COMPARATIVE STUDY OF PARBOILING EFFECTS ON THE PHYSICO-CHEMICAL PROPERTIES OF TWO VARIETIES OF NERICA RICE (*Oryza sativa*)

by

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DECLARATION

I hereby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

The parboiling effect on physicochemical properties of two local varieties of rice (Nerica 1 and Nerica 2) grown in Ghana was studied by physical and physicochemical analyses during steaming at three different temperature periods of 100^{o}C at 10mins, 110^{o}C at 15mins and 120^{o}C at 25mins. The results showed that the effect of parboiling process on the quality indicators through the kinetic parameters followed the first order kinetic model of initial steps of steaming and final reaction rate constant values were dependent on steaming temperature and period. Both Nerica 1 and Nerica 2 showed similar behaviour during steaming process. The Arrhenius-type of equation described the strong temperature effect on the physical and physicochemical properties with k-values ranging from 0.188 to 0.530 for lightness; 0.272 to 0.327 for hardness; 0.133 to 0.336 for maximum viscosity; and 0.211 to 0.856 for breakdown value.

Keywords: *Paddy rice, Physicochemical Properties, Steaming, Parboiling, Reaction Rate Value, And Physical Properties*

DEDICATION

This thesis is dedicated to my parents, siblings and all loved friends for their prayers, support, love and encouragement.

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To God be the glory, great things he has done.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF STUDY

Rice is important to Ghana's economy and agriculture, accounting for nearly 15% of the Gross Domestic Product (GDP). Rice is an important staple in Ghana and per capital consumption has increased steadily. However, most of the increase in consumption is met from imports.

Thailand is a leading rice exporter, especially of parboiled rice. Parboiled rice is actively produced in Thailand for export mainly to South Africa, Nigeria and various countries in Asia, Europe, the Mediterranean and the Middle East. Some of these imported varieties are prone to insect infestation during shipping or at storage when not properly parboiled. Parboiling improves rice quality thus increasing product price. Among the foodstuffs, rice is the staple food which is predominantly parboiled. It supplies about 77.30 % calories, 67.10% proteins and 67.30% fats for everyday diet (BBS, 1996). The parboiling process is a method used in the world rice processing industry. Generally, the majority of the developing countries consume parboiled rice especially in the Indian Sub-continent where it originated a long time ago. It was reported that about one-fifth of the world's rice is parboiled (Bhattacharya, 1985). This seems to be increasing day by day, because the growth rate of the population in these countries is higher and the most consumed food is rice.

Parboiling is a hydrothermic treatment given to rough rice, and consists of soaking, steaming and drying. During the parboiling process, starch gelatinization takes place, a thermochemical reaction between the starch granules and heat energy in the presence of water. This starch gelatinization changes the physicochemical properties of rice (Bhattacharya & SubbaRao, 1966; Bhattacharya and Indudhara Swamy, 1967; Raghavendra Rao and Juliano, 1970; Gariboldi, 1972; Kimura, 1983; Bhattacharya, 1985; Itoh and Kawamura, 1985; Kimura, 1991; Kimura *et al*., 1993; 1995; Islam *et al*., 2001), which affects the other processing operations of storage, milling, cooking and eating quality. Islam *et al*. (2001) evaluated the quality of parboiled rice by its physical properties of maximum viscosity, hardness of brown rice, hardness and adhesion of cooked rice, volume expansion ratio and solid content, utilizing the first-order kinetic model. They identified the rate of change of quality and the quality index of parboiled rice with the reaction rate constant and final values of the quality indicators. The quality of parboiled rice was greatly affected by the severity of the parboiling treatment; severely treated rough rice produces a product of lesser quality. For wider acceptability of parboiled rice, processing equipment and conditions should be developed to produce a better quality product. Parboiling of rough rice at higher temperatures generally produces a dark coloured product (Bhattacharya, 1985; Kimura *et al*., 1993). Therefore, parboiling at lower temperatures (80 to 100°C) is preferable to produce a better quality product for consumer acceptance.

Rice (*Oryza sativa* L.) is considered as a main staple food and is a major source of nutrients in many parts of the world. Consumers prefer to eat unpolished rice because of the nutrient value in the bran. Therefore, demands for brown rice and parboiled rice are increasing because of their high value in nutrition and health importance associated with eating this type of rice. However, brown rice has some disadvantages such as slower absorption of liquid into the kernel because the bran contains fibre, which increases cooking time and furthermore, the oil content in the bran shortens its shelf life, as the bran becomes rancid. Therefore, parboiling is one alternative to reduce these problems.

