

**PARBOILING CHARACTERISTICS OF SELECTED RICE VARIETIES FROM  
NIGERIA**

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**A thesis submitted to McGill University in partial fulfilment of the  
requirements of the degree of  
Master of Science  
December, 2013**

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## **DEDICATION**

I dedicate this piece of work to the Almighty God, my parents Mr. and Mrs. W.C. Ejebe and everyone who in one way or the other accompanied me in this journey

## ABSTRACT

Rice (*Oryza sativa* Linn) stands out as the major food crop for about a half of human race. It ranks third after wheat and maize in terms of worldwide production. In many parts of West-Africa, *Oryza glaberrima* Steud is the variety popularly grown. Hybridization between *Oryza sativa* and *Oryza glaberrima* for desirable qualities led to development and production of new varieties of rice. After harvesting rice is usually processed before it can be distributed to consumers. One of the most popular processing operations commonly practiced in Nigeria and other African countries is parboiling involving soaking of raw rice in water, followed by steam heat treatment and drying. Scientific studies in how variety and parboiling conditions influence rice final qualities are not available. The main purpose of this work was to study the effect of variety, steeping temperature and time on thermophysical properties of parboiled rice.

In this study, water absorption characteristics of some rice varieties (Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44) from Nigeria was studied at 30, 45, 60 and 75°C by measuring the weight gain by grains as a function of time during soaking. Differences in moisture content among the selected varieties of paddy during soaking were significant ( $P < 0.05$ ) at all temperatures considered in this study. Results showed 60°C to be the optimum soaking temperature of paddy. Optimum soaking time to reach saturation moisture at 60°C soaking water temperature for FARO 44, FARO 52 and Bisalayi was 7 h, while it took 6 and 8 h for FARO 60 and FARO 61, respectively, to attain saturation.

Using the experimental moisture data, a non-linear regression procedure was applied to an analytical solution to Fick's second law of the diffusion for an infinite cylinder. The predicted values of instantaneous moisture contents were in good agreement with the experiential data. The predicted moisture content during soaking of rice was found to correlate positively with the

measure values of moisture content with  $R^2$  values between 0.981 – 0.990. Water absorption rate was found to increase with soaking temperature, while water saturation time decreased with temperature. Average values of diffusion coefficients of moisture during soaking of paddy rices were estimated. It was found that FRAO 44 and FARO 52 varieties have lower diffusivity than other varieties (namely Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44) used in the study. The activation energies of the diffusivity through different varieties of rice grains were calculated using Arrhenius-type equation for diffusion dependence on temperature and were determined as 41.96, 38.69, 40.16, 34.05 and 42.12 kJ/mole for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44 for the respectively rice variety above.

The physical and thermal properties of the four popular improved parboiled rice varieties (FARO 61, FARO 60, FARO 52 and FARO 44) and one popular local parboiled rice variety (Bisalayi) from Nigeria were determined at different steaming times 5 – 20 min. Results showed that steaming time has effect ( $P < 0.05$ ) on both the physical and gelatinization properties of rice. The improved rice varieties used in this study show better hardness and were less discolored than the local variety. For all the rice varieties studied, no residual gelatinization enthalpy was observed at the different steaming times, showing that steaming completely gelatinized rice starch.

## RÉSUMÉ

Le riz (*Oryza sativa* Linn) est connu comme étant la principale culture vivrière pour environ la moitié de la population humaine. Le riz occupe le 3<sup>e</sup> rang en importance après le blé et le maïs en termes de production dans le monde. Dans de nombreuses régions de l'Afrique de l'Ouest, *Oryza glaberrima* Steud est la variété de préférence. L'hybridation entre *Oryza sativa* et *Oryza glaberrima* a conduit au développement et à la production de nouvelles variétés de riz aux qualités désirables. Après la récolte, le riz est habituellement préparé avant d'être distribué aux consommateurs. L'étuvage du riz est un des traitements les plus populaires couramment pratiqués au Nigeria et d'autres pays africains impliquant un temps de trempage des grains de riz paddy dans l'eau, suivi d'un traitement thermique à la vapeur et du séchage. Peu d'études se sont penchées sur l'influence des paramètres d'étuvage et des variétés de riz sur la qualité finale du produit. Le but principal de cette étude était d'évaluer l'impact de la variété de riz, de la température et du temps sur les propriétés thermophysiques du riz étuvé.

Dans la présente étude, les caractéristiques d'absorption de l'eau de certaines variétés de riz du Nigeria (Bislayi , FARO 61, FARO 60, FARO 52 et FARO 44) ont été étudiées à 30 , 45 , 60 et 75°C en mesurant le gain de poids des grains pendant le trempage en fonction du temps. Les différences de teneur en eau parmi les variétés de riz paddy durant le trempage étaient significatives ( $P < 0.05$ ) pour toutes les températures étudiées. Les résultats démontrent que 60°C serait la température de trempage optimale pour le paddy. Le temps de trempage optimal pour atteindre la saturation en eau à une température de trempage de 60°C était de 7h pour les variétés FARO 44, FARO 52 et Bislayi et un temps de 6h et 8h pour FARO 60 et FARO 61 de façon respective.

A partir des données expérimentales de teneur en eau, une procédure de régression non linéaire a été appliquée pour une solution analytique de la deuxième loi de Fick pour la diffusion d'un cylindre infini. Les valeurs prédites de la teneur en eau instantanée sont en accord avec les données expérimental. Un efficient de corrélation variant entre 0.981 – 0.990. Il a été trouvé que le taux d'absorption de l'eau augmente avec la température de trempage, tandis que le temps de saturation diminue avec la température. Les valeurs moyennes des coefficients de diffusion d'humidité pendant le trempage du paddy ont été estimées. Il a été constaté que les variétés FARO 44 et FARO 52 présentent une plus faible diffusivité que les autres variétés (à savoir Bisalayi, FARO 61, FARO 60, FARO 52) de l'étude. Les énergies d'activation de la diffusivité au travers des différentes variétés de grains ont été calculées en utilisant l'équation de type Arrhenius pour la dépendance de la diffusion en fonction de la température. Les énergies d'activation étaient respectivement 41.96, 38.69, 40.16, 34.05 et 42.12 kJ/mole pour Bisalayi, FARO 61, FARO 60, FARO 52 et FARO 44.

Les propriétés physiques et thermiques des quatre variétés de riz améliorées les plus populaires (FARO 61, FARO 60, FARO 52 et FARO 44) et d'une variété populaire de riz locale (Bisalayi) du Nigeria ont été déterminées à différents moments entre 5 et 20 min durant l'étuvage. Les résultats démontrent que le temps d'étuvage a un effet ( $P < 0.05$ ) autant sur les propriétés physiques et de gélatinisation du riz. Les variétés de riz améliorées utilisées dans cette étude ont montré une meilleure dureté et étaient moins décolorées que la variété de riz locale. Pour toutes les variétés de riz étudiées, aucune enthalpie résiduelle de gélatinisation a été observée aux différents moments durant l'étuvage, ce qui démontre que l'étuvage a déjà complètement gélatinisé l'amidon du riz.

## ACKNOWLEDGMENT

I would like to first of all thank the **Almighty God** the maker of all things, the giver of wisdom, the author and sustainer of life for his faithfulness throughout the duration of this thesis and for all the unmerited favours I received from Him in Canada. Also I want to thank my parents **Mr. and Mrs. W.C. Ejebe** and my siblings, **Ijeoma, Nneka, Nnadozie and Odinakachi** for their overwhelming love, prayers, encouragement, advice and strength during my studies. In the same vein, I deeply appreciate my uncle **Dr. G.C. Ejebe** and his family for the immense support they gave me throughout this journey.

My heartfelt gratitude goes to my thesis supervisor, **Prof. Michael O. Ngadi** for his mentorship, critique, support and fatherly care during this thesis. It was indeed a great opportunity to have received guidance and direction under your efficient leadership. You inspired me not only in academics but also in other important aspects of life requiring patience and perseverance.

My profound gratitude goes to my lab members for their support and assistance during my work. My special thanks go to **Peter Adewale, Ogan Mba, Dr. Akinbode Adediji and Hernan Reysanchez** for their sincere advice, encouragement, support and brotherly concern at several challenging points during my thesis. I'm highly indebted to you guys. In the same way, I would like to thank **Jamshid Rahimi, Chijioke Nwampka, Ebenezer Kwofie, and Wathsala Tennakoon** for their numerous help. I appreciate **Audrey Yank** for her numerous help especially, in translation of the Abstract to French. In a very special way, I would like to thank **Dr. Amaka Odenigbo** (a.k.a. Nwanne di n'amba I of Canada) for her motherly care for me. 'Antym', you shall live long.

I will like to acknowledge **Mr. Yvan Gariepy** of Bioresource Engineering department and **Mr. Guy Rimmer** of Plant Science for their help with the use of some of the lab equipment. I wish to thank the administrative staff of my department, **Ms Susan Gregus**, **Ms Abida Subhan** and **Ms Patricia Singleton**.

Finally, I would like to appreciate the financial assistance provided by **Africa Rice** and **Canadian International Development Agency (CIDA)** in support of this project.

## **CONTRIBUTION OF AUTHORS**

In this work, chapters 3 and 4 are manuscripts which have been prepared and would be submitted for publication. The research work reported here was performed and completed by the student Chijioke Ejebe. He was responsible for the design of experiment, experimental setup, data analysis and preparation of the manuscripts and thesis. Professor Michael O. Ngadi is the thesis supervisor, providing scientific advice and technical supervision.

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## CHAPTER ONE:

### INTRODUCTION AND OBJECTIVES

#### 1.1 General introduction

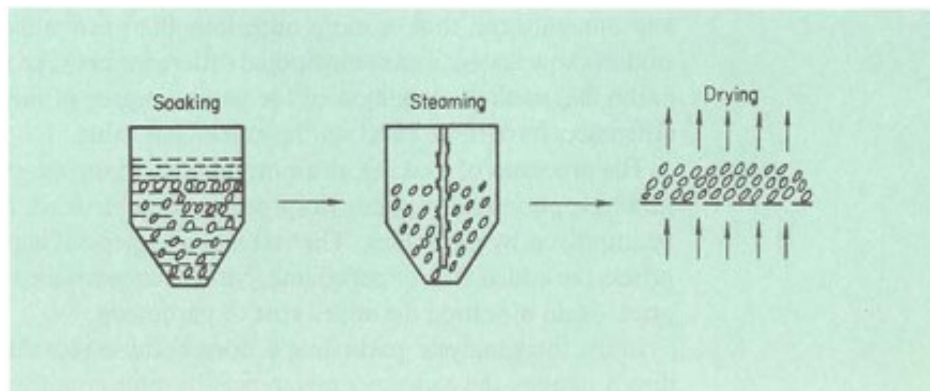
Cereals such as maize, wheat, barley, millet and rice constitute major staple foods in many parts of the world. They supply one or more of the three macronutrients (carbohydrates, proteins and fats) and also micronutrients and minerals vital for survival and health. Rice (*Oryza sativa* Linn) stands out as the major food crop for about a half of human race. It ranks third after wheat and maize in terms of worldwide production. Africa accounts for over 32 % of the global imports at a record level of 9 million tonnes in 2006. In recent years, rice has become the most rapidly growing food source in sub-Saharan Africa and production has been expanding at the rate of 6 % per annum. As at 2012 West-Africa's paddy production stood at 13,078,655 tonnes amounting to 48 % of the total quantity produced in Africa (FAOSTAT, 2012).

Rice (*Oryza glaberrima* Steud) is the variety popularly grown in many parts of West-Africa. Hybridization between *Oryza sativa* and *Oryza glaberrima* for desirable qualities led to development and production of New Rice for Africa popularly known as NERICA (Olembo et al., 2010). In Africa, rice is usually distributed and consumed as white parboiled rice (table rice), that is, processed rice in grain form. White rice is produced from paddy or rough rice, which is rice in its raw form.

Several operations are carried out, after rice harvesting, in order to obtain the white rice. The major processes are threshing, parboiling and milling. Among these three stages, parboiling stands out as the most important operation having the potential of improving the milling efficiency and economic values of paddy rice as well as nutritive quality of the finished product.

Conventionally, parboiling involves soaking paddy in water to achieve uniform moisture in the rice, followed by steam-heating the soaked paddy to gelatinize rice starch and finally drying the steamed product to the appropriate moisture content (12 – 14% w.b.) required for milling.

During soaking of paddy, temperature, variety, and time of exposure affect the rate at which moisture enters into the kernel. Inadequate soaking due to excess or insufficient amount of moisture in the grain can affect the overall quality of the product (Bhattacharya and Rao, 1966a). Therefore, control of the soaking process can be improved with better knowledge of water movement and distribution in the different varieties of paddy.



**Figure 1.1: The three stages in rice parboiling**

(Source: Wimberly, 1983)

In Nigeria, paddy parboiling is practiced mostly in the Northern part of the country. Among many varieties of rice found, FARO 61, FARO 60, FARO 52 and FARO 44 are the most common improved (lowland) varieties while Bisalayi is a popular local varieties produced and consumed in the country. Since most of the parboiled rice come from local producers, the process (steaming) time vary among producers. Such variation may result in quality differences in the end product and possible over utilization of energy during steaming operation. Steaming is

generally carried out to heal cracks or fissures in the kernel which develop during harvesting or other post-harvest operations such as threshing. Heat is required to gelatinize the rice starch in the grains. The viscous starch components flow and cement the cracks in the grain. Steam is used instead of dry air since steam does not remove moisture from the paddy. As conventionally practiced in Africa and most parts of the world, the steam used in parboiling is from boiling water at about 100°C. The duration of steaming can affect the properties of the milled rice, especially, its physical properties such as hardness and colour as well as its thermal properties such as gelatinization temperature and gelatinization enthalpy (Parnsakhorn and Noomhorm, 2008; Patindol et al., 2008; Marshall, 1993). Improved rice kernel hardness increases milling yield and is of importance to rice processors. To the consumer, harder rice is preferred to soft rice since the former cooks better than the latter (Ayamdoo, 2013b). Steaming operation, which produces parboiled rice, requires a lot of energy to produce steam for the process. Information from the energy of gelatinization during steaming aids in evaluating the optimum steaming time and can reduce energy utilization due to over-steaming. Data on parboiling characteristics of rice is vital for rice processors around the world. Information on parboiling characteristics of rice varieties from Africa would help in the optimization of the process. However, literature is limited, for instance, there is no information on the hydration characteristics of the varieties used in this study. There are also no data on the steaming characteristics, especially, the degree of gelatinization during parboiling of any rice variety from West Africa.

## **1.2 Objectives**

In hydration process, it is highly relevant and of practical importance to forecast the moisture movement in seeds as a function of time and temperature. This, however, depends on the availability of moisture diffusivity information for the seed in question. Thus the main objective

of this research project was to determine the diffusion coefficients at different steeping temperature and to study the degree of gelatinization during steaming for selected varieties of rice from Nigeria. The specific objectives were:

- 1) To determine the hydration characteristics of selected rice varieties (Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44) at different soaking temperatures
- 2) To generate moisture diffusivity data for the selected rice varieties
- 3) To determine temperature dependency on the soaking process
- 4) To evaluate some physical properties of the selected rice varieties at different steaming times
- 5) To calculate the degree of gelatinization during steaming of the selected varieties

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Rice production in Nigeria

Rice production in Nigeria started as far back as 1500 BC with the low-yielding local cultivar *O. glaberrima* Steud (Hardcastle, 1959). The earliest cultivation of the high-yielding Asian rice, *O. sativa* L. started around 1890 with the introduction of upland varieties to the high forest zone in Western Nigeria (Hardcastle, 1959; Atanda et al., 1978). In the pursuit of better rice quality, West Africa Rice Development Association (WARDA), developed a new rice variety popularly called New Rice for Africa (NERICA) by hybridization between *O. sativa* and *O. glaberrima* (Olembo et al., 2010). Table 2.1 lists the total area under rice cultivation in West-African countries as of 2002.

