QUALITY AND ACCEPTABILITY OF NEW RICE VARIETIES (*Oryza sativa* L.) IN KILOMBERO DISTRICT, MOROGORO TANZANIA

JUMA WENELA

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FOOD SCIENCE OF THE SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

2013

ABSTRACT

The objectives of this work were to study the quality and acceptability of new rice varieties (*Oryza sativa* L.). The rice varieties (TXD88, NERICA4, NERICA1, TXD85 and TXD306) were analyzed for rough rice quality indices, proximate composition, milling quality, cooking time, physicochemical properties and sensory evaluation. The rough rice quality indices were 5.96 – 14.62% (immature grains); 30.91 – 36.78g (1000 grains' weight); 7.81 – 9.05mm (length) and 3.14 – 3.65 (length/width ratio). All five varieties with respect to rough rice quality indices were good. The proximate composition for the five varieties were variable with respective ranges being 11.86 – 13.40%; 7.41 – 9.00%; 0.77 – 1.02%; 1.73 – 3.01%; 1.14 – 1.23%; and 74.25 – 76.97% for moisture, crude protein, crude fibre, crude fat, ash and NFE respectively. These were found to be significantly different except for ash content ($P < 0.05$). The results revealed that the five varieties had proximate composition not far from those documented varieties. The milling quality parameters were 0.001 – 0.304%; 0.61 – 3.20%; 15.46 – 57.16%; 14.75 – 55.05% and 65.65 – 70.31% for dockage, chalkiness, brokens, head rice and total recovery respectively. All 5 varieties were significantly different ($P < 0.05$) in the measured milling quality indices with variety TXD88 ranking highest in all milling parameters. The cooking time for the 5 varieties ranged from 19.34 – 24.14 min with variety NERICA1 being the best by having the shortest cooking time and the worst being TXD85 which had the highest cooking time. The rest of the 3 varieties had intermediate cooking times that were not significantly different ($P < 0.05$). The physicochemical properties values were 15.03 – 27.25% (amylose); 37.33 – 84.00mm (gel consistency) and 2 – 4 (ASV). All were significantly different ($P < 0.05$). Based on these results NERICA varieties were higher in amylose content. Sensory evaluation results showed that TXD88 was the most significantly preferred compared to other varieties. The preference was significantly different ($P < 0.05$) for all sensory attributes. It was concluded in this study that TXD88 was best in sensory quality, milling processes and low amylose content. Also, NERICA varieties were higher in protein and amylose content and TXD306, NERICA4 and TXD88 had gel consistency values implying that they are soft when cooked. TXD88 variety was the best rice variety due to its low amylose content and scored high in taste. This is consistent with the principle that there is an inverse relationship between amylose content and taste.

DECLARATION

I, **Juma Wenela** do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution for a degree award.

Mr. Juma Wenela — Date

(MSc. Candidate)

The above declaration confirmed

Prof. E.E. Maeda — Date

(Supervisor)

COPYRIGHT

ACKNOWLEDGEMENT

As there are so many individuals who have contributed to the successful completion of this dissertation it is impossible to mention all their names. I will therefore express my thanks to some of them.

I am initially expressing my thanks to the Almighty God for taking me this far in my academic sojourn notwithstanding myriads of challenges.

I wish to express my sincere gratitude and respect to my supervisor Professor E.E. Maeda (Sokoine University of Agriculture) for his kindness, ideas, patience and knowledgeable advice throughout my dissertation. I am thankful for his willingness to take time to make suggestions and rally round me to achieve my research study goals. His knowledge and experience through the long discussions that we had, have greatly contributed to the quality of this work.

I am also expressing my unreserved appreciation to my Sponsor, The Belgium Technical Corporation (BTC) for the financial support towards this study. I wish to express my profound gratitude to the Ministry of Agriculture, Food Security and Cooperatives (MAFC) for granting me leave to pursue postgraduate studies culminating to the award of MSc. degree.

I articulate my sincere thanks to the staff of Food Science and Technology for their inputs and encouragement during proposal presentation. I wish to spot the support from Mr.

Kategile, P., Mr. Mufui, G., Mr. Kessy, T.T. and Mr. Ndomondo, M. for their assistance in material collection and chemical analyses.

I wish to extend my sincere admiration to my very special contemporaries of MSc. Food Science 2010 – 2012, John George Komakoma, Daniel Willium Ndiyo, Zenobius Slyvester Kahere and Erasto Isaac Mhina. Others are; Jesca George Rubugu, Emmanuela Selestine Massawe, Christina Paschal Tewele, Rita Mirondo Akinyi, Edimitha Protace Rwiza, Caresma Chuwa and Felista Joseph Mpore. To my cherished friends I appreciate your great acquaintance and countless breathtaking moments that we simultaneously shared here in Sokoine University of Agriculture (SUA).

DEDICATION

This work is dedicated to: The Lord Jesus Christ for his faithful guidance throughout my life, my exquisite father the Late Dr. Yohana Nusuhela Mwamahonje Haonga (Deceased on 2/7/1996 during my affectionate age), May the Almighty God rest his Soul in Eternal peace, Amen. Also my Mothers, Edda Yohana Mwamahonje and Anne Yohana Mwamahonje who God almighty decided to create and nurture me and through them to be what I am. Without forgetting my find irresistible Annastasia Kaberege (*My Oxygen*) and my young at heart brother Furaha Yohana Mwamahonje, for their exceedingly heartening my studies and may the Almighty God bless them all, Amen.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ACRONYMS AND SYMBOLS

ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
ARC	Africa Rice Centre
BTC	Belgium Technical Cooperation
DALDO	District Agricultural and Livestock Development Officer
DASP	Department of Animal Science and Production
DMRT	Duncan’s Multiple Range Test
FAO	Food and Agriculture Organization of the United Nations
INRA	Institut National de la Recherche Agronomique
IRRI	International Rice Research Institute
KATRIN	Kilombero Agricultural Training and Research Institute
MAFSC	Ministry of Agriculture Food Security and Cooperatives
MRCO	Morogoro Regional Commissioner’s Office
NERICA	New Rice for Africa
RLDC	Rural Livelihood Development Company
SUA	Sokoine University of Agriculture
URT	United Republic of Tanzania
URTPHC	United Republic of Tanzania Population and Housing Censuses
USAID	United States agency for International Development
FGIS	Federal Grain Inspection Services
USSRM	United States Standards for Milled Rice
WARDA	West Africa Rice Development Association
WHO	World Health Organization of the United Nations

WTO	World Trade Organization
B.C	Before Christ
n	normal (with respect to hexane and propanol)
nm	nanometre
μm	micrometre
v/v	volume by volume
w/w	weight by weight
ppb	parts per billion
M	Molarity
W	Watt
L	Litre
N	Normality
R^2	Coefficient of determination
χ^2	Chi–square
Kcal	Kilocalories
KJ	Kilojoules
KI	Potassium Iodide
NaOH	Sodium Hydroxide
KOH	Potassium hydroxide
$CuSO_4$	Copper Sulphate
K_2SO_4	Potassium Sulphate
HCl	Hydrochloric acid

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Rice (*Oryza sativa* L.) is one of the most important staple food crops for half of humanity and dietary mainstay of mankind, which provides more than one half of dietary protein to people (Fresco, 2005). Rice provides about 75% of the calories and 55% of the protein in the average daily diet of the people (Kaul, 2002). Moreover, it is one of the most important staple cereals in human nutrition, consumed by about 75% of the global population (Anjum *et al.,* 2007). In many countries essential development efforts are concentrated on rice to meet domestic needs for food. In the developing countries of Asia, rice is also an important item of international trade (FAO and Juliano, 1993). Currently, rice is grown in over 75% of the African countries with a total population close to 800 million people (Wilfred and Consultant, 2006).

In Tanzania total area under rice cultivation in 2005 was 702 000 hectares of which 90% is under small scale farmers and the rest under large scale (MAFC, 2009). The leading rice cultivation regions in Tanzania are Shinyanga, Tabora, Mwanza, Mbeya, Rukwa and Morogoro. The Kilimanjaro, Arusha, Manyara, Iringa, Mara, Tanga and Kigoma regions also contribute to the total rice production to a lesser extent (MAFC, 2009). Rice while an important staple in Tanzania, is considered a more affluent food product. As Tanzania urbanizes and the population becomes more prosperous, the demand for rice has grown. Unlike maize, rice is viewed as more of a cash crop despite the fact that many rice producers also grow rice for consumption and for sale (USAID, 2010).

Rice quality refers to many aspects ranging from physical; (shape, length, width, brokenness, partial milled, chalkiness and contaminants), physicochemical; (amylose, gel consistency, gelatinization temperature and cooking time), nutrients content; (moisture, protein, fat, minerals and others), sensory; (colour, texture, aroma, mouth feel, taste and acceptability) and milling behaviours. Different countries have their own measures of rice quality and systems of control, but such systems and control lack uniformity among countries. Lack of uniformity renders its international trade more difficult and less transparency creates areas of argument concern as well as uncertainty, and therefore planning for national supply is fraught with pitfalls (Lee, 2001). The future demand for rice as a dietary protein will increase due to projected increase in world population.

Rice grain quality denotes different properties to various groups in the post–harvest system (Juliano and Duff, 1989). To the farmers, refer to quality of seed for planting material and dry grain for consumption, with minimum moisture, microbial deterioration and spoilage. The millers or traders look for low moisture, variety integrity and high total and head milled rice yield. Market quality of rice is mainly determined by physical properties and variety name, whereas cooking and eating quality is determined by physicochemical properties, particularly apparent amylose content. Nutritional value is mainly determined by the milled rice protein content. Consumers in all the countries studied by Juliano *et al.* (1989) prefer higher head rice yield and more translucent grains. Although variety is the principal factor contributing to grain quality, good post–harvest handling can maintain or even improve it. High income consumers pay higher premiums for a larger number of quality characteristics than low income consumers, reflecting their ability to pay. Preferences do vary much across income levels; with one exception of lower income consumers buy rice which is of low quality.

1.2 Problem Statement and Justification

Most of the developing countries, Tanzania being one suffer much on the rice quality. Rice quality is one of the most important characters, as it exerts large effect on the market value and consumer acceptance. Next to yield, grain quality is the most important factor considered by plant breeders. Although the demand for rice is likely to increase, the rice breeding stations and institutions had tried to improve indigenous rice and release new rice varieties, the form and quality of the rice varieties that meet consumer preferences are not fully known. Experience shows that, the rice plant covered by the term grain quality to a large extent determines market price and acceptance by the consumers (Tokpah, 2010).

Despite there being new improved rice varieties (NERICA1, NERICA2, NERICA4, NERICA7 and NERICA WAB 450), semi–aromatic varieties (SARO comprising of varieties TXD306, TXD88 and TXD85 in Kilombero District, experience shows that quality attributes on new rice varieties have not being taken aboard. Following increases in yield of new rice varieties in Tanzania, quality of the grain has turned to be a looming crisis and some other quality attributes recently emerged to become important constraints to the rice production claiming between 10 – 40% yield losses due to poor quality (De Padua, 1979). High yield alone without good grain qualities is however, regarded inadequate as the two have an influence in adoption of a particular rice grain variety. This study is intended to provide farmers and consumers information on quality attributes associated with new rice varieties.

1.3 Objectives

1.3.1 General objective

The general objective of the study is to assess the quality and acceptability of the new rice varieties (*Oryza Sativa* L.) in Kilombero District.

1.3.2 Specific objectives

The targeted specific objectives that were investigated are:

i. To conduct a survey on quality knowledge of farmers, rice milling operators, cooked rice vendors and consumers which have influence on new rice variety acceptability;

ii. To establish the post–harvest physical characteristics of the new rice varieties so that the consumers will know expressly the difference and physical quality of each new rice variety;

iii. To assess the nutrient contents in the new rice varieties so that will persuade the consumers on acceptability of the new rice varieties and their products;

iv. To differentiate the milling characteristics the new rice varieties so as to give information and acceptability on milling quality and behaviours to rice millers operators;

v. To ascertain the physicochemical characteristics of the new rice varieties of which are highly correlated with eating quality so as to enable end–users to have knowledge and be able to manage that quality in rice food chain and

vi. To evaluate the cooking time and sensory attributes of the new rice varieties of which will influence consumers, cooked rice vendors and traders to be in position to accept new rice varieties with good eating characteristics.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rice

Rice is the monocot seed plant of the genus *Oryza* and of the grass family Poaceae (formally Graminae) which includes twenty wild species and two cultivated ones; *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice) (Oko and Ugwu, 2011). *Oryza sativa* is the most commonly grown species throughout the world today. Rice has been considered the best staple food among all cereals and is the staple food for over three billion people constituting over half of the world's population (Cantral and Reeves, 2002, cited by Oko and Ugwu, 2011). Rice grows from the Equator of Latitudes 53^{o}N (in China) and 35 – 40^{o}S to elevations (in tropical regions) as high as 2400 meters above sea level (Kenmore, 2003). Rice is the world's most consumed cereal after wheat, provides more than 50% of the daily calories ingested by more than half of the world population (Sun *et al.,* 2006). It is so important in Asia that it influence local language and beliefs. In classical Chinese, the same term refers to both "rice" and "agriculture". In many official languages and local dialectics the verb "to eat" means "to eat rice". Indeed, the words "rice" and "food" are sometimes one and the same in eastern semantics (INRA, 2008).

Rice (*Oryza sativa* L.) is recognized as a source of starch in the diet and is generally consumed as either whole grain or as flour ingredients. Rice varieties have different qualities that suit different food applications. Just in recitation, the above selection of grains in the marketplace, many rice grain qualities have to be mentioned. Physical grain qualities include grain shape, translucency and whiteness of the grain. To rice consumers cooking qualities include texture when hot and cold, cooking time and digestibility (Ward, 2009). While grain qualities are genetically inherited, environmental conditions, agronomic practices, grain handling and storage affect grain quality (Ward, 2009). Rice genetic resources are important reservoirs of genes and could be exploited to broaden the existing narrow genetic base and to enrich the existing varieties with important favorable traits (Zeng *et al.*, 2007).

2.2 Rice Origin and Distribution

Rice (*Oryza sativa* L.) was probably first domesticated in the Yangtze River Valley in China (Vaughan *et al.*, 2008), perhaps about 7000 years ago, after which it spread to other parts of Asia. Rice has been gathered, cultivated and consumed by women and men worldwide for more than 10 000 years longer than any other crop (Kenmore, 2003). The general consensus is that, rice domestication occurred independently in China, India and Indonesia, thereby giving rise to three races of rice; *sinica* (also known as *japonica*), *indica* (in India) and *javanica* (also known as *bulu* in Indonesia). In the beginning rice grew wild, but today most countries cultivate different varieties belonging to the *Oryza* type which has around twenty different species. Only two of them offer an agriculture interest for humans; *Oryza sativa*; common Asian rice found in most rice producing countries which originated in the Far East at the foot of the Himalayas. *O. sativa japonica* grew on the Chinese side of the mountains and *O. sativa indica* on the Indian side. The majority of the cultivated varieties belong to this species, which is characterized by its plasticity and taste qualities.

Oryza glaberrima Steud, an annual species originating in West Africa covering a large region extending from the central Delta of the Niger River to Senegal. Between 1500 and 800 B.C. the African species *Oryza glaberrima*, propagated from its original center the Delta of Niger River and extended to Senegal (Porteres, 1956). However, it never developed far from its original region, its cultivation even declined in favour of the Asian species possibly brought to the African continent by the Arabians coming from the East Coast from the 7th to 11th centuries.

2.3 Rice Classification

There are two rice varieties grown across the world with the most dominant being *O. Sativa* species grown mostly in Asia and the species *O. glaberrima* being confined to Africa. In the African region *O. glaberrima* varieties are fast being replaced by the *O. sativa*, which has much higher yields than the *O. glaberrima* a characteristic that has prevailed over the special advantages afforded by the *O. glaberrima* in the form of weed tolerance, pest resistance or fast maturing growth (Linares, 2002). In the late 1990s, the West Africa Rice Development Association (WARDA) which in recent times has broadened its role in the whole of Africa to be the African Rice Centre (ARC), managed to cross the two species (*O. glaberrema* and *O. Sativa*) into an inter–species hybrid called "NERICA" (standing for "New Rice for Africa") which combines the ruggedness of local African rice with the high productivity of the Asian rice.

2.4 Global Rice Production

Rice is grown and harvested on every continent except Antarctica, where conditions make its growth impossible (Abbas *et al.*, 2011). Rice (*Oryza sativa* L.) is one of the leading crops in the world and a close second to wheat in importance as a cereal staple (Toriyama *et al.*, 2005). The world's population exceeds 6.5 billion individuals and over half are dependent on rice for at least a portion of their diet for the rice industry, a high quality rice product at a profitable price is the goal (Fairhurst and Dobermann, 2002). The majority of all rice produced comes from India, China, Japan, Indonesia, Thailand, Burma and

Bangladesh. Rice cultivation is the principal activity and source of income for millions of households around the globe and several countries of Asia and Africa are highly dependent on rice as a source of foreign exchange earnings and government revenue. Asia is the biggest rice producer accounting for 90% of the world's production and consumption of rice (Paranthaman *et al.,* 2009). China and India which account for more than one–third of global population supply over half of the world's rice. In 2009 with favourable growing conditions and improved economic incentives, the global rice cultivated area was forecasted to rise by 1.5% from 156.3 to 158.6 million hectares and the yield by 2.4% from 4.2 to 4.3 tonnes of paddy per hectare (FAO, 2008).

2.5 Rice Production in Africa

Rice has become a commodity of strategic significance across to a large extent of Africa driven by changing food preferences in the urban and rural areas compounded by high population growth rates and rapid urbanization. According to FAO (2008) statistics reported in the Rice Market Monitor between 2000 and 2008 production of milled rice grew by 59% from 4.6 – 7.2 million metric tonnes. In the same period consumption grew from 9.6 – 13.3 million metric tonnes a 38% increase (FAO, 2008). Rice statistics in West Africa are notoriously unreliable, however and other analysts maintain that, the gap between production and consumption is actually growing (Campbell *et al.*, 2009). Based on this overall global trend, the rice has been forecasted to reduce its prices (MAFC, 2009). According to Wilfred and Consultant (2006), rice is the main staple food of the populations in Cape Verde, Comoros, Gambia, Guinea, Guinea–Bissau, Liberia, Madagascar, Egypt, Reunion, Senegal and Sierra Leone and is also an important food of the populations in Côte d'Ivoire, Mali, Mauritania, Niger, Nigeria, and Tanzania. In addition, rice has become an important food security factor in Angola, Benin, Burkina Faso, Chad, Ghana and Uganda.

2.6 Rice Production in Tanzania

The Tanzania rice production sector is a success story among countries that have recently started to adopt rice on a major scale, have had a long tradition of rice cultivation (MAFC, 2009). In Tanzania, rice is one of the far and wide grown crops and is the second most important food crop in terms of number of households, area planted and production volume (RLDC, 2009). Priority areas of rice production are grouped addicted to three major rice ecosystems/ecologies. These are presented in order of priority as irrigated lowland ecosystem which is 8% of suitable land, upland ecosystem which is 20% of suitable land and rain–fed lowland ecosystem which covers 72% of suitable land for rice production which is 21 million hectares (MAFC, 2009).

Besides meeting local consumption demands, rice sector is a major source of income and employment in rural areas. In East and Southern Africa (ESA), Tanzania is the second rice producer after Madagascar, with a production of 900 000 tonnes for a total area under cultivation of 681 000 hectares in 2008 (ARC, 2009). With the population of approximately 40 million, annual growth rate of 2.8% and annual milled rice consumption per capita of 25kg, the forecasted production to meet demand is expected to increase annually at around 100 000 tonnes of milled rice (CARD, 2009).

Consumption of rice is gradually increasing and the per capita consumption in 2007 was 25.4 kg. Self Sufficiency Ratio (SSR) is 84.5% while a recommended level of SSR is above 120% for ensuring a country's sustainable food availability (MAFC, 2009). Identified gaps to meet local demand are usually met through imports; for example, to meet the domestic demand in 2001 – 2005, fifty thousand to hundred thousand tonnes of milled rice were imported (URT, 2009). Therefore, there is growing concern about the foreign currency drain resulting from rice import. To avoid the foreign exchange drain and negative impact of an unstable global market, the Tanzanian Government is now seriously considering increasing her self–sufficiency ratio of rice. The surplus harvest is expected to be exported and earn foreign exchange (MAFC, 2009). The demand and supply situation of the rice market in Tanzania shows that, there is high demand that cannot be sufficiently supplied by the local production; varying from a self sufficiency ratio of over 80% in good years, where as in bad years only about two third of the consumption is produced in the country and the rest has been supplied by the imports (RLDC, 2009).

2.7 Rice Varieties

The TXD306 is a high yielding variety (SARO 5) which is an improved grain quality and aromatic highly preferred by consumers and farmers. The TXD85 and TXD88 varieties lack acceptable aroma notwithstanding being endowed with improved grain quality and high yielding varieties improved at KATRIN from the *O. sativa* species (MAFC, 2009). For the New Rice for Africa (NERICA) varieties WARDA found it is highly necessary to combine the toughness of *O. glaberrima* due to its rich reservoirs of genes for resistance to local stresses (although low yielding) with *O. sativa*, the productive one in spite of its low adaptability to rain–fed uplands (WARDA, 2004). This was a formidable scientific challenge which had resulted in the failure of previous attempts to develop a reliable variety since the two species have evolved separately over millennia and is so different. NERICA has unique combined assets such as: higher yields (by 50% without fertilizer and more than 200% with fertilizer), earlier maturity (by 30 – 50days), resistance to local stresses and higher protein content by 25% (WARDA, 2004).

2.8 Rice Quality

Rice grain quality is determined by a combination of varietal properties and environmental conditions which occur during crop production, harvesting, processing and handling (Gummert, 2010). Varietal properties include: chemical characteristics (gelatinization temperature, apparent amylose content, gel consistency, alkali spreading value and aroma); physical characteristics are shape and size, colour of grain, chalkiness, bulk density, thermal conductivity, equilibrium moisture content and grain flow–ability (IRRI, 2010). Environmental properties are either additional to the normal varietal qualities or are the consequence of certain varietal qualities being lost or modified during processing (Gummert, 2010). Important environmental reduced properties are: moisture content, grain purity, physical and pest damage, cracked grains, presence of immature grains (IRRI, 2009b). The milling–related characteristics (head rice recoveries, grain dimensions, whiteness, milling degree and chalkiness) are likely affected by environmental changes (Siebenmorgen *et al.*, 2007). Milling–related characteristics are relevant measures of value because these are of major concern to consumers (IRRI, 2009a). Rice quality therefore, can be divided into five broad descriptive categories; these interrelated categories are milling quality, cooking and eating quality, processing quality, nutritive quality and purity/cleanliness standards (Siebenmorgen *et al.*, 2007). Each category is described by a specific set of criteria that collectively determine the suitability of rice for a specific end–user. The quality of grain is best when it reaches physiological maturity (Pan *et al.*, 2007). Poor management from that point forward determines the rate of decline in quality but is unable to stop some decline in quality from occurring.