1.2 SCOPE OF THE STUDY

The parboiling process is a world processing industry in which the population of developing countries eats parboiled rice. About one-fifth of the world's rice is parboiled (Bhattacharya, 1985). So, it can be regarded as one of the most important processing methods in rice industry. These include soaking, either cold or hot water method, steaming with steam at gauge or atmospheric pressure, and drying naturally under sunshine or shade method or artificially by the mechanical dryer with hot air. Parboiling makes rice easier to process by hand, improves its nutritional profile (excepting its vitamin-B content, which is denatured in the process), and changes its texture. Polishing rice by hand, that is, removing the bran layer is easier if the rice has been parboiled. It is, however, somewhat more difficult to process mechanically. The bran of parboiled rice is somewhat oily, and tends to clog machinery. Most parboiled rice is milled in the same way as white rice.

Parboiling rice drives nutrients, especially thiamine, from the bran into the grain, so that parboiled white rice is 80% nutritionally similar to brown rice. Because of this, parboiling was adopted by North American rice growers in the early 20th century. The starches in parboiled rice become gelatinized, making it harder and glassier than other rice. Parboiled rice usually has small amounts of milk added to it to prevent the grain from over hardening. Parboiled rice takes more time to cook, and the cooked rice is firmer and less sticky. In North America, parboiled rice is generally partially or fully precooked by the processor. However, pressure and warmer soaking temperature are commonly employed in modern processes to reduce processing time. More recently, the use of fluidization techniques (Soponronnarit *et al*., 2006) and ohmic heating (Sivashanmugam and Arivazhagan, 2008) to parboil rice have been reported. Parboiled rice accounts for about 15% of the world's milled rice (Bhattacharya, 2004), and its market has been increasing especially in industrialized countries (Efferson, 1985). It is the staple food in southern Asian countries such as India, Sri Lanka, Pakistan, Nepal and Bangladesh (Juliano and Hicks, 1996; Bhattacharya, 2004; Roy *et al*., 2007). It belongs to the most popular rice products in Europe including Belgium, Germany, Italy and Spain (Efferson, 1985; Bhattacharya, 2004; Fuhlbrugge, 2004; Vegas, 2008). There is also a high demand for parboiled rice in Saudi Arabia, Turkey, Jamaica, Yemen, Ghana, and Nigeria (Otegbayo *et al*., 2001; Bhattacharya, 2004; Tomlins *et al*., 2005; Vegas, 2008).

Parboiling is accompanied by some profound changes in rice physical, chemical and functional properties. Starch granules undergo irreversible swelling and fusion as a result of gelatinization (Rao and Juliano, 1970a; Ali and Bhattacharya, 1980; Juliano and Hicks, 1996). Protein bodies are disrupted (Rao and Juliano, 1970) and protein barriers are inferred to form through disulfide cross-linking (Derycke *et al*., 2005). Lipids form complexes with amylose, which, along with protein barriers, may contribute to restricted swelling and solubilization of starch during cooking (Biliaderis *et al*., 1993; Derycke *et al*., 2005).

Parboiling also results in inward diffusion of water-soluble vitamins and other bran components (Juliano and Hicks, 1996). Such changes in chemical components during parboiling, in turn, contribute to harder kernels upon drying, improved milling yields, more translucent but amber coloured head rice, firmer and less sticky cooked rice, higher retention of minerals and water-soluble vitamins, increased health promoting starch fraction (resistant starch), and longer shelf life (Pedersen *et al.*, 1989; Juliano and Hicks, 1996; Kar *et al*., 1999; Otegbayo *et al.*, 2001; Bhattacharya, 2004; Derycke *et al*., 2005; Heinemann *et al.*, 2005; Kim *et al*., 2006).

Parboiled rice is most often used in the industrial and food service markets because of its ease of preparation, durability, and stability to overcooking (Juliano and Hicks, 1996; Vegas, 2008). The traditional feedstock for parboiling is rough rice or paddy. The siliceous hulls in rough rice, however, have a poor thermal conductivity and slow down heat transfer to the endosperm (Kar *et al.*, 1999). This makes rough rice parboiling more time and heat energy consuming. Moreover, very little information is available regarding the reaction kinetics of parboiling treatment.