Rice is a progressively important crop in Nigeria for several reasons. It is mainly grown for internal and sub-regional trade as well as for home consumption. Rice serves as a staple food to most of the Nigerian population, while for some, it has been considered as a luxury food for special occasions only. However, with increased availability of the crop, it has become part of the everyday diet of many Nigerians.

A wide range of indigenous and improved varieties of rice can be found in Nigeria, especially, NERICA, which was introduced in the last twenty years. The new varieties are produced and distributed by research institutes such as National Cereal Research Institute (NCRI) and West Africa Rice Development Association (WARDA) now called Africa Rice. The spread of these strains is determined by their perceived success, and farmers multiply seed for

their own plots when they see a variety doing better in someone else's field, or if a variety is fetching a better price in the market than others.

**Table 2.1: Total area (hectares) under rice cultivation in various ecologies across countries in West Africa**

Country	Total area (ha)	Mangrove swamp	Deep water	Irrigated lowland	Rainfed lowland	Rainfed upland
Mauritania	23,000	0	0	23,000	0	0
Senegal	75,000	6,000	0	33,750	35,250	0
Mali	252,000	0	161,280	52,920	30,240	7,560
Burkina Faso	25,000	0	0	6,750	16,250	2,000
Niger	28,000	0	14,000	14,000	0	0
Chad	31,000	0	28,520	620	1,860	0
Cameroon	15,000	0	0	14,700	300	0
Gambia	19,000	2,660	0	1,330	12,160	3,040
Guinea-Bissau	65,000	31,850	0	0	14,300	18,850
Guinea	650,000	84,500	65,000	32,500	162,500	305,500
Sierra Leone	356,000	10,680	0	0	103,240	245,640
Liberia	135,500	0	0	0	8,100	126,900
Côte d'Ivoire	575,000	0	17,250	34,500	69,000	454,250
Ghana	81,000	0	0	12,150	12,150	56,700
Togo	30,000	0	0	600	5,400	8,190
Benin	9,000	0	0	360	360	8,190
Nigeria	1,642,000	16,420	82,100	262,720	788,160	492,600
<b>Total West Africa</b>	<b>4,011,000</b>	<b>160,440</b>	<b>360,990</b>	<b>481,320</b>	<b>1,243,410</b>	<b>1,764,840</b>

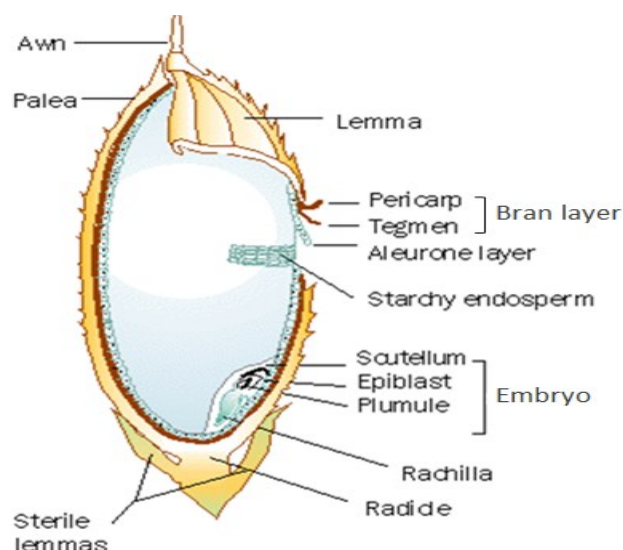
*Source: Somado et al., (2008)*

Most farmers produce one rice crop each year, but some have made irrigation channels which allow them to harvest two or more times in a year. This allows them to plant seedlings

when there is less danger from disease or pests. Also, frequent planting exhausts the soil more rapidly and as fertilizers are expensive, many farmers are noticing the falling productivity of the soil. Fertilizers and herbicides are costly and rice is favoured as a crop because it needs fewer inputs than maize. Some farmers use methods of green manuring by which grass is allowed to grow and is then ploughed back into the soil. The use of organic fertilizers, though, is time consuming, and is not common, many farmers resign themselves to buying fertilizers which they consider to be too expensive.

## 2.2 Rice processing in Nigeria

Rice in its raw form is generally known as rough rice, raw rice, paddy or paddy rice. Paddy is the major raw material from which milled rice grains and rice flours are obtained. Paddy rice is produced by threshing after harvesting and pre-drying of rice. From its exterior, a rough rice grain is mainly composed of the non-edible palea or husk, the bran layer, aleurone layer, the starchy endosperm and the embryo or germ as depicted in Figure 2.1.



**Figure 2.1: A grain of rough rice (paddy).**

Source: <http://www.knowledgebank.irri.org> (Morphology of the rice grain)

The endosperm contains starch, protein and fat and serves as the regular edible rice. A typical rice processing steps is shown in Figure 2.2

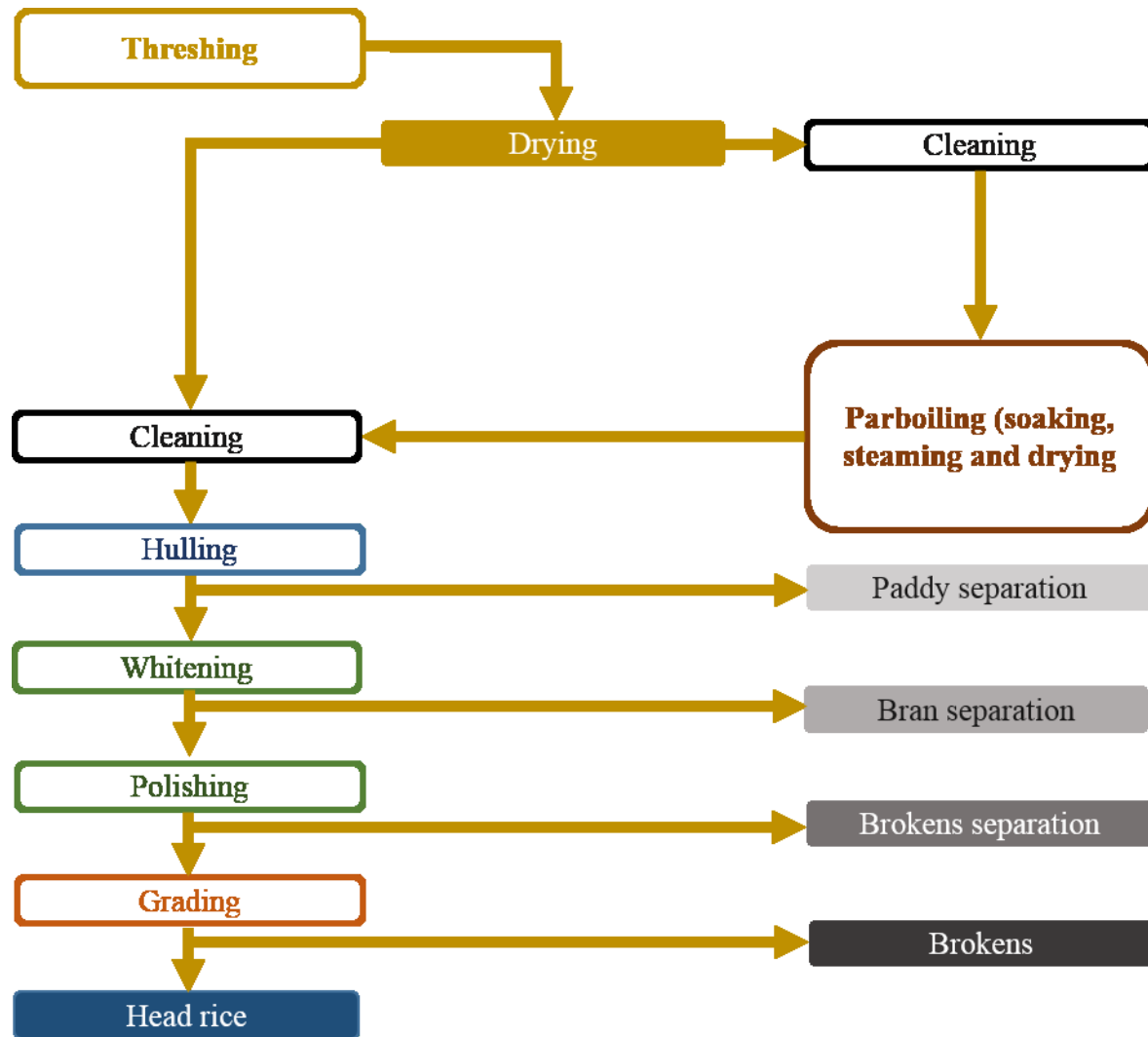
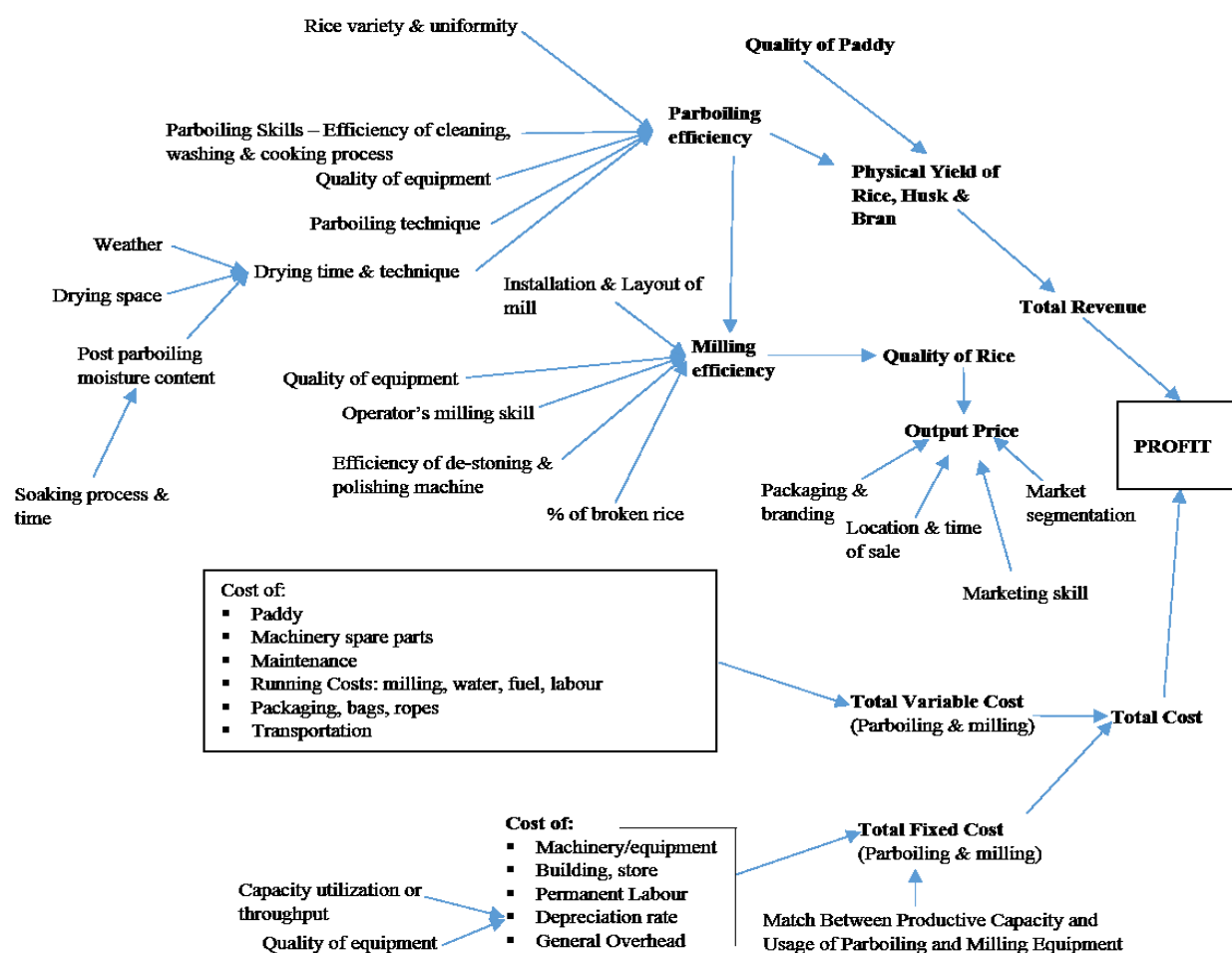


Figure 2.2: Rice processing operation

Threshing may be done by beating the grain using a flail or threshing rack, a threshing floor or a threshing machine such as combine harvester. This process involves the application of impact, friction or a combined action to the harvested rice to loosen the paddy grains from the straw or scaly chaff. The resulting paddy rice is cleaned and stored or goes on to the next postharvest processing stage involving parboiling and milling.

Parboiling of paddy is the most important processing operation apart from milling. It basically involves soaking, followed by rapid heating using steam and slowly drying the product. This operation brings about some physical and chemical modification in rice and has been shown to be of economic and nutritive advantages to rice processors and consumers (Rao & Juliano, 1970). In Nigeria, all paddy processed is parboiled before milling. As shown in Figure 2.3, it is recognized that the efficiency of parboiling operation has a great influence on the technical performance of milling and therefore on the quality of rice as well as the market value of the end product.



**Figure 2.3: Determinants of technical and financial efficiency in rice processing**

Source: Ogunforowa (2007)

During the soaking stage, paddy rice absorbs water, leading to the swelling of rice starch granules. The application of heat using steam results in pre-gelatinization of rice starch. The level of distribution of moisture in the rice grain during soaking and the duration and intensity of heat treatment during steaming have great influence on the overall properties of the parboiled product (Velupillai and Verma, 1982).

Soaking is usually carried out in cold or warm water. It has been shown that the higher the water temperature, the faster the soaking process (Miah et al., 2002). However, the temperature of soaking water should not exceed the gelatinization temperature of the rice starch or the paddy will be cooked. Wimberly (1983) reported that paddy soaked in water at ambient temperature of (20 – 30°C) takes 36 – 48 hrs to reach saturation moisture content of 30 – 35 % wet basis, while soaking done in hot water at 60 – 65°C takes between 2 – 4 hrs. However, the scenario may be different for different varieties of paddies. Studies show that some varieties of paddy reach saturation after 23 hrs of soaking in plain water at room temperature (Bello et al., 2004) while other varieties reach saturation after 24 hrs of soaking in water at 30°C as germination of seed was observed after this time (Lu et al., 1994). Despite some problems such as seed germination, rice dissolution and starch fermentation due to respiration of paddy grains may occur due to prolonged soaking in water at room temperature. Fermentation can lead to excessive production of aflatoxins by fungi and other microorganisms in the paddy. Thus temperature of soaking water and duration of soaking affects the solubilization of substances in the product in addition to colour, smell and taste of rice. In most sub-Saharan African countries, including Nigeria, warm water soaking is done by introducing paddy in warm water heated up to 30 – 70°C and allowing the product to stand for 10 – 24 hrs after removal of the heat source (Manful et al., 2008; Ayamdoo et al., 2013a). This allows the product to imbibe water and

become saturated. Since higher temperature of soak water reduces the overall soaking period, the shortest duration of soaking is achieved by maintaining a constant water temperature. The amount of water needed for optimum soaking is approximately 1.3 times the weight of the paddy (Wimberly, 1983).

Steaming is a crucial step in the parboiling process which brings about the fundamental break in the properties of parboiled rice from those of raw rice. Soaking ushers in moisture, an essential component required for gelatinization reaction while steaming, brings about heating which completes the process. Steam does not remove moisture from paddy during parboiling, thus, it is preferred to other methods of heating. Furthermore, steaming has other preferable properties over other methods such as the high heat content, high heat transfer and ease of handling.