2.8.1 Rice post harvest handling practices

2.8.1.1 Rice drying

The first secret to successful processing and storage of post harvested rice is drying the grain to an optimum moisture level of 12 – 14% weight/weight (w/w) (Mabbett, 2011). Moisture content within this range is sufficiently low to inhibit enzyme and microbial activity during storage. In order to prevent postharvest deterioration paddy should be dried to a water activity of 0.7 that will facilitate safe storage by reducing respiration, inhibiting mould growth and preventing production of mycotoxins (Magan *et al.,* 2004). In addition, low water activity (a_w) enhances easy removal of the outer covering (bran or husk) by hulling with minimum breakage of grains to give good quality shelled rice. It would be ideal to develop a drying method that can concurrently accomplish drying and disinfestations of harvested rough rice with high rice milling quality.

2.8.1.2 Rough rice cleaning

Cleaning of the rice to remove foreign seeds and trashes is important because of their subsequent effects on the storability and milling quality. Rice with impurities is more likely to deteriorate in storage. Impurities also reduce the milling recovery rates, particularly if stones are mixed with the rice. Unclean rice also increases the maintenance requirements on the milling machines and replacement of spare parts. Cleaning is mostly done by hand winnowers, which take an advantage of windy conditions. Other rough rice cleaners include winnowing basket, wooden or metal boxes with perforations and combination of the above (Duff and Toquero, 1975). In some areas, a manually operated wooden winnower is used for cleaning paddy. These are not equipped with screens and high air velocities are used to blow away most of the impurities (Khan, 1973).

2.8.1.3 Rice storage

Rice is harvested from the field and threshed to produce what is most often called paddy rice or rough rice. Rice is usually harvested at about 18 – 24% moisture content and must be dried to about 12 – 14% so that it can be stored safely (IRRI, 2009a). Quantitative losses in storage are defined as grains lost to birds, rodents and insects and in some cases theft. Qualitative losses in storage are discoloration, aroma deterioration and cracking of grains and this include the reduction in germination rate.

2.8.2 Rough rice quality indices

2.8.2.1 Immature rough rice

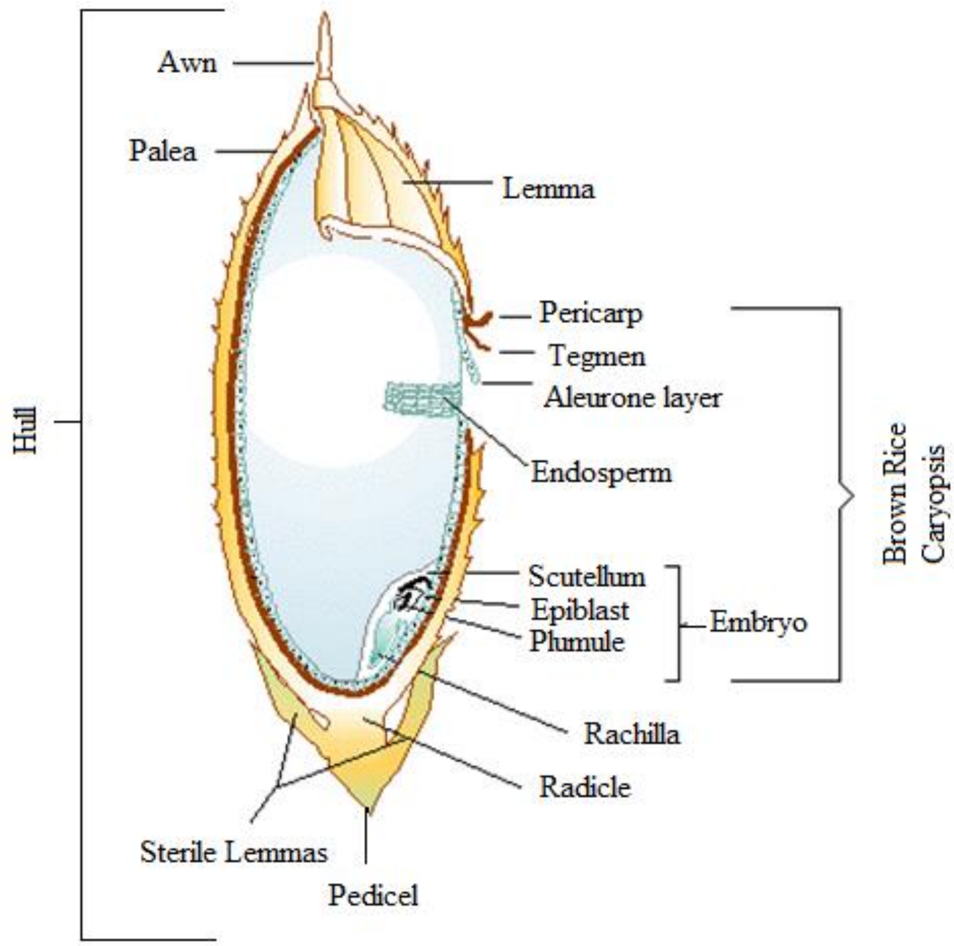
The immature rice kernels are very slender and chalky, and this results in excessive production of bran, broken grains and brewer's rice. Thus, the amount of immature paddy grains in a lot to be milled, has a major effect on head rice yield, milling, rice kernel weight and quality (Bautista and Siebenmorgen, 2005). According to IRRI (2009a), the optimal stage to harvest grain is at about 20 – 24% grain moisture or about 30 days after flowering; after that, the harvest is too late, many grains are lost either due to shattering divices drying or cracking during threshing, both scenarios lead to grain breakage during milling. Early–maturing rice grains are very prone to shattering (dropping from the seed head) before the later–maturing grains ripen (USDA, 1996). Mature kernels on a panicle exist at very different moisture content levels representing different maturity and kernel strength levels differently (Bautista and Siebenmorgen, 2005). Immature kernels can be a source of milling quality reduction because for being typically weak in structure and often break during milling (Siebenmorgen *et al*., 2006). Also, immature rice grains are green but turn to purple black colour as at maturity. Rice grains on any given stem mature at different times and on the secondary stems they mature later than on the main stems.

2.8.2.2 1000 grains' rice weight

According to Hill (2005), rice kernel weight differs among varieties in the variety section from a 1000 kernels weight for the small seeded rice variety *Koshihikari* 23.8g to M–401 and S–102 at 32g and 34g respectively. However, rice kernel weight can be reduced by poor management or bad luck (such as draining too soon or from drying the field (Jafari *et al.,* 2007). Fields that is too dry at the end of the harvest can limit grain filling and reduce rice kernel weight and quality.

2.8.2.3 Rice grains' shape and size

There are two factors contributing to the appearance of a rice grain and these being its length and shape. The length of the paddy grain is variable even within a variety, attributed to variation in lengths of the awn and the pedicel (Fig. 1). It is for this reason that, the type of paddy is not determined by the length of the rough grain but by the length of the brown rice kernel (IRRI, 2009b). On threshing, it is important to watch at what point the rough grain will break off its panicle, because the pedicel (the panicle bears rice spikelet, which develop into grains) should not be a part of the grain, else it will have a reduced milled rice recovery through the increase of husk production. Husking characteristics of paddy are dependent upon its shape and size (Shitanda *et al.,* 2001).



Source: IRRI (2009b).

Figure 1: Rough rice grain morphology

There is no international standard for brown rice grain size and shape. IRRI uses the following 5 scales for size: extra long, >7.50mm; long, 6.61 – 7.50mm; medium, 5.51 – 6.60mm and short, 4.50mm. Grain shape is characterized based on length–to–width ratio: slender, >3.0; medium, 2.1 – 3.0; bold 1.1 – 2.0 and round, 1.0 (FAO and Juliano, 1993). To obtain better quality–milled rice, knowledge on paddy grain physical properties is necessary for modeling of dynamic abrasion in a rice milling operation as well as for designing suitable polishing systems (Mohapatra and Bal, 2004).

2.8.3 Chemical composition of milled rice

Analysis of the accumulated chemical composition in food is important and for cereal in all cases it shows that the highest percentage proximate composition of the staple food crops is carbohydrate followed by crude protein, moisture, crude fibre, ash and fat for cereals (Table 1) while in tubers, moisture is the highest (Edeogu *et al.,* 2007). The degree of milling and polishing determines the amount of nutrients removed. Rice grain quality affects the nutritional and commercial value of grains, and is of immense importance to those involved in producing, processing and consuming rice (Yi *et al.,* 2009). Rice quality does not only imply the physical appearance or qualities, rather it encompasses both, the chemical and cooking characteristics; therefore, it is necessary to include the nutritional values derivable from rice into consideration when choosing a particular rice variety (Oko and Onyekwere, 2010). Rice at 12% moisture contains approximately 80% starch and 7% protein (Wells, 1999). Polished rice is mainly made up of starch, protein, lipid and moisture. The protein content of polished rice in 22 *japonica* rice varieties ranged from 5.9 to 7.9% and 6.0 to 13.6% in brown rice among 1518 Chinese *japonica* varieties (Lestari *et al.*, 2009). Starch occurs in the endosperm as small many–sided granules while protein is present as particles that lie between the starch granules. Starch comprises 76.7 – 78.4% in polished rice with 14% moisture content (Huang *et al.*, 1998). Rice grain also contains sugars, fat, dietary fibre and minerals. The determination of food composition is fundamental to theoretical and applied investigations in food science and technology. This is often the basis for establishing the nutritional value and overall acceptance of the food from the consumers' stand point (Aganga and Tshwenyane, 2004).

Table 1: Proximate composition of rice relative to other cereal crops

	Cereal crops					
Proximate	**Wheat**	**Corn**	**Rice**	**Rye**	**Sorghum**	**Millet**
Moisture	13.0	13.8	12.0	11.0	11.0	11.8
Protein	14.0	8.9	7.5	12.1	11.0	9.9
Fat	2.2	3.9	1.9	1.7	3.3	2.9
Ash	1.7	1.2	1.2	1.8	1.7	2.5
Fibre	2.3	2.0	0.9	2.0	1.7	3.2
NFE	69.1	72.2	77.4	73.4	73.0	72.9

Source: Lorenz and Kulp, (1991).

2.8.3.1 Moisture content in rice

Moisture content has a clear influence on all aspects of paddy and rice quality and it is essential that, paddy be milled at the proper moisture content to obtain the highest head rice yield. Paddy is at its optimum milling potential at moisture content of 14% wet weight basis (Wilfred and Consultant, 2006). Grains with high moisture content are too soft to withstand hulling pressure which results in grain breakage and possibly grain pulverization. Grain that is too dry becomes brittle and has greater breakage (Pan *et al.,* 2007). Moisture content and temperature during drying process is also critical as it determines whether small fissures and/or full cracks are introduced into the grain structure (Park *et al.,* 2001).

The standard inspection for brown rice designated the value of 15% as the maximum moisture content, it is allowed however, to be raised by 0.5% (Afsar *et al.,* 2001). Although the equilibrium moisture content of the rice grains varies depending on the preceding conditions that they have undergone, it is determined by the compactness of the tissues filled with endosperm starch. Under high humidity conditions it is higher with soft cultivars than with the hard type ones and also higher with opaque rice than with perfect rice. The equilibrium moisture content is greatly influenced by hysteresis. The value resulting from hydration as well as dehydration under an ambient relative humidity ranging from 11.1 to 86.7% was examined by Tsutsumi *et al.* (2003).

2.8.3.2 Crude protein in milled rice

Cultivars with early maturity generally exhibit a higher level of protein content compared with those with late maturity (Honjo, 1971). Among grains of different properties in appearance with an identical sample, white–belly rice also exhibits a lower content than the normal rice (Nagato *et al*., 1972). High ambient temperature (Honjo, 1971; Kataoka, 1975) and high water temperature (Honjo, 1971) increase protein content in rice. Brown rice from upland rice crops exhibited higher protein content than that of flooded rice by 30% (Taira, 1970). The reason for the difference has been related to the different conditions of irrigation. Another effect of the soil conditions has been identified in the circumstances associated with peat soil. The higher protein content was linked to the presence of peat soil (Taira *et al*., 1977).

2.8.3.3 Carbohydrate in milled rice

Starch is the major carbohydrate constituent of milled rice at about 90% (Table 2) of the dry matter (FAO and Juliano, 1993). Starch is a polymer of D–glucose linked a –1–4) α glycosidic linkage and usually consists of an essentially linear fraction, amylose, and a branched fraction, amylopectin at points a –(1–6) α glycosidic linkage (FAO and Juliano, 1993).

Starch is present for all intents and purposes only in the endosperm cells of mature rice, where it exists as compound polyhedral granules 3 – 9μm in size. De Vizia *et al.* (1975), reported good absorption of various cooked starches, including rice starch in one and three month–old infants (absorption coefficient > 99%). Similar high energy starch digestibility was observed for no waxy and waxy cooked milled rice. Thus, primary reason for cooking milled rice is to improve digestibility of the starch by destroying the crystalline structure of the starch granule.

Table 2: Proximate composition of rough rice and its milling fractions at 14 % moisture on dry weight basis (g)

	Composition parameters							
Rice fraction	**Protein**	**%Fat**	**%Fibre**	**%Ash**	**%NFE**	**Neutral detergent**	**Energy (Kcal)**	**Density (g/ml)**
Rough rice	5.8 – 7.7	1.5 – 2.3	7.2 – 10.4	2.9 – 5.2	64 – 73	16.4 – 19.2	378	1.17 – 1.23
Brown rice	7.1 – 8.3	1.6 – 2.8	0.6 – 1.0	1.0 – 1.5	73 – 87	2.9 – 3.9	363 – 385	1.31
Milled rice	6.3 – 7.1	0.3 – 0.5	0.2 – 0.5	0.3 – 0.8	77 – 89	0.7 – 2.3	349 – 373	1.44 – 1.46
Rice bran	11.3 – 14.9	15.0 – 19.7	7.0 – 11.4	6.6 – 9.9	34 – 62	24 – 29	399 – 476	1.16 – 1.29
Rice hull	2.0 – 2.8	0.3 – 0.8	34.5 – 45.9	13.2 – 21	22 – 34	66 – 74	265 – 332	0.67 – 0.74

Source: Pedersen and Eggum (1983).

2.8.3.4 Lipid in milled rice

Lipids are defined as natural substances which dissolve in an organic solvent. The lipid or fat content of rice is mainly in the bran fraction (20%, on dry matter basis), specifically as lipid bodies or spherosomes in the aleurone layer and bran. However, about 1.5 – 1.7% is present in milled rice, mainly as non–starch lipids extracted by ether, and chloroform–methanol and cold water saturated butanol (Juliano and Goddard, 1986). The major fatty acids of these lipids are linoleic, oleic and palmitic acids (Taira *et al.,* 1988). Essential fatty acids in rice oil are about 29 – 42% linoleic acid and 0.8 – 1.0% linolenic acid (Jaiswal, 1983). The content of essential fatty acids may be increased with temperature during grain development, but at the expense of reduction in total oil content (Taira *et al.,* 1979).

Glycolipids are mainly monoacyl lipids (fatty acids and lysophosphatides) complicated with amylose (Choudhury and Juliano, 1980). The glycolipid content is lowest for waxy starch granules 0.2 % and it is highest for intermediate amylose rice 1.0% and may be slightly lower in high amylose rice (Juliano and Goddard, 1986). However, glycolipids contribute little to the energy content of the rice grain. Lipids in plant seeds are mainly studied for their physiological metabolism and food nutrition.

2.8.3.5 Ash and mineral content

The ash content in proximate analysis of a food sample gives an idea of the mineral elements present in the food. Dietary fiber, minerals and B complex vitamins are highest in the bran and lowest in the aleurone layers (Noreen *et al.,* 2009). In terms of mineral element composition, potassium is the most abundant mineral found in rice followed by magnesium and calcium. Microelements include copper, iron, molybdenum, manganese and zinc (Oko and Onyekwere, 2010). Mineral contents significantly differ among rice varieties, milling fractions, soil type and growing conditions (Shabbir *et al.,* 2008). Rice also contains some important anti–nutritional factors, most of which are concentrated in the bran which includes phytate, trypsin inhibitor, oryzacystatin, and haemagglutinin–lectin (FAO and Juliano, 1993). Binding of minerals with phytic acid decrease bioavailability of Ca, Fe, P, Zn and other trace elements to human and monogastric animals. According to Fox and Tao (1989), phytic acid is usually found as a complex with essential minerals and proteins, and produce an adverse effect on the bioavailability and digestibility of these essential nutrients.

2.8.4 Milled rice quality indices

2.8.4.1 Rice milling

The basic objective of rice milling is to remove the husk and the bran layers, and produce an edible, white rice kernel that appeals to the customer. A rice milling system can be a simple one or a two step process, or a multi stage process. This process usually takes two to three cycles within a milling machine, depending on the required milling degree (Wilfred and Consultant, 2006). To improve on quality, milled rice (a mixture of different sizes of whole and broken rice grains) is separated into grades using appropriate sieves ready for storage or marketing and consumption. A commercial rice miller has the following objectives: to produce edible rice that appeals to the customer; i.e. rice that is sufficiently milled, free of dockage and maximize the total milled rice recovery out of paddy minimize grain breakage (Guisse, 2010).

2.8.4.2 Dockage

All matter other than rough rice that can be readily removed from the rough rice is known as dockage, normally achieved by the use of appropriate sieves and cleaning devices. It may also include underdeveloped, shriveled and small pieces of kernels of rough rice that are either poorly separated from the dockage or poor recovery following rescreening or re–cleaning (USDA, 2009). Pieces of metal or stones are often found in the rough rice after harvesting and pose damage risk to shelling by passing the rough rice between a set of rollers which operates. Hence the first in milling is to eliminate foreign material from the rough rice prior to shelling/milling (Schramm, 2010).

2.8.4.3 Brokens in milled rice

Milling rice can yield 4 – 40% broken kernels depending on the quality of the incoming rice and the milling equipment (Guisse, 2010). Most high quality rice is sold with less than 4% brokens and so brokens must be removed in the milling process (RLDC, 2009). Drying of the rice (including while in the field prior to harvest) is a critical component in regards to milling quality to reduce brokens. Rice that is cracked during drying will have a lower percentage of head rice yield and will have an acceptable appearance after cooking. As rice kernels mature on a panicle it has variable moisture content representing various maturity and kernel strength levels (Bautista and Siebenmorgen, 2005).

2.8.4.4 Milled rice chalkiness

Chalkiness is caused by incompletely filled starchy endosperm which disrupts light transmission, due to opaque regions. Many studies have shown that the percentage of grains with chalkiness is a quantitative trait affected by genetic makeup and environmental conditions (especially weather) during the grain–filling period (Yamakawa *et al.,* 2007). In most cereals, chalky areas have lower mechanical strength on crush tests and may break during handling. The broken portion is more easily invaded by some storage pests. If part of the milled rice kernel is opaque rather than translucent, it is often characterized as “chalky” (Nikuni *et al.*, 1969).

Chalkiness in rice kernels is an undesirable characteristic because it degrades the visual appearance and cooking quality of milled rice. Previous research by Cooper *et al.* (2008) conducted in controlled–air chambers has shown that increasing nighttime air temperatures during kernel reproductive stages will dramatically increase chalkiness and reduce heard rice yields in several cultivars. Rice whiteness is a combination of varietal physical characteristics and the degree of milling. In a major discovery IRRI uncovered important genetic information on what makes rice chalky an undesirable trait that can grain value by up to 25% (Fitzgerald, 2011). The discovery could lead to higher quality "chalk–free" rice; chalk–free rice has higher milling recovery, which means better returns for farmers. Chalk, the white, opaque portion in rice, increases the chances of the rice grain breaking when milled which reduces the amount of rice recovered and downgrades rice quality assessment rating.

2.8.4.5 Head rice yield

"Head rice" or head rice percentage is the weight of head grain or whole kernels in the rice lot. Head rice normally includes broken kernels that are 75 – 80% of the whole kernel (Liu *et al*., 2009). Head rice yield typically varies with the moisture content at which rice is harvested. The harvest moisture content at which head rice yield is maximal under specific weather conditions is approximately 19 – 21% for long–grain cultivars and 22 – 24% for medium–grains (Siebenmorgen *et al.*, 2007). High head rice yield is one of the most important criteria for measuring milled rice quality. Broken grain normally has only half of the value of head rice (Bell *et al*., 2000). The characteristics that must be maintained during drying include head yield, colour and cooking quality. The head rice yield is especially sensitive to the mode of drying and is usually used to assess the overall effectiveness of the drying process. The head rice yield may increase if drying is postponed for a day in order for the internal moisture gradients in the kernels and the different moisture contents between the individual kernels to equilibrate (Webb, 1985).

2.8.4.6 Rice milling recovery

Head rice yield is the weight percentage of rough rice that remains as whole rice (three fourths kernel or greater) after complete milling. Environmental conditions such as drought, low sunlight intensity, disease, inadequate or excessive nitrogen and early draining water in hot weather all intensify stress on rice kernels (Guisse, 2010). The tendency of kernels to break under stress differs somewhat among varieties.

2.8.5 Cooking of milled rice

Cooking rice has traditionally been a process which required attention to ensure that rice is cooked properly. It is reasonable to consider that the cooking process of rice comprises of the gradual absorption of water from the surface to the inner portion of the rice grain and physicochemical changes or reactions of rice constituents with water by heating. The deformation ratio of cooked rice grains showed a clear linear relationship with cooking time at various cooking temperatures (Jafari *et al.*, 2007). Dedicated rice cookers date from long ago in human history. Most dedicated home rice cookers are of electric type. Electric rice cookers automate the process by mechanically or electronically controlling heat and timing, thus freeing up a heating element on the cooking range that had to be occupied otherwise for rice cooking. Based on these Suzuki *et al.* (1976) concluded that the cooking rate was limited by the reaction rate of the rice component with water at temperatures below 100°C, and it was limited by the diffusion of water through the cooked layer toward the interface of uncooked core where the reaction occurs.

The time required for cooking rice depends on amount of rice, power of the heating elements and atmospheric pressure, thus it is not constant. Most of rice cooking takes about 30 minutes to one hour for most of electric rice cookers to complete cooking (Jafari *et al.,* 2007). There some physical characteristics of rice such as grain thickness has a major effect on the volume expansion ratio of the cooked rice followed by degree of milling and then by apparent amylose content of the grain (Mohapatra and Bal, 2007). Pressure–cooker models are not influenced by atmospheric pressure. The special features distinguish high–end models from lower–cost, simpler models.

2.8.6 Physicochemical properties of milled rice that indirectly relate to eating quality

2.4.6.1 Amylose content of milled rice

Starches from various sources contain different amounts of amylose and amylopectin which influence physicochemical properties such as gelatinization, retro–degradation, water absorption and paste viscosity. For those reasons, the amylose content must be determined accurately (Hoover and Ratnayake, 2001). Amylose content is considered one of the most important quality factors of rice since it is acknowledged that, amylose content is a good index of water absorption and textural properties of rice. Amylose content can range from 15 to 30% and can indicate the cooked texture of the rice (Juliano, 1971; Ward, 2009). The texture of cooked rice and its gloss are principally determined by the amylose: amylopectin ratio of the starch. Increasing the amylose content improves the capacity of the starch granule to absorb water and expand in volume without collapsing because of the greater capacity of amylose to hydrogen bond or retrograde. However, over time, as more rice varieties were developed with different quality traits as well as with the increasing global exchange of germplasm, it became more evident that amylose is not always consistent in predicting the cooking properties of rice (Jimenez *et al.*, 2012). Thus, the amylose content is an index of resistance to disintegration during cooking. It has been shown that, an increase in amylose content improves the firmness of cooked parboiled rice, the correlation coefficient (r) between amylose content and firmness being 0.62 (Adeyemi, 2009).