Bandyonpadhyay and Ghose (1965), and Bandyipadhyay and Ray (1976) studied the hydration kinetics of paddy during soaking and reported that soaking was influenced by two different mechanisms, one below and the other above the gelatinization temperature which reflected in the appreciable difference in the activation energies for these ranges (Bandyipadhyay and Ray, 1976 cited in Islam, 1998). Suzuki *et al*. (1976) studied the kinetics on cooking of rice and reported that with the cooking temperature range of 75-150°Ċ, the cooking rate constant changed around 110°Ċ. The activation energy of cooking at temperatures below and above 110°Ċ was about 19000 and 8800 cal /mol, respectively. Bakshi and Singh (2000) studied the water diffusion and starch gelatinization during rice parboiling and reported that parboiling process is limited by the reaction of starch with below 85 °Ċ and by diffusion of water above 85°Ċ.

They reported the activation energy of 18534 and 85-10470 cal /mol for the temperature range of 50-120°Ċ, respectively. Kimura *et al*. (1993) and Bhattacharya (1996) studied the reaction kinetics of parboiling treatment on colour value and reported that both reaction rate constant and final colour value increase due to increasing the severity of parboiling treatment. In this respect, for better understanding the reaction kinetics of parboiling treatment on the physicochemical properties and cooking quality of parboiled rice, a great deal of fundamental study is still needed for selecting the proper quality indicators for optimizing the parboiling process.

1.3 OBJECTIVES

The main aim of this study was:

To determine the thermal properties, that is, gelatinization parameters of parboiled rice produced locally.

The specific objectives were:

i) To study the effect of parboiling treatment on the physical properties of locally grown rice.

ii) To compare the quality indicators of parboiled rice produced.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 PHYSICAL PROPERTIES OF PARBOILED RICE

Parboiling is a hydrothermal process in which the crystalline form of starch is changed into an amorphous one due to the irreversible swelling and fusion of starch. This is accomplished by soaking, steaming, drying and milling the rice. The parboiling process is to produce physical, chemical and organoleptic modifications in the rice with economic and nutritional advantages.

The indica varieties which are long, slender and flat grains are used more often for parboiling because the operations of steeping and heating are quicker and easier as water and heat rapidly reach the centre of the endosperm. These differences are described by Webb (1975). The milled kernels of long grain varieties called "hard rice" usually cook dry and flaky with a minimum splitting, and the cooked grains tend to remain separate. Also, they are characterized by high amylase content and a medium high gelatinizing temperature. Therefore, long grain rices are used for canned soups and quick cooked products.

On the other hand, the short grain varieties, referred to as ''soft rice'' are more moist and firm when cooked and the grains tend to stick together. Also, they have lower amylase content and lower gelatinizing temperature. Therefore, they are used for making dry cereals and baby foods. It is a premilling treatment given to paddy prior to its milling to achieve maximum recovery of head rice and to minimise breakages. Parboiling treatment was first developed in some Asian countries to reduce the milling loss. In this process paddy is soaked and the wet paddy is heated and then dried.

The paddy grain is mainly composed of polygonal starch granules. The voids or intergranular spaces are filled with air and moisture. Due to these voids, cracks develop and cause breakage during milling. This breakage may be reduced by gelatinising the starch. During the gelatinization process starch swells and fills the voids. During the soaking of paddy, water penetrates into starch granules and results in swelling of grains. In heating, the energy weakens the granule structure and more surfaces become available for water absorption and results in an irreversible granule swelling called gelatinization of starch. Its temperature is called gelatinization temperature and it is specific for each variety.

Theoretically soaking of paddy can be done at or below its gelatinization temperature. The lower the temperature used, the slower the process of soaking and vice versa. Soaking period can be reduced by subjecting the paddy to vacuum for a few minutes before soaking and/or soaking under pressure in hot water. Heat of gelatinization of starch is supplied by saturated steam. Parboiled paddy may be dried in the shade, sun or hot air. Shade drying takes a longer time but gives excellent milling. Rapid drying in sun or with hot air causes higher breakage during milling.

2.2 EFFECTS OF PARBOILING ON MILLING

In raw rice milling, several factors are responsible for breakage of kernel. Cracking of kernel is one of the main factors for breakage. Cracks develop because of delayed harvesting, threshing or rapid drying. Immature and chalky kernels break easily. The type and design of the milling machinery influences milling outturn and quality. Rice breakage is related to milling conditions, particularly the relative humidity, temperature and the extent of milling. During shelling or husking operation, breakage occurs.

