	<.0001
JAMILA	14	72.8666667	0.5205232	<.0001
JAMILA	16	72.7566667	0.5205232	<.0001

VAR	MOIST	HRR LSMEAN	Standard Error	Pr> |t|
FARO44	12	85.6566667	0.7731657	<.0001
FARO44	14	87.1600000	0.7731657	<.0001
FARO44	16	87.4900000	0.7731657	<.0001
JAMILA	12	84.2333333	0.7731657	<.0001
JAMILA	14	86.9266667	0.7731657	<.0001
JAMILA	16	85.1066667	0.7731657	<.0001

The CORR Procedure

7 Variables: BD AR GD GH RF MR HRR

Simple Statistics

Variable	N	Mean	StdDev	Sum	Minimum	Maximum	Label
BD	18	0.54180	0.02061	9.75240	0.51000	0.58600	BD
AR	18	31.05556	0.93760	559.00000	29.00000	32.00000	AR
GD	18	3.72817	0.06433	67.10700	3.61700	3.79700	GD
GH	18	41.14167	4.76166	740.55000	36.27000	49.00000	GH
RF	18	62.74167	7.69847	1129	48.92000	73.07000	RF
MR	18	71.42111	1.29453	1286	69.34000	73.58000	MR
HRR	18	86.09556	1.65814	1550	81.77000	88.19000	HRR

Pearson Correlation Coefficients, N = 18
Prob> |r| under H0: Rho=0

	BD	AR	GD	GH	RF	MR	HRR
BD	1.00000	0.36040	-0.20584	-0.17202	-0.62808	-0.16705	0.41896
BD		0.1418	0.4125	0.4949	0.0053	0.5076	0.0835
AR	0.36040	1.00000	-0.24496	0.18299	-0.57765	-0.08293	0.52459
AR	0.1418		0.3272	0.4674	0.0121	0.7436	0.0254
GD	-0.20584	-0.24496	1.00000	0.63737	0.71759	0.46339	-0.00032
GD	0.4125	0.3272		0.0044	0.0008	0.0528	0.9990
GH	-0.17202	0.18299	0.63737	1.00000	0.54114	0.30895	0.30673
GH	0.4949	0.4674	0.0044		0.0204	0.2122	0.2157
RF	-0.62808	-0.57765	0.71759	0.54114	1.00000	0.40766	-0.22412
RF	0.0053	0.0121	0.0008	0.0204		0.0931	0.3713
MR	-0.16705	-0.08293	0.46339	0.30895	0.40766	1.00000	0.17878
MR	0.5076	0.7436	0.0528	0.2122	0.0931		0.4778
HRR	0.41896	0.52459	-0.00032	0.30673	-0.22412	0.17878	1.00000
HRR	0.0835	0.0254	0.9990	0.2157	0.3713	0.4778	

APPENDIX D

Student-Newman-Keuls test

```
"General Analysis of Variance."
BLOCK Rep
TREATMENTS Moist*Var
COVARIATE "No Covariate"
ANOVA [PRINT=aovtable,information,means; FACT=32; CONTRASTS=7;
PCONTRASTS=7; FPROB=yes;\
 PSE=diff] AR
```

Tables of means

Variate: GD

Grand mean 3.72811

Moist	**1**	**2**	**3**
	3.70667	**3.78500**	**3.69267**

Var	**1**	**2**
	3.69178	**3.76444**

Moist	**Var**	**1**	**2**
1		**3.67367**	**3.73967**
2		**3.78400**	**3.78600**
3		**3.61767**	**3.76767**

Tables of means

Variate: GH

Grand mean 41.1406

Moist	1	2	3
	38.9000	47.0350	37.4867

Var	1	2
	41.1233	41.1578

Moist	Var	1	2
1		36.2700	41.5300
2		49.0000	45.0700
3		38.1000	36.8733

Tables of means

Variate: RF

Grand mean 62.74

Moist	1	2	3
	55.82	68.88	63.53

Var	1	2
	57.69	67.80

Moist	Var	1	2
1		48.92	62.72
2		64.68	73.07
3		59.46	67.60

APPENDIX E:

Showing the Secondary and primary drying as well as the quality testing equipment and operation Activities respectively.

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Plate 3.6: Secondary Conventional Drying of the Collected Samples

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Plate 3.7: On Farm Primary Conventional Drying of the Harvested Paddy Rice

Plate 3.8: The Arrangement (Comprising the Test husker, Test mill and Test Grader machine) Set up for the Quality Analysis

Plate 3.9: Test Husking Operation to Obtain Brown Rice

Plate 3.10: Milled Rice Samples after the Milling Operation

Plate 3.11: Head Rice Samples Obtained using the Rice Grading Machine