Amylose content of milled rice is determined by using the colorimetric iodine assay index method (Merca and Juliano, 1981). Amylose content is an important factor that determines the eating quality of rice. Higher amylose content corresponds to harder texture in general. However, varieties with the same amylose content do not always have similar cooking properties. NERICA varieties show a wide range of amylose content from 15.4 to 28.5% with an average of 25.0% (Futakuchi and Sie, 2009). Amylose content has a strong influence on rice texture which is the most dominant factor to affect rice taste. Amylose is a necessary but not sufficient factor, so we need to look at supplementary factors.

2.8.6.2 Milled rice gel consistency

Gel consistency measures the tendency of the cooked rice to consolidate after cooling. Gel consistency is associated with harder cooked rice and this feature is particularly evident in high amylose rice (Nikuni *et al.*, 1969). If gel consistency is hard, then cooked rice tends to be less sticky. Harder gel consistency means often the cooked rice is harder (especially in rice with high amylose content) and if gel consistency is soft, then the cooked rice is tender and is a preferred characteristic. Gel consistency is a standard assay used to classify the processing and cooking quality of rice cultivars with high amylose content (Nguyet *et al.*, 2010). Gel consistency measures the flow characteristics of rice gel. Also, gel consistency is an excellent index of texture, especially among rice varieties with high amylose content to differentiate soft and firm cooking properties (Cagampang *et al.*, 1973).

2.8.6.3 Milled rice gelatinization temperature

Gelatinization temperature a physical property of starch, is the range of temperature contained by which the starch granules start to swell irreversibly in hot water with simultaneous loss of birefringence (in polarized light) and crystallinity (Kaosa–ard and Juliano, 1990). Gelatinization temperature involves visual observation of the degree of dispersion grains of milled rice after immersion in 1.5% or 1.7% KOH overnight (Little *et al.*, 1958). Starch gelatinization is a dynamic procedure that involves disruption of the molecular order within the starch granule on heating in excess water above a certain temperature threshold (Atwell *et al.*, 1988; Cooke and Gidley, 1992). Alkali spreading value is inversely related to the temperature at which rice starch granules gelatinize. Values are from 2 to 7 and are determined by comparing the dispersion to that of check samples of known behaviour. It is also measured with a Differential Scanning Calorimeter, an instrument that measures energy transfer to and from a sample while it is heated. Rice has a gelatinization temperature in a range of 65 – 80°C (Ward, 2009). Thus, the alkali spreading value provides a simple means of classifying rice into high, intermediate and low gelatinization temperature types. Gelatinization temperature appears to be directly related to rice cooking times, and lower gelatinization temperature is desired for higher quality rice (Juliano and Perez, 1983). Classifying rice varieties according to gelatinization temperature is useful in determining which are appropriate for use in parboiling, quick cooking, puffing, extruding, and other rice cooking and processing technologies. The alkali spreading value measures the extent of disintegration of whole–milled rice in contact with dilute alkali. Classification is as follows; low, $< 70^{o}C$; intermediate, $70 – 74^{o}C$ and high, $74.5 – 80^{o}C$. Alkali spreading values correspond to gelatinization temperature as follows: 1 – 2, high; 3, high intermediate; 4 – 5, intermediate; 6 – 7, low (Adeyemi, 2009).

In many rice growing countries, there is a distinct preference for rice with intermediate gelatinization temperature (Dawson *et al.*, 1958). A low ambient temperature during ripening may increase amylose content and independently reduce gelatinization temperature. *Indica* rice cultivars are generally more resistant and indecomposable to alkali compared with *japonica* cultivars as has already been reported by many researchers. However, differences in alkali solubility between lowland rice and upland rice cultivars, and glutinous and non glutinous ones are both small (Ebata, 1968). This pattern of responses of the grain types to an alkali solution can be connected with that of differences in the characteristics of cooked rice.

2.8.7 Cooked rice sensory attributes

2.8.7.1 Rice eating quality and consumers preferences

There is tremendous variation in tastes and preferences for rice across the world. Geographically, the production of different qualities of rice follows the tastes and preferences of the region where it is consumed (Braun and Bos, 2005). Sensory evaluation offers the opportunity to obtain a complete analysis of the textural properties of the food as perceived by the human senses (Pichetnawin, 2004). A number of processes occur while food is being masticated, including; deformation, flow, comminuting, mixing and hydration with saliva and sometimes change in temperature, size, shape, and surface roughness of the food particles. All of these changes are recorded with great sensitivity by human senses, but many of them are difficult to measure by objective methods.

People from different regions have different tastes and preferences (Braun and Bos, 2005). The Japanese prefer short–grain *japonica* rice that is soft and relatively sticky when cooked. Thais support well milled, long grain *indica* rice that is soft but flaky when cooked. In many traditional rice markets (India, Pakistan and Thailand), fragrant rice fetch the highest prices and nontraditional markets (such as those in the West), fragrant rice is considered spoiled or contaminated rice (Efferson, 1985). Those in the Middle East prefer rice pilaf treated with butter or vegetable oil (Eve 1973). Consumers in Bangladesh, Nigeria and Liberia are said to prefer parboiled rice. What consumers consider good rice mostly depends partly on historical and socio–cultural factors. Top quality rice in one region may be considered low–quality in another region. Consumer preferences in eating quality need to be incorporated into the concept "good quality rice". It is possible to translate consumer preference for cooking quality into measurable chemical properties. Cooking quality depends on a number of characteristics: amylose content, gelatinization temperature, gel consistency, grain elongation and aroma.

Evaluation of eating quality in early breeding generations of rice is critical to developing varieties with better palatability (Lestari *et al.*, 2009). As rice consumption continues to expand and markets become more competitive, there is an increasing need for quantitative data regarding the effects of postharvest handling on sensory characteristics of cooked rice (Meullenet *et al.*, 2000). Eating quality of the rice is a complex quality, in which a number of components are involved. It is not always possible to identify factors influencing eating quality. According to Lestari *et al.* (2009), some key physicochemical properties affecting the eating quality are amylose content, pasting properties, gel consistency, gelatinization temperature and protein content.

To meet required functional and sensory properties, rice cultivars are chosen based on specific amylose content because of the strong associations between amylose and desired properties. Because amylose content plays such a pivotal role in the properties of rice, it is used at early stages of breeding programs to select and discard breeding material. For the time being, the standard method used for determining eating quality is composed of sensory tests (panel tests), in which a number of testers evaluate the quality by means of tasting cooked rice. Sensory tests are based on subjective evaluations through senses of vision, flavour, taste and texture. Good eating quality is also associated with stickiness, sweet flavor, glossiness of the cooked rice and palatability. Palatability, the trait directly related to rice eating quality, is determined by aroma, appearance, taste and texture (Lestari *et al.,* 2009). Sensory properties of freshly cooked rice have been described by 14 parameters, 11 of which correlate strongly, either positively or negatively, with the amylose content of rice (Champagne *et al.*, 2004). It is therefore of importance to determine the quality of rice so as to assess its suitability for a particular end–use and to ascertain whether it meets specific requirements of cleanliness, purity and quality.

2.8.7.2 Cooked rice aroma and flavour

The aroma and flavour of rice can be characterized and analytically measured by trained panelists in descriptive sensory analysis (Meilgaard *et al.*, 2007). Descriptive analysis is useful in evaluating sensory changes over time with respect to pre–harvest and postharvest conditions and shelf life (Meilgaard *et al.*, 2007). Combined use of descriptive and preference sensory panels provide accurate assessment and identify quality characteristics desired by various consumers and markets. Descriptive scores can also be correlated to volatile compound concentrations responsible for perceived aroma and flavour or serve as markers for these attributes. The 2–acetyl–1–pyrroline (2–AP) is an over 100 compounds found in the volatile components of cooked rice (Yajima *et al.*, 1979; Mahatheeranont *et al.*, 2001). The 2–AP has been reported to be the principal one creating the scent in aromatic rice varieties. Varieties known as aromatics (like Jasmine, Della and Dellrose) have approximately 100 – 2000 ppb 2 – AP while non–aromatics have less than 20 ppb, although several volatile flavour compounds have been identified that are responsible for fragrance (Yajima *et al.*, 1979; Mahatheeranont *et al.*, 2001), 2–acetyl–1–pyrroline (2–AP) is the major active compound in fragrant rice (Lorieux *et al.*, 1996).

Environment, fertilization and cultural practices affect the amylose and protein contents of rice cultivars which in turn may influence the aroma and flavour of the cooked rice. Low protein rice samples of the same cultivar are reported to be more flavourful than those with higher protein (Champagne *et al.*, 2007). This observation was corroborated by two descriptive sensory panels (Park *et al.*, 2001; Champagne *et al*., 2004), who found rice with lower protein content to have higher levels of desirable sweet aroma/taste and lower levels of undesirable flavour attributes.

Flavour is an impression perceived through the chemical senses from a product in the mouth. According to Meilgaard *et al*. (2007), when defined in this manner, flavour includes aromatics (olfactory perceptions caused by volatile substances released from a product in the mouth through the posterior nerves).

2.8.7.3 Cooked rice taste

Tastes (gustatory perceptions [salty, sweet, sour and bitter] are caused by soluble substances in the mouth) chemical feeling factors that stimulate nerve ends in the soft membranes of the buccal and nasal cavities (astringency, spice heat, cooling, bite, metallic flavor, umami taste).

2.8.7.4 Cooked rice texture

Food texture is a group of physical properties that derives from the structure of food and is related to deformation, disintegration and flow under force that is subjectively sensed by the feelings of touch, hearing and sight (Pichetnawin, 2004). Texture of the rice grains namely, the physical property of the cooked rice such as stickiness and hardness generally is recognized to be an attribute which affects the eating quality of the cooked rice, rather than the appearance quality such as luster and hue and the organoleptic properties such as taste and aroma. Texture is a dominating importance for certain categories of foods, particularly those with a bland flavour such as rice and pasta (Wilkinson, 2000). Measurement of cooked rice texture attributes by sensory and instrumental methods is significant because of the increased popularity of rice and rice products by globally diverse cultures (Lyon *et al.*, 2000). Many factors influence cooked rice texture including cultivar, physicochemical properties, postharvest handling practices (milling degree, drying conditions and final moisture) and cooking method. In this association, an alkali test method is used to chemically examine the texture and eating quality of the rice. Since texture refers to a group of properties, any one or a combination of which may at a time, it is most accurate to refer a textural properties.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The Study Area, Location and Description

Kilombero is one of the six Districts of the Morogoro region in Tanzania, and is 440km South–West of Dar es Salaam. The District is situated South–West of Morogoro at Latitude 8°15'0, South of the Equator and at Longitude 36°25'0 East of Greenwich. The District extends from the middle to far South–West of Morogoro region. It is bordered with Morogoro Rural to the East and Kilosa District to North–East. The North and West borders are Mufindi and Njombe Districts of Iringa region while at its South and South–East it shares the border with Songea–rural (Ruvuma Region) and Ulanga District respectively.

3.2 Study Population and Ethnic Groups

According to Tanzania Population and Housing census 2002, Kilombero District had a population of 322 779 people, 73 393 households with inter–censal growth rate of 3.9% and population density of 23.7 person/km^2 (URTPHC, 2002). There are various groups, which grow crops like paddy, maize, banana and sugar canes and raise livestock. Mostly these includes; Wandamba (people of the Valley), Wambunga, Wabena, Wahehe and nowadays Wasukuma (MRCO, 2006).

3.3 Materials and Reagents

3.3.1 Materials

Five new rice varieties (Semi–aromatic; TXD306, TXD88 and TXD85; upland rice NERICA1 and NERICA4) harvested in July, 2011 cropping season were collected from Kilombero Agricultural Training and Research Institute (KATRIN).

3.3.2 Chemicals and reagents

Chemicals and reagents for chemical analyses (proximate and physicochemical) such as *n*–Hexane (Petroleum ether), *n*–Propanol, 95% Ethanol, Dimethylsulfoxide (DMSO) and Thymol blue ($C_6H_4SO_2OC.[C_6H_2–2–CH_3–5–CH(CH_3)_24–OH]_2$) were purchased from Green Life Technologies Limited (GLTL) Importers and Suppliers of the Chemicals Laboratory Equipment, Apparatus, Hospital Equipments and Glassware.

3.4 The study Design

The study design was Cross–sectional survey whereby, the study was conducted once. The survey using questionnaires (Appendix 1) was used to interview key informants (rice farmers, cooked rice vendors and rice milling machine operators). This was followed by laboratory experiments that evaluated differences in milling quality, proximate composition, sensory quality, physicochemical properties and cooking time. A two way analysis of variance experimental model was used in the laboratory studies and the treatment (classification or grouping criteria) being the 5 new rice varieties with each being replicated 3 times (proximate composition, cooking time, and all physical chemical parameters), 5 times (1000 grain weight), 20 times (grain length and grain width ratio) and 25 times for all sensory evaluation parameters.

3.5 Data Collection

3.5.1 Field survey

The field survey was conducted in Kilombero district to gather information on farmers' knowledge in the paddy postharvest storage practices, consumers' knowledge on rice quality indices, preparation and cooking practices and awareness of existence of new rice varieties. The district authorities allowed survey to be conducted in five wards (Kibaoni, Ifakara, Mbingu, Mang'ula and Kidatu) with potential rice production, rice milling machine and cooked rice vendors (Fig 2).

3.5.2 Measurement of rough rice quality indices

3.5.2.1 Determination of grain length and grain length /width ratio

Grain length and width were measured using a Micrometer Screw Gauge purchased from Green Life Technologies Limited (GLTL). Twenty (20) rough rice kernels from each of five varieties were randomly selected from 1000 clean seeds mentioned before counting were hulled to get brown rice according to the procedure described by Gummert (2004). The length and width data were used to calculate length to width ratio with a view of assessing the overall paddy shape (Slender, >3.0; Medium, 2.1 – 3.0; Bold 1.1 – 2.0 and Round, 1.0) as shown in the following formula:

$$\text{Length to Width ratio} = \frac{\text{Average brown rice length (mm)}}{\text{Average brown rice width (mm)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

For the size; (extra long, >7.50mm; long, 6.61–7.50mm; medium, 5.51–6.60mm and short, 4.50mm.

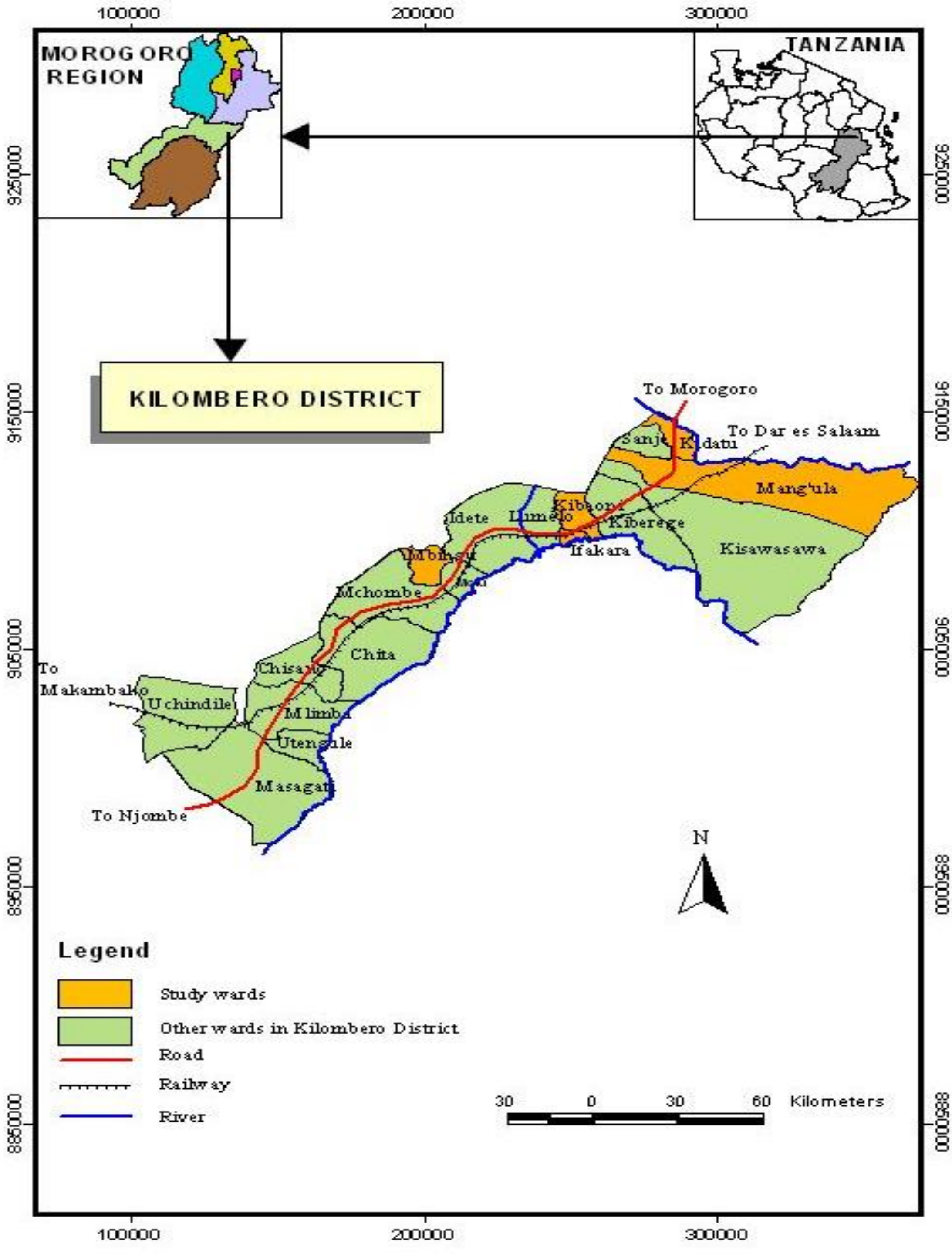


Figure 2: A Map of Kilombero District and geographical location of surveyed wards (Kibaoni, Ifakara, Mbingu, Mang'ula and Kidatu) coloured orange

3.5.2.2 Measurement of immature rice grains

Immature grains are empty caused by sterility and pre–harvest infections and insect attack. In rice, immature grains are greenish in colour; white (usually opaque) grains caused by incomplete grain filling and may result from pests or disease. Exactly 25g of grain samples, immature grains were selected and weighed. The immature grains percentage was calculated using formula:

$$\%\text{Immature grain} = \left(\frac{\text{Weight of immature grain (g)}}{\text{Weight of sample (25g)}}\right) \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

3.5.2.3 1000 rough grain counting

The 1000 rough grain counting was done at Department of Crop Science and Production (DCSP). A thoroughly mixed lot (post corning/ quartering) was free from debris (foreign matters) and immature grains. The cleaned grain each of the five varieties was passed through a special grain counting machine (Count–A–Pak, Model 77 Totalizer Machine) to automatically count a preset number of 1000 grains. Exactly 1000 grains is the standard number commonly viewed as a starting value (IRRI, 2009b). It is on this principle that a Count–A–Pak, Model 77 Totalizer Machine was used to count 1000 rice grains of each variety. The machine is so precise that it counts 1000 grains after being preset.

3.5.3 Proximate analysis

3.5.3.1 Moisture determination

The moisture content in the five rice varieties flour was determined in triplicates by oven drying method (AOAC, 1995). Exactly 3.00g were dried in an oven set at 105^{o}C overnight. Samples were then taken out from the oven and put in a desiccator with partially covered lid for 30 minutes to allow coolling to room temperature and then weighed. The moisture content was calculated using the formula:

$$(\%)\text{Moisture} = \left(\frac{W1 - W2}{W1}\right) \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where;

W1 = Weight (g) of the sample before drying and

W2 = Weight (g) of the sample after drying.

3.5.3.2 Crude protein determination

Crude protein in rice flour was determined by Kjeldahl's method (AOAC, 1995). Exactly 1.00g of pre–dried samples in triplicate were weighed onto tared filter papers and quantitatively transferred into a digestion flasks followed by addition of mixed catalyst (1.00g of $CuSO_4$ and 5.00g of K_2SO_4 and 0.50g) and 25mls of concentrated H_2SO_4. The contents of the flask were digested by heating in a fume chamber at 420^{o}C until the colour of the solution changed from black to a clear green blue. The contents of the flask were cooled to room temperature and diluted to exactly 100mls with distilled water. Exactly 10mls of the aliquot of the digested solution was quantitatively transferred into a distilling flask and mixed with 15mls of 40% NaOH. The mixture was distilled while collecting distillate into a receiving flask that contained 50mls of 4% boric acid mixed indicator solution. After collecting about 60 – 80mls of the distillate the mixture was titrated against 0.1N Hydrochloric acid (HCl) using methyl red indicator until colour changed from blue to green orange marking the endpoint). The percentage of protein nitrogen was calculated using the following formula:

$$\%Nitrogen = \left(\frac{(Titre\text{-}Blank)mls \times 0.014077}{Weight\ of\ the\ Sample\ (g)}\right) \times 100 \quad \ldots\ldots\ldots\ldots(4)$$

The percentage protein was calculated from the percentage nitrogen using the factor 6.25 for the plant material as follows:

$$\%\ Protein = \%\ Nitrogen \times 6.25$$

3.5.3.3 Crude fibre determination

The percentage crude fibre was determined by AOAC (1995). Exactly 2.00g of the rice flour were transferred into a 500mls conical flask followed by 200mls of boiled 1.25% H_2SO_4 solution. The mixture was boiled for 30 minutes under reflux. The digest was filtered through a Whatman filter paper number 54. The residue was washed with boiling water until the washing was free from acid. The acid free residue was quantitatively transferred into the refluxing flask followed by exactly 200mls of 1.25% sodium hydroxide solution and refluxed for 30minutes. The digest was filtered, washed with boiling water, then alcohol and lastly with diethyl ether before being dried at 100^{o}C for one hour. The dried residue was transferred into a porcelain crucible and incinerated for one hour at 400 – 500^{o}C using a muffle furnace (Shimadzu Corp, Kyoto Japan). The crucibles were removed from the furnace and let to cool in the desiccator and immediately transferred and weighed. Percentage fibre was calculated using the following equation:

$$\%Crude\ fibre = \left(\frac{W1 - W2}{W}\right) \times 100 \quad \ldots\ldots\ldots\ldots(5)$$

Where;

W = Weight of the sample (g);

W1 = Weight of the crucible with dried residue after digestion (g) and

W2 = Weight of the crucible with ash.

3.5.3.4 Crude fat determination

Crude fat content in the rice flour was determined by Soxhlet continuous ether extraction method (AOAC, 1995). Exactly 5.00g portions of the ground samples were weighed and poured into an extraction thimble and plugged with free fat cotton wool. Each thimble was placed into the Soxhlet extractor. Exactly 150mls of the petroleum was poured into a dry 250ml quick fit flask of known weight fitted with the extractor and condenser units, samples were refluxed for 8 hours. After extraction, the crude fat petroleum mixture was at a low heat and the petroleum ether evaporated to near dryness flask containing crude fat extracted were further dried in the oven at 105^{o}C for 30min, cooled in a desiccator and weighed. The percentage crude fat was determined by using the formula:

$$\%Fat = \left(\frac{\text{Weight of Crude Fat (g)}}{\text{Weight of Sample (g)}}\right) \times 100 \quad \ldots\ldots(6)$$

3.5.3.5 Ash determination

Ash content in the rice flour was determined by a standard method (AOAC, 1995). Exactly 1.00g of rice flour was placed in a pre–weighed dry crucible. The crucible and the sample was placed in the muffle furnace set at 550^{o}C incineration of the sample was for 12hours. The crucible and ash were cooled in a desiccator to room temperature and weighed. Percentage ash was calculated using the following equation:

$$\%\text{ Ash content} = \left(\frac{W2 - W1}{W}\right) \times 100 \quad \ldots\ldots(7)$$

Where;

W2 = Weight of the crucible and sample (g);

W1 = Weight of the crucible and ash (g) and

W = Weight of the sample (1.00g).