Parboiling of paddy results in reduction of breakage. The improvement in milling quality is due to hardness imparted to kernels because of gelatinization of starch. It has been found that due to swelling of starch, the cracks, incomplete filling, and chalkiness are completely healed. Such a phenomenon improves the milling qualities of paddy. The most advantageous aspect of parboiling is the increase in the head yield of rice. During polishing, the polish percentage and breakage increase with time, but parboiled rice takes a longer time than raw rice to attain the same degree of polishing.

2.3 EFFECT OF PARBOILING ON NUTRITIONAL QUALITIES

The bran of parboiled rice contains less starch and more oil than raw rice bran as it comes out in the form of flakes. Therefore, separation of bran without loss of endosperm is possible. The nutrients of rice are in large quantity in outer layers than the endosperm. Parboiled rice contains more protein, vitamins and minerals. Better nutrients availability in parboiled rice is attributed to the hydrothermal treatment. The nutrients from the upper layers penetrate to the endosperm and parboiled rice needs lesser degree of polishing. Parboiled rice contains less oil or fat after soaking and heating or steaming. Certain enzymatic changes are brought about which help in release of oil from the kernel. The oil with this hydrothermal treatment moves toward the upper layers of the kernel and thus is removed along with bran during milling.

2.4 EFFECT OF PARBOILING ON COOKING QUALITIES

Rice is the staple food of nearly two-thirds of the world’s population. Although consumer preferences vary from region to region, the majority of consumers prefer well-milled or white rice containing little or no bran on the endosperm. Cooking qualities of rice are generally represented by time of cooking, swelling capacity, expansion ratio, gruel quality and pastiness.

Parboiled rice takes longer cooking time for required softness and roughly double the time than raw rice to attain the same level of softness in cooking. Water adsorption capacity of parboiled rice is more than raw rice when it is fully cooked. But the expansion ratio both along the length and breadth of parboiled rice was found to be less than that of raw rice. Parboiled rice cooks more flaky than raw rice and loss of solids into gruel is also less.

2.5 EFFECT OF PROCESSING CONDITIONS ON THERMAL PROPERTIES OF PARBOILED RICE

Parboiling is the hydrothermic treatment given to rough rice; it consists of soaking, steaming and drying. During the parboiling process, starch gelatinization takes place, a thermochemical reaction between the starch granules and heat energy in the presence of water. The starch gelatinization brings about changes in the physicochemical properties of rice (Raghavendra Rao and Juliano, 1970; Kimura, 1983; Bhattacharya, 1985; Itoh and Kawamura, 1985; Kimura, 1991; Kimura *et al.*, 1993; 1995; Islam *et al.*, 2001), which affects the other processing operations of storage, milling, cooking and eating qualities. Islam *et al.* (2002) studied the effect of processing conditions on the physical properties, the quality indicators of parboiled rice: moisture content after steaming, hardness, milling yield, lightness and colour value, produced at lower (80^{o}C, 90^{o}C and 100°C) and higher (110^{o}C and 120°C) temperatures.

They reported that parboiled rice produced at lower temperature provided a better quality product than that produced at higher temperatures. Differential scanning calorimetry (DSC) is a widely used technique which provides quantitative information about the gelatinization, retrogradation and phase transitions of various starches (Nakazawa *et al.*, 2003; Biliaderis *et al.*, 1986). The technique is also gaining in importance for characterization of the thermo-physical changes of parboiled rice (Mahanta *et al.*, 1989; Biliaderis *et al.*, 1993; Marshall *et al.*, 1993;

Ong and Blanshard, 1995). As true of the physicochemical properties, the thermal properties of rice are also changed by the parboiling treatment, which affects the final cooked rice quality (Biliaderis *et al*., 1993). Thermal properties, that is, the gelatinization parameters of parboiled rice were evaluated with respect to peak temperature and residual gelatinization enthalpy. Before investigating the cooking behaviour of parboiled rice, information on those gelatinization parameters is needed for different parboiling treatments.

CHAPTER THREE

3.0 MATERIALS AND METHODS

The physical experimental analysis work of this research was carried out at the Food and Postharvest Engineering Laboratory at the Department of Agricultural Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi. However, the autoclave steaming experiment was carried out at the Biochemistry Laboratory, Department of Biochemistry, KNUST.

Nerica 1 and Nerica 2 varieties of rice grown in Ghana were obtained from Tamale, Northern Region for this study. Milling was carried out at the Experimental Laboratory of Ghana Irrigation Development Authority (GIDA), Ashaiman. Colour measurement, pasting and textural analyses were carried out at the Food Research Institute (FRI), Accra, Ghana.