In modern plants, paddy is heated using pressurized steam to produce parboiled rice. The case is different to traditional settings used in Nigeria and other West African countries where steam is produced directly from boiling water at atmospheric pressure and does not exceed 100°C. The duration of steaming among other factors play an important role in the properties of parboiled rice. Steaming period is dependent on the steaming arrangement since the size of the steaming vessel and the quantity of paddy affects the level of heat distribution and therefore, the overall time for the process (Wimberly, 1983). Traditionally, steaming could be said to have reached completion when splitting of husk is observed (Longtau, 2003).

Drying, which entails the reduction in moisture content, completes the rice parboiling process. This is done to bring the moisture level of the parboiled product to about 12 – 13 % representing the moisture content level required to ensure minimal grain breakage during milling

(Biswas et al., 1988). As a best practice, drying should be done slowly so as to avoid internal stresses which could develop in the grain and cause breakage during milling (Lançon et al., 2003; Wimberly, 1983).

The objectives of rice milling are: (1) to remove the hulls and bran from harvested dried or parboiled rough rice and (2) to produce milled, polished, or white rice. The meaning of the term “milling” differs, not only in many different industries in which the term is used, but also within the grain industry. For example, in the rice industry, milling can either refer to the overall processes in a rice mill-cleaning, shelling, bran removal, size separation, etc, or simply refer to the one operation of removing of the bran or outer layers from the brown rice to produce a whole grain white rice product (Wadsworth, 1991).

When paddy is properly parboiled and milled, maximum yield which corresponds to the yield of edible rice with minimum amount of broken grains, is achieved. Parboiling produces harder grain and seals any fissures in the kernel. Any breakages mainly arise by mechanical action of the milling machines. Desirable results from the treatment depend to a great extent on the drying operation. Before it is parboiled, the paddy must be properly cleaned and graded according to size, and weight. Milling will be stress-free, and the chance of breakage in the machines is minimized, if the machine is properly adjusted.

Degree of milling defines the quantity of bran removed during whitening. Milling parboiled paddy becomes a difficult operation not only because the process has hardened and merged the outer layers with the endosperm but also because of the fatty substances, especially those contained in the germ, have been dissolved and distributed throughout the kernel. These substances make the grains slippery during the process of polishing and tend to cause the bran to

cake. To avoid this, the whitening machines must be exhaustively air-cooled, usually, by means of a central aspiration system.

When the paddy is put directly into the huller without prior shelling, the hull, which came off the kernel during the first stage, acts as an abrasive and, at the same time, absorbs some of the fatty substances, thus facilitating polishing. Rice bran is darker in color and contains more fatty substances compared to those obtained after milling raw paddy rice as a result of the spread of the fats in the germ toward the perispermic layers. For best result during milling operation, dried paddy should be left for about 7 days to allow for internal moisture, stress and hardness stabilization (Islam et al., 2002).

### **2.3 Hydration kinetics of cereals**

Steeping of cereals and legumes is a vital part of food processing operations like germination, cooking, mixing and preparing a product from it. Hydration is a complicated process and indicates the physical and chemical changes taking place during processing. In addition to that, processing of cereals in many cases requires that the seeds be hydrated first to hasten the sequential extraction or cooking. Therefore, permeation of water into these materials is crucial in the processing industry. The rate of water absorption has significance in the design of foods. As a means to control and predict water absorption, optimizing the hydration condition is important since moisture diffusion governs the subsequent operations and the quality of the final product.

The diffusion properties of rice are important for the design and operation of parboiling systems. (Engels et al., 1986; Takeuchi et al., 1997). According to the authors, water absorption and desorption during soaking or drying of grains are governed by diffusion. Thus, a correct description of the rates of soaking or drying of rice greatly depends on the accurate estimation of water movement within a grain. Several authors have studied water absorption and desorption of

cereals by using different procedures. Kang et al. (1999) used finite element diffusion model to predict the distributions of moisture and diffusion coefficients within a wheat kernel. Tagawa et al. (2003) described the relationship between moisture movement in wheat and barley by mathematical models obtained by solving Fick's second law of diffusion.

Studies on hydration and dehydration kinetic during water uptake in rice grains have been on-going. Steffe and Singh (1980) developed a theoretical model base on liquid diffusivity to predict the drying of white, brown and rough rice. The influence of temperature on the diffusivity of different components of rice was observed in their study. Further attempts have also been made by several authors to estimate the diffusivity and activation energies during soaking of different varieties of paddy as shown in Table 2.2.

**Table 2.2: Activation energies and diffusivities of rough rice available from literature**

Rough rice	Temperature range (°C)	Diffusivity ( $\times 10^{-11} \text{ m}^2/\text{s}$ )	$E_a$ (kJ/mol)	Reference
Short grain (S6)	50 – 85	-	32.9	Baskshi and Singh (1980)
Long grain	25 – 55	1.40 – 3.34	25.4	Bello et al., (2007)
	60 – 90	4.01 – 9.36	30.0	
Long grain (Gallo, RP2)	25 – 65	1.56 – 7.20	-	Bello et al., 2004
PR 116	30 – 60	2.56 – 7.92	31.50	Thakur and Gupta (2006)

$E_a$ - activation energy

## **2.4 Water absorption characteristics of biological materials**

Water absorption can be defined as the rate at which water is taken in and morphed into another object or material. All organic polymeric materials will absorb moisture to some extent resulting in swelling, dissolving, leaching, plasticizing and/or hydrolyzing, which can result in discoloration embrittlement, loss of mechanical and electrical properties, lower resistance to heat and weathering and stress cracking, etc.

### **2.4.1 Importance of soaking**

Soaking or Steeping of agricultural materials is technically a mass transfer phenomenon characterized by moisture absorption into the product. Steeping is often a pre-treatment given to food materials and constitutes a critical stage during processes such as cooking, fermentation and malting. The hydration process alters the textural properties of food materials such as legumes and thereby facilitating nutrient extraction. Soaking, prior to grinding operation, results in grains with softer hard pit, enhancing the grinding process. Cooking time and solid losses during processing of beans are reduced by steeping (Wang et al. 1979).

In rice processing, paddy is soaked to achieve quick and uniform water absorption in rice kernel up to the center (core) of the grain, such that during steaming, the chalkiness and white portions are eliminated (Bhattacharya and Rao, 1966a; Wimberly, 1983, Ayamdoo et al., 2013a). Rice embryo is rich in phosphorus and low in calcium, sodium, and silicon. In pure rice embryo, 75% of the total phosphorus is present as phytate phosphorus. In pericarp and aleurone, 91% of the total phosphorus is phytate *P* (O'Dell et al. 1972). Furthermore, studies show that the bioavailability of minerals, e.g. zinc from rice is low due to the fact that these minerals are present as insoluble complexes with antinutritional food components like phytic acid (Liang et al., 2008). Soaking alone done at low temperature such as 30°C was found to be inefficient in

improving mineral bioavailability, but in combination with other treatments or with optimized soaking conditions can improve the bioavailability of minerals in rice (Lestienne et al, 2004). Soaking carried out in water at room temperature provokes seed germination, which could have an adverse effect on the quality of rice. Water has a thermal conductivity value greater than that of rough rice. Steeping, therefore, facilitates the transfer of heat from the surface of the husk to the endosperm of rice grain (Luh and Mickus, 1991). Thus, in order to maintain a better quality of rice, it is necessary to reduce the soaking time of rough rice. This can be achieved with a good knowledge of factors that affect water uptake in rice. Understanding water absorption in paddy during soaking is of practical importance since it affects subsequent processing operations and the quality of the final product. The amount of water absorbed by seeds during steeping is influenced by several factors such as initial moisture content, variety of seed, soaking time, pH and temperature of the soaking water.

## **2.5 Factors affecting water absorption in rice**

Steeping is a gradual process controlled by the diffusion of water in the grain (Engels et al., 1986). Consequently, soaking at room temperature may lead to microbial contamination which affects the quality of the product. Complete soaking is attained when there is an optimal absorption of water at the center of the soaked grains and when opaque white portions are eliminated in kernels after steaming of soaked paddy (Bhattacharya and Rao, 1966a; Wimberly, 1983). The moisture content of adequately steeped paddy has been reported to be approximately 30% (w.b.) (Bhattacharya and Rao, 1966a; Gariboldi, 1974; Wimberly, 1983).

Some alternative methods to reduce soaking time had been suggested by different authors. Diverse investigations on how temperature, pressure, aging, soaking media,

concentration, physiochemical properties and other nutritional composition affect water absorption capacities of rice have been conducted.

### **2.5.1 Effects of aqueous solutions**

Solutes and aqueous solutions of acids and alkalis had been shown to cause partial remotion in corn pericarp, thus, making the waxy cuticle that envelopes the endosperm more permeable to water (Haros and Suarez, 1999). Efforts to adapt similar approach to hasten water absorption by rice have also been made by different researchers. In their study, Metcalf and Lund (1985) reported the effect of salt, sucrose and/or glyceryl monostearate. They found that water uptake was enhanced with the presence of glyceryl monostearate and by steaming the samples prior to soaking in the presence of sucrose. Bello et al., (2004) reported that the addition of acids (ClH, CH<sub>3</sub>COOH, PO<sub>4</sub>H<sub>3</sub>) does not affect the rate of water uptake by rough rice, but alkali solutions (NaOH and Na<sub>2</sub>CO<sub>3</sub>) hastened water absorption and effectively reduced the soaking time. In addition to this, the authors also suggested that dehusking and debranning raw rice also increased the hydration rate of rice. Increase in the hydration rate of paddy by dehulling had also been reported by other authors (Bakshi and Singh, 1980).

### **2.5.2 Effects of pressure**

It is known that pressure has considerable influence in increasing the rate of reaction as applied in many aspects of food engineering. At elevated pressure, rice grains absorb large amounts of water due to structural modifications in their macromolecules and the degradation of cell membranes (Watanabe et al., 1991). Velupillai and Verma (1982) demonstrated that hydrostatic pressure reduced the soaking time during parboiling medium grain rough rice soaked at sub-gelatinization temperature. The authors reported that the physical properties of colour and translucency of the finished product was not affected by the application of pressure. As the

physical quality of rice is not adversely affected by the application of pressure which shortens the soaking time, reduction of process times could be achieved. Ahromrit et al., (2004) reported an increase in hydration rate during soaking at high pressure ( $> 600\text{MPa}$ ) of Thai glutinous rice. Their study was in agreement with previous work published by Douzals et al., (1996). The authors demonstrated that increase in hydrogen bonding between water and starch at higher pressure further promotes water uptake. Bello et al., (2008) studied hydration kinetics of rice under vacuum and pressure at temperatures of 15, 35 and  $55^{\circ}\text{C}$  in comparison to hydration at atmospheric pressure. Their findings show that soaking at vacuum and pressure increase hydration rate and reached higher saturation moisture content while shortening the soaking time than soaking under atmospheric pressure. However, pressure soaking was found to have higher hydration rate and saturation moisture content and needed less time than vacuum soaking.

### **2.5.3 Varietal differences**

Different cultivars of rice are grown across different countries in the world. The influences of genetic make-up and environmental factors result in differences in physical and chemical composition of rice. Supplementary to processing conditions such as those mentioned above, chemical properties, especially that of amylose content, which vary among different varieties, also influences water uptake behaviour during soaking of paddy rice (Metcalf and Lund, 1985). Differences in gelatinization temperature have been found to be only significant during soaking in water at temperatures above  $60^{\circ}\text{C}$  (Biswas et al., 1988).

## **2.6 Properties of parboiled rice**

Botanically, parboiled and raw rice are one and the same. The features of parboiled rice which makes it distinct from the untreated sample arising from the hydration, chemical and thermal transition it undergoes during processing.

The effect of parboiling on the size, shape and appearance of grain has been studied by some authors (Bhattacharya and Ali, 1985; Otegbayo et al., 2001). In their study, the authors observed that the size and shape of the milled parboiled rice were slightly distinct from those of the product having a shorter length and a flatter surface. This difference in shape and size could be related to the realignment of plastic kernel substance within the husk during heat treatment. Similar observation was made later by authors in which it was added that such observed changes in parboiled rice grain was true for paddies parboiled using the conventional method (Sowbhagya et al., 1993).

Gelatinization of rice starch during parboiling has been found to be accompanied by changes in the appearance of parboiled rice. The usual opaque or the so called ‘white portions’ in rice have been reported to be eliminated during parboiling, making the end product more translucent and glassy than the non-parboiled rice (Velupillai and Verma (1982). This observation is basically due to fusion of the gelatinized starch granules as well as the disrupted protein bodies, resulting in denseness reducing light scattering at the granule boundaries (Bhattacharya, 2011). The fusion of the starch granules and the protein bodies also give rise to harder rice kernels. Increase in translucency is of economic advantage to rice marketers. Rice consumers are willing to pay more for rice with an attractive appearance and less broken grain (Ayamdoo et al., 2013b).

Grain colour is one of the noticeable properties of parboiled rice compared to raw rice. The former have a shade of amber which could be darker depending on the intensity of the parboiling treatment. Investigations by several authors demonstrated that discolouration was due to nonenzymatic browning of the Maillard reaction due to enhanced level of reducing sugar and amino acids during heat treatment of rice by steaming (Houston et al., 1956; Mecham, et al.,

1961). The degree of heat treatment due to time and temperature during soaking and steaming results in more serious discolouration (Bhattacharya and Ali, 1985; Islam et al., 2002). Intensity of discolouration due to high temperature (70 – 80°C) of soaking water and prolonged exposure in soaking medium is basically due to absorption by the grain of husk component dissolved in the soak water once the husk has been opened due to increase in net heat treatment.

Improved milling resistance, exhibited through reduction in grain breakage during milling, is one of the unique characteristics of parboiled rice as compared to raw rice. This trend has shown to be consistent as documented by several writers. Improvement in kernel hardness due to fusion of gelatinized starch granules and disrupted protein bodies may be part of the reason for improved milling quality of parboiled rice. However, studies show that the bulk of improvement is as a result of cooking and swelling of the starchy endosperm, which heals all the pre-existing defects developed during some postharvest operations that gives parboiled rice this precious quality (Bhattacharya, 1969). Though properly parboiled rice increases milling resistance, inadequate drying can compromise the whole process leading to high breakage during milling.

The preference in taste and cooking behaviour of parboiled rice over non-parboiled rice is known by rice processors and consumers in most developing countries such as Nigeria. Efforts have been made by scientists to understand the mystery that underlies these differences. Milled parboiled rice has been found to cook slower (high cooking resistance), but retained better shape, disintegrated less in cooking water and is less sticky than raw rice (Bhattacharya, 1985; Parnsakhorn and Noomhorm, 2008). These changes found in parboiled rice was as a result of initial starch gelatinization and some sort of reassociation of lipid-amylose complex I and/or II taking place during cooking (Priestley, 1976; Billiaderis et al., 1992; Billiaderis, 1993). It must

be added that the degree or severity of parboiling also determines the extent of the changes enumerated above. For example, pressure parboiling of paddy at extended steaming period induces rice with firmer grains and a high cooking resistance than parboiling done at atmospheric pressure and/or in shorter time. This is due to the transformation of starch leading to the formation of amylose complex and some sort of amylose retrogradation under harsh processing conditions.

Improvement in nutritive value such as B vitamins and other trace minerals is the most significant parameter among all other properties of parboiled rice. The efficacy of parboiling in improving thiamine, riboflavin and nicotinic acid of rice is well known and has been investigated by many researchers (Done, 1949; Rao and Bhattacharya, 1966; Manful et al, 2007). Milling of parboiled paddy results in rice grain with higher nutrients than non-parboiled rice. This follows from the fact that during parboiling, vitamins from the rice bran migrate to the endosperm, leaving only traces of these vitamins in the bran. Since little amount of vitamins are left in the bran of parboiled rice, milling of parboiled rice yields rice with more vitamins than found in of untreated paddy.

Similar to vitamins, sugars, amino acids and minerals also increase in rice during parboiling of paddy. Significant enzymatic conversion of nonreducing to reducing sugar in addition to the production of sugars take place. Considerable amount of sugar leach out into the soaking water and further reduction during steaming, owing to Maillard reaction occurred. Also as in the case of vitamins, there is reduced loss of sugar in milled parboiled rice than in milled untreated rice.