3.5.3.6 Nitrogen Free Extract (NFE) determination

The carbohydrate content in the rice flour was determined by difference (AOAC, 1995). The following relationship was used.

% NFE = 100 - (%Crude Protein + % Crude Fat + % Crude Fibre + %Ash) …..……....(8)

Where;

NFE = Nitrogen Free Extract

3.5.4 Determination of rice milling quality indices

Each of the five rice varieties i.e. TXD 88, NERICA 4, NERICA 1, TXD 85 and TXD 306, exactly 162g in triplicate were weighed prior to subsequent treatments. Corning and quartering sampling was used to obtain analytical samples for each variety. The test rice milling was done at the Department of Crop Science and Production (DCSP) (Horticulture section), Sokoine University of Agriculture (SUA). The Grainman Model 60–220–50–2AT Rice Miller Tester with automatic timer was used (Plate 1). The Grainman Rice Miller Tester done in a batch process (Pan *et al.*, 2007).

Plate 1: Grainman Rice Miller with lever arm press during dehulling rough grain rice

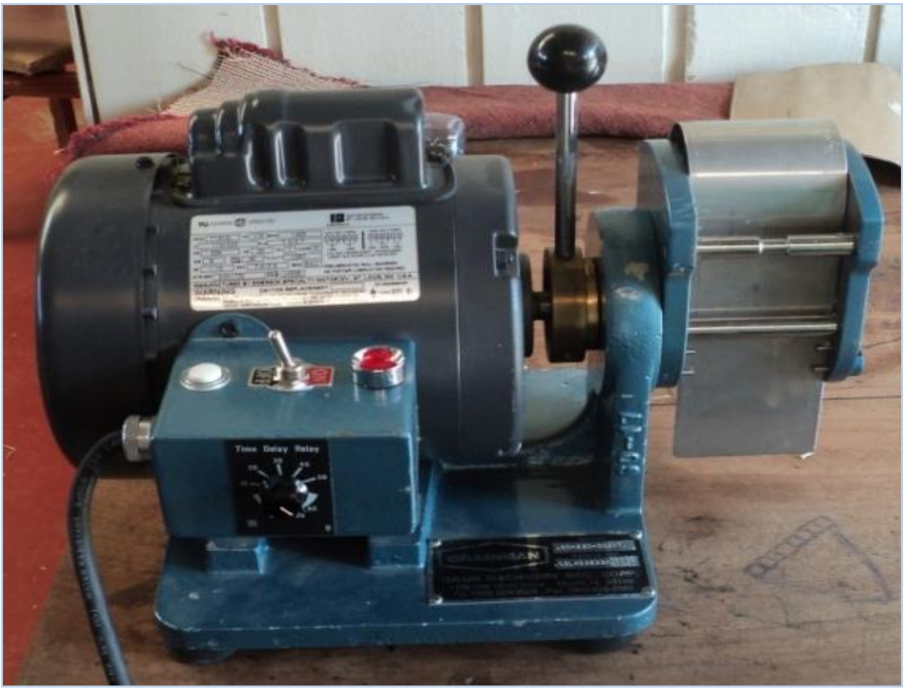


Plate 2: Grainman Rice Miller without lever arm for polishing brown rice after hulling

Measuring milled rice quality indices was determined by the Method described by IRRI (2010) for which the following rice quality indices were assessed:

i. Dockage is all matter other than rice that can be readily removed from the rough rice by the use of appropriate sieves and cleaning devices. Exactly 162g of rough rice were weighed followed by selecting and weighing the foreign matter. The percentage dockage was determined by following equation:

$$\%\text{ Dockage} = \left(\frac{\text{Weight of the dockage (g)}}{\text{Total weight of milled rice (g)}}\right) \times 100 \quad \text{..........................(9)}$$

ii. Chalkiness is caused by incompletely filled starchy endosperm which disrupts light transmission, causing opaque regions. In most cereals, chalky areas have lower mechanical strength on crush tests and may break during handling. The broken portion is more easily invaded by certain storage pests. From the total milled rice chalky grains were visually selected, segregated and weighed and the percentage chalky were determined by the following formula:

$$\%\text{Chalky grains} = \left(\frac{\text{Weight of Chalky grains (g)}}{\text{Weight of milled rice (g)}}\right) \times 100 \quad \text{......................(10)}$$

iii. Brokens grain rice normally includes broken kernels that are <75% of the whole kernel. The broken grains were selected segregated from the whole grains, weighed and the broken percentage was determined by the following equation:

$$\%\text{Brokens} = \left(\frac{\text{Weight of the broken grains (g)}}{\text{Weight of the paddy sample (162g)}}\right) \times 100 \quad \text{......................(11)}$$

iv. Head rice yield percentage is the weight of whole kernels in the milled lot. Head rice normally includes broken kernels that are 75 – 80% of the whole kernel. The head rice yield was computed by the equation shown below:

$$\% \text{ Head rice} = \left(\frac{\text{Weight of the whole grains (g)}}{\text{Weight of the paddy sample (162g)}}\right) \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots(12)$$

v. Milling recovery yield is the percentage of milled rice which includes the brokens and whole grains. This is computed by the following equation:

$$\% \text{ Milling recovery} = \left(\frac{\text{Weight of milled grains (g)}}{\text{Weight of the sample (162g)}}\right) \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots(13)$$

3.5.5 Measurement of cooking time of five rice varieties

Samples of five milled rice varieties were cooked as described by Champagne *et al*. (1997). The cooking was done in triplicate using rice cooker–steamers (1.2L capacity, NIKAI, NR 679. 500W). A stop watch in mobile option was used to measure the time from switching on of rice cooker–steamers to automatically shift to the warm setting to indicate completion of cooking.

3.5.6 Determination of physicochemical properties of milled that indirectly related to eating quality

3.5.6.1 Determination of amylose content

Amylose content in the rice flour was determined by basic protocol method (Hoover and Ratnayake, 2001). Exactly 5.00g of rice flour was defatted by using continuous ether extraction method as described in section (3.5.5.4) instead of petroleum ether 75% (v/v) *n*–propanol in water was used. The defatted sample was dried in air for 12 hours thereafter in an oven set at 30^oC for 24 hours. Exactly 20mg of the dry defatted samples were transferred into a 20mls bottom screw–cap tube fitted with tightly fitting Teflon cap. Standard solutions covering concentration range from 0% to 100% using mixtures of pure amylose and amylopectin according to the detailed scheme depicting amylopectin/ amylose volumetric ratios detailed in Table 3.

Table 3: Amylose/Amylopectin ratio (%) for preparation of standard solution

Parameter	**Mixture ratio of amylose and Amyloectin (%) series**								
Amylose	0	10	20	40	50	60	80	90	100
Amylopectin	100	90	80	60	50	40	20	90	0

Source: Hoover and Ratnayake (2001).

To each 20mg of the standard mixture as shown in Table 3, 8mls of 90% (v/v) dimethylsulfoxide (DMSO) (CH_3SOCH_3) solution in water were transferred into 20mls tube and vigorously mixed using vortex mixer (Reidolph, REAX 2000, W42, Made in German) for two minutes. The mixture in 20mls round–bottomed tube was heated in a water bath set at 85^oC for 15 minutes with intermittent hand mixing and then allowed to cool at room temperature and after 45 minutes there was no gel formation in the cooled mixture. The contents from 20mls bottom screw–cap tube was poured into 25mls volumetric flask, and then diluted to the mark with distilled water. Exactly 1.00ml of diluted sample was measured into a 50mls volumetric flask, followed by dilution with 40mls of distilled water. Exactly 5mls of (0.0025M I_2/0.0065MKI) iodine solution was added and mixed by hand vigorously and allowed for 15 minutes to stand for colour development and finally filled to the mark by distilled water. Measurement of absorbance at 600nm by (Thermo Electronic, Model: Helios Epsilon CAT 9423UVE 1000E, Made in

USA) spectrophotometer was used. The reagent blank contained all reagents in the same amount without the sample fat free– rice starch.

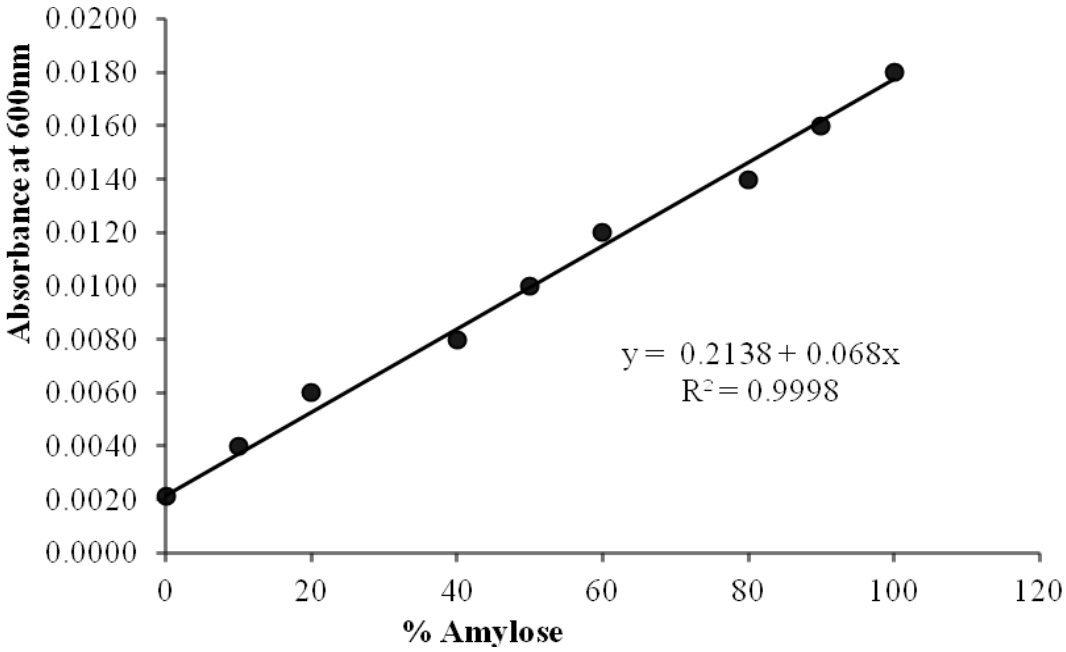


Figure 3: Plot of absorbance at 600 nm against percentage amylose (w/w) for mixture of potato amylose and amylopectin with iodine. The absorbance (0.2138) of 0% amylose is due to the I_2 affinity for the long outer branches of amylopectin

The plotted curve (Fig 3) for mixture of pure amylose and amylopectin were used to determine the regression equation for the curve and that equation was used to determine percentage amylose content of the samples. The regression equation for the plotted curve (Fig 3) was: y = 0.2138 + 0.0168x (R^2 = 0.9998), where; 0.2138 nm is the absorbance of 0% amylose due to the iodine affinity of the long outer branches of amylopectin, x = % amylose and y = absorbance at 600nm.

$$\%Amylose = \frac{Absorbance - 0.2138}{0.0168} \quad \text{……..……..…………………...………………(14)}$$

3.5.6.3 Determination of gel consistency

Rice flour gel consistency was determined by the method described by Juliano (1973). Exactly 100mg of milled rice flour placed in 13 x 100mm culture tubes. Exactly 0.2ml of 95% ethanol containing 0.025% thymol blue ($C_6H_4SO_2OC.[C_6H_2–2–CH_3–5–CH(CH_3)_24–OH]_2$) indicator was added. The mixture was shaken for 30 seconds using vortex shaker (Reidolph, REAX 2000, W42, Made in German). Immediately 2mls of 0.2N KOH solution was added and the mixture dispersed. The culture tubes were fitted with glass marbles and placed in water bath at 100^oC for 8 minutes. The culture tubes containing mixture were removed from the water bath and let to stand at a room temperature for 5 minutes. The cooled tubes were placed in ice cold water for 15 minutes. The culture tubes with mixture were laid horizontally over a graph paper gel length (mm) from the bottom of the culture tubes were measured after 45 minutes. The gel length served as indices of Gel consistency for which 61 – 100; 41 – 60; 36 – 40 and 26 – 35 millimeters were indicative of soft, medium, medium hard and hard consistency respectively (Juliano, 1973).

3.5.6.4 Determination of Alkali Spread Value (ASV)

Gelatinization temperature was indexed by alkali spreading test (Little *et al.*, 1958). From each 5 rice varieties, 6 milled kernels were placed into a petridish to which 15ml of 1.7% KOH solution were added. The grains were carefully separated from each other by forceps and incubated at ambient temperature for 23 hours to allow spreading of the grains. Grains swollen to the extent of a cottony center and a cloudy white collar were given an alkali spread value (ASV) as (1= grain not affected; 2= grain swollen; 3= grain swollen, collar incomplete and narrow; 4= grain swollen, collar complete and wide; 5= grain split or segmented, collar complete and wide; 6= grain dispersed, merging with collar and 7= grain completely dispersed and intermingled).

3.5.7 Sensory evaluation of cooked rice

Five coded samples representing the five varieties each weighing 0.5g were placed in disposable plates and evaluated by a semi trained sensory panel. The panel consisted of 25 members from the Department of Food Science and Technology (DFST) at SUA. It was also gender balanced comprising of 12 females and 13 males. Each panelist evaluated the 5 samples for 7 hedonic parameters (colour, aroma, taste, texture, mouth feel, consistency and overall acceptability) using a 5 point scale (5 = like very much, 4 = like moderately, 3 = neither like nor dislike, 2 = dislike moderately and 1 = dislike very much) (Larmond, 1977) (Appendix 9). Necessary precautions were taken to prevent carry–over flavour during tasting by ensuring that, the panelists rinsed with water their mouths' after each sample of sensory evaluation (Srisawas and Jindal, 2007).

3.6 Statistical Data Analyses

The Predictive Analytics Software (PASW) Statistics version 16.0 was used to analyze data from questionnaires (Nie *et al.*, 1968). The frequency complaints (Rice grain size and shape, chalkiness, brokenness, colour of milled rice, aroma, and mixed rice varieties) from key informants (rice farmers, rice machine miller operators and cooked rice vendors) inference were tested for significance by Chi–square test at ($P< 0.05$). Data from Laboratory (Milling parameters, Proximate composition, Cooking time, Physicochemical properties and Sensory evaluation) were subjected to Two–way Analysis of Variance using GenStat package version 13.3 (Payne, 2011) (Appendix 2,3,4,5,6 and 8). Therein, F–test, Means, F–probability, Coefficient of Variation (C.V), Standard Error (S.E) was calculated. Multiple comparisons by Duncan Multiple Range Test (DMRT) were used to test for varietal differences at ($P< 0.05$). Simple correlation coefficients were calculated to make the relationships between quality indices (Appendix 7).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Consumer Groups Including Vendors Perception on Rice Quality Indices

Pre–empting reasons for introducing new varieties were investigated by conducting a Cross–sectional survey which involved administering questionnaires (Appendix 1) to farmers, rice machine operators and cooked rice vendors. Based on the survey there were indications that there are critical parameters favourable to the groups within the study (Table 4). A two way (3x6 contingency analysis which tested for independence of the quality complained about by key groups within the rice production and consumption chain, was highly significant implying a high dependence of the quality parameters and consumer groups within the chain (Table 4). Hence it was justifiable to investigate the quality of the new rice varieties.

Table 4: Frequency of rice quality indices as related to consumers groups

Quality index complained parameter	**Consumer groups**			**Total**
	Farmers	**Rice machine miller operators**	**Cooked rice vendors**	
Rice grain size and shape	15	5	7	27
Chalkiness	12	25	20	57
Brokenness	20	28	24	72
Colour of milled rice	23	12	22	57
Aroma	28	5	18	51
Mixed rice varieties	23	26	32	81
Total	**121**	**101**	**123**	**345**

$\chi^2 = 31.6485 > \chi^2_{0.05, 10} = 18.307$

4.2 Rough Rice Quality Indices

4.2.1 Immature grain rice

Immature grains were highest (14.65%) in TXD85 and lowest in NERICA4 rice varieties (4.75%). Whereas the two NERICA varieties had the lowest immature grains they were statistically similar and yet significantly different from varieteis TXD88 and TXD85 which had slightly higher percentage of immature grains ($P < 0.05$) as summarized in Table 5. The low percentage of immature grains in the NERICA varieties is indicative that the grains in their panicles ripped within the same time and this impart desirable milling quality properties to the varieties. Varieties with higher percentage immature grains notably TXD85 lead to poor total recovery, brokenness and long duration of grain milling. Higher percentage immature grains in semi–aromatic varieties was probably due to little water avaliable during florescence period.

4.2.2 1000 grains weight of rough rice

The 1000 grains weight of five rice varieties ranged from 30.91 to 36.78g in TXD 88 and NERICA 1 rice varieties (Table 5). The two NERICA varieties and TXD306 had statistically similar 1000 grain weights as shown in Table 5 ($P > 0.05$). Varieties TXD85 and TXD88 had significantly higher 1000 grain weights. The differences in grain weight were probably caused by inherent variability in maturity, genetic makeup and grain size. Test of 1000 grains weight is useful for comparative indication of coarseness of the grains and total rice yield for farmers and at market levels in measuring rice yield. Grain weight measurement provides the relative proportion of unfilled, shriveled and immature kernels (Dipti *et al.,* 2003). According to Hill (2005) from literature, kernel weight differred among varieties in the variety section from a 1000 kernel weight for the small seeded *koshihikari* 23.8g to M–401 and S–102 at 32g and 34g respectively, of which the current study is within that range. According to the current study comprising of 5 varieties conforms to a Tokpah (2010) report the 1000 seed weight ranged from 27 – 30grams for 6 varieties, 30 – 33grams for 9 varieties, 33 – 36 grams for 6 varieties and 36 – 39grams for 8 varieties and above 39grams for 17 varieties. Kernel weight can be reduced by poor management or early draining away water in the field. Fields that is too dry at the end of the harvest can limit grain filling and reduce kernel weight as well as quality.

Table 5: The rough rice quality indices before milling

	Rough Rice Quality Indices			
Rice variety	**Immature (%)**	**Weight/1000 Grains**	**GL (mm)**	**L/W ratio**
TXD88	14.62[a]	30.91[c]	7.81[d]	3.14[b]
NERICA4	4.75[c]	36.50[a]	8.82[b]	3.72[a]
NERICA1	4.77[c]	36.78[a]	8.84[b]	3.68[a]
TXD85	14.65[a]	33.51[b]	8.07[c]	3.23[b]
TXD306	5.96[b]	36.18[a]	9.05[a]	3.65[a]
L.S.D (0.05)	1.175	0.66	0.205	0.175
S.E	0.62	0.493	0.325	0.277
% C.V	7.0	1.4	3.8	8.0

L.S.D = Least Significant Differences of means at ($P < 0.05$), S.E = Standard Error and % C.V = % Coefficient of Variation.

Means not sharing the same superscript letter in a column are significantly different at ($P < 0.05$) by DMRT test.

4.2.3 Grain length and size

The grain length in five rice varieties ranged from 7.81 to 9.05mm (Table 5). The TXD306 variety had the longest grain length yet significantly different from varieties two NERICA varieties which were statistically similar in grain length and yet significantly different from TXD88 and TXD85 which had slightly lower in grain length (P< 0.05) as summarized in Table 5. The five rice varieties were extra long length indicating that they received good agricultural practices in the field with respect to grain size. The difference in length among varieties was probably due to the genetic variation. Uniformity, shape and size are considered the first characteristics of quality in rice unlike other cereals as rice is consumed as a whole grain. According to MAFC (2009), in Tanzania, rice consumers prefer long grains In addition Campbell *et al.* (2009) reported that, long grain white rice with an intermediate level of starch dominates the markets in most of West Africa except for those markets that prefer parboiled or broken rice. Therefore, two of the factors contributing to appearance of grain are its length and shape. The physical dimensions of rice kernels are of vital interest to those engaged in the rice industry (Anon., 2007). These characteristics have to be achieved within newly named released new rice varieties for they influence in cleaning, grading equipment, drying operations processing and marketing.

4.2.4 Grain shape of five brown rice varieties

The shape (Length/ Width ratio) of the five rice varieties grain ranged from 3.14 to 3.72 (Table 5). The two NERICA varieties and TXD306 had statistically similar grain shape yet significantly different from TXD88 and TXD85 varieties which had slightly small in shape (P< 0.05) as summarized in Table 5. The five rice varieties were characterized as slender (>3.0) (CAC, 1990). The difference in shape of the five new rice varieties was probably due to genetic variations. .Appearance is a critical quality attribute for rice as rice buyers, millers and consumers judge the quality of rice on the uniformity of its size and shape as well as the appearance of its overall size–shape relationship (Armstrong *et al.*, 2005). Grain size and shape are most critical criteria of rice quality that breeders have to consider in developing new varieties. If a variety does not conform to recognized standards for grain size, shape and weight it can be rejected for release.

4.3 Varietal Characterization with Respect to Proximate Analysis

Proximate composition of five milled new rice varieties is presented in Table 6. Most rice consumers prefer milled white rice despite the valuable food contents of brown rice which are lost when the bran is removed during milling. Health conscious people in the European countries where rice is not a staple food prefer brown rice (Oko and Onyekwere, 2010). Quality of rice does not only imply the physical appearance but rather its chemical composition and cooking quality characteristics. Therefore, there is need to also consider nutritional value traits in rice varieties in a rice breeding program.

4.3.1 Milled rice moisture content

Moisture content of the five new rice varieties ranged from 11.86 to 13.40% in (Table 6). The five varieties were found to differ significantly in moisture content ($P< 0.05$) as summarized in Table 6. According to IRRI (2005), paddy is at its milling potential at moisture content of 14% wet weight (w/w) basis. High percentage moisture content affects the milling characteristics, storage, cooking preparation and the taste of cooked rice (Xheng and Lan, 2006; Ebuehi and Oyewole, 2007). The difference in moisture contents in all varieties was possibly due to variation in varieties caused by genetic inheritance in maturity rate of individual variety. According to Wilfred and Consultant, (2006), the degree of grain maturity normally are determined by measuring its moisture content using an appropriate moisture meter, and the optimum harvest moisture for rice being 21 – 24% weight wet basis. The low moisture contents of the five new rice varieties show that the products have been sufficiently dried to minimize microbial growth.

4.3.2 Milled rice dry matter content

The dry matter of the five rice varieties samples ranged from 86.60 to 88.14%. The dry matter content in all five varieties was found to differ significantly ($P < 0.05$) as summarized in Table 6. The low dry matter content in TXD 306 rice variety was probably attributed by the highest moisture content than other varieties. The higher dry matter content in TXD85 is an indicative that, there will be higher carbohydrates content as two have positive correlation coefficient but negatively correlated (–0.95) to moisture content (Appendix 7).

Table 6: Proximate Composition parameters means for five new rice varieties

	Proximate composition parameters (%)						
Rice variety	**Moisture**	**DM**	**CP**	**CF**	**CF**	**Ash**	**NFE**
TXD88	12.06^{cd}	87.94^{ab}	7.41^{c}	0.86^{b}	2.09^{bc}	1.21^{a}	76.38^{a}
NERICA4	12.81^{ab}	87.19^{cd}	9.00^{a}	0.77^{b}	1.83^{bc}	1.23^{a}	74.32^{c}
NERICA1	12.60^{bc}	87.40^{bc}	7.73^{b}	1.02^{a}	2.13^{b}	1.22^{a}	75.30^{b}
TXD85	11.86^{d}	88.14^{a}	7.44^{c}	0.82^{b}	1.73^{c}	1.17^{a}	76.97^{a}
TXD306	13.40^{a}	86.60^{d}	7.28^{d}	0.98^{b}	3.01^{a}	1.14^{a}	74.25^{c}
L.S.D (0.05)	0.3599	0.1561	0.06	0.07	0.2305	0.15593	0.5511
S.E	0.19	0.19	0.03	0.03	0.12	0.08	0.29
% C.V	1.5	0.2	0.4	4.0	5.7	6.9	0.4

DM= Dry Matter, CP= Crude Protein, CF= Crude Fibre, CF= Crude Fat

L.S.D = Least Significant Differences of means at ($P < 0.05$), S.E = Standard Error and % C.V = % Coefficient of Variation.

Means not sharing the same superscript letter in a column are significantly different at ($P < 0.005$) by DMRT

Each value is an average of three observations.

4.3.3 Milled rice crude protein content

The crude protein of the five rice varieties results on dry basis ranged from 7.28 to 9.00% (Table 6). Whereas the two semi–aromatic TXD88 and TXD85 had the low protein content slightly higher percentage to TXD306, they were statistically similar and yet significantly different from two NERICA varieties which had slightly higher percentage protein content ($P < 0.05$) as summarized in Table 6. The significant difference in protein content in five rice varieties was probably due to genetic variations and environmental conditions. According to WARDA (2006), reported that NERICA rice varieties have higher protein content by 25% compared to imported varieties. The protein content in the current study are within the range reported by Rosniyana *et al*. (2011) that protein content in rice range from 8.85 to 9.91% for white rice and brown rice respectively. In addition, Banerjee *et al.* (2011) reported the protein content range from 4.91 to 12.08% in 258 diverse rice landraces maintained in the Germplasm Section of Indira Gandhi Agricultural University at Raipur, Chhattisgarh. Srisawas and Jindal (2007), found the protein content in 14 rice varieties ranged from 6.38 to 8.99% which is highly closed to the current study. This level of protein in rice is very essential as it forms the basic building blocks for cells and tissue repairs in the human body of rice consumers. Tanzanians can benefit from this extra protein in many angles; to improved health, substitution of costlier protein sources and mental development in youths. Environment, fertilization and cultural practices affect the amylose and protein contents of rice cultivars which in turn may influence positively the aroma and flavour of the cooked rice.

4.3.4 Crude fibre in milled rice

In Table 6 results of crude fibre in five rice varieties show the range of 0.77 – 1.02%. The four rice varieties had statistically similar crude fibre content as shown in Table 6 ($P > 0.05$). NERICA 1 variety had significantly higher percentage of crude fibre. The differences of crude fibre content in rice variety probably were due to the degree of milling and genetic makeup. The findings in the current study are somehow less compared to 1.0 – 2.0% of five new lowland rice varieties reported by Oko and Onyekwere (2010). From literature the standard content of fibre in rice is 0.5 – 1.0% for well milled rice. Fiber comprises those components of food crop that cannot be broken down by human digestive enzymes. The presence of high amount of crude fibre in new rice varieties will improve and maintain health status of rice consumers. They help to lower serum cholesterol levels in humans (Edeogu *et al.*, 2007). There is a relationship between the absence of fibre in diet and the incidence of a wide range of diseases in man (Eastword, 1974). The presence of fibre in diet increases the bulk of faeces which has a laxative effect in the gut. The major types of fiber in rice are cellulose, hemicellulose, lignin, pectin and gums (some hemicelluloses and storage polysaccharides).

4.3.5 Crude fat in milled rice

The fat content in five rice varieties ranged from 1.73 to 3.01% (Table 6). Whereas the two varieties NERICA4 and TXD88 were statistically similar and yet significantly different from varieties TXD306 and NERICA 1 which had slightly higher percentage crude fat content ($P< 0.05$) as summarized in Table 6. The difference in the total lipid contents in the five new rice varieties was probably caused by the cultivars responses in milling process. This is supported by Siebenmorgen *et al.* (2005) that if a sample contained more lipids it would logically take a longer milling duration to achieve a comparable degree of milling relative to samples that have lower lipid content. Moreover on that, Rosniyana *et al.* (2004) stated that the major proportion of fat is present in bran and embryo of which during milling most of the fat is removed with the bran and polish. Lipids are contained in all tissues of the plant and are mainly deposited in the aleurone layer and embryo of the seed. Fats in the rice are not only essential energy source for germination and growth of plants but also for the human being. Rice lipids contain a larger amount of the linoleic acid which is responsible for the decrease of cholesterol in blood. Lipid content and fatty acid composition are determinants of oil crops. Fats and oils are sources of energy in the diet and the most concentrated form of energy in food (9 Kcal or 38 KJ/gram) yielding more than twice as much energy per gram as either carbohydrates or proteins (Edeogu *et al.,* 2007). The results of the current study are in agreement with earlier researchers' results reported by Oko and Ugwu (2010), obtained fat content in range of 0.5 – 3.5% from five rice varieties. Rosniyana *et al.* (2011) reported that, milled rice had 0.34% fat content which was lower than brown rice which had 3% fat content. In addition on that Oko and Onyekwere (2010), found the crude fat content in five new lowland rice varieties in range of 1.5 – 3.5%, the differences in findings may be attributed to the degree of milling and varieties.

4.3.6 Ash content in milled rice

The range of ash content in Table 6 was 1.14 – 1.23%, although the investigation shows no significant difference between all five rice varieties (P> 0.05). The ash content of a food gives an idea of the mineral elements present in that food. The amount of ash content can be supported with Ibukun (2008) that the ash content in effect of prolonged parboiling duration to be in a range of 1.15 – 2.77%. In addition of that, Oko and Onyekwere (2011) found the range 0.5 – 1.0% ash content in five new lowland rice varieties. Also, Oko and Ugwu (2011) in the five major rice varieties in *Abakaliki* South–eastern Nigeria found the ash content ranged between 0.50 and 2.1% of which the current study is within that range. Although there were some variations between the study and that of other authors such as Ibukun (2008), Oko and Ugwu (2011) and Oko and Onyekwere (2011), may be these variations in ash content had been attributed to such factors like the rate of fertilization application and the availability of soil nutrients as well as species differences. The milling processes such as bran removal in which more minerals and vitamins are lost also affects the mineral content of rice (Rivero *et al.*, 2006).

4.3.7 Soluble carbohydrates in milled rice

The results of carbohydrate content in rice varieties ranged from 74.25 to 76.97%. The two varieties TXD88 and TXD85 had statistically similar soluble carbohydrate content and yet significantly different from NERICA 1, NERICA 4 and TXD306 which had slightly lower percentage of soluble carbohydrate content ($P< 0.05$) as summarized in Table 6. The difference in soluble carbohydrate content perhaps was caused by moisture content as has negative correlation of (–0.95) to carbohydrate (Appendix 7). The results of carbohydrate content for all rice varieties were in agreement to Ibukun, (2008) who found carbohydrate in five rice varieties ranging from 76.22 to 78.20% of which the current studies approaches. Also, Oko and Onyekwere (2010) reported the results obtained for carbohydrate in the five rice varieties ranged from 51.53 to 85.57. In addition Rosniyana *et al.* (2011) stated that, carbohydrate is the major constituent of rice and present in the range of 76.45 to 81.23%. The high percentage carbohydrate contents of the all rice varieties in study shows that the five new rice varieties are good source of energy for rice consumers.

4.4 Milled Rice Quality Indices

The basic objective of a rice milling system is to remove the husks and the bran layers to produce an edible, white rice kernel that appeals to the customers. That is sufficiently milled with maximum total milled rice recovery out of paddy, with a minimum of broken kernels and free of husks, stones, and other non–grain materials.

4.4.1 Dockage

The results of dockage in five rice varieties ranged from 0.001% to 0.306% (Table 7). Whereas the three varieties had the lowest dockage they were statistically similar and yet significantly different from varieties TXD85 and TXD306 which had higher percentage of dockages (P< 0.05) as summarized in Table 7. The differences in dockage percentage were probably caused by poor post–harvest handling practices. All materials other than paddy or rice kernels are called foreign matter or impurities which includes soil, stones, weed seeds, fragments of rice stalk, dust, husk, and dead insects. The foreign matters can be mixed with grains after harvest due to poor post harvest handling especially through beating the harvested paddy on tarpaulin or plastic sheets. The presence of impurities and foreign matter could result in grain deterioration during storage period, also affects the quality of milled rice and accelerates the wear and tear of the milling machines' parts. This is supported by Wilfred and Consultant (2006) that 63.1% of the foreign matter is contaminated throuhg beating the paddy on bare ground, 8.9% against a log, 4.7% drum or special wooden frame/rack and 2.5% by some conventional threshing machine. The poor traditional threshing and later drying methods are responsible for the heavy contamination that the crop usually suffers from soil, sand and small stones, snail shells, weed seed, straw, and immature and unfilled grains. Rice quality is influenced by characteristics under genetic control, environmental conditions and processing techniques in the case of purity. In the latter case, characteristics are principally a function of handling, storage and distribution. ARC (2009) stated that the quality and homogeneity of paddy delivered to rice millers is not always good, poor practices by farmers in harvesting, threshing, drying and storing generally contribute to lowering the quality of locally produced rice by mixing good paddy with damaged grains as well as foreign matters.

4.4.2 Chalkiness appearance in milled rice

The results in Table 7 of chalkiness in the five milled new rice varieties were ranged from 0.62 to 3.20%. Whereas the all five rice vareities had significantly different (P< 0.05) as summarized in Table 7. The differences in chalkiness were probably caused by inherent variability in maturity and genetic makeup. Chalkiness in rice is caused by many factors, such as harvesting at too high moisture contents, uneven ripening of the grains in a panicle leading to excessive numbers of immature grains, high temperatures during ripening and genetic factors. With agreement to Bautista *et al*. (2009) that, lower chalkiness or higher chalkiness is accredited by nighttime temperatures too lower or higher respectively. Also from literature many studies have shown that percentage of grains with chalkiness is a quantitative trait affected by genetic background and environmental conditions (especially weather) during the grain–filling period (Yamakawa *et al.*, 2007). Chalkiness is undesirable in virtually all instances as detracts from overall appearance, uniformity, and generally results in lower mill yields because chalky grains tend to be weak and break easily. However, non uniformity in chalkiness may result in over processing some of the grain and under processing of others with exception to parboiled rice where the process tends to strengthen grains.

4.4.3 Brokens in milled rice

The brokens of the five new rice varieties in Table 7 were ranged from 57.16 to 15.46%. NERICA 1 variety had statistically higher percentage brokens as shown in Table 7 (P< 0.05). Variety TXD88 had significantly low percentage brokens as summarized in Table 7. The brokenness in NERICA vareities were probably caused by genetic makeup. The higher brokenness of the rice varieties almost certainly were due to overexposure of mature paddy to fluctuating temperature, chalkiness and moisture conditions which lead to development of fissures and cracks in individual kernel. Also, diseases such as rice blast or sheath blight can cause milling quality reductions (Candole *et al.,* 2000). Sometimes brokenness can be caused by machine type, unreplaced machnes parts and technology rather than envirnmental conditions and genetics. According to Wilfred and Consultant (2006) noted that, in highly efficient milling machine, 26% of the yield will be broken rice, with the remaining 39% whole head rice, 11% bran and 24% husks. Cracks in the kernel are the most important factor contributing to rice breakage during milling which results in reduces milled rice recovery and head rice yields. Broken rice sells as a low quality, low cost product in most markets; this is a challenge to market due to its poor demand (Wilfred and Consultant, 2006; Campbell *et al*., 2009).

Table 7: Milling quality parameters and cooking time means for five new rice varieties

	Post milling quality indices of the five rice varieties (%)					
Rice variety	**Dockage**	**Brokens**	**Chalkiness**	**HRY**	**TRY**	**CT (Min)**
TXD88	0.0010^{c}	15.46^{e}	0.615^{d}	55.05^{a}	70.31^{a}	22.03^{b}
NERICA4	0.0078^{c}	47.96^{c}	0.685^{cd}	17.69^{c}	65.65^{d}	22.53^{b}
NERICA1	0.0039^{c}	57.16^{a}	0.929^{bc}	8.80^{e}	65.96^{d}	19.34^{c}
TXD85	0.086^{b}	35.28^{d}	1.186^{b}	33.95^{b}	69.23^{b}	24.14^{a}
TXD306	0.304^{a}	52.64^{b}	3.205^{a}	14.75^{d}	67.39^{c}	22.10^{b}
L.S.D (0.05)	0.0564	2.471	0.2766	2.339	0.747	1.312
S.E	0.03	1.312	0.1469	1.242	0.397	0.697
% C.V	37.0	3.1	11.1	4.8	0.6	3.2

L.S.D = Least Significant Differences of means at (P< 0.05), S.E = Standard Error, % C.V = % Coefficient of Variation, HRY= Head Rice Yield, TRY= Total Rice Yield and CT = Cooking Time.

Means in a column not sharing a common superscript letter are significantly different at (P< 0.05) by DMRT.

Each value is an average of three observations.

4.4.4 Head rice yield

The head rice yield in five rice varieties ranged from 8.80 to 55.05% (Table 7). Whereas TXD88 had the highest head rice yield percentage yet statistically different from NERICA 1, NERICA 4, TXD85 and TXD306 which had low percentage head rice yield ($P < 0.05$) as summarized in Table 7. The low percentage of head rice yields in the five rice varieties were possibly caused by higher percentages of brokenness and the differences between rice varieties was probably caused by genetic makeup and pre–harvest agricultural practices especially moisture level at harvesting. Head rice yield typically varies with the moisture content at which rice is harvested. The harvest moisture content at which head rice yield is maximum under Arkansas weather conditions, is approximately 19 to 21% for long–grain cultivars and 22 to 24% for medium–grains (Siebenmorgen *et al.,* 2007). To gain and maintain the optimum milling quality, rice must be harvested at proper moisture content which is 20 – 24% grain moisture or about 30 days after flowering and should be dried up to 14% moisture content the optimal stage to harvest paddy (IRRI, 2009b). Dipti *et al.* (2003) stated that a quality head rice yield should have at least 70%, but highest in current study was 55.05% proving that the head rice yield was poorly either due to pre–harvest or post harvest handling practices. Generally, head rice yield is more sensitive to the changes in milling and polishing conditions in the tested ranges than total milling recovery (Pan *et al.,* 2007).

4.4.5 Total milling recovery of rice

The results of total milling recovery in five rice varieties ranged from 65.65 to 70.31% (Table 7). Whereas the two NERICA varieties had lowest total milling recovery they were statistically similar and yet significantly different from TXD88, TXD85 and TXD306 which had slightly higher percentage total milling recovery ($P > 0.05$). as summarized in Table 7. The results imply that the differences in total milling yield recoveries were probably caused by genetic variation, pre–harvest and postharvest handling practices. As all rice varieties were milled at constant duration of time, probably lower yield in NERICA varities was due to small brokenness particles passed through with paddy husks. Maximum milling recovery range from 69 – 70% depending on rice variety, but because of grain imperfections and the presence of unfilled grains; commercial millers are happy when they achieve 65% milling recovery (IRRI, 2009b; RLDC, 2009). This optional range of 65 – 70% is happily to say all five rice varieties have a good total milling recovery. The results from the current study are in agreement with previous reports that, on rice milling most rice varieties consist roughly of 69% starchy endosperm also referred to as total milled rice which contains whole and broken grains (WARDA 2004; Wilfred and Consultant, 2006).

4.5 Cooking Time of the Five New Rice Varieties

In Table 7 the cooking time results of five rice varieties ranged from 19.34 to 24.14min. Three rice varieties had statistically similar cooking time as shown in Table 7 ($P > 0.05$). Variety NERICA 1 had significantly lower cooking time and TXD85 had highest cooking time. The differences of cooking time in the five rice varieties perhaps was due to the rate of water absorption in rice kernel, hardness and genetic makeup. Cooking of rice is closely related to eating quality because the texture of cooked rice depends on the degree of cooking. The extent of water absorbed by rice during cooking is considered an economic quality as it give some estimate of the volume increase during cooking. With conformity to Suzuki *et al*. (1976) who concluded that the cooking rate was limited by the reaction rate of the rice component with water at temperatures below 100°C, and it was limited by the diffusion of water through the cooked layer toward the interface of uncooked core where the reaction occurs. According to Juliano *et al.* (1981), rice differs in optimum cooking time in excess water between 15 and 25min without pre–soaking. The current study is nearly similar to Danbaba *et al.* (2011) findings that the cooking time for twelve *Ofadas* rice varieties ranged from 17 to 24min, although it is contrary to the report of Otegbayo *et al.* (2001) who reported the cooking time of 52 – 56min in two local rice varieties collected from the same region. Since the texture of cooked rice is a major feature of its quality, the prediction of the behaviour of rice during cooking is essential to understanding cooking quality of rice. The magnitude of losses of nutrient is higher as a result of prolonged cooking time duration especially for protein content.

4.6 Grain Physicochemical Quality Parameters that Indirectly Related to Eating Quality

4.6.1 Amylose content in five rice varieties

In Table 8 the results of amylose content for the five new rice varieties ranged from 15.03 to 27.25%. Whereas the two NERICA varieties had the highest amylose content they were statistically similar yet significantly different from TXD88, TXD 85 and TXD306 which had slightly low percentage amylose content ($P< 0.05$) as summarized in Fig. 4. The differences in amylose content in rice varieties were probably caused by genetic makeup. Amylose content in rice are grouped into waxy (0 – 2%), very low (3 – 9%), low (10 – 20), intermediate (20 – 25%) and high (>25) (Jimenez *et al.,* 2010). According to Chen and Bergman (2007), amylose content of rice starch ranges from 0 – 30% (w/w). Amylose is a necessary, although not sufficient factor for the physicochemical properties determination of rice quality. Knowing characteristics of rice varieties will contribute to the improvement in marketing through labelling and rice cooking quality by using the given information to end–users.

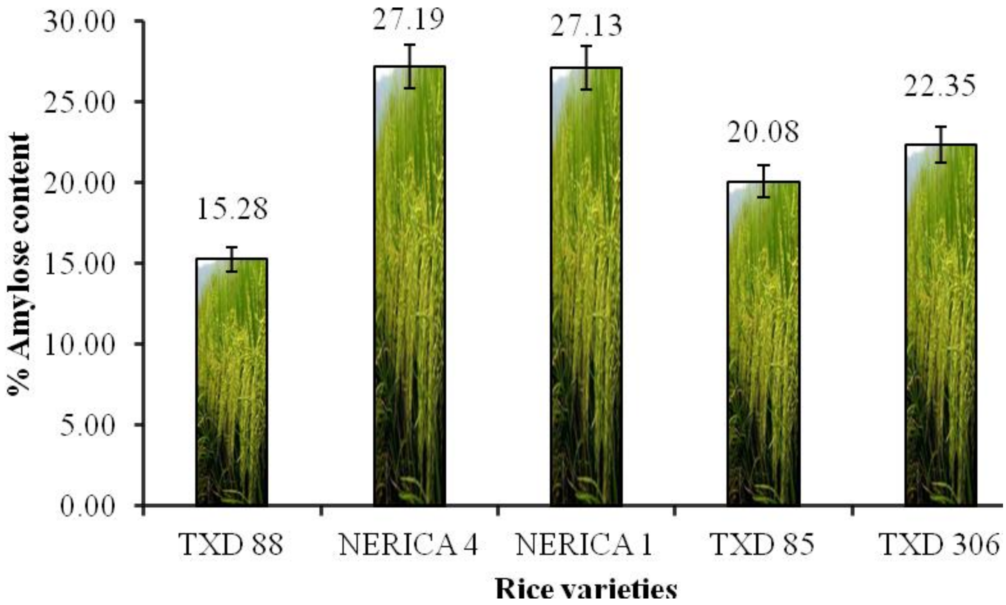


Figure 4: Percentage amylose content in five rice varieties

4.6.2 Gel consistency in rice flour for the five varieties

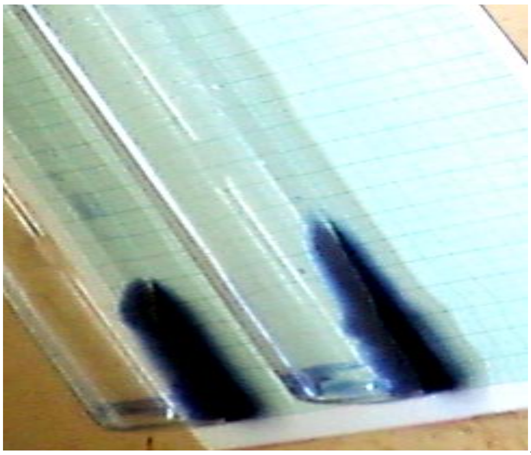
In Table 8 the gel consistency range in the five rice varieties were from 37.33 to 84.00mm. The two varieties TXD88 and NERICA 4 had statistically similar gel consistency as shown in Table 8 ($P > 0.05$). Variety TXD306 had significantly higher gel consistency and variety NERICA 1 had significantly lower gel consistency ($P < 0.05$). The differences in gel consistency were probably caused by genetic makeup. Gel consistency is responsible for softness of rice when cooked; hence TXD306 rice variety was softer than other rice varieties, although the range of soft is 60 – 100mm of which three varieties have (Table 8). Varieties with high length gel consistency are soft–textured and those with low are firm–textured (Plate 2). In most markets, rice with soft to medium gel consistency is more acceptable than rice with hard gel consistency; therefore breeders have to develop high–yielding varieties with soft gel consistency.