In addition to vitamins and sugars, mineral contents in parboiled rice have been studied by several authors (Bhattacharya and Ali, 1985). The authors reported that the changes in

mineral contents in milled rice due to parboiling were not noticeable. However, the composition of ash, phosphorous, calcium, iron, manganese, molybdenum and chromium was found to be higher in milled parboiled rice than in the raw rice. Parboiling also remedied the milling loss of the minerals as in the case of vitamins and sugars. The changes in the nutritive properties of rice due to parboiling can be explained by two major theories. The most primitive of theories was that the water-soluble components dissolve and diffuse into the endosperm during the soaking stage in rice parboiling. The second theory is related to subsequent work by some authors which revealed that gelatinization of rice starch during parboiling results in adhesion of vitamins and minerals to the starchy endosperm. These constituents remain immobilized during milling of rice, and results in reduced loss of nutrients of the final product (Rao and Bhattacharya, 1966; Ali and Bhattacharya, 1980a).

After parboiling, it is required that rice be stored for further processing or subsequent distribution. The storage quality of rice depends on the spoilage (rancidity) of its fat and sensitivity to insect and microbial invasion. McCaskill and Orthoefer (1994) reported that deterioration of lipids in the bran layer occurs due to hydrolytic and oxidative rancidity and the deterioration of bran is mainly due to hydrolytic rancidity, catalyzed by lipase which is concentrated in bran and germ layer. During parboiling, lipase is inactivated, thus development of free fatty acid (FFA) is terminated. This alters the storage property of parboiled rice leading to extended shelf life of the product.

## **2.7 Rice uses**

Different species of rice have varying textural qualities. The choice of a particular specie also varies by domestic and foreign consumers because different ethnic groups prefer various textures in home-cooked rice. Rice processors also need all grain types and textural qualities for use in

various types of prepared and convenience-type, rice-containing products, such as dry breakfast cereals, parboiled rice, quick-cooking rice, canned rice, canned soups, dry rice soup mixes, baby foods, and frozen dishes, etc. (Hsieh and Luh, 1991).

Rice contains several vitamins, especially the B vitamins, and minerals required for a healthy living. Some of its uses are as food while some are medicinal. As staple food rice is consumed by more than 60 percent of the world's population usually in the form of 'table rice' by cooking it and serving with sauce. For people in the northern part of Nigeria and some other African countries, rice is an indispensable food. It is often used for producing a thick rice porridge named *tuwo or tuwoshinkafa* made from the grinding of rice into powder form and mixing in boiling water. This flour is however boiled and made ready for consumption with the aid of delicious stew.

Rice starch is used as a by-product in making ice cream, custard powder, puddings, gel and in brewing of potable alcohol. In addition, rice bran is used in confectionery products like bread, snacks, cookies. The defatted bran is also used as cattle feed, organic fertilizer (compost), and medicinal purpose and in wax making (Umadevi et al., 2012).

Oil from rice bran is used as edible oil and in the manufacturing of soap and fatty acids. It is also used in cosmetics, synthetic fibers, detergents and emulsifiers.

Flaked and parched rice are made from parboiled rice and used in many preparations easily digestible. Rice husk is used as a fuel either directly or as briquettes, in board and paper manufacturing, packing or building materials and as an insulator. It is also used for compost making and chemical derivatives.

Broken rice is used for making food item like breakfast cereals, baby foods, rice flour, noodles, rice cakes, and also used as poultry feed. Rice straw is mainly used as animal feed, fuel, mushroom bed, for mulching in horticultural crops and in preparation of paper and compost. Rice is believed by some to have medicinal properties. Although, this is not scientifically proven effective, it has been used in many countries for medicinal purpose according to health reports. For instance in Nigeria, the bran from rice is extracted and used as an excellent source of Vitamin B to prevent and cure *beri-beri*. Besides, the Yorubas (people from the South-West region of Nigeria) also produce a medicinal kind of pap called *Gbangba*, this is done by grinding the rice into liquid form, after this the liquid rice is cooked with lemon grass, lemon orange and grape. It is believed to have medicinal power that can cure malaria when served hot.

In Malaysia, in the Medicinal Book of Malayan Medicine, it is prescribed that boiled rice "greens" can be used as an eye lotion and for use against acute inflammation of the inner body tissues. The book also recommends applying a mixture of dried, powdered rice on certain skin ailments. In Cambodia, the hulls (husk) of mature rice plants are considered useful for treating dysentery. The hulls of a three-month old rice plant are thought to be diuretic.

Meanwhile in China, they believe rice strengthens the spleen, as well as "weak stomach," increases appetite, and cures indigestion. Dried sprouted rice grains were once used as an external medicine to aid in digestion, give tone to muscles, and expel gas from the stomach and intestines.

In India, rice water is prescribed by the Pharmacopoeia of India as an ointment to counteract inflamed surface.

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## CONNECTING TEXT

In this chapter, the hydration characteristics of rice varieties from Nigeria were investigated to understand the effect of temperature and variety on water diffusivity during soaking. This would aid in optimizing the soaking process during rice parboiling operation. Selected varieties of rice used in this study include four improved varieties namely FARO 44, FARO 52, FARO 60, FARO 61 and one local variety (Bisalayi). Paddy rice were soaked in water at different temperatures 30, 45, 60 and 75<sup>0</sup>C for different time periods 1 – 9 h. Experimental values of moisture content were fitted to Fick's second law of the diffusion in an infinite cylinder using PROC MODEL of Statistical Analysis Software (SAS 9.2).

CHAPTER THREE:  
**HYDRATION CHARACTERISTICS OF SELECTED VARIETIES OF PADDY RICE  
FROM NIGERIA**

**ABSTRACT**

In this study, water absorption characteristics of some rice varieties (Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44) from Nigeria were studied at 30, 45, 60 and 75°C by determining the increase in grain weight as a function of time during soaking. Differences in moisture content among the selected varieties of paddy during soaking were significant ( $P < 0.05$ ) at all temperatures considered. Using the experimental moisture data, a non-linear regression procedure was applied to an analytical solution to Fick's second law of the diffusion for an infinite cylinder. The predicted moisture content during soaking of rice was found to correlate positively with the measure values of moisture content with  $R^2$  values between 0.981 – 0.990. Water absorption rate was found to increase with soaking temperature, while water saturation time decreased with temperature. Average values of diffusion coefficients of moisture during soaking of paddy rice at different temperature (30, 45, 60 and 75°C) were estimated as  $6.25 \times 10^{-11}$ ,  $6.28 \times 10^{-11}$ ,  $7.02 \times 10^{-11}$ , and  $5.51 \times 10^{-11}$  and  $5.52 \times 10^{-11} \text{ m}^2/\text{s}$  for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, respectively. The activation energies of the diffusivity through different varieties of rice grains were calculated using Arrhenius-type equation for diffusion dependence on temperature and were determined as 41.96, 38.69, 40.16, 34.05 and 42.12 kJ/mole for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44 for the respectively rice variety above.

**Keywords:** Rice paddy; Parboiling; Hydration rates; Saturation time; Diffusion coefficient; Activation energy

### 3.1 INTRODUCTION

Parboiling is a pre-milling hydrothermal (heating and hydration) handling of paddy (rough rice) which brings about substantial physical and chemical alterations in rice. The main purpose of this process is to gelatinize the starch granules, transforming the ordered structure of the starch into a disordered one. Starch gelatinization imparts additional hardness to the rice grains and makes them to withstand harsher milling (Rao & Juliano, 1970; Bhattacharya, 1985). Research shows that parboiled rice also has better organoleptic properties, retains more nutrients and cooks better than non-parboiled rice (Rao & Juliano, 1970).

Paddy parboiling process is made up of three stages: soaking of paddy to saturation moisture content (SMC), steam heat treatment of the soaked paddy to gelatinize the rice starch and drying the steamed product to moisture content adequate for milling. Soaking is an essential operation done to achieve fast and uniform distribution of moisture in grains required for efficient gelatinization of starch granules during steaming operation, but it is time-consuming. Complete soaking is attained when there is an optimal absorption of water in the center of the soaked grains and when no white belly is observed in kernels of parboiled paddy. The moisture content corresponding to this condition is the SMC and has been found to be approximately 30% (w.b.) (Bhattacharya and Rao, 1966a; Gariboldi, 1974; Wimberly, 1983). At this moisture content, steaming operation produced more translucent grains (Velupillai and Verma, 1982). Bhattacharya and Rao (1966a) reported that insufficient soaking causes breakage of paddy during milling. Over-soaking ( $SMC > 31\%$ ) due to excess water absorption induces husk splitting and leaching of paddy constituents (Bhattacharya et al.; 1966b).

Traditionally, soaking of paddy is done by steeping the product in water at ambient temperature, and allowing it to stay for 2 – 3 days before draining the water. Increasing the

temperature of soaking water, generally to that of starch gelatinization, reduces the time required for paddy to reach saturation (Bhattacharya and Rao, 1966a; Miah et al., 2002).

Soaking is a critical unit operation. Therefore the understanding of the characteristics of water movement during soaking of rice is of practical importance. More so it affects the quality of the final product. However, each variety of paddy has a unique optimal soaking time at different temperatures, that is, the time required to reach saturation. Hydration characteristics of different varieties of paddy have been studied. Bhattacharya and Rao (1966a) reported that freshly harvested paddy has lower hydration rate than stored grains. Hydration rate during soaking of high amylose rough rice varieties from Bangladesh was found to differ owing to difference in gelatinization temperatures (Biswas and Juliano, 1988). It is not only essential to understand how fast water absorption takes place, but also to know how one can predict the soaking time at different water temperatures.

Differential scanning calorimeter (DSC) has been employed to measure gelatinization properties of rice (Marshall and Normand, 1989; Saif et al., 2003; Ahmed et al., 2005). The authors reported a range of gelatinization temperatures of 60 – 94°C.

There are published data on hydration characteristics of South American and Asian rice grains in the literature (Bello et al., 2008; Thakur and Gupta, 2006). However, the studies on water absorption characteristics of paddy varieties from West Africa and mainly Nigeria are very few. The objective of the study was to:

- 1) Study hydration characteristics of different varieties of rice paddy (namely Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44) from Nigeria at 30, 45, 60 and 75°C soaking temperatures.

- 2) Determine moisture diffusivity and activation energy during hydration of the rice paddies.

## **3.2 MATERIALS AND METHODS**

### **3.2.1 Material sourcing**

Samples of four improved rice varieties (FARO 44, FARO 52, FARO 60, FARO 61) used in this study were harvested in December, 2012 and collected from the Breeding Unit of Rice Research Program, National Cereal Research Institute (NCRI) Badeggi Niger State, Nigeria. One local variety (Bisalayi) was also harvested in the same period and obtained from crop improvement unit of Kano State Agriculture and Rural Development Agency (KNARDA). They were packed in nylon jute bags and transported in February, 2013 to the Bioresource Engineering Department, McGill University, Montreal, Canada and stored at room temperature. Prior to experiments, the unparboiled paddy samples were taken out, thoroughly cleaned and extraneous materials and flawed grains were removed. The moisture contents of the samples were determined by the fixed air-oven method drying at 120°C for 24 h in triplicates and found to be  $0.0713 \pm 0.0023$  g/g d.b.

### **3.2.2 Determination of the physical characteristics of paddy**

Physical characteristics of the paddy varieties were determined according to Varnamkhasti et al. (2008) with slight modifications. For each rice variety, 50 grains were selected at random and their principle dimensions length (L), breadth (B), and thickness ( $T_G$ ) measured using a digital vernier caliper to the accuracy of 0.01mm. Using the different values, the equivalent diameter ( $D_p$ ) in mm considering a prolate spheroid shape for a paddy grain was calculated according to (Mohsenin, 1986).

$$D_p = \left( L \frac{(B+T_G)^2}{4} \right)^{\frac{1}{3}} \quad (1)$$

where  $D_p$  is the equivalent diameter,  $L$ , the grain length,  $B$ , the breadth of the grain and  $T_G$ , the grain thickness

### 3.2.3 Soaking procedure

Samples of Paddy ( $\approx 10$  g) in duplicates were placed in wire mesh and soaked in a 500 ml beaker containing 400 ml of distilled water. Before the run, the beaker was placed in a stirred water bath (T 1404 B Lauda, Lauda Dr. R. Wobser GMBH & Co., Germany) which was set to the desired temperature for the experiment. The temperature of the waterbath was controlled at ( $\pm 0.2^\circ\text{C}$ ) and the soaking temperatures were 30, 45, 60, and  $75^\circ\text{C}$ . Samples were drawn at different intervals (1, 2, 3, 4, 5, 6, 7, 8 and 9h) and the soaked samples (without net) was surface-dried with paper towel to remove adhering surface water. The blotting procedure was repeated twice (Becker, 1960) after which samples were reweighed in a balance with 0.0001 g accuracy to determine the increase in sample mass. Moisture content was measured by drying soaked sample with a fixed air-oven at  $105^\circ\text{C}$  for 24 h.

### 3.2.4 Determination of effective diffusivity and activation energy

The hydration kinetics of paddy rices were analyzed according to Fick's second law of diffusion.

To simulate this, the following assumptions were made:

- a) The effective diffusivity is constant
- b) The swelling of grain during water absorption is negligible
- c) The surface of the grain reaches saturation instantaneously upon immersion in water.

The analytical solution to the diffusion equation is an infinite series (Crank, 1975) and was applied to model hydration process during soaking of paddy rice.

$$MR = \frac{M(t)-M_e}{M_0-M_e} = \sum_{n=1}^{\infty} B_i \exp(-D_{eff}\lambda_i^2 t) \quad (2)$$

where MR is the moisture ratio,  $M_0$  is the initial moisture content,  $M(t)$  is the instantaneous moisture content  $M_e$  is the equilibrium moisture content,  $B_i$  is constant depending on the shape of the product (geometrically, rice grain could be considered as a cylinder),  $D_{eff}$  is the diffusivity ( $m^2/s$ ) and  $\lambda$  is the geometrical shape factor. As time gets larger, the infinite series on the right hand side of Eq. 2 converges such that the momentary moisture content can be expressed as:

$$M(t) = M_e + (M_0 - M_e)B_1 \exp(-kt) \quad (3)$$

$$\text{where } k = D_{eff}\lambda_1^2 \quad (4)$$

To determine the equilibrium moisture content another set of samples were soaked for 30 h at 30°C, 24 h at 45°C, 15 h at 60°C and 10 h at 75°C. These conditions were selected due to the fact that prolonged soaking in water temperature at 30°C may result in germination of rice kernels (Lu et al., 1993). Shorter soaking periods were chosen for higher temperatures since absorption rate were faster at higher temperatures than at lower temperature. The equilibrium moisture content was estimated by regression analysis of the experimental data using equation 3.

The correct model could be estimated from the empirical values of  $B_1$  and this was evaluated by applying a non-linear regression procedure (PROC MODEL) using SAS 9.2 to Eq. (3) (known as the Henderson and Pabis diffusion equation). The optimal soaking time was taken as the minimum time required to reach the saturation moisture content.

Temperature dependence of diffusion coefficient is generally described using Arrhenius-type relationship to obtain an agreement of the predicted value with experimental data:

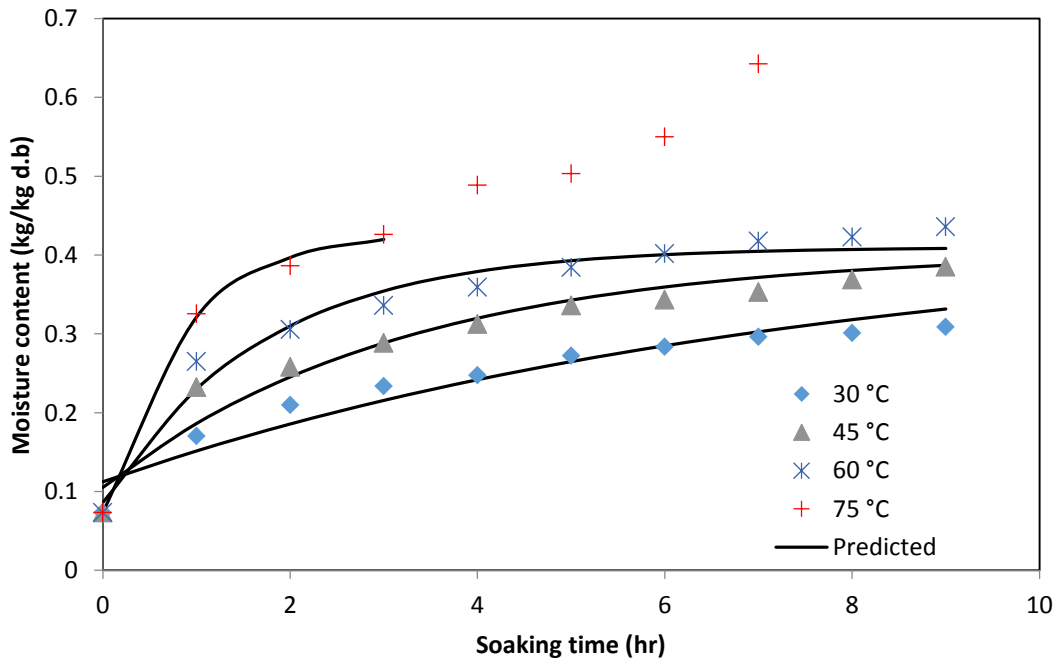
$$D_{\text{eff}} = D_0 \exp\left(-\frac{E_a}{RT}\right) \quad (5)$$

Where  $D_0$  is the diffusivity constant ( $\text{m}^2/\text{s}$ ),  $E_a$  is the activation energy ( $\text{kJ}/\text{mole}$ ),  $R$  is the gas constant ( $8.314 \text{ J}/\text{mole}/\text{K}$ ) and  $T$  is the absolute temperature.

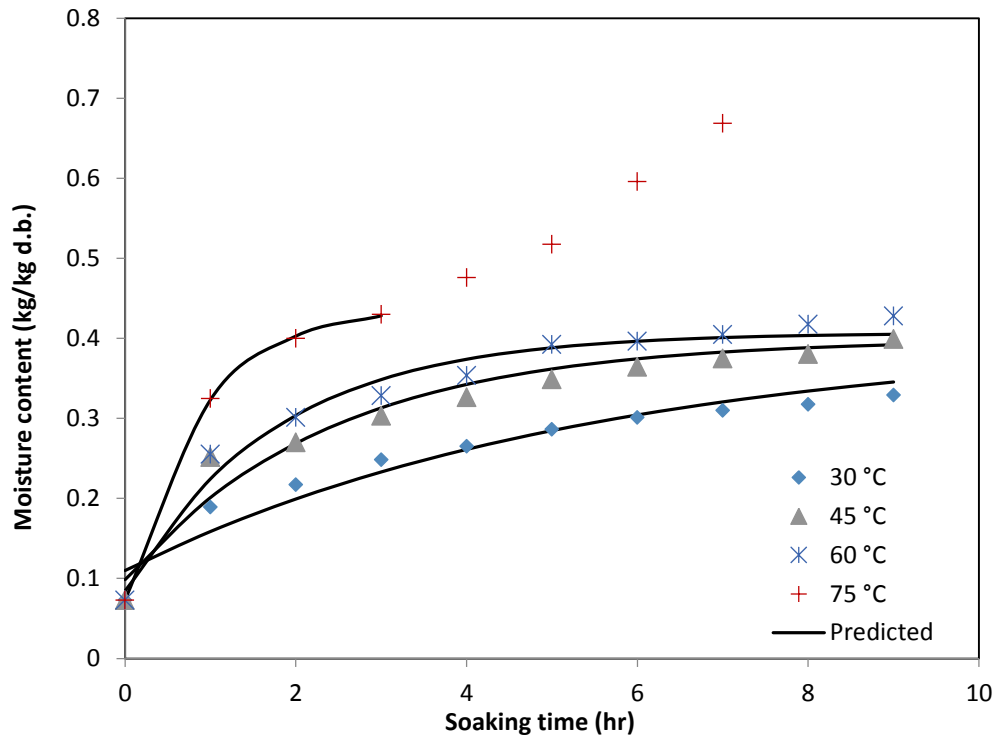
### 3.3 RESULTS AND DISCUSSION

#### 3.3.1 Water absorption curves of paddy

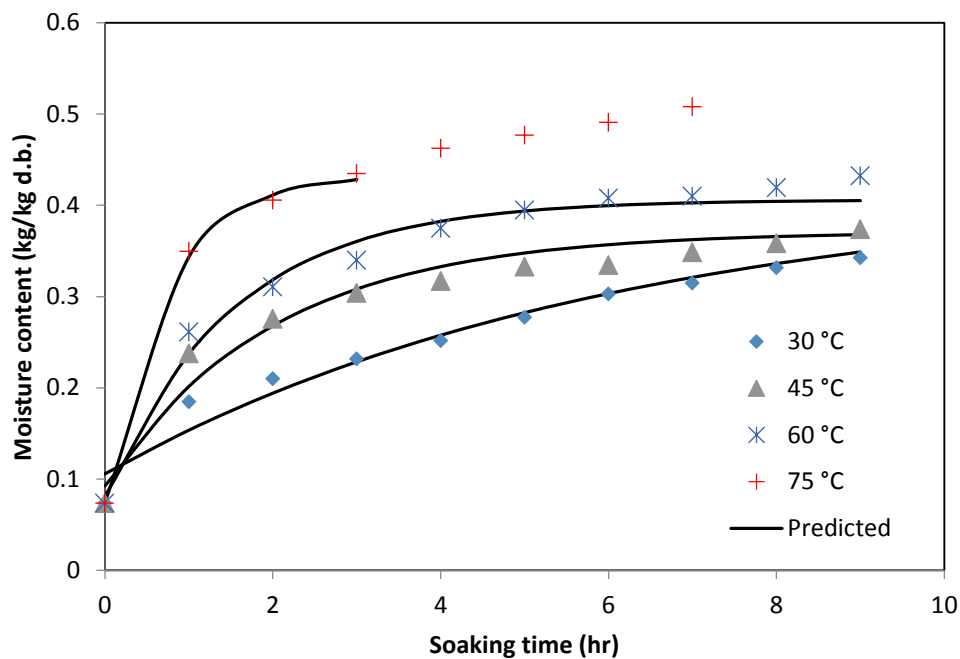
The relationship between moisture content of paddy rice and soaking period at different temperatures is shown in Figs. 3.1 – 3.5 for FARO 44, FARO 52, FARO 60, FARO 61 and Bisalayi varieties, respectively.



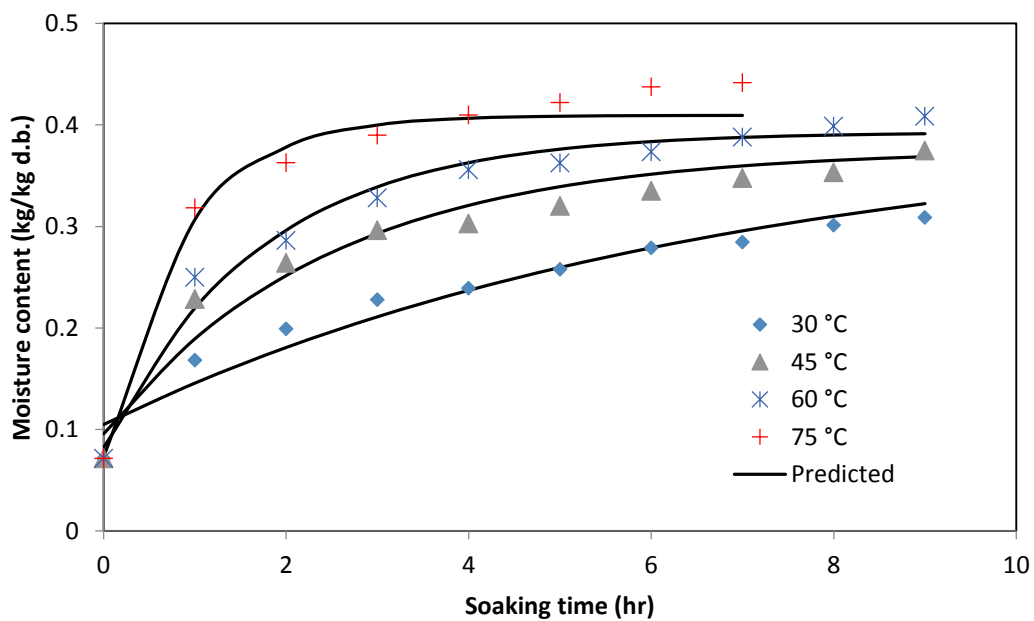
**Figure 3.1: Moisture gain by FARO 44 rice variety at different soaking temperatures**



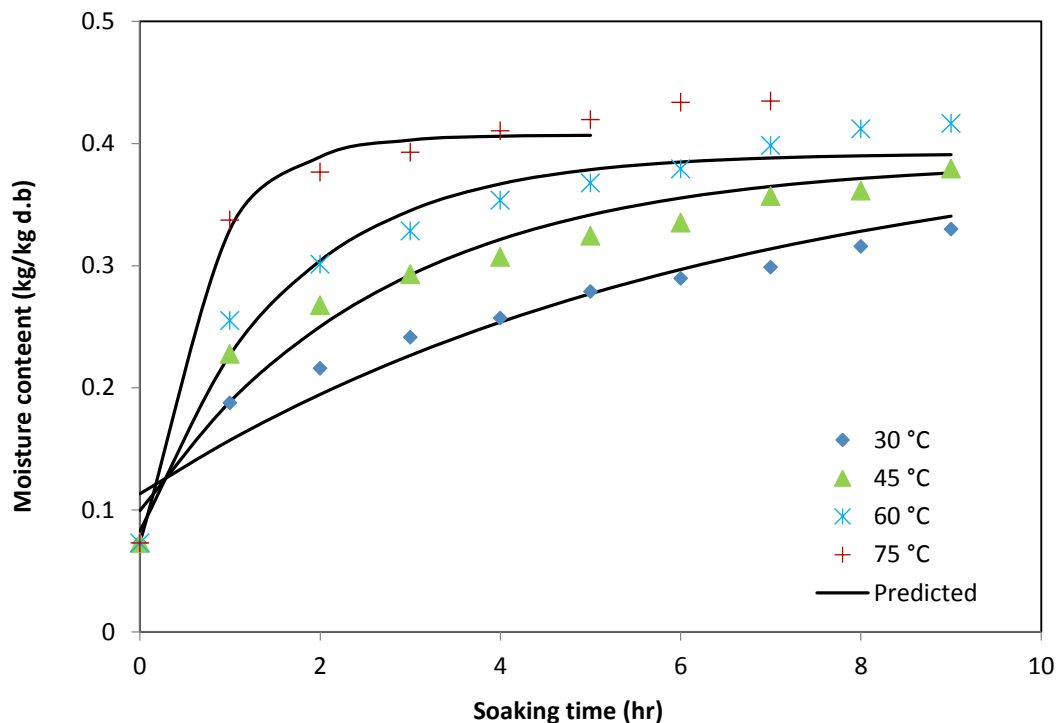
**Figure 3.2: Moisture gain by FARO 52 rice variety at different soaking temperatures**



**Figure 3.3: Moisture gain by FARO 60 rice variety at different soaking temperatures**



**Figure 3.4: Moisture gain by FARO 61 rice variety at different soaking temperatures**



**Figure 3.5: Moisture gain by Bisalayi rice variety at different soaking temperatures**

During soaking up at 60°C (30, 45, and 60°C), paddies absorbed water at a slow rate and reached equilibrium. This observation was consistent with finding by other authors during soaking of other rice (Bhattacharya and Rao, 1966a; Bello et al., 2004). The saturation moisture content for rice in this study was found to be between 37.05 – 42.70 % dry basis. During soaking, FARO – 44, 52 and 60 exhibited similar water absorption characteristics. However, a rapid deviation in the soaking characteristics from the normal trend was observed when soaking water temperature at 75°C was used for FARO – 44, 52 and 60. This could be as a result of volume expansion of starches of FARO – 44, 52 and 60 under the influence of high temperature. The increase in water uptake of FARO – 44, 52 and 60 continued without flattening out in the time range of the experiment. A further increase in water uptake was observed accompanied by husk splitting. This observation could be due to the fact that the starch gelatinization

temperatures of FARO – 44, 52 and 60 fall within the temperature range of 60 to 75°C. Igathinathane et al. (2005) reported that as husks split, endosperms of paddies may react with water resulting in excess hydration or over-soaking of paddy. This observation was also made for rice used in this study. Husk splitting for FARO 44, 52 and 60 was observed after 3 h of soaking at 75°C.

Furthermore, FARO 61 and Bisalayi were found to have similar water absorption characteristic curves. At 75°C soaking water temperature, husk splitting was observed after 5 hours of soaking for FARO 61 and Bisalayi. Bhattacharya et al. (1966b) reported that over-soaking due to prolonged steeping of paddy can lead to excessive migration of dissolved husk component to the endosperm thereby causing adverse colour change and result in poor quality of parboiled rice. Adverse colour change can also result from severe soaking at high temperature, leading to nonenzymatic browning as a result of chemical reaction of reducing sugar at high temperature. In order to optimize the soaking process, water temperature of 60°C was recommended since it does not result in husk splitting during soaking. At 60°C soaking water temperature, FARO – 44, 52 and Bisalayi were found to reach saturation after 7 h of soaking, while FARO – 60 and 61 attained saturation after 6 and 8 h, respectively. Soaking periods, resulting in deviation from normal hydration characteristics before the splitting of husk were used in estimating the kinetic parameter for 75°C.

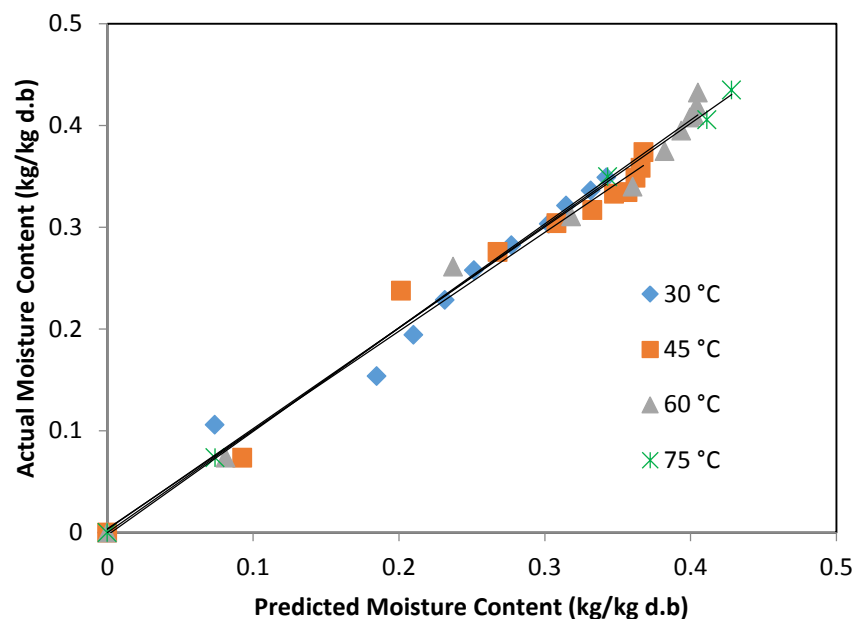
### **3.3.2 Estimation of kinetic parameters**

In order to estimate moisture diffusivity during soaking of different varieties of paddy, a non-linear regression procedure was applied to Eq. (3) as stated in the material and methods. The estimated values of parameters for different varieties of paddy are given in Table 3.1. As expected, coefficient of water absorption ( $k$ ) increased with soaking temperature.