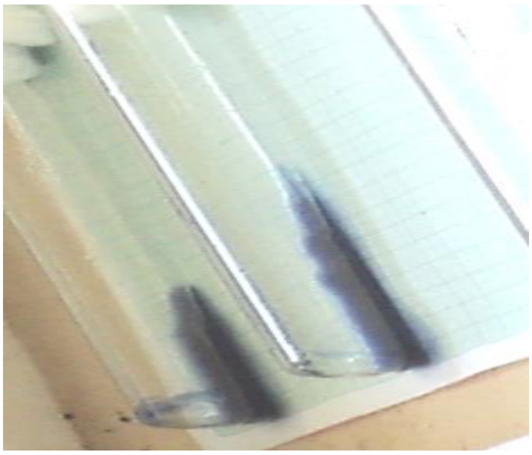
Table 8: Physicochemical parameter means that are inderectly related to eating quality for five new rice varieties

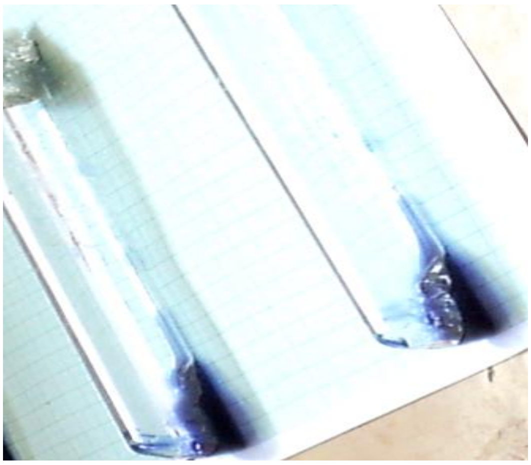
	Physicochemical properties of milled rice		
Rice variety	**Amylose content (%)**	**Gel consistency (mm)**	**ASV**
TXD88	15.03^{d}	62.00^{b}	3
NERICA4	27.25^{a}	71.67^{b}	4
NERICA1	27.13^{a}	37.33^{d}	3
TXD85	20.08^{c}	50.67^{c}	2
TXD306	22.35^{b}	84.00^{a}	3
L.S.D (0.05)	0.45259	10.21	
S.E	0.24038	5.42	
% C.V	1.1	8.9	

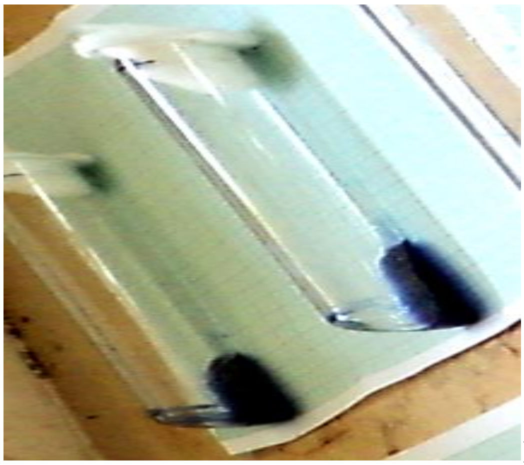
L.S.D = Least Significant Differences of means at ($P < 0.05$), S.E = Standard Error and % C.V = % Coefficient of Variation, ASV = Alkali Spread Value.
Means not sharing a common superscript letter in a column are significantly different ($P < 0.05$) by DMRT

Gel consistency is a standard assay used to classify the processing and cooking quality of different rice cultivars with high amylose content (Nguyet *et al.*, 2010). Also, gel consistency is an excellent index of texture, especially among rice varieties with high amylose content to differentiate soft and firm cooking properties (Cagampang *et al.*, 1973).


A


B


C .


D

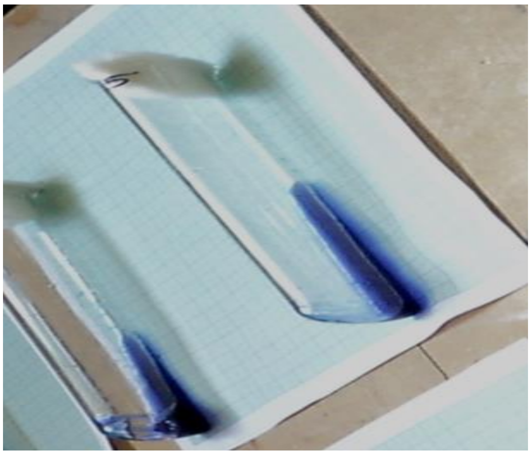

E

Plate 3: Gel consistency length (index of softness) of five new rice varieties in 13 x 100mm culture tubes with blue colour of Thymol blue indicator distance migrated (flow) after 45minutes. The codes A, B, C, D and E respectively represent gels for new rice varieties TXD88, NERICA4, NERICA1, TXD85 and TXD306

Most of farmers cook rice without knowledge of which physicochemical properties are in that rice variety which affects the cooking quality of rice. The gel consistency obtained in current study will help to give information on how to cook new rice varieties with high amylose content, hard gel consistency through training them on rice–water ratio during cooking which is the problem in adoption of new rice varieties.

4.6.3 Gelatinization temperature (Alkali Spreading Value)

The results in Table 8 of alkali spread value in five rice varieties ranged from 2 to 4. Alkali spread value is a physical property of starch presenting the range of temperature by which the starch granules start to swell irreversibly in hot water with simultaneous loss of birefringence (in polarized light) and crystallinity (Kaosa–ard and Juliano, 1990). In this study the small alkali spread values in the five new rice varieties give the ideas of difficult in decomposing (Plate 3). Alkali spreading value is inversely related to the temperature at which rice starch granules gelatinize. The five new rice varieties showed high (2), high intermediate (3) and intermediate (4) gelatinization temperature; meaning that will require high temperature and more fuel during cooking for starch component to gelatinized. The range of alkali spread value in this study is in agreement with Danbaba *et al*., (2011) who reported intermediate gelatinization temperature from *Ofadas* 8, 9 and 10 rice varieties with 3 alkali spread value.

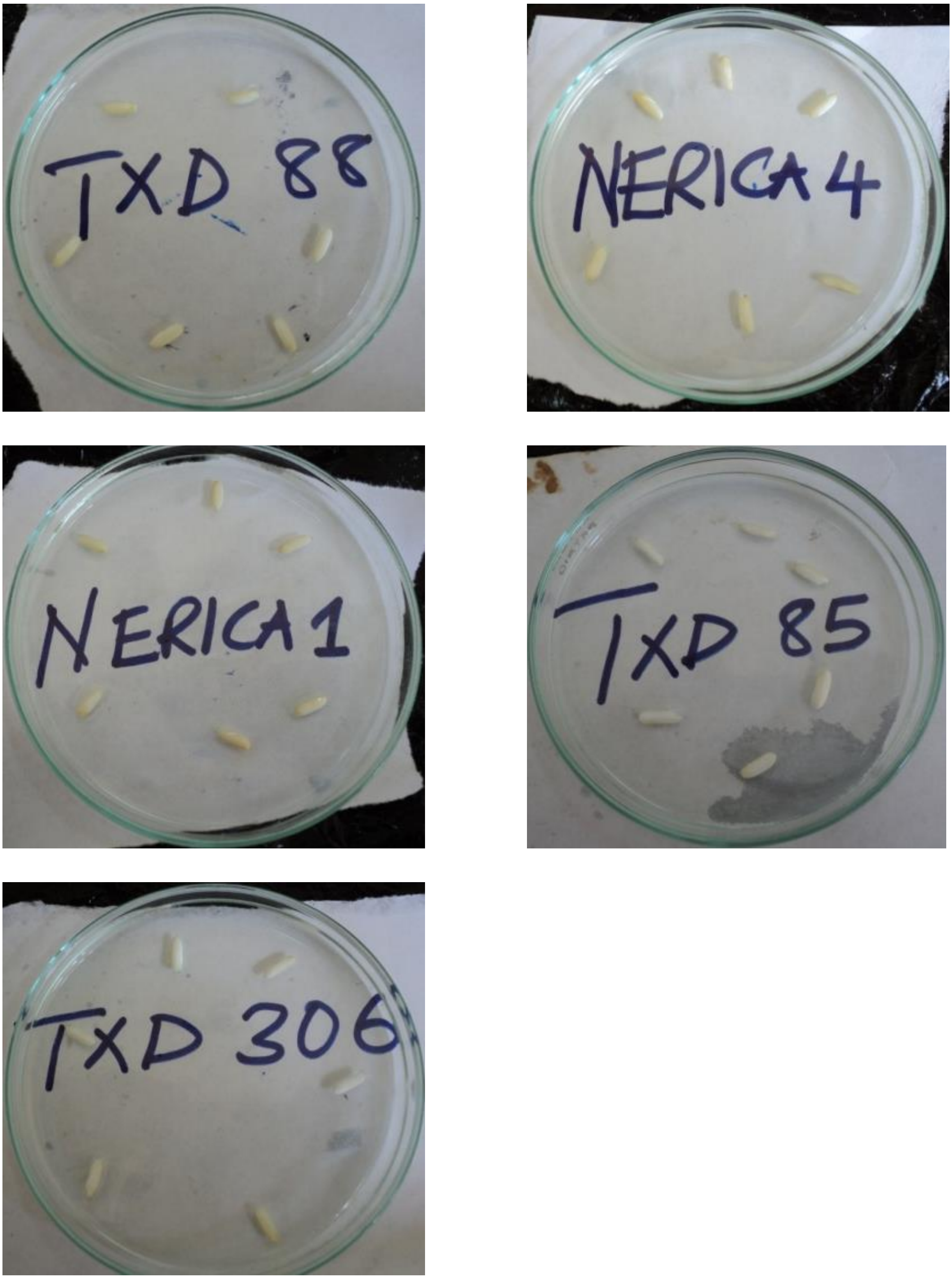


Plate 4: Alkali Spread Value (an index of cooking time) of the five new rice varieties (TXD88, NERICA4, NERICA1, TXD85 and TXD306) with six kernels after being soaked in 1.7%KOH solution at 39°C for 23 hours

The intermediate alkali spread value indicates that, the five new rice varieties were *indica* cultivars as from literature Ebata (1968) explained that, *indica* rice cultivars are generally more resistant and indecomposable from this study to alkali compared with *japonica* cultivars. Therefore the gelatinization properties of rice starch will boost understanding of the properties of the rice grain and help in quality improvement both for the food industry and the rice breeding industry.

4.7 Sensory Evaluation of Cooked Rice

Descriptive sensory analysis methodology is commonly used by the trained panelists for evaluating the intensity of the sensory attributes of cooked rice. Sensory evaluation of cooked rice eating qualities is a difficult task to carry out routinely on a day–to–day basis (Srisawas and Jindal, 2007). Rice varieties are categorized according to grain dimensions and selective physicochemical traits that reflect on the eating quality of cooked rice. The predictions of peak overall sensory acceptability scores correspond to the optimum cooking and their impact on sensory eating quality to the development of baseline information for consumers and rice industry.

4.7.1 Colour of cooked rice

The mean scores results in Table 9 for the colour of the five cooked rice varieties ranged from 3.20 to 4.72. The TXD88 variety had the highest mean colour score and yet significantly different from four varieties ($P < 0.05$) as shown in Table 9. Varieties TXD85 and TXD306 had statistically similar mean colour scores yet significantly different from NERICA varieties which had slightly low mean colour scores as summarized in Table 9. The differences in mean colour scores were probably caused by genetic makeup of cultivars. Colour in rice has higher influence on consumer preferences, some like white colour and some like yellowish colour in believe that it could contain more nutrients than white colour. However, all five rice varieties got higher scores in colour sensory attributes compared to other attributes, meaning that colour is not a problem in the five new rice varieties for quality of appearance.

4.7.2 Taste of cooked rice

The scores taste for the five new rice varieties ranged from 2.48 to 4.40 (Table 9). Whereas the two NERICA varieties had the lowest mean taste scores they were statistically similar and yet significantly different from TXD88, TXD85 and TXD306 which had slightly higher taste mean scores ($P < 0.05$) as summarized in Table 9. The differences in taste mean scores were possibly due to the higher protein and amylose contents. Rice with lower protein content have higher levels of desirable sweet aroma/taste and lower levels of undesirable flavour attributes (Park *et al.*, 2001; Champagne *et al.*, 2004). According to the current study taste of cooked rice has negative correlation coefficient (–0.80 and –0.80) to protein and amylose contents in rice respectively (Appendix 7).

Table 9: Comparisons of sensory attributes scores among five new rice varieties

	Sensory attributes mean score						
Rice variety	**Colour**	**Aroma**	**Taste**	**Texture**	**Mouth feel**	**Consistency**	**O.A**
TXD88	4.72^{a}	4.40^{a}	4.16^{a}	4.04^{a}	4.36^{a}	4.20^{a}	4.52^{a}
NERICA4	3.20^{d}	2.48^{c}	2.68^{d}	2.72^{c}	2.52^{c}	2.56^{c}	2.56^{d}
NERICA1	3.76^{c}	3.32^{b}	3.04^{d}	3.20^{bc}	3.32^{b}	3.28^{b}	3.24^{c}
TXD85	4.24^{b}	3.32^{b}	3.48^{bc}	3.52^{ab}	3.64^{b}	3.60^{b}	3.80^{b}
TXD306	4.28^{b}	3.92^{a}	3.64^{ab}	3.72^{ab}	3.72^{b}	3.44^{b}	3.84^{b}
L.S.D (0.05)	0.4257	0.5630	0.5453	0.63	0.5983	0.5916	0.5355
S.E	0.7583	1.0027	0.9713	1.122	1.0656	1.0537	0.9538
% C.V	18.8	28.7	18.8	32.6	30.3	30.8	26.6

O.A = Overall Acceptability, L.S.D = Least Significant Differences of means at ($P< 0.05$), S.E = Standard Error and
% C.V = Coefficient of Variation.
Means not sharing a common superscript letter in a column are significantly different ($P <0.05$) by DMRT.
Each value is an average of 25 panelists.

4.7.3 Aroma of cooked rice

In Table 9 the mean scores for aroma in cooked rice of five rice varieties ranged from 2.68 to 4.16. The two rice varieties TXD 88 and TXD 306 had the highest aroma mean scores, they were statistically similar and yet significantly different from varieties NERICA1, NERICA 4 and TXD85 which had slightly low aroma mean scores ($P< 0.05$) as summarized in Table 9. Varieties NERICA 1 and TXD85 had statistically similar aroma mean scores ($P> 0.05$). The differences in aroma mean scores were probably caused by genetic makeup. According to Park *et al.* (2001) and Champagne *et al,* (2004), rice with lower protein content have higher levels of desirable sweet aroma/taste and lower levels of undesirable flavour attributes. Also, Terao *et al.* (2005) found that, growing rice cultivar under elevated CO_2 concentration decreased the protein content but did not change the sensory properties to a level they could be detected by taste panel evaluation. Temperature affects the contents of certain compounds of individual cultivars differently (Liu *et al.*, 1996). Fragrant or scented rice that obtains a premium price in international markets is characterized by its natural fragrance or pleasant aroma and good taste quality (Yi *et al.*, 2009).

4.7.4 Mouth feel of cooked rice

The mean scores of mouth feel in Table 9 for the five new rice varieties ranged from 2.72 to 4.04. The three varieties TXD306, TXD85 and NERICA 1 had statistically similar mouth feel as shown in Table 9 (P> 0.05). Variety NERICA 4 had significantly lower mouth feel mean score while TXD88 variety had highest mouth feel mean score. The significant differences in mouth feel mean scores in rice varieties probably were due to varietal differences in genetic makeup whereby each variety has its physicochemical properties which influence palatability and mouth feel. According to Sun *et al*. (2011) the correlation coefficient analysis shows that palatability is negatively correlated with protein content. Palatability is a complex trait in which many factors are involved, but mainly affected by protein content and amylose content which is positively correlated to protein content. From the current study there was a negative correlation relationship between mouth feel and protein and amylose contents (–0.88) and (–0.89) respectively (Appendix 7). This can be concluded that the rice variety with low protein content (Table 6) and low amylose content (Fig. 4) has higher acceptability to consumers and this is clearly reflected with variety TXD88 which was highly accepted by panelists (Table 9).

4.7.5 Texture of cooked rice

In Table 9 the mean scores for texture of the five cooked rice varieties ranged from 2.52 to 4.36. Rice varieties TXD85 and TXD306 had statistically similar texture mean scores as shown in Table 9 (P> 0.05). Variety TXD88 the highest texture mean score and yet significantly different from the other varieties which had slightly low texture mean scores (P< 0.05). The differences in texture mean scores were probably caused by the genetic makeup and environmental conditions where the paddy was grown. The highest texture means score in TXD 88 possibly was influenced by lower amylose content. Texture of cooked rice has negative correlation (–0.89) with amylose content and protein (–0.88) in the current study (Appendix 7). Sensory and functional end–use quality characteristics of varying rice cultivars are directly affected by amylose content such as rice flavour and texture (Champagne *et al.,* 2004). Characterization of amylose kernel distributions is relevant to sensory and functionality as more uniform rice tends towards more uniform performance in various food processing (Philpot *et al.,* 2006).

4.7.6 Cooked rice consistency

The consistency mean scores of cooked rice varieties ranged from 2.56 to 4.20 (Tables 9). Three rice varieties TXD85, TXD306 and NERICA 1 had statistically similar consistency mean scores as shown in Table 9 (P> 0.05). Variety TXD88 had statistically higher consistency mean score while NERICA 4 had significantly low consistency (P< 0.05). The differences in consistency mean scores perhaps were influenced with lower scores of colour, aroma, taste, texture and mouth feel (Table 9). Consistency is particularly an important trait to consumers in many countries, because most rice is consumed in a whole grain form. Numerous factors constitute general appearance including grain size and shape, uniformity, translucency, chalkiness, colour, damaged and imperfect grains.

4.7.7 Cooked rice acceptability

The mean scores of the overall acceptability for the five new rice varieties ranged from 2.56 to 4.52 (Table 9). Two rice varieties TXD85 and TXD306 had statistically similar overall acceptability mean scores as shown Table 9 (P> 0.05). Variety TXD 88 had significantly higher overall acceptability mean scores. Variety NERICA 4 had significantly low overall acceptability mean score as shown in Table 9. The differences in overall acceptability means scores in rice varieties perhaps were influenced by the varietal differences through the genes. The low overall eating quality in NERICA4 and NERICA1 was probably affected by higher protein and amylose contents which are influenced by environmental factors such as growing temperature and soil fertility but mainly can be determined by genetic control. The statement can be supported by (Srisawas and Jindal, 2007) that the amount of water required for achieving the peak overall acceptability scores of cooked rice increased markedly with an increase in the amylose content. Still, no panelist showed a total dislike for the all five new rice varieties. According to Campbell *et al.* (2009) the West African rice market is primarily segmented on the basis of quality attributes that match different consumers' preferences, which are complex and vary by locality whereby dominant preferences vary by country, between rural and urban areas and often between various regions within a country. The difference in overall acceptability is not much wonderful, even within a given urban household; consumers prefer different types of rice depending on the specific meal they are preparing that day. According to MAFC (2009) rice consumers in Tanzania are very keen on the grain size, colour, taste/flavour and cooking attributes of rice where majority of the consumers prefer both aromatic to non–aromatic rice varieties. General appearance of the milled and cooked rice is frequently the first quality rating assigned to a lot of milled and cooked rice.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the survey conducted during this study, rice production and consumption chain had significant complaints on grain size and shape, chalkiness, brokens, mixed aroma rice varieties, long cooking time and gelatinization tendency. Also, the post harvest management handling practices notably cleaning, drying and storage has to be improved with a view of preventing contamination and colour change in stored grains.

The five new varieties (TXD88, NERICA4, NERICA1, TXD85 and TXD306) showed great variability in size, shape, proximate composition, milling parameters, cooking time, amylose content (which has an inverse relationship with taste), gel consistency (softness) and in sensory attributes. Notwithstanding the variability in these quality indices, the following conclusions were drawn: Firstly the rough rice indices for all the varieties (immature grains, 1000 grains' weight, grains length and grain length width ratio) were within acceptable standards. Secondly the two NERICAs varieties had high protein content implying that they can be used as protein fortifiers for rice based cooked and fried products. NERICA 1 which was endowed with high fibre content (1.02%) can be used by diabetics and patients whose diet demands high fibre intake. Variety TXD 306 which has been shown to be relatively high in fat content is a good source of dietary calories (energy). In general the five rice varieties have considerable amount of nutrients such as carbohydrates and fat as potential energy source, protein for body repairs and crude fibre for effective digestibility of food.

TXD 88 with relatively low amylose content was the best variety with respect to taste and texture. The two new rice varieties (NERICA 1 and NERICA 4) with relatively high amylose content which is an undesirable attribute as it has a suppressing effect on taste. This is demonstrated by negative correlations between amylose content and taste and texture (–0.94 and –0.89) for the NIRECA 1 and NERICA 4 varieties respectively. These two rice varieties had in effect scored relatively low sensory ratings. Variety TXD 88 has good taste as manifested by having low amylose content (Table 8); it also has a good texture since its gel consistency within the softness grade. Furthermore, the NERICA 4 and TXD 306 are comparable to variety TXD88 with regard to texture.

In this study it has been explained that, rice quality is an important aspect for consumers and marketing. The differences observed in five new rice varieties are probably linked to their genotypic makeup. Nevertheless their phenotypic expressions notably chalkiness were probably induced by the storage environment especially high temperatures and humidity pre–harvest. There are some differences that were caused by pre–harvest and post harvest practices these can be controlled easily through pre–harvest and post harvest handling practices for quality to be maintained.

5.2 Recommendations

Since the nutrients composition in the investigated varieties was relatively high its investigation need to be enhanced in all new rice varieties. Therefore, efforts should be made to ensure availability of these good rice seeds to farmers, which will subsequently get to the consumer for derivation of the above–mentioned nutrients.

Milling quality parameters such as dockage, chalkiness and brokenness have undesirable effect on perception and these have to be scrutinized for new varieties. Dockage has effect on machine parts, economic and consumers; chalkiness increase brokens to rice during milling and reduce the head rice and price at market It is recommended that TXD88 variety which ranked first in milling quality parameters need to be multiplied more and provided to farmers for more production.

The TXD88 variety rated highly in sensory evaluation and low amylose content. The correlation coefficient of amylose content and 1000 grains weight was 0.95 which it is true that the 1000 grains weight of TXD88 was 30.91g and amylose content 15.03% being lowest and NERICA1 had 36.78g of 1000 grains weight being highest had amylose content 27.13%. Therefore, low amylose content rice varieties are highly recommended for consumers.

There is currently meager promotion of rice production in general. This means that, inadequate promotion of the rice quality, price, availability and cooking instructions (possibly hinder adoption of new rice varieties). To generate consumer confidence in rice and rice products, quality enhancement must precede promotion efforts.

Complementary research studies need to be conducted in the seventeen NERICA varieties (NERICA 2, NERICA 3, NERICA 5, NERICA 6, NERICA 7, NERICA 8, NERICA 9, NERICA 10, NERICA 11, NERICA 12, NERICA 13, NERICA 14, NERICA 15, NERICA 16, NERICA 17, NERICA 18 and WAB 450) which were not part of the present study to improve the choice of new rice varieties. Furthermore, the rice quality with good yielding, milling, tolerance to weed, drought and pests should be generated. Also, research could be done on the cost analysis of indigenous rice varieties compared to new rice varieties.

This study should be repeated in different ecological zones using different rice varieties to generate more information on postharvest handling practices and different ecological zones with relation to quality of rice varieties producers, traders and consumers.

REFERENCES

Abbas, A., Murtaza, S., Aslam, F., Khawar, A., Rafique, S. and Nahee, S. (2011). Effect of Processing on Nutritional Value of Rice (*Oryza sativa* L.). *World Journal of Medical Sciences* 6(2): 68 – 73.

Adeyemi, I.A. (2009). Some Quality Factors of Raw And Processed Rice: *Nigerian Food Journal (NIFOJ).* [http://www.nifst.org/Editorials/FOOD–FORUM/] Site Visited on 26/3/2012.

Afsar, A.K.M.N., Baqw, M., Rawman, M. and Rouf, M.A. (2001). Grades, Standards and Inspection Procedures of Fuce in Bangladesh. Bangladesh Food Management and Research Support Project. Ministry of Food, Government of the People's Republic of Bangladesh. International Food Policy Research Institute. FMRsP Working Pap., (20). [http://pdf.usaid.gov/pdf_docs/PNACN994.pdf] Site Visited on 23/5/2012.

Aganga, A.A. and Tshwenyane, S. (2004). Potentials of Guinea Grass (*Panicum maximum*) as Forage Crop in Livestock Production. *Pakistan Journal of Nutrition* 3(1): 1 – 4.