The characteristic lengths (radii) of the infinite cylinder model were calculated assuming that the model cylinder has the same volume and length as the rice kernel (Engels et al., 1986). The average values of radii for the infinite cylinder were 0.86, 0.87, 0.87, 0.83 and 0.84 mm for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, respectively. The average value of  $B_1$  for all varieties was observed to be  $0.944 \pm 0.0064$  which is close to the theoretical value for diffusion model in infinite cylinder (0.69). Similar observation was made for other paddy rice and was reported to be  $0.917 \pm 0.0495$  (Thakur and Gupta, 2006). Thus, it can be concluded that the water absorption characteristics of paddy rice were similar to those of an infinite cylindrical model. The predicted moisture content during soaking of rice was found to correlate positively with the measure values of moisture content with  $R^2$  values between 0.981 – 0.990. Figure 3.6 shows a typical correlation curve for FARO 60 variety.

**Table 3.1: Kinetic parameters of Eq. 3 for different varieties of paddy during soaking at different temperatures**

Varieties	Temperature	B	k	R <sup>2</sup>	MSE
Bisalayi	30	0.881±0.001	0.159±0.002	0.950	0.00050
	45	0.915±0.003	0.373±0.011	0.944	0.0006
	60	0.969 ±0.013	0.629 ± 0.048	0.976	0.0004
	75	0.998± 0.002	1.464 ± 0.065	0.994	0.0002
FARO 61	30	0.898 ± 0.003	0.149 ± 0.001	0.963	0.0004
	45	0.920 ±0.009	0.406 ± 0.008	0.938	0.0007
	60	0.966 ± 0.010	0.583 ± 0.022	0.978	0.0003
	75	0.995 ± 0.002	1.187 ± 0.040	0.992	0.0001
FARO 60	30	0.907 ± 0.0003	0.165 ± 0.005	0.834	0.0003
	45	0.936 ± 0.011	0.400 ± 0.009	0.931	0.0008
	60	0.977 ± 0.002	0.655 ± 0.033	0.985	0.0003
	75	0.999 ± 0.0002	1.379 ± 0.114	0.999	0.0000
FARO 52	30	0.887 ± 0.011	0.183 ± 0.006	0.951	0.0005
	45	0.921 ± 0.002	0.418 ± 0.001	0.948	0.0006
	60	0.965 ± 0.009	0.569 ± 0.044	0.978	0.0004
	75	0.999 ± 0.001	1.145 ± 0.076	0.999	0.00002
FARO 44	30	0.890 ± 0.004	0.133± 0.003	0.952	0.0005
	45	0.904 ± 0.008	0.316 ± 0.002	0.943	0.0007
	60	0.962 ± 0.002	0.587 ± 0.014	0.972	0.0005
	75	0.999 ± 0.005	1.186 ± 0.089	0.997	0.0002



**Figure 3.6: Correlation curve of FARO 60 rice variety**

The variation of effective diffusivity of paddy rice with temperature and the values of activation energies for different varieties of paddy rice are shown in Table 3.2. The values obtained for diffusivity for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44 was statistically analyzed to understand varietal significance on water absorption of paddy.

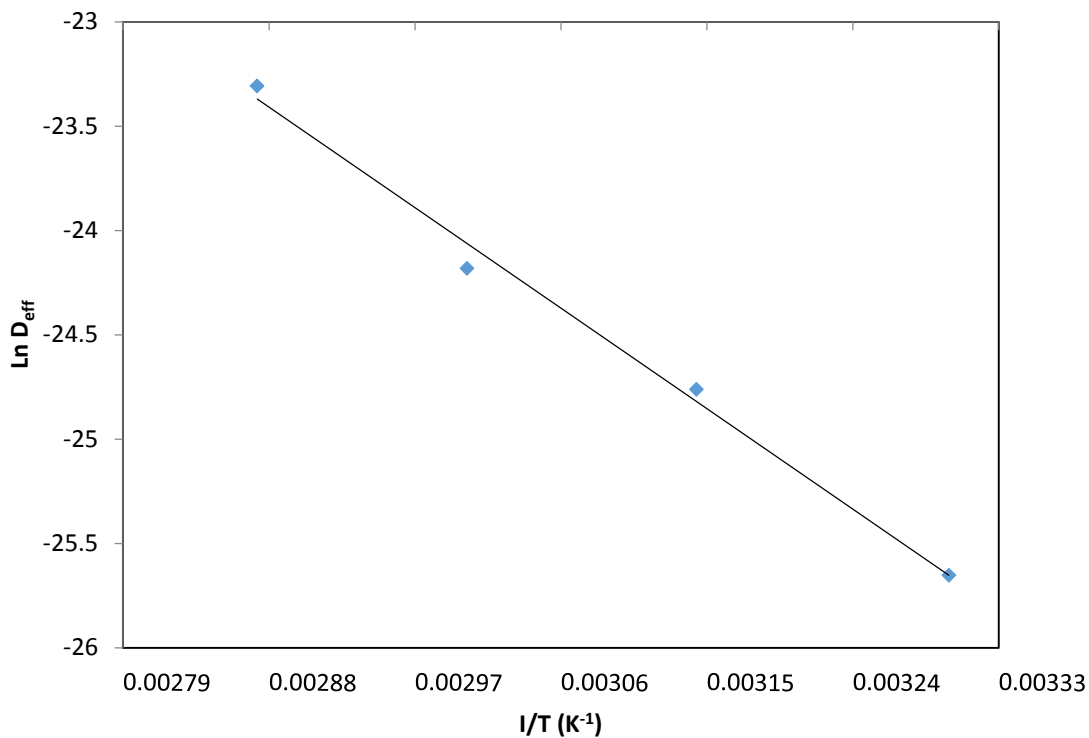
**Table 3.2: Diffusion coefficient and activation energy of paddy rices**

Variety	$D_0$ (m <sup>2</sup> /s)	Temperature (°C)	$D_{\text{eff}}$ (m <sup>2</sup> /s)	$E_a$ (kJ/mol)	$R^2$
Bisalayi	3.34E – 4	30	7.23E-12	44.47	0.99
		45	1.76E-11		
		60	3.14E-11		
		75	7.54E-11		
FARO 61	8.10E – 5	30	1.15E-12	40.78	0.98
		45	8.64E-12		
		60	1.78E-11		
		75	7.37E-11		
FARO 60	1.5E – 4	30	7.83E-12	42.13	0.99
		45	1.96E-11		
		60	3.35E-11		
		75	7.22E-11		
FARO 52	1.55E – 5	30	7.83E-12	36.42	0.98
		45	1.86E-11		
		60	2.66E-11		
		75	5.53E-11		
FARO 44	2.74E – 4	30	5.8E-12	44.50	0.99
		45	1.4E-11		
		60	2.78E-11		
		75	5.83E-11		

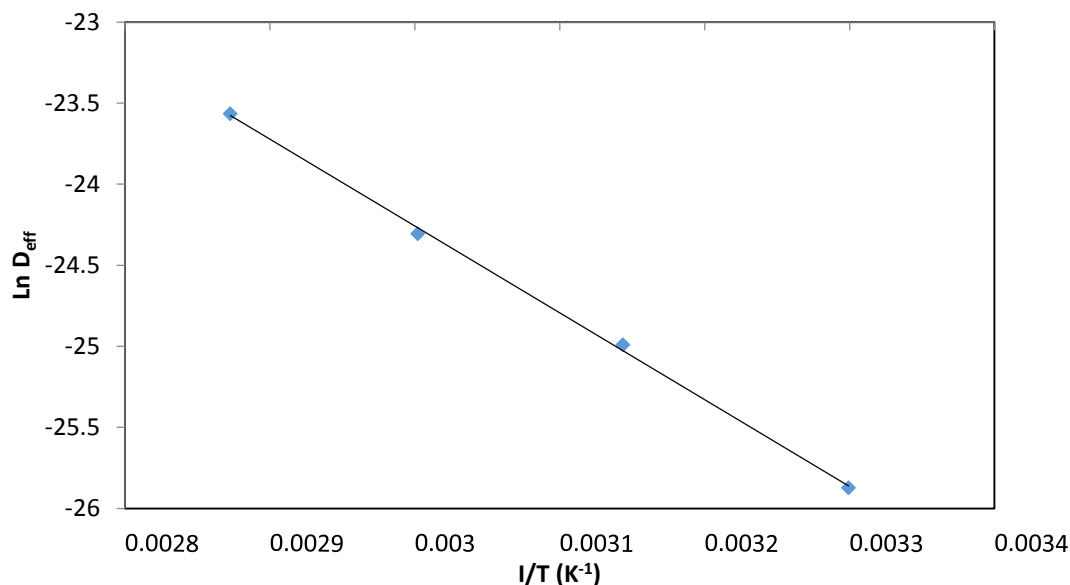
$E_a$  - activation energy

The result of analysis of variance (ANOVA) at a 0.5% confidence level during soaking at water temperature of 30 and 45°C shows no statistical difference in Bisalayi, FARO 61, FARO 60, and FARO 52 except for FARO 44. This observation suggests that the husk of FARO 44 provided more barriers to water penetration during soaking at 30 and 45°C water temperatures than the husk of other varieties of paddy used in this study. During higher soak water temperatures (60 and 75°C), Bisalayi and FARO 60 were found to have the highest diffusivity ( $P < 0.05$ ), while FARO 44 and FARO 52 has the lowest diffusivity values. This could be that in addition to husk, the bran of FARO 44 and FARO 52 further retards water absorption during

soaking. Kaptso et al.(2008) reported a positive correlation between diffusivity and seed coats of different varieties of cowpea and groundnut, suggesting that seed coverings can play an important role during hydration of seeds. Bello et al. (2004) and Thakur and Gupta (2006) also reported that husk and bran layer declines the rate of water absorption during soaking of rice. The values obtained are in close agreement with those reported in the literature for other varieties of paddy (Bello et al., 2004; Thakur and Gupta, 2006). The plots of  $\ln(D_{\text{eff}})$  against the reciprocal of absolute temperature show a linear relation and are presented in Figs. 3.7 and 3.8.



**Figure 3.7: Arrhenius curve for the effect of soaking temperature on the effective diffusivity of Bisalayi paddy rice**



**Figure 3.8: Arrhenius curve for the effect of soaking temperature on the effective diffusivity of FARO 44 paddy rice**

### 3.4 CONCLUSION

Hydration characteristics of different varieties of paddy from West Africa (Nigeria) (FARO 61, FARO 60, FARO 52, FARO 44 and Bisalayi) were studied during soaking at low temperature (30 and 45°C) and high temperature (60 and 75°C) to determine the optimal soaking time for each variety of paddy. Our findings show that the increase in temperature results in the increase of rate of water absorption and reduced the time for reaching saturation moisture content for paddy. However, during steeping at water temperature of 75°C, FARO – 44, 52 and 60 absorbed more water than Bisalayi and FARO 61, leading to husk splitting. Soaking in water temperature at 60°C did not result in excess water absorption nor husk splitting in paddy rice. Optimal soaking time (time to reach saturation moisture content) was observed to be 7 h for Bisalayi, FARO 44 and FARO 52, while for FARO 60 and FARO 61 the values were 6 and 8 h, respectively. Thus, excess water absorption during soaking of FARO 44, FARO 52 and FARO 60 could be due to swelling and gelatinization of their starch.

A suitable prediction of water absorption during soaking of FARO 61, FARO 60, FARO 52, FARO 44 and Bisalayi was possible by fitting experimental data to Fick's diffusion equation with a high  $R^2$  value of 0.981 – 0.990. The diffusivity of Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44 were  $7.23 \times 10^{-12} - 7.54 \times 10^{-11} \text{ m}^2/\text{s}$ ;  $1.15 \times 10^{-12} - 7.37 \times 10^{-11} \text{ m}^2/\text{s}$ ;  $7.83 \times 10^{-12} - 7.22 \times 10^{-11} \text{ m}^2/\text{s}$ ;  $7.83 \times 10^{-12} - 5.53 \times 10^{-11} \text{ m}^2/\text{s}$  and  $5.80 \times 10^{-12} - 5.83 \times 10^{-11} \text{ m}^2/\text{s}$ , respectively with temperature range 30 – 75°C.

An Arrhenius type equation described the strong dependence of diffusivity on temperature with activation values of 44.47, 40.78, 42.13, 36.42 and 44.50 kJ/mol for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, respectively.

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### **CONNECTING TEXT**

Based on the results from chapter 3, paddy was steamed for different time periods to evaluate the effect of steaming on the physical and thermal (gelatinization) properties. Rice cultivars were soaked at water temperature of 60°C. FARO 44, FARO 52 and Bisalayi were soaked for 7 h of soaking, while FARO 60 and FARO 61 were soaked for 6 and 8 h, respectively, to saturation moisture content. Four levels of treatment time were chosen (5 – 20 minutes) for steaming. Physical properties which include percentage translucency, kernel hardness and lightness value were analyzed. Differential Scanning Calorimetry (DSC) was employed to study the thermal properties of rice samples.

## CHAPTER FOUR

### EFFECT OF STEAMING ON PHYSICAL AND THERMAL PROPERTIES OF PARBOILED RICE

#### **ABSTRACT**

Physical and thermal properties of four improved parboiled rice varieties (FARO 61, FARO 60, FARO 52 and FARO 44) and a local parboiled rice variety (Bisalayi) from Nigeria were investigated for the effects of steaming conditions on the varieties. Translucency improved significantly ( $P < 0.05$ ) with parboiling and was different depending on variety; however, no effect of steaming time was found. The improved rice varieties showed better hardness and were less discolored than the local variety. FARO 61 was found to have the highest hardness with values of 79.36–158.17 N corresponding to steaming for 0–20 min, respectively, while the local variety (Bisalayi) has the least hardness of 59.45–113.65 N for the respective steaming times. For all the rice varieties studied, no residual gelatinization enthalpy was observed at the different steaming times which show that steaming completely gelatinized the rice starch during parboiling process.

**Keywords:** Rice paddy; Parboiling; Steaming; Translucency; Hardness; Lightness; Gelatinization.

## 4.1 INTRODUCTION

Parboiling is a pre-milling hydrothermal (hydration and heat) treatment of paddy (rough rice) which brings about substantial physical and chemical alterations in rice. The main purpose of this process is to pre-gelatinize the starch granules, transforming the crystalline structure of the starch into an amorphous one. Starch gelatinization, imparts additional hardness to the rice grains and allows them to withstand harsher milling (Rao & Juliano, 1970; Bhattacharya, 1985; Islam et al, 2002a). It is reported that parboiled rice also has better organoleptic properties, retains more nutrients and cooks better than non-parboiled rice (Rao & Juliano, 1970; Sareepuang et al., 2008; Lamberts et al., 2008). In generally, parboiling process consists of three stages namely: soaking of paddy to saturation moisture content (SMC), steam heat treatment of the soaked paddy to partially gelatinize the rice starch, thereby eliminating white portions and cementing crack developed in rice during harvesting and/or threshing and finally drying the steamed product to obtain an adequate moisture content for milling.

Chalkiness or white portion is an undesirable quality of parboiled rice. Parboiling brings about positive modifications in rice during which vitamins and minerals are transferred from the aleurone and germ into the starchy endosperm. These transformations are accompanied by reduction in white portion, and give milled rice more translucent appearance (Juliano and Bechtel, 1985). A common problem with parboiling, especially by employing high temperature and pressure and longer processing time, is darkening of the grain (Bhattacharya, 1995). Also, steaming operation, which brings about the gelatinization of starch, requires a lot of energy to produce steam for the process. Therefore it is therefore necessary to establish optimal processing conditions required to obtain better qualities of the finished product while saving energy and time. Marshall et al. (1993) studied the relationship between percentage of gelatinization and

head yield (the primary parameter used to quantify rice milling quality given by the ratio of weight of rice grains that are three-quarters intact to the total weight of milled parboiled rice) of parboiled rice. They reported that maximum head rice yield could be achieved when the rice starch is 40% gelatinized during parboiling of and that extensive parboiling or extensive starch gelatinization is not required to obtain maximum head rice yields.

Since most of the parboiled rice come from local producers, the processes (steaming) time vary among producers. Such variation may result in quality differences in the end product and possible over utilization of energy during steaming operation. The objective of this work was therefore to:

- 1) Study the effect of steaming time on physical properties (translucency, hardness, lightness, and colour intensity) of parboiled rice varieties
- 2) Evaluate the effect of steaming time on thermal properties (degree of gelatinization) of parboiled rice varieties
- 3) Determine the optimum steaming condition required to obtain optimal quality of parboiled rice.

The outcome of this work will allow a harmonization of the steaming process to obtain similar qualities of rice from local producers. The knowledge generated from this work should save energy and investment.

## **4.2 MATERIALS AND METHODS**

### **4.2.1 Samples**

Samples of five improved rice paddy varieties (FARO 44, FARO 52, FARO 60, FARO 61) used in this study were obtained as stated in Chapter 3

#### 4.2.2 Steaming procedure

Based on the result obtained from hydration experiment on optimal soaking time (to reach moisture content of approx. 40% d.b.) for different rices during soaking at 60°C, 180-g batches in duplicated of paddies were soaked at 60°C for 6 h for FARO 60, 7 h (for Bisalayi, FARO 44 and FARO 52) and 8 h FARO 61. At the end of the soaking period, samples were steamed in an autoclave (Consolidated still and sterilizer) at 100°C for 5, 10, 15 and 20 min. The average moisture content after steaming was between 42 – 45 % dry weight basis. Samples were dried at room temperature (20 -25°C) to a moisture content range of 13 – 16 % (d.b.).

Parboiled paddy samples were de-husked using an electric compact rice husker (TR 200, Kett Electric Laboratory, Tokyo) and polished using a test polisher (Pearlest, Kett Electric Laboratory, Tokyo).

#### 4.2.3 Kernel translucency

Grain translucency was determined by adopting the method of Marshall et al. (1993) with slight modification as follows: 200 well-milled whole kernel grains were selected at random from each variety at each steaming time. Translucency was assessed subjectively from the randomly selected kernels by selecting only those grains that were completely translucent. Grains were placed on black table surface illuminated from above by a fluorescent lights. Completely translucent kernels were separated from those with white portion. Percentage of translucency was determined as follows:

$$\% \text{ Translucency} = \frac{\text{Translucent grains}}{\text{Total number of grains (200)}} \times 100 \quad (1)$$

#### 4.2.4 Hardness

About 25 grains of rough rice were randomly selected from each sample. Hardness of 25 unfissured whole brown rice kernels was measure using a compression method (Instron 4502,

Canton MA, USA). The average bio-yield point value (Mohsenin, 1980) of the 25 measurements was expressed as the hardness in newtons (N). Brown rice kernels were put on the base plate and the bio-yield point value measured in flat position (Islam et al., 2001). A 500 N load cell, a probe of 3.84 mm diameter and 5 mm/min compression rate were used. The probe was set to travel a distance of 2.25mm into the sample.

#### **4.2.5 Lightness value**

A spectrophotometer (CM – 3500d, Minolta Co., Ltd., Japan) was used to measure the lightness and saturation of the colour intensity value of the whole kernel milled rice utilizing the  $L^*a^*b^*$  uniform colour space procedure. The value of  $L^*$  expresses the lightness value,  $a^*$  and  $b^*$  represent red/green and yellowness/blue coordinates, respectively of the  $L^*$ ,  $a^*$  and  $b^*$  colour space system. The instrument was calibrated with a standard white plate having  $L^*$ ,  $a^*$  and  $b^*$  values of 98.80, -0.22 and -0.39, respectively and zero calibration cylinder (CIE  $L^* = 0.09$ , average reflectance = 0.01%) Each measurement was replicated seven times and the average value was considered.

#### **4.2.6 Determination of thermal properties of rice varieties**

The thermal (gelatinization) properties were determined with a Differential Scanning Calorimeter (DSC Q100, TA instruments, Wilmington, DE USA). Heat flow and temperature calibrations of the DSC were performed using pure indium with heat of fusion and a melting temperature of 28.41 J/g and 156.66°C respectively. The instrument was coupled with refrigerated cooling system. Nitrogen was used as a purge gas at a flow rate of 50 ml/min.

Raw and parboiled rice were de-husked using an electric compact rice de-husker (TR 200, Kett Electric Laboratory, Tokyo) and polished using a test polisher (Pearlest, Kett Electric Laboratory, Tokyo). Rice flour was then prepared by grinding samples of the polished rice using

a coffee grinder (SUMEET Multi Grind, India) and passed through 0.075 mm sieve (Fisher brand test sieve, Fisher scientific co., USA).

An empty aluminum pan (40  $\mu$ l) was tarred on a balance and a mass of  $3 \pm 0.01$ mg flour was carefully measured into the center of the pan. Considering the moisture content of each sample, appropriate volume of distilled water was added to the pan by micropipette to achieve a water/flour ratio of 2:1. This ratio accounts for more than 60% moisture, corresponding to the moisture content required for rice gelatinization and to obtain a single endotherm during DSC experiment (Billiaderis et al., 1986). The pans were hermetically sealed with TA sample crimping device. The sealed samples were stored at room temperature for one hour to stabilize before thermal scanning. The pans were placed in the sample cells of the DSC while an empty pan was sealed and placed in the reference cell of the DSC.

The refrigerated cooling system was turned on and the flour samples were heated from 20°C to 100°C at a heating rate of 10°C/min. The onset ( $T_o$ ), peak ( $T_p$ ) and conclusion ( $T_c$ ) temperatures of gelatinization and the residual gelatinization enthalpy ( $\Delta H$ ) were determined with the Universal Analysis Version 1.2 software supplied by the DSC Company. The residual gelatinization enthalpy was measured in J/g of dry solid weight as the area under Heat flow against temperature. A mathematical expression describing the enthalpy of gelatinization is presented in Equation 2.

$$\Delta H = C_p \Delta T \quad (2)$$

Where  $\Delta H$  is the enthalpy of gelatinization (J/g),  $C_p$  is the specific heat capacity of the sample (rice slurry) (J/g/°C),  $\Delta T$  is the change in temperature (°C) during thermal event.

#### 4.2.7 Statistical analysis

The data of the effect of the independent variables (steaming time and variety) on the dependent variables (percentage of translucency, hardness, lightness, gelatinization temperature and gelatinization enthalpy) were statistically analyzed using SAS software (version 9.2), and where there was significant effect, means were separated using the Duncan's multiple range test ( $P < 0.05$ ).

### 4.3 RESULTS AND DISCUSSION

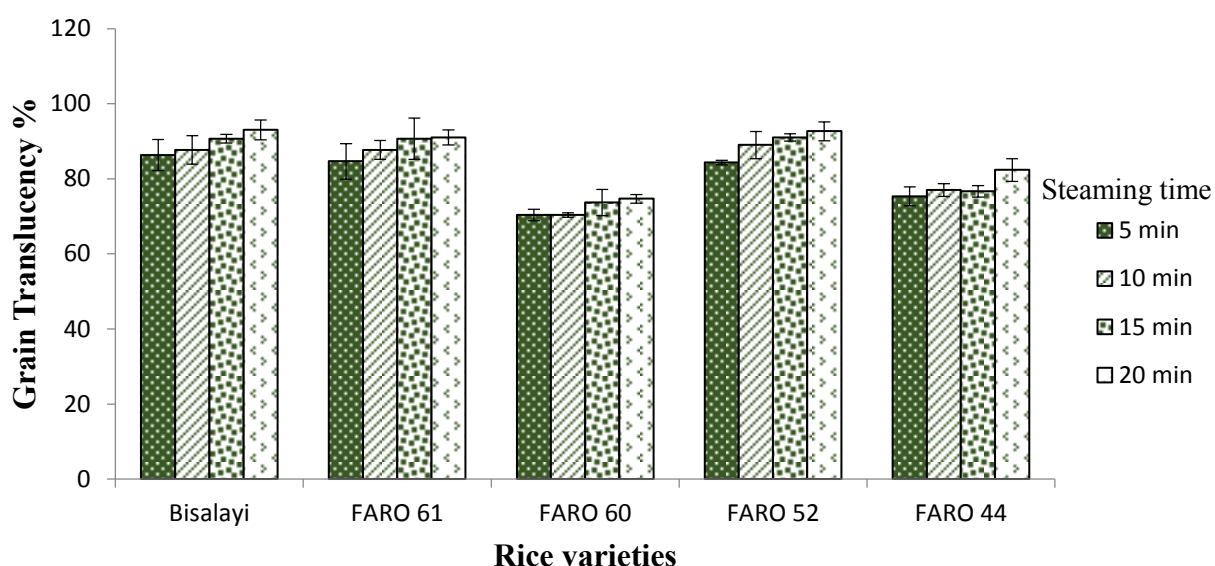
#### 4.3.1 Translucency

The presence of white portions or chalkiness in grain is an important quality indicator in rice. Chalkiness causes softness in grains and has other unwanted effects. Chalkiness can be determined by visualizing a grain with the naked eyes or by the use of transmitted light (Bhattacharya, 2011). One major importance of parboiling is its effectiveness in eliminating white core in rice grains, thereby improving the translucency. Change in translucency during parboiling of selected paddy rice (FARO 61 variety) is shown in Figure 4.1. Adequate soaking enables water to reach the center of rice grains and facilitates the elimination of white portions when enough heat from steam is applied to paddy.



**Figure 4.1: Translucence of parboiled FARO 61 variety, steamed at different times. The labels represent the following: R: Untreated sample; A: 5 min; B: 10 min; C: 15 min; D: 20 min**

Translucency varied from Bisalayi: 23.67 – 93.00; FARO 61: 27.67 – 91.00; FARO 60: 19.67 – 74.67; FARO 52: 28.00 – 92.67; and FARO 44: 22.33 – 82.33, respectively, for a steaming time between 0 – 20 min. Steaming show significant influence ( $p < 0.05$ ) on percentage of translucency for all the varieties studied between untreated sample and 5 min of treatment. Percentage change in translucency of parboiled rice is shown in Figure 4.2.



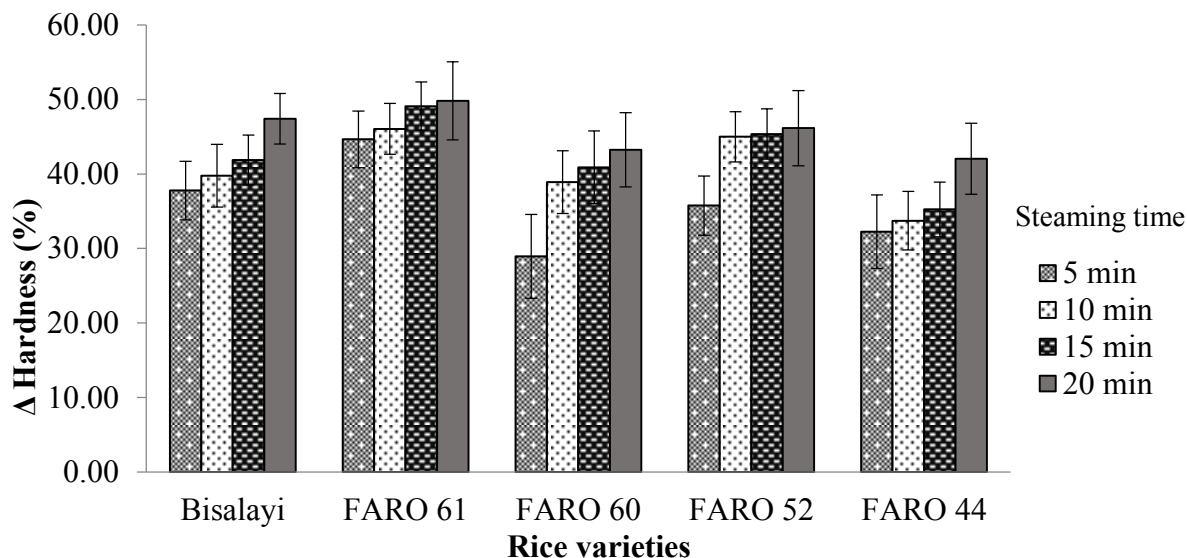
**Figure 4.2: Percentage change in translucency of parboiled rice**

There was no observable difference in percentage translucency during steaming from 5 – 20 min for paddy, except for FARO 44. Furthermore, FARO 60 and FARO 44 show lower translucency compared to other varieties of rice. Chalkiness or white portion in rice is as a result of poorly developed which gives an opaque appearance in rice (Bhattacharya, 2011). Steaming resulted in gelatinization of rice starch, thereby converting the opaque crystalline starch in rice into a clear amorphous structure. A possible explanation of the low values of percentage translucency obtained for FARO 60 and FARO 44 could be related to high degree of poorly

formed starch components (amylose and amylopectin) in FARO 60 and FARO 44 than the rest of rice varieties studied.

#### **4.3.2 Hardness**

Steaming process greatly improves milling quality of paddy rice by imparting hardness to the grains so making them resistant to breakage during milling. This reduces breakage losses and increases yield during milling and is of economic advantage to rice producers and millers. Biswas and Juliano (1988) and Islam et al. (2000) reported that hardness of rice increases during steaming, especially, due to heat treatment. In this study, hardness of rice was found to increase with steaming duration and ranged from 59.45 – 113.65, 79.39 – 158.17, 77.24 – 136.70, 73.59 – 136.65, and 73.14 – 126.20 for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, respectively. Steaming show substantial influence ( $p < 0.05$ ) on hardness for all the varieties studied. FARO 61 was found to have the highest hardness with initial value of 79.36 N which increased to 143.39, 147.05, 155.93 and 158.17 N with increase in steaming time from 5, 10, 15 and 20 min, respectively. Conversely, the local variety (Bisalayi) was found to have the lowest hardness value compared to the improved varieties. Differences in values of initial hardness of the selected varieties of paddy could be due to different levels of cracks or fissures imparted on paddy during harvesting and threshing. Thus during steaming, the starchy endosperm melts and re-unites to seal all cracks, thereby, imparting hardness to rice. As shown in Figure 4.3, hardness percentage increases in during steaming of paddy. Initial increase in hardness during 10 min of steaming was more pronounced in FARO 61 and FARO 52 than in the other varieties. This could be explained to be as a result of rapid fusion between the gelatinized starch and protein bodies in FARO 61 and FARO 52.