Anjum, F.M. Pasha, I., Bugti, M.A. and Batt, M.S. (2007). Mineral Composition of Different Rice Varieties and their Milling Fractions. *Pakistan Journal of Agricultural Science* 44(2): 51 – 58.

Anonymous, (2007). Albert Agriculture and Food: Using 1000 Kernel Weight for Calculating Seeding Rate and Harvest Losses.

[http//www1.agric.gov.ad/$department/deptdocs.nfs/all/agdex8] Site Visited on 19/7/2012.

AOAC (1995). Official Methods of Analysis, 16th (Ed). Vol. II, AOAC Inc., Arlington, Washington, D.C. 49pp.

ARC (2009). Africa Rice Center (AfricaRice) Annual Report 2009: Increasing Investment in Africa's Rice Sector. Cotonou, Benin. 68pp.

Armstrong, B.G., Aldredl, G.P., Armstrong, T.A., Blakeney, A.B. and Lewin, L.G. (2005). Measuring Rice Grain Dimensions with an Image Analyser. [http//www.regional.org.au/au/Cereals_cd/pdf/86armstrong.pdf.] Site Visited on 19/5/2012.

Atwell, W.A., Hood, L.F. and Lineback, D.R. (1988). The Terminology and Methodology Associated with Starch Phenomena. *Cereal Foods World* 33: 306 – 311.

Banerjee, S., Chandel, G., Mandal, N., Meena, B.M. and Saluja, T. (2011). Assessment of Nutritive Value in Milled Rice Grain of Some Indian Rice Landraces and their Molecular Characterization. *Bangladesh Journal of Agricultural Research* 36(3): 369 – 380.

Bautista, R.C. and Siebenmorgen, T.J. (2005). Individual Rice Kernel Moisture Content Variability Trends. *Applied Engineering in Agriculture* 21(4): 637 – 643.

Bautista, R.C., Siebenmorgen, T.J. and Counce, P.A. (2009). Rice Kernel Chalkiness and Milling Quality Relationship of Selected Cultivars. [http://www.uaex.edu/] Site Visited on 22/4/2012.

Bell, M.A., Bakker, R.R., De Padua, D.B. and Rickman, J. (2000). *Rice Quality Management– Principles and Some Lessons*. Makati, Philippines. 110pp.

Braun, J.V. and Bos, M.S. (2005). The changing economics and politics of rice: Implications for food security, globalization, and environmental sustainability. In: *Rife is Life*: Scientific Perspectives for the 21st Century. (Edited by Toriyama, K.), 4 – 7 November 2004. Los Baños, Philippines. 570 – 590pp.

CAC, (1990). *Proposed Draft Standard for Rice*. Food standards Programme. CX/CPL/90/5. Rome, FAO. 8pp.

Cagampang, G.B., Perez, C.M. and Juliano, B.O. (1973). A Gel Consistency Test for Eating Quality in Rice. *Journal of Science of Food and Agriculture* 24: 1589 – 1594.

Campbell, R., Hannah, S. and Donald, S. (2009). Global Food Security Response West Africa Rice Value Chain Analysis: microREPORT. USAID. [http://www.scribd.com/doc/GFSR–West–Africa–Rice–Value–Chain–Analysis] Site Vistited on 12/3/2012.

Candole, B., Siebenmorgen, T.J., Lee, F. and Cartwright, R. (2000). Effect of Rice Blast and Sheath Blight on the Physical Properties of Selected Rice Cultivars. *Cereal Chemistry* 77(5): 535 – 540.

CARD (2009). *Support Workshop for the Formulation of National Rice Development Strategies*. Secretariat of the Coalition for African Rice Development (CARD), Africa Rice Center, 2nd – 5th February 2009, Cotonou, Benin. 64pp.

Champagne, E.T., Bett–Garber, K.L., Grimm, C.C. and McClung, A. M. (2007). Effects of Organic Fertility Management on Physicochemical Properties and Sensory Quality of Diverse Rice Cultivars. *Cereal Chemistry* 84(4): 320 – 327.

Champagne, E.T., Bett–Garber, K.L., McClung, A.M. and Bergman, C. (2004). Sensory Characteristics of Diverse Rice Cultivars as Influenced by Genetic and Environmental Factors. *Cereal Chemisry* 81: 237 – 243.

Chen, M.H. and Bergman, C.J. (2007). Method for Determining the Amylose Content, Molecular Weights and Weight–and Molar–Based Distributions of Degree of Polymerization of Amylose and Fine–Structure of the Amylopectin. *Carbohydrates Polymers* 69: 562 – 578.

Choudhury, N.H. and Juliano, B.O. (1980). Effect of' Amylose Content on the Lipids of Mature Rice Grain. *Phytochemistry* 19: 1385 – 1389.

Cooke, D. and Gidley, M.J. (1992). Loss of Crystalline and Molecular Order During Starch Gelatinization: Origin of the Enthalpy Transition. *Journal of Carbohydrate Research* 227: 103 – 112.

Cooper, N.T.W., Siebenmorgen, T.J. and Counce, P.A. (2008). Effects of nighttime temperature during kernel development on rice physico chemical properties. *Cereal Chemistry* 85(3): 276 – 282.

Danbaba, N., Anounye, J.C., Gana, A.S., Abo, M.E. and Ukwungwu, M.N. (2011). Grain Quality Characteristics of *Ofada* Rice (*Oryza Sativa* L.): Cooking and Eating Quality. *International Food Research Journal* 18: 629 – 634.

Dawson, E.H, Little, R.R. and Hilder, G.B. (1958). Different Effect of Dilute Alkali on 25 Varieties of Milled White Rice. *Journal of Cereal Chemistry* 35: 111 – 126.

De Padua, D.B. (1979). A Critical Review of the Losses in the Rice Post Production System in Southern Asian Countries. In: *Interfaces Between Agriculture, Nutrition and Food Science. Proceeding of a UN–IRRI Workshop IRRI*, (1997) Los Beños, Laguna, Philippines, IRRI: pp. 89 – 104.

De vizia, B. Ciccimarra, F. De Cicco, N. and Auricchio, S. (1975). Digestibility of Starch in Infants and Children. *Journal of Pediatrics* 86: 50 – 55.

Dipti, S.S. Bari M.N. and Kabir, K.A. (2003). Grain Quality Characteristics of Some Beruin Rice Varieties of Bangladesh. *Pakistan Journal of Nutrition* 2(4): 242 – 245.

Duff, B. and Toquero, Z. (Eds.) (1975). *Factors Affecting the Efficiency of Mechanization: Farm Level Rice Post–Production Systems*. University of the Philippines at Los Baños, Philippines. 45pp.

Eastword, M.A. (1974). Dietary Fiber in Human Nutrition. *Journal of Food Science* 30 (11): 784 – 788.

Ebata, M. (1968). Studies on Alkali Decomposition in Rice Kernels: 2 Effects of Varieties and Some Ripening Conditions on Alkali Decomposition of Milled White Rice. *Processing Crop Science Society Japan* 37: 499 – 503.

Ebuehi, O.A. and Oyewole, A.C. (2007). Effect of Cooking and Soaking on Physical Characteristics, Nutrient Composition and Sensory Evaluation of Indigenous and Foreign Rice Varieties in Nigeria. *Nigerian African Journal of Biotechnology* 6(8): 1016 – 1020.

Edeogu, C.O., Ezeonu, F.C. Okaka, A.N.C. Ekuma, C.E. and EIom, S.O. (2007). Proximate Compositions of Staple Food Crops in Ebonyi State, South Eastern Nigeria. *International Journal of Biotechnology and Biochemistry*. [http://findarticles.com/p/articles/mi_html] Site Visited on 27/4/2012.

Efferson, J.N. (1985). Rice Quality in World Markets in Rice Grain Quality and Marketing. Paper Presented at the International Rice Research Conference, 1 – 5 June 1985. Los Baños, Laguna Philippines, pp. 47 – 53.

Eve, P. (1973). *Cooking with rice*. Farrar, Straus and Giroux, New York, USA. 184pp.

Fairhurst, T.H. and Dobermann, A. (2002). Rice in the Global Food Supply. In: *Rice Production Special Supplement Publication*. (Edited by Armstrong, D.L. and Griffin, K.P.), Saskatoon, Saskatchewan, Canpotex Ltd, Canada. pp.16 – 48.

FAO (2008). Food Outlook November Edition, 2008. [http://www.fao.org] Site Visited on 26/4/2012.

FAO and Juliano, B.O. (1993). Grain structure, composition and consumers' criteria for quality. In: *Rice in human nutrition*. (Published with the Collaboration of the International Rice Research Institute Food and Agriculture Organization of the United Nations). Rome, Italy: pp.35 – 59.

Fitzgerald, M. (2011). "Chalky" discovery could increase value of rice by 25%. *IRRI Food and Agriculture* 25: 1523 – 1527.

Fox, M.R.S, and Tao, S.H. (1989). Antinutritive effects of phytate and other phosphorylated derivatives. *Nutrition Toxicology* 3: 59 – 62.

Fresco, L. (2005). Rice is life. *Journal of Food Composition Analysis* 18: 249 – 253.

Futakuchi, K. and Sie, M. (2009). Better Exploitation of African Rice (*Oryza graberrima* Steud.) in Varietal Development for Resource–Poor Farmers in West and Central Africa. *Agricultural Journal* 4(2): 96 – 102.

Guisse, R. (2010). Post Harvest Losses of Rice (*Oryza sativa* L.) From Harvesting to Milling: A Case Study in Besease and Nobewam in The Ejisu Juabeng District in The Ashanti Region of Ghana. Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. 94pp.

Gummert, M. (2004). Training Manual measurements: Agricultural Engineering Unit. IRRI, Los Baños, Philippines. pp.1 – 58.

Gummert, M. (2010). Rice Quality: Rice Science for the Better World. [http://www.knowledgebank.irri.org] Site Visited on 16/7/2012.

Hill, J. (2005). Rice Growth and Development: California Rice Production Workshop, 1st January 2005, California, USA. [http://www.plantsciences.ucdavis.edu/pdf] Site Visited on 28/3/2012.

Honjo, K. (1971). Studies in Protein Content in Rice Grains: Variations in Protein Content among Rice Cultivars and Influences of Environmental Factors on the Protein Content. *Processing Crop Science Society in Japan* 40: 183 – 189.

Hoover, R. and Ratnayake, W.S. (2001). Determination of Total Amylose Content of Starch. In: *Current Protocols in Food Analytical Chemistry*. Memorial University of Newfoundland St. John's, Canada. 5pp.

Huang, Y.S., Sun, Z.X., Hu, P.S. and Tang, S.Q. (1998). Present Situation and Prospects for the Research on Rice Grain Quality Forming. *Chinese Journal of Rice Science* 12(3): 172 – 176.

Ibukun, E.O. (2008). Effect of Prolonged Parboiling Duration on Proximate Composition of Rice. *Scientific Research and Essay* 3(7): 323 – 325.

INRA (2008). Rice in the World: Origin and History. [http://www.orecinternational.org/] Site Visited on 16/7/2012.

IRRI (2005). Rice knowledge Bank. [http://www.Knowledgebank.irri.org/rkb/ricemilling/] Site Visited on 25/5/2012.

IRRI (2009a). Pakistan Rice Bank: *Rice Quality Training Manual.* Worldwide Rice Information. [http://pkricebank.blogspot.com/html] Site Visited on 22/3/2012.

IRRI (2009b). Milling/ Processing: *Rice Knowledge Bank.* (CIMMYT) International Maize and Wheat Improvement Centre. [http://www.knowledgebank.irri.org/rkb/] Site Visited 01/3/2012.

IRRI (2010). Rice Knowledge Bank: Procedures for Measuring Quality of Paddy Grain [http://www.knowledgebank.irri.org/quality–characteristics–of–paddy/procedures–for–measuring–quality–of–paddy–grain.html] Site Visited on 21/3/2012.

Jaiswal, P.K. (1983). Specification of Rice Bran Oil and Extractions. In: *Rice Bran Oil, Status and Prospects*. (Edited by Pradesh, A.), 13 August 1983, Southern Zone, Hyderabad, India. pp. 64 – 77.

Jimenez, R.R. Resurreccion, A.P. and Fitzgerald, M.A. (2012). Moving from Apparent to Actual Amylose in Rice. Presented at the 28th International Rice Research Conference, 8–12th November 2010, Hanoi, Vietnam. 3pp.

Juliano, B.O. and Duff, B. (1989). Setting priorities for rice grain quality research. Paper presented at 12th ASEAN Technical Seminar on Grain Postharvest Technology, 29 – 31 August 1989, Surabaya, Indonesia. 66pp.

Juliano, B.O. and Goddard, M.S. (1986). Cause of Varietal Difference in Insulin and Glucose Responses to Ingested Rice. *Journal of Quality Plant and Plant Foods in Human Nutrition* 36: 35 – 41.

Juliano, B.O. and Perez, C.M. (1983). Major Factors Affecting Cooked Milled Rice Hardness and Cooking Time. *Journal of Texture Studies* 14: 235 – 243.

Juliano, B.O., Perez, C.M., Barber, S., Blakeney, A.B., Iwasaki, T., Shibuya, N., Keneaster, K.K., Chung, S., Laignelet, B., Launay, B., del Mundo, A.M., Suzuki, H., Shiki, J., Tsulji, S., Tokoyama, J., Tatsumi, K., Webb, B.D. (1981). International Cooperative Comparison of Instrument Methods for Cooked Rice Texture. *Journal of Texture Studies* 12: 17 – 18.

Juliano, B.O., Perez, C.M., Maranan, C.L., Abansi, C.L. and Duff, B. (1989). Grain Quality Characteristics of Rice in Philippine Retail Markets. *Journal of Philippine Agriculture* 72: 113 – 122.

Kaosa–ard M. and Juliano B. O. (1990). Assessing Rice Quality Characteristics and Prices. In: *Selected International Markets*. Rice Grain Marketing and Quality Issues Selected Papers from the International Rice Research Conference 27 – 31 August 1990, Seoul, Korea. 250pp.

Kataoka, K. (1975). Studies on Chemical Quality of the Rice Kernel: Effect of Temperature on Protein Content. *Journal of Tamagawa University* 15: 96 – 100.

Kaul, A.K., Khan, M.R.I. and Munir, K.M. (Eds.) (2002). *National Workshop on Rice Research: Feeding the Extra Millions by 2025*. Bangladesh Rice Research Institute, Gazipur. 122pp.

Kenmore, P. (2003). Sustainable Rice Production, Food Security and Enhanced Livelihoods. In *"Rice Science":* (Edited by Mew, T.W., Brar, D.S., Peng, S., Dawe, D. and Hardy, B.). Innovations and Impact for Livelihood. pp. 27 – 34.

Khan, A.U. (1973). Rice Drying and Processing Equipment for Southern Asia. *Journal of Trans American Society Agriculture Engineering* 16: 1131 – 1135.

Larmond, E. (1977). Laboratory Methods for Sensory Evaluation of Foods. 1637 Publication, Canada Department of Agriculture, Ottawa, Canada. 74pp.

Lee, M.H. (2001). Low Temperature Tolerance in Rice: The Korean Experience. Increased Lowland rice Production in the Mekong Region (Edited by Fukai, S. and Basnayake, J.). ACIAR Proceedings 101. IRRI, Makati, Philippines. 79pp.

Lestari, P., Ham, T.H., Lee, H.H., Woo, M.O. and Jiang, W. (2009). PCR Marker–Based Evaluation of the Eating Quality of Japonica Rice (*Oryza sativa* L.). *Journal of Agriculture and Food Chemistry* 57: 2754 – 2762.

Linares, O.F. (2002). African rice (*Oryza glaberrima* Steud.): History and Future Potential. *Proceedings of National Academy of Sciences of The United States of America* 99(25): 16360 – 16365.

Little, R.R., Hilder, G.B. and Dawson, E.H. (1958). Differential Effect of Dilute Alkali on 25 Varieties of Milled White Rice. *Cereal Chemistry* 35: 111 – 126.

Liu, T.T, Wu, C.M. and Yau, N.J.N. (1996). Descriptive Analysis of Odour of Cooked Rice Maintained at 18 and 60^{o}C. *Journal of Food Science* 23: 761 – 766.

Lorenz, K. and Kulp, K. (1991). Handbook of Cereal Science and Technology. Marcel Dekker Inc. 270, Madison Avenue, New York. 882pp.

Lorieux, M., Petrov, M., Huang, N., Guiderdoni, E. and Ghesquiere, A. (1996). Aroma in rice: Genetic Analysis of Quantitative Trait. *Journal of Theory and Applied Genetics* 93: 1145 – 1151.

Lyon, B.G., Champagne, E.T. Vinyard, B.T. and Windham, W.R. (2000). Sensory and Instrumental Relationships of Texture of Cooked Rice From Selected Cultivars and Postharvest Handling Practices. *Cereal Chemistry* 77(1): 64 – 69.

Mabbett, T. (2011). Wet and Dry Rice Processing Methods. Far Eastern Agriculture is Published by Alain Charles Publishing Ltd. [http://www.fareasternagriculture.com/] Site Visited on 25/3/2012.

MAFC (2009). National rice Development Strategy Final Draft. Dar es Salaam, Tanzania. [http://www.agriculture.go.tz/highlights/AnnualReport.pdf] Site Visited on 24/3/2012.

Magan, N., Aldred, D. and Sanchis, V. (2004). The Role of Spoilage Fungi in Seed Deterioration.[http://www.drugswell.com/winow/new/Fungal_Biotechnology_in_Agricultural_Food_and_Environmental_Applications.pdf] site visited on 21/7/2012.

Mahatheeranont, S., Keawsa–ard, S. and Dumri, K. (2001). Quantification of the Rice Aroma Compound, 2–Acetyl–1–Pyrroline, in Uncooked Khao Dawk Mali 105 Brown Rice. *Journal of Agricultural Food Chemistry* 49: 773 – 779.

Meilgaard, M., Civille, G.V, and Carr, B.T. (2007). *Sensory Evaluation Techniques*. CRC Press: Boca Raton, FL.448pp.

Merca, F. E. and Juliano, B.O. (1981). Physicochemical and Cooking Properties of Some Fine Rice Varieties. *Pakistan Journal of Nutrition* 1(4): 188 – 190.

Meullenet, J.F., Bradley, P. Marks, J.A. Hankins, V.K.G. and Daniels, M.J. (2000). Sensory Quality of Cooked Long–Grain Rice as Affected by Rough Rice Moisture Content, Storage Temperature, and Storage Duration. *Journal of Cereal Chemistry* 77(2): 259 – 263.

Mohapatra, D. and Bal, S. (2007). Effect of Degree of Milling on Specific Energy Consumption, Optical Measurements and Cooking Quality of Rice. *Journal of Food Engineering* 80: 119 – 125.

MRCO, (2007). Land, People and Climate. Morogoro Economy. [http://www.tanzania.go.tz/regions/Morogoro.pdf] Site Visited on 28/3/2012.

Nagato, K. Ebata, M. and Ishikawa, M. (1972). Protein Content of Developing and Mature Rice Grains. *Journal of Processing Crop Science Society Japan* 41: 472 – 479.

Nguyet, T.A. Daygon, V.D. and Fitzgerald, M. (2010). A Single Nucleotide Polymorphism on The Waxy Gene Explains Gel Consistency. The 28th International Rice Research Conference, 8 – 12 November 2010. Hanoi, Vietnam. 3pp.

Nie, N.H., Hadlai, C.H. and Bent, D.H. (1968). SPSS Computer Program. [www4.unescobkk.org/.b2/2–introduction–to–spss–pasw–statistics/] Site Visited on 25/7/2012.

Nikuni, Z., Hizukuri, S., Kumagai, K., Hasegawa, H., Moriwaki,. Fukui,T., Doi, K., Nara, S. and Maeda, I. (1969). The Effect of Temperature during Maturation Period on The Physic–Chemical Properties of Potatoes and Rice Starches. *Mena Institute of Science Industry Research* 26: 1 – 27.

Noreen, N., Shah, H., Anjum , F. Masood, T. and Faisal, S. (2009). Variation in Mineral Composition and Phytic Acid Content in Different Rice Varieties during Home

Traditional Cooking Processes. *Pakistan Journal Life society for science* 7(1): 11 – 15.

Oko, A.O. and Onyekwere, S.C. (2010). Studies on The Proximate Chemical Compositions and Mineral Element Contents of Five New Lowland Rice Varieties Planted in Ebonyi State. *International Journal of Biotechnology and Biochemistry* 6(6) 949 – 955.

Oko, A.O. and Ugwu, S.I. (2011). The Proximate and Mineral Compositions Of Five Major Rice Varieties in Abakaliki, South–Eastern Nigeria. *International Journal of Plant Physiology and Biochemistry* 3(2): 25 – 27.

Otegbayo, B.O., Osamuel, F. and Fashakin, J.B. (2001). Effect of Parboiling on The Physicochemical Qualities of Two Local Rice Varieties in Nigeria. *The Journal of Food Technology in Africa* 6(4): 130 – 132.

Pan, Z., Thompson, J. F., Amaratunga, K.S., Anderson, P.T. and Zheng, X. (2007). Effect of Cooling Methods and Milling Procedures on The Appraisal of Rice Milling Quality. *Journal of Trans. ASAE* 48(5): 1865 – 1871.

Paranthaman, R., Alagusundaram, K. and Indhumathi, J. (2009). Production of Protease from Rice Mill Wastes by *Aspergillus Niger* in Solid State Fermentation. *World Journal of Agricultural Sciences* 5(3): 308 – 312.

Park, J.K., Kim, S.S. and Kim, K.O. (2001). Effect of Milling Ratio on Sensory Properties of Cooked Rice and on Physicochemical Properties of Milled and Cooked Rice. *Journal of Cereal Chemistry* 78: 151 – 156.

Payne, R.W., Harding, S.A., Murray, D.A., Soutar, D.M., Baird, D.B., Glaser, A.I., Welham, S.J., Gilmour, A.R., Thompson, R., Webster, R., RafieeJafari, A., Varnamkhasti, M.G., Mobli, H. (2011). A Guide to Anova and Design in GenStat®. VSN International, 5 The Waterhouse, Waterhouse Street, Hemel Hempstead, Hertfordshire HP1 1ES, UK. 123pp.

Pedersen, B. and Eggum, B.O. (1983). The Influence of Milling on the Nutritive Value of The Flour From Cereal Grains. *Plant Foods for Human Nutrition* 32: 185 – 196.

Philpot, K., Martin, M. Butardo, Jr., V. Willoughby, D. and Fitzgerald, M. (2006). Environmental Factors that Affect the Ability of Amylose to Contribute to Retro gradation in Gels Made from Rice Flour. *Journal of Agricultural Food Chemistry* 54: 5182 – 5190.

Pichetnawin, T. (2004). Effect of Modified Starches on Quality Attributes of Rice Crackers. Graduate School. Silpakorn University, Bangkok, Thailand. 87pp.

Porteres, R. (1956). Taxonomie Agrobotanique des Riz Cultives (*O. sativa* Linn.) et (*O.graberrima* Steud.) *Journal of Agriculture Tropical Botanic Application* 3: 341 – 384.

Rafiee, S., Heidarysoltanabadi, M. and Kheiralipour, K. (2007). Some Engineering Properties of Paddy (*var. Sazandegi*). *International Journal of Agriculture and Biology* 9(5): 763 – 766.