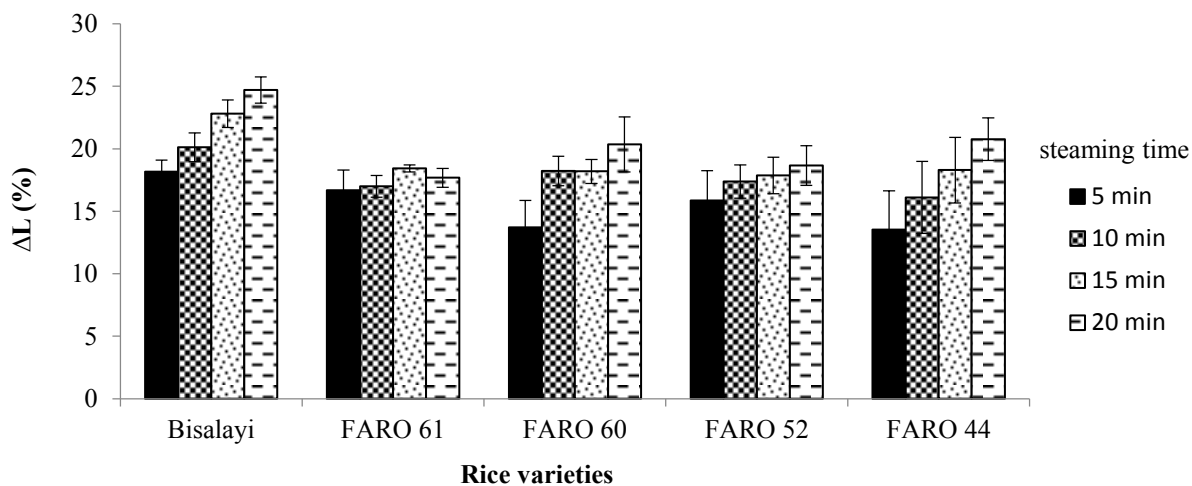
**Figure 4.3: Percentage change in hardness of rice due to parboiling**

The optimal grain hardness was achieved at 20 min of steaming for Bisalayi and FARO 44 while for FARO 61, FARO 60 and FARO 52 it was attained at 15 min. The varietal difference in hardness of rice grains could be due to the difference in the structural arrangement of starch granules among rice varieties in addition to varying extent of bonding between gelatinized starch and ruptured protein bodies. The extent of adhesion between gelatinized starch granules and ruptured protein bodies during steaming among different varieties can affect the hardness of rice due to steaming (Bhattacharya, 2011). Kernel hardness is a very important attribute especially during milling and storage of rice. This is important in the context of African environment.

#### **4.3.3 Lightness value**

Discolouration of rice as a result of parboiling is another important quality indicator that affects market value and consumer acceptability of the product. The lightness value of selected varieties of rice significantly decreased ( $P < 0.05$ ) with steaming time. The effect of lightness at different steaming times is shown in Figure 4.4. The lightness value decreased as the steaming time

increases with values of 78.34 – 58.98 N, 71.27 – 58.67 N, 73.85 – 59.06 N, 70.21 – 57.00 N and 69.75 – 58.67 N for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44 respectively, corresponding to 0 – 20 min of steaming. Steaming time significantly ( $P < 0.05$ ) affected lightness value of Bisalayi (local variety) more than the FARO varieties. This clearly shows that prolonged steaming period during parboiling of rough rice adversely affects lightness and colour quality of rice. Bhattacharya & Rao (1966) as well as Islam et al. (2002) reported that severe parboiling, such as extended steaming time greatly affect the colour of parboiled rice. The varietal difference in colour change observed in this work could be due to a more rapid nonenzymatic browning of the Maillard reaction in the Bisalayi than in the FARO varieties. Mir and John Don Bosco (2013) reported that difference in genetic makeup could also result in varietal difference in colour of parboiled rice.



**Figure 4.4: Percentage change in lightness value of rice due to steaming**

#### 4.3.4 Degree of gelatinization

One of the major advantages of parboiling is to improve the hardness of rice and thus reduce kernel breakage during milling operation. Steaming operation, which produces parboiled rice, requires a lot of energy to produce steam for the process. Comparison of gelatinization properties of rice varieties of selected unparboiled rice varieties from Nigeria and those reported by some authors are shown in Table 4.1. For Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, gelatinization temperature ranged from 72.78 – 83.78°C, 73.90 – 82.55°C, 73.16 – 80.98°C, 64.24 – 77.70 °C, and 64.37 – 75.26°C, respectively while gelatinization enthalpies for the respective varieties are 5.76, 3.62, 3.15, 1.55 and 2.35 J/g. Rice varieties from West Africa have been found to exhibit low gelatinization enthalpies (Traore et al., 2011; Odenigbo et al., 2013). Raw samples of Bisalayi, FARO 61 and FARO 60 have peak gelatinization temperature in the range reported in the literature by Normand and Marshall, 1989; Miah et al., 2002. However, FARO 52 and FARO 44 have lower values compared to other varieties used in this work. The enthalpy range of the selected varieties of rice used in this study was also found to be lower than those reported by previous authors (Normand and Marshall, 1989; Miah et al., 2002; Islam et al., 2002b).

**Table 4.1: Comparison of Gelatinization properties of non-parboiled paddy rice varieties.**

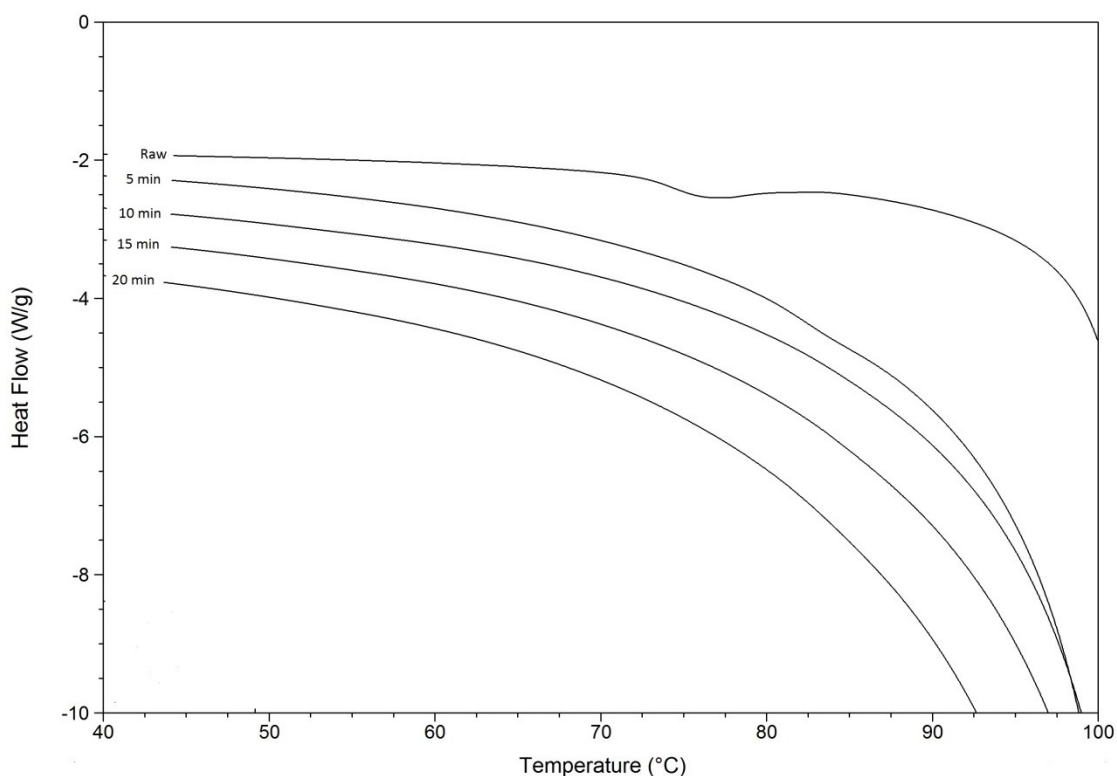
Parameter	Variety							
	Other authors			This study				
	<b>Lemont (Normand and Marshall 1989)</b>	<b>Long grain rice BR4 (Miah et al.2002)</b>	<b>Bella Panta (Islam et al. 2002b)</b>	<b>Bisalayi</b>	<b>FARO 61</b>	<b>FARO 60</b>	<b>FARO 52</b>	<b>FARO 44</b>
T <sub>o</sub> , °C	70.30±0.10	-	-	72.78±0.38 <sup>a</sup>	73.90±0.18 <sup>a</sup>	73.16±0.08 <sup>a</sup>	64.24±0.16 <sup>b</sup>	64.37±0.82 <sup>b</sup>
T <sub>p</sub> , °C	75.90±0.00	73.40±0.50	-	76.61±0.16 <sup>a</sup>	77.03±0.08 <sup>a</sup>	76.07±0.06 <sup>a</sup>	68.79±0.28 <sup>b</sup>	69.31±1.43 <sup>b</sup>
T <sub>c</sub> , °C	83.80±0.10	85.00±0.80	-	83.78±1.03 <sup>a</sup>	82.55±0.85 <sup>a</sup>	80.98±0.08 <sup>a</sup>	77.70±1.10 <sup>b</sup>	75.26±0.47 <sup>b</sup>
ΔH, J/g	10.30±0.10	8.16±2.17	7.50±0.00	5.76±1.49 <sup>a</sup>	3.62±0.65 <sup>ab</sup>	3.15±0.37 <sup>b</sup>	1.55±0.74 <sup>b</sup>	2.35±0.08 <sup>b</sup>

Means with the same superscript along the lines are not significantly different at P < 0.05

T<sub>o</sub>, T<sub>p</sub>, and T<sub>c</sub> are onset, peak and conclusion gelatinization temperatures, respectively

ΔH is the gelatinization enthalpy

During steaming of different varieties of paddies at 100°C for 5 – 20 min, it was observed that there was no residual enthalpy of gelatinization of the parboiled samples at the different steaming times. This could be due to low gelatinization enthalpies (1.55 – 5.76 J/g) of the raw parboiled rices used in this study. Marshall et al. (1993) and Islam et al. (2002b) studied the gelatinization properties of rice with respect to different parboiling conditions. They observed a decrease in gelatinization enthalpy with severity of parboiling and related it to the degree of starch gelatinization during heat processing. Marshall et al. (1993) proposed that during parboiling, rice starch only requires 40% gelatinization for maximum head rice yield to be obtained. Figure 4.5 shows a typical thermogram at different parboiling periods of selected rice varieties from Nigeria.



**Figure 4.5: Thermogram of raw and parboiled Bisalayi rice flour (soaked at 60°C, steamed at 100°C for 5, 10, 15 and 20 min)**

Miah et al. (2002) reported that the residual enthalpy of starch after hot soaking of paddy dropped from 6.03 to 0.86 J/g after 120 mins, amounting to 86% gelatinized starch in rice. Normand and Marshall, (1993) showed that the enthalpy of Lemont rice variety decreased from 14.6 – 2.2 J/g during conventional parboiling of rough rice in a pressure cooker for 8 min at 121°C. The result obtained by the authors show that approximately 85.6% of the starch was gelatinized during steaming.

Thus the degree of gelatinization during parboiling of selected varieties of rice from Nigeria could not be estimated in this work. Steaming, therefore, completely gelatinized the rice starch during processing.

#### **4.4 CONCLUSION**

The physical (translucency, hardness, lightness value) and thermal (gelatinization) properties during steaming of selected rice varieties from Nigeria were investigated. The findings from this study show that steaming time significantly affects physical and thermal properties of parboiled rice. Percentage translucency ranged from 23.67 – 93.00, 27.67 – 91.00, 19.67 – 74.67, 28.00 – 92.67 and 22.33 – 82.33 for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, respectively, 0 – 20 mins steaming, with FARO 60 and FARO 44 having lower percentage of translucency than other varieties of rice at the end of 20 min of steaming. Steaming resulted in gelatinization of rice starch, thereby transforming the opaque crystalline starch in rice into an a clear amorphous structure. The low values of percentage translucency obtained for FARO 60 and FARO 44 could be due to high degree of poorly formed starch components (amylose and amylopectin) in FARO 60 and FARO 44 than the rest of rice varieties

The improved rice varieties used in this study show better hardness than the local variety which might be due to the difference in the structural arrangement of starch granules among rice

varieties in addition to varying extent of bonding between gelatinized starch and ruptured protein bodies. Hardness of rice was found to increase with steaming duration and ranged from 59.45 – 113.65 N, 79.39 – 158.17 N, 77.24 – 136.70 N, 73.59 – 136.65 N, and 73.14 – 126.20 N for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, respectively. The optimal grain hardness was achieved at 20 min of steaming for Bisalayi and FARO 44 while for FARO 61, FARO 60 and FARO 52 it was attained at 15 min.

Bisalayi (local variety) was found to be more discoloured more than the FARO (improved) varieties. Lightness value decreased with increase in steaming period with values of 78.34 – 58.98 , 71.27 – 58.67 , 73.85 – 59.06 , 70.21 – 57.00 and 69.75 – 58.67 for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44 respectively, corresponding to 0 – 20 min of steaming. The varietal difference in colour change observed could be related to a more rapid nonenzymatic browning of the Maillard reaction in the Bisalayi than in the FARO varieties in addition to genetic make-up among cultivars.

Steaming completely gelatinized rice starch in samples, thus, there was no residual enthalpy of gelatinization after steaming of paddy.

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## CHAPTER FIVE:

### SUMMARY AND CONCLUSION

Rice is one of the most important cereals in the world. Most people in Africa, especially sub-Saharan countries like Nigeria consider rice a major staple food. New rice varieties are being developed in West-African countries including Nigeria. After harvesting and threshing, paddy rice (raw rice) is processed by parboiling (soaking, steaming and drying of paddy rice) to impart desirable physical and chemical attributes to the product leading to economic advantage to rice processors and marketers as well as nutritional benefit to consumers. None uniformity in rice processing method and the dearth of information about these new varieties has led to inconsistency in quality. There was therefore the need to study the effect of differences in parboiling conditions and variety on quality attributes of improved and local varieties in Nigeria.

Hydration characteristics of selected popular varieties of rice namely Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44 were investigated at various soaking water temperatures of 30, 45, 60 and 75°C. The study showed that the time to reach saturation moisture at 60°C soaking water temperature for FARO 44, FARO 52 and Bisalayi was 7 h, while it took 6 and 8 h for FARO 60 and FARO 61, respectively, attained saturation. Soaking at 75°C resulted in deviation from water absorption characteristics for paddy rice and was more sever for FARO 44, FARO 52 and FARO 60.

Furthermore, the study showed that an appropriate prediction of water absorption during soaking of FARO 61, FARO 60, FARO 52, FARO 44 and Bisalayi was possible by fitting experimental data to Fick's diffusion equation with a high  $R^2$  value of 0.981 – 0.990. The diffusivity of Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44 were  $7.23 \times 10^{-12}$  –  $7.54 \times$

$10^{-11} \text{ m}^2/\text{s}$ ;  $1.15 \times 10^{-12} - 7.37 \times 10^{-11} \text{ m}^2/\text{s}$ ;  $7.83 \times 10^{-12} - 7.22 \times 10^{-11} \text{ m}^2/\text{s}$ ;  $7.83 \times 10^{-12} - 5.53 \times 10^{-11} \text{ m}^2/\text{s}$  and  $5.80 \times 10^{-12} - 5.83 \times 10^{-11} \text{ m}^2/\text{s}$ , respectively with temperature range  $30 - 75^\circ\text{C}$ .

An Arrhenius type equation described the strong dependence of diffusivity on temperature with activation values of 44.47, 40.78, 42.13, 36.42 and 44.50 kJ/mol for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, respectively.

During parboiling, steaming was found to have significant effect on the physical properties of translucency, hardness, lightness value as well as thermal (gelatinization) properties of rice. Percentage translucency ranged from 23.67 – 93.00, 27.67 – 91.00, 19.67 – 74.67, 28.00 – 92.67 and 22.33 – 82.33 for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, respectively, 0 – 20 mins steaming, with FARO 60 and FARO 44 having lower percentage of translucency than other varieties of rice at the end of 20 min of steaming.

Hardness of rice increased with steaming period and ranged from 59.45 – 113.65, 79.39 – 158.17, 77.24 – 136.70, 73.59 – 136.65, and 73.14 – 126.20 for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, respectively. The optimal grain hardness was achieved at 20 min of steaming for Bisalayi and FARO 44 while for FARO 61, FARO 60 and FARO 52 it was attained at 15 min. Lightness value decreased with increase in steaming period with values of 78.34 – 58.98 N, 71.27 – 58.67 N, 73.85 – 59.06 N, 70.21 – 57.00 N and 69.75 – 58.67 N for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44 respectively, corresponding to 0 – 20 min of steaming. Bisalayi (local variety) was found to be more discoloured more than the FARO (improved) varieties.

There was no residual enthalpy of gelatinization of parboiled rice varieties during steaming. Thus, this indicated that steaming completely gelatinized the rice starch in the samples.