Rivero, H., Mario, J. Raquel, H., Lorena, F., Liliana, V. and Elena, D. (2006). Concentration of As, Ca, Cd Cr, Cu, Fe, Hg, K Mg, Mo, Na, Pb, and Zn in Uruguayan rice, Determined by AAS. *Atomic Spectroscopy* 27(2): 48 – 55.

RLDC (2009). Rice Sector Strategy. Improving Rice Profitability Through Increased Productivity and Better Marketing Focusing on Tanzania’s Central Corridor. [http://www.rldc.co.tz/docs/Rice.pdf] Site Visited on 22/3/2012.

Rosniyana, A., Sarmin, S. and Norin, S. (2011). Quality Evaluation of Brown Rice Flour Made From Malaysian Rice Variety (MR220). The 12th ASEAN Food Conference, 16 – 18 June 2011, BITEC Bangna, Bangkok, Thailand. 3pp.

Rosniyana, A., Shariffah Norin, S.A. and Hashifah, M.A. (2004). Effect of Heat Treatment on the Physicochemical and Cooking Properties of Rice at Different Moisture Contents. *Journal of Tropical Agriculture and Food Science* 32(2): 155 – 162.

Schramm, R.C. (2010). Value–added Processing of Rice and Rice by–products. Louisiana State University of Agricultural and Mechanical College, USA, 86pp.

Shabbir, M. A., Anjum, F.M., Zahoor, T. and Nawaz, H. (2008). Mineral and Pasting Characterization of *Indica* Rice Varieties with Different Milling Fractions. *International Journal of Agriculture and Biology* 10: 556 – 560.

Shitanda, D., Nishiyama, Y. and Koide, S. (2001). Performance Analysis of an Impeller Husker Considering the Physical and Mechanical Properties of Paddy Rice. *Journal of Agriculture Engineering* 79: 195 – 203.

Siebenmorgen, T.J., Bautista, R.C. and Counce, P.A. (2007). Optimal Harvest Moisture Contents for Maximizing Milling Quality of Long–Grain and Medium–Grain Rice Cultivars. *Journal of Applied Engineering in Agriculture* 23(4): 517 – 527.

Siebenmorgen, T.J., Bautista, R.C. and Meullenet, J.F. (2006). Predicting Rice Physico-chemical Properties Using Thickness Fraction Properties. *Cereal Chemistry* 83(3): 275 – 283.

Siebenmorgen, T.J., Matsler, A.L. and Earp, C.F. (2005). Milling Characteristics of Rice Cultivars and Hybrids. *Journal of Cereal Chemistry* 83(2):169–172.

Srisawas, W. and Jindal, V.K. (2007). Sensory Evaluation of Cooked Rice in Relation to Water–to–Rice Ratio and Physicochemical Properties. *Journal of Texture Studies* 38(1): 21 – 41.

Sun, M.M., Abdula, S.E., Lee, H.J. Cho, Y.C., Han, L.Z., Koh, H.J.and Cho, Y.G. (2011). Molecular Aspect of Good Eating Quality Formation in Japonica Rice. Dorian Q. Fuller, Editor University College London, United Kingdom. *PLoS One* 6(4): 183 – 185.

Sun, S., Hao, W. and Lin, H. (2006). Identification of Qualities for Cooking and Eating Quality of Rice Grain. *Journal of Rice Science* 13(3): 161–169.

Suzuki, K., Kubota, K., Omichi, M. and Hosaka, H. (1976). Kinetic Studies on Cooking of Rice. *Journal of Food Science* 41: 180 – 183.

Taira, H, Taira, H. and Yamazaki, K. (1977). Variation in Protein, Fat, and Ash Contents of the Brown Rice Grains Among Soil Types and Cultivars. *Japan Journal Crop Science* 46: 157 – 163.

Taira, H. (1970). Protein Content in Hulled Grains of the Upland Rice Cultivars. *Journal of Nutrition and Food* 23: 94 – 97.

Taira, H., Nakagahra, M. and Nagamine, T. (1988). Fatty Acid Composition of *Indica*, *Sinica*, *Japonica*, and *Japonica* Groups of Non glutinous Brown Rice. *Journal of Agriculture and Food Chemistry* 50: 3031 – 3035.

Taira, H., Taira, H. and Maeshige, M. (1979). Influence of variety and crop year on lipid content and fatty acids composition of the lowland non–glutinous brown rice. *Japanese Journal of Crop Science* 48(2): 220 – 228.

Terao, T., Miura, S., Yanagihara, T., Hirose, T., Nagata, K., Tabuchi, H., Kim, H.Y., Lieffering, M., Okada, M. and Kobayashi, K. (2005). Influence of Free–Air CO_2 Enrichment (FACE) on the Eating Quality of Rice. *Journal of Agricultural Food Science* 85: 1861 – 1868.

Tokpah, E.S. (2010). Seed and Grain Quality Characteristics of Some Rice Varieties in Ghana. College of Agriculture and Natural Resources of the Kwame Nkrumah University of Science and Technology. Accra, Ghana. 76pp.

Toriyama, K, Heong K.L., Hardy, B. (2005). Rice is life: Scientific Perspectives for The 21st Century. Proceedings of the World Rice Research Conference Held in Tokyo and Tsukuba, Japan, 4 – 7 November 2004. Tsukuba (Japan): and International Rice Research Institute, Los Baños, Philippines. 590pp.

Tsutsumi, H., Nishikawa, M., Katagi, M. and Tsuchihashi, H. (2003). Adsorption and Stability of Suxamethonium and Its Major Hydrolysis Product Succinylmonochlorine Using Liquid Chromatograph Electrospray Ionization Mass Spectrometry. *Journal of Health Science* 49(4): 285 – 291.

URT, (2009). AGSTATS for Food Security, Vol.1 2007/08 Final Food Crop Production Forecast for 2008/09 Food Security–Executive Summary, Ministry of Agriculture Food and Cooperatives. Dar es Salaam, Tanzania. 11pp.

URTPHC (2002). Tanzania Population and Housing Census. [http://www.tanzania.go.tz/2002census] Site Visited on 28/4/2012.

USAID (2010). Agenda for Action: MicroCLIR/CIBER Assessment. The legal, policy, regulatory and institutional constraints to the growth of maize and rice in Tanzania Agenda for Action August 2010. [http://bizclir.com/galleries/country–assessments/Tanzania_MicroCLIR.pdf] Site Visited on 22/3/2012.

USDA (1996). Buckwheat: An Economic Assessment of the Feasibility of Providing Multiple–Peril Crop Insurance. [http://www.rma.usda.gov/pilots/pdf] Site Visited on 22/3/2012.

USDA (2009). Rice Inspection Handbook. Federal Grain Inspection Service. Washington, D.C., USA. 33pp.

Vaughan, D.A., Lu, B.R. and Tomooka, N. (2008). The Evolving Story of Rice Evolution. *Journal of Plant Science* 1(74): 394 – 408.

Ward, R. (2009). Rice Cereal Quality. Cereal Chemist, Yanco Agricultural Institute, Yanco. Primefact 908. [www.rirdc.gov.au/programs/rice.html] Site Visited on 22/2/2012.

WARDA (2004). "The Rice Challenge in Africa" [http//www.warda.org] Site Visited on 26/3/2012.

WARDA (2006). NERICA and the United Nations Millennium Development Goals. [http://www.africarice.org/publications/nerica comp/module%2016_Low.pdf] Site Visited on 22/4/2012.

Webb, B.D. (1985). Rice quality and grades. In: *Rice: Production and Utilization*. (Edited by Luh, B. S.) AVI Publishing Company, Inc., Nostrand Reinhold, New York Westport, pp. 543–565.

Webb, B.D. (1991). Rice Quality and Grades. In: *Rice Production and Utilization*. (Edited by Luh, B.S.) AVI Publishing Company, Inc., Nostrand New York Westport, USA. pp. 89–119.

Wells, B.R. (1999). Rice Research Studies. (Edited by Norman, R.J. and Beyrolaty, C.A.). Arkansas Agricultural Experiment Station. Fayetteville, Arkansas, USA. 522pp.

Wilfred, O.R. and Consultant, L. (2006). Final Survey Report on the Status of Rice Production, Processing and Marketing in Uganda. [http://www.mofa.go.jp/mofaj/gaiko/oda/bunya/agriculture/pdf/uganda_report.pdf] Site Visited on 24/3/2012.

Wilkinson, G., Dijksterhuis, G.B. and Minekus, M. (2000). From Food Structure to Food Texture. *Trends in Food Science and Technology* 11: 442 – 450.

Xheng, X. and Lan, Y. (2007). Effects of Drying Temperature and Moisture Content on Rice Taste Quality. *Journal of Agriculture Engineering International* 49: 24 – 27.

Yajima, I., Yanai, T., Nakamura, M., Sakakibara, H. and Hayashi, K. (1979). Volatile Flavour Components of Cooked *Kaorimai* (Scented rice, *O. sativa japonica*). *Journal of Agriculture Biology and Chemistry* 43: 2425 – 2429.

Yamakawa, H., Hirose, T., Kuroda, M. and Yamaguchi, T. (2007). Comprehensive Expression Profiling of Rice Grain Filling–Related Genes Under High Temperature Using DNA Microarray. *Plant Physiology* 144: 258 – 277.

Yi, M., New, K.T., Vanavichit, A., Chai–arree, W. and Toojinda, T. (2009). Marker Assisted Backcross Breeding to Improve Cooking Quality Traits in Myanmar Rice Cultivar Manawthukha. *Field Crops Research* 113: 178 – 186.

Zeng, Y., Zhang, H., Li, Z., Shen, S., Sun, J., Wang, M., Liao, D., Liu, X., Wang, X., Xiao, F. and Wen, G. (2007). Evaluation of Genetic Diversity of Rice Landraces (*Oryza sativa* L.) in Yunnan, China. *Breeding Science* 57: 91 – 99.

APPENDICES

Appendix 1: Questionnaires for rice farmers, rice milling operators and cooked rice vendors

a: Personal information

1. Respondent name:…………………………..…………………………..
2. Ward name……………………………………..……………………….
3. Village name:…………….……………..……………………………………..
4. Sex of respondent 1 = Male, 2 = Female

b: Questionnaire for agricultural self–employed farmers

1. Do you dry rice before going for milling?

   1= Yes 2 = No

2. If Yes, you dry for how long period of time?

   1 = Zero hour 2 = One hour, 3 = Three hour 4 = Six hour 5 = Other specify

3. If No, why you do not dry rough rice before milling?

   1 = No enough time 2 = Not necessary 3 = It was dried after threshing 4 = Fear of animals 5 = Other specify

4. Which criterion do you consider first before going for milling rough rice?

   1 = Head rice 2 = Machine type 3 = Operator 4 = Distance 5 = Other specify

5. Is there any difference in milling rice varieties?

   1 = Yes, 2 = No

6. If Yes, what is the difference?

   1 = Brokenness, 2 = Degree of milling, 3 = Head rice, 4 = Whiteness, 5 = Other specify

7. Which rice characteristic do you think is good for your opinion?

   1 = Colour, 2 = Cooking time, 3 = Degree of milling,

   4 = Aroma/ flavour, 5 = Other specify

8. If the cooked rice is sticking on the spoon what do you think is a causative?

   1= Much water used to cook, 2 = New rice variety, 3 = Poor cooking, 4 = Poor variety, 5 = Other specify

9. What causes chalkiness in your milled rice?

   1 = Variety, 2 = Weather conditions, 3 = Soil condition, 4 = Late maturity, 5 = Other specify

c: Questionnaire for milling section

1. Which criterion do you consider before starting milling rough rice?

   1 = Variety, 2 = Dryness, 3 = Dirtiness, 4 = Grain size, 5 = Other specify

2. From the experience of milling different rice varieties, is there any different in milling among rice varieties?

   1 = Yes, 2 = No

3. If Yes, what is the difference in milling of those rice varieties?

   1 = Head rice, 2 = Degree of milling, 3 = Brokenness, 4 = Partially milled,

   5 = Other specify

4. From your experience, which rice variety has a good milling behaviour?

   1 = NERICA, 2 = SARO, 3 = Supa, 4 = Tule na Bwana, 5 = Other specify

5. Do you get any complaints from customers?

   1 = Yes, 2 = No

6. If Yes, what are the complaints from the customers?

   1 = Partially milled, 2 = Dirty milled rice, 3 = Brokenness, 4 = Poor head rice,

   5 = Other specify

7. If there is brokens in milled rice what do you think is a causative?

   1= Variety, 2 = Maturity, 3 = Agricultural practices, 4 = Dryness, 5 = Other specify

8. What do you think that it leads to poor milled head rice?

   1= Dryness, 2 = Variety, 3 = Maturity, 4 = Shape 5 = Other specify

9. Is there any difference due to the size of rice grain?

   1 = Yes, 2 = No

10. Do you add anything to the rice in order to persuade the customers during selling?

    1 = Yes, 2 = No

11. If Yes, what you add to the milled rice to persuade the customers?

    1 = Cooking oil, 2 = Mix with other variety at the top, 3 = Add water, 4 = Add food colour, 5 = Other specify

12. Do you mix different rice varieties during milling?

    1 = Yes, 2 = No

13. If Yes, why you do so?

    1 = Improve milling, 2 = Increase profit, 3 = Improve appearance, 4 = Reduce brokenness

d: Questionnaire for cooked rice vendors (Sensory evaluation)

1. Which rice variety do you cook mostly for your customers?

   1 = NERICA, 2 = SARO, 3 = Supa, 4 = Tule na bwana, 5 = Other specify

2. Why do you prefer that rice variety in (1) above?

   1 = Aroma/flavour, 2 = Gelatinization temperature, 3 = Softness, 4 = Long grain, 5 = Other specify

3. How many times do you wash rice before cooking?

   1 = 0, 2 = 1, 3 = 2, 4 = 3, 5 = 4

4. From your experience, which rice variety do the customers prefer to eat mostly?

   1 = NERICA, 2 = SARO, 3 = Supa, 4 = Tule na bwana, 5 = Other specify

5. How do you detect that rice is now ready for serving?

   1 = Aroma, 2 = Taste, 3 = Cooked smell, 4 = Increase in volume,

   5 = Other specify

6. What are the common challenges from the customers about cooked rice?

   1 = Poor taste, 2 = High water holding capacity, 3 = Unattractive colour, 4 = Stone/sand contamination, 5 = Other specify

7. Do you ever cook new rice varieties?

   1 = Yes, 2 = No

8. If Yes, there is any difference in cooking?

   1 = Yes, 2 = No

9. If Yes, what are the difference?

   1 = Colour, 2 = Texture, 3 = Aroma/flavour, 4 = Gelatinization temperature, 5 = Other specify

10. Is there any difference between indigenous and new rice varieties?

    1 = Yes, 2 = No

11. If Yes, what is the difference between new rice variety and indigenous?

    1 = Early maturity, 2 = Aroma/flavour, 3 = Good cooking, 4 = Gelatinization temperature, 5 = Other specify

12. Do you get appreciation from your customers, that you cook rice well?

    1 =Yes, 2 = No

13. If Yes, which rice characteristic does it encourage customers?

    1 = Colour, 2 = Aroma, 3 = Firmness, 4 = Softness, 5 = Other specify

14. Do you add anything to the rice to increase the volume/persuade the customers

    1 = Yes, 2 = No

15. If Yes, what you add in cooked rice

    1= Yeast, 2 = Sodium carbonate, 3 = Oil, 4 = Soot, 5 = Other specify

16. Do you cook different rice varieties all together?

    1 = Yes, 2 = No.

17. If Yes, why you do so?

    1 = Improve flavour, 2 = Increase income, 3 = Improve appearance, 4 = Improve texture, 5 = Other specify.

Appendix 2: Five rice varietal Analysis of Variance (ANOVA) from immature grain and five milling parameter indices analysis of variance Tables

				Rice milling quality indices			
Source of variation	**Df**	**% Immature**	**% Dockage**	**% Brokenness**	**% Chalkiness**	**% HRY**	**% TRY**
Replication	2	0.8361	0.0010627	0.382	0.06256	0.597	0.2324
Variety	4	81.5269*	0.0513932*	846.067*	3.46685*	1048.98*	12.2324*
Residual	8	0.3896	0.0008980	1.722	0.02158	1.543	0.1575
Total	14						
F–value		209.24	57.23	491.28	106.68	679.94	78.24
F–probability		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Df = Degree of freedom, HRY = Head Rice Yield and TRY = Total Rice Yield

*Varietal significantly different at an F–test (df $_{4,8}$) at P = 0.05

Appendix 3: Five varietal Analysis of Variance parameters (ANOVA) from two rough grain quality indices analysis of variance Tables

		Phyical properties	
Source of variation	**Degree of freedom**	**Grain length (mm)**	**Length/Width ratio**
Replication	19	0.1965	0.11836
Variety	4	5.9204*	1.51605*
Residual	76	0.1058	0.07692
Total	99		
F–value		55.94	19.71
F–probability		<0.001	<0.001

*Varietal significantly different at an F–test (d.f $_{4, 76}$) at P = 0.05

Appendix 4: Five varietal Analysis of Variance (ANOVA) parameter from 1000grains weight of analysis of varaince Table

		Parameter
Source of variation	**Degree of freedom**	**Weight/1000 grain**
Replication	4	0.6562
Variety	4	31.8564*
Residual	16	0.2430
Total	24	
F–value		131.12
F–probability		<0.001

*Varietal Significantly different at an F–test (d.f $_{4, 16}$) at P = 0.05

Appendix 5: Five rice varietal Analysis of Variance (ANOVA) parameters from cooking time and seven proximate composition analysis of variance Tables

			Seven Proximate composition (%) of five rice varieties						
SoV	**Df**	**CT (min)**	**Moisture**	**Dry matter**	**Crude Protein**	**Crude Fibre**	**Crude Fat**	**Ash**	**NFE**
Replication	2	0.0039	0.23041	0.23041	0.00042	0.00026	0.00801	0.00836	0.12797
Variety	4	8.9577*	1.12003*	1.12003*	1.56962*	0.02698*	0.81833*	0.00415*	4.42146*
Residual	8	0.4853	0.03653	0.03653	0.00086	0.00119	0.01499	0.00686	0.08568
Total	14								
F–value		18.46	30.66	30.66	1821.61	22.61	54.58	0.60	0.670
F–probability		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.670	<0.001

SoV = Source of Variation, Df = Degree of freedom and NFE = Nitrogen Free Extract

*Varietal significantly different an F–test (d.f $_{4,76}$) at P = 0.05

Appendix 6: Five rice varietal Analysis of Variance (ANOVA) parameters from three physicochemical properties analysis of variance Tables

		Physicochemical properties		
Source of Variation	**Df**	**%AC**	**GC (mm)**	**ASV**
Replication	2	0.19843	11.47	0.00000
Variety	4	79.25321*	982.93*	1.50000*
Residual	8	0.05778	29.38	0.00000
Total	14			
F–value		1371.61	33.45	
F–probability		<0.001	<0.001	

*Varietal significantly different at an F–test (df $_{4,8}$) at P = 0.05

Appendix 7: Correlation Coefficient (C.V) in five new rice varieties in milling, proximate, sensory and physicochemical parameters

Parameter	HR	TY	CHK	IMM	MC	CP	CHO	FAT	CF	TST	TXT	MF	OA	WT	GL	CT	GC	AC
HR	1																	
TY	0.91	1																
CHK	–0.38	–0.07	1															
IMM	0.90	0.95	–0.27	1														
MC	–0.70	–0.65	0.70	–0.82	1													
CP	–0.32	–0.65	–0.46	–0.51	0.18	1												
CHO	0.71	0.78	–0.45	0.90	–0.95	–0.48	1											
FAT	–0.31	–0.09	0.89	–0.37	0.78	–0.46	–0.55	1										
CF	–0.46	–0.22	0.49	–0.40	0.44	–0.54	–0.24	0.67	1									
TST	0.76	0.90	0.21	0.72	–0.31	–0.80	0.51	0.32	0.14	1								
TXT	0.66	0.85	0.30	0.67	–0.25	–0.88	0.49	0.40	0.26	0.99	1							
MF	0.69	0.87	0.17	0.71	–0.36	–0.88	0.58	0.29	0.27	0.98	0.99	1						
OA	0.74	0.90	0.18	0.75	–0.37	–0.86	0.59	0.27	0.19	0.99	0.99	0.99	1					
WT	–0.99	–0.95	0.34	–0.93	0.73	0.44	–0.77	0.27	0.36	–0.81	–0.73	–0.77	–0.81	1				
GL	–0.94	–0.88	0.53	–0.95	0.90	0.33	–0.90	0.53	0.46	–0.63	–0.55	–0.62	–0.65	0.95	1			
CT	0.45	0.49	0.08	0.58	–0.33	0.00	0.35	–0.27	–0.75	0.20	0.14	0.07	0.17	–0.41	–0.43	1		
GC	0.00	–0.01	0.60	–0.18	0.62	0.11	–0.58	0.58	–0.21	0.15	0.12	–0.04	0.03	0.07	0.30	0.39	1	
AC	–0.92	–0.98	0.02	–0.89	0.53	0.64	–0.66	–0.03	0.19	–0.94	–0.89	–0.89	–0.93	0.95	0.83	–0.43	–0.12	1

R= Head rice, TY=Total Yield, CHK= Chalkiness, MC= Moisture Content, CP= Crude protein, CHO= Carbohydrate, CF= Crude Fibre, TST= Taste, TXT= Texture, MF= Mouth feel, OA= Overall Acceptability, WT= Weight/1000grains, GL= Grain Length, CT= Cooking Time, GC= Gel Consistency and AC= Amylose content.

Appendix 8: Five rice varietal Analysis of Variance (ANOVA) from seven sensory attributes analysis of variance Tables

		Sensory evaluation attributes of five rice varieties						
Source of variation	**Df**	**Colour**	**Aroma**	**Taste**	**Texture**	**Mouth feel**	**Consistency**	**O. A**
Replication	2	2.0000	1.6333	1.6010	1.4680	1.350	1.615	1.458
Variety	4	8.4000*	8.0600*	13.068*	11.248*	6.380*	8.752*	13.468*
Residual	8	0.5750	0.9433	1.0060	1.1350	1.259	1.110	0.9097
Total	14							
F–value		14.61	8.54	13.00	9.91	5.07	7.88	14.81
F–probability		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

D.f = Degree of freedom and O.A = Overall acceptability

* Varietal significantly different at an F–test (df $_{4,8}$) at P = 0.05

Appendix 9: Sensory evaluation form for five new rice varieties, seven sensory attributes and five hedonic scales

Date:………………………………………………………………………………………

Time:………………………………………………………………………………………

Name:……………………………………………………………………………………..

Sex:………………………………………………………………………………………..

Age:………………………………………………………………………………………..

Please assess the colour, aroma, texture, mouth feel, consistency and overall acceptability for each of the five (5) coded samples. Indicate how much you like or dislike by checking against the appropriate sample attributes and indicate your preference (5 – 1) in the column against each attribute by putting the appropriate number.

Key: 5 – Like very much

4 – Like slightly

3 – Neither like nor dislike

2 – Dislike slightly

1 – Dislike very much

		Random coded numbers for five samples				
S/No	**Sensory attribute**	**0442**	**0853**	**0253**	**0662**	**0041**
1	Colour					
2	Taste					
3	Aroma					
4	Mouth feel					
5	Consistency					
6	Texture					
7	Overall acceptability					

Comments:…………………………………………………………………………………

…………………………………………………………………………………………..