3.1 SAMPLE PREPARATION

The average initial moisture content of rice grain was 13±1% (w.b). Before conducting the experiment, rough rice packed in a 5kg polyethylene bag was kept in a laboratory at room temperature.

3.1.1 Preparation of paddy rice

After removing the stored paddy from the polyethylene bag, samples were brought to room temperature by holding for 1 day. Some of the samples were then poured into a basin of water to float unfilled grains, lighter particles and straw particles which were then removed by hand. The water was then poured off for the samples to be at the bottom of the basin.

3.2 PARBOILING PROCESS

3.2.1 Soaking Condition

Two samples weighting 1000 g each of paddy rice were soaked in nylon filter cloth immersed in hot water at 50^{o}C and 70^{o}C for 2h, 3h, 4h and 5h and then drained respectively for each soaking temperatures. While a control sample weighing 1000g was soaked at 26^{o}C in nylon filter cloth immersed in cold water or room temperature for 2h, 3h, 4h and 5h and then drained.

Figure 3.1. Thermostatic Water Bath

3.2.2 Steaming Condition

The second step of the parboiling process is steaming to increase rice moisture to 30–35% (w.b) (Kimura, *et al*., 1976; Bhattacharya, 1985). Steaming was done using an autoclave at 100^o C, 110^{o}C and 120^{o}C for 10min, 15min and 25min respectively.

Figure 3.2. An Autoclave

3.2.3 Drying condition

The steamed rice was then dried on trays at room temperature (30±1^{o} C, 60±5 %RH) resulting in the final moisture content of 13±1% (w.b.). After drying, samples were stored in airtight polyethylene bags for moisture equilibration and hardness stabilization (Kimura, 1991). Physicochemical analyses were performed after two weeks. The effects of initial soaking temperature, soaking time and steaming condition on various quality parameters were investigated. Two initial soaking temperatures (50^{o}C, 70^{o}C), four soaking times (2h, 3h, 4 h and 5h) and three steaming times (10, 15 and 25 min) were evaluated. Hence, twenty treatment combinations were tested.

3.3 MATHEMATICAL MODEL

Food research system usually follows either a zero or first order kinetics as reported by Arabshahi and Lund (1985). During food processing, estimation of these kinetic parameters led to understanding of the changes that occur (Arabshahi and Lund, 1985; Rao, 1986; Holdsworth, 1990) and can be used for process maximization, scale-up and for better control of the process and quality of the finished product of parboiled rice. For the first order kinetic reaction, the reaction rate constant can be calculated from the equation below:

$$\frac{dM}{dt} = k\,(M_e - M) \qquad \text{– —→ (1)}$$

Where, M = quality indicator at any time t

t = Time (min)

k = kinetic reaction rate constant (min^{-1}),

M_e= Final value of any quality indicator,

or, $$\frac{dM}{(M_e - M)} = kdt$$ (separating M and t)

or, $-Ln(M_e-M) = kt + C$ (Integrating the above equation, where, C = constant of integration) at initial conditions at,

$t= 0, \quad M = M_o$

The valve of C becomes:

$Ln(M_e – M_o)$

Substituting for C, the equation becomes

$-Ln(M_e – M) = kt – Ln(M_e – M_o)$

or, $$Ln\frac{M_e - M}{M_e - M_o} = -kt$$

or, $M_e – M = (M_e – M_o)*exp(–kt)$

or, $M = M_e + (M_o – M_e)*exp(–kt)$ $\longrightarrow$ (2)

by using nonlinear regression technique, K and Me values can be calculated using equation two (2). For understanding the molecular mechanism of chemical reaction, the effect of temperature on the reaction rate is of utmost concern. The Arrhenius Equation was used to interpret the influence of temperature on the rates of chemical reaction. According to this equation, a rate constant (K) is the product of a pre-exponential factor A and an exponential factor:

$$K = Ae^{-E/RT} \longrightarrow (3)$$

Or, $-LnK = E/RT – Ln (A)$

Where, K = kinetic reaction rate constant (min^{-1}),

A = Frequency factor (min^{-1}),

E = Activation Energy (J/mol),

R = Gas constant (8.314J/(mol.K)),

T = Temperature (K).

3.4. ANALYTICAL METHODS

3.4.0 Measurement of physical properties

3.4.1 Moisture content

The moisture content was determined using a duplicate sample of different grams of soaked paddy rice at different soaking temperatures and hourly intervals for four samples. They were dried in an oven at 105^{o}C temperature for twenty hours (24hrs) with both their initial and final masses determined using an electronic balance. The moisture content was calculated from the following formula:

$$\text{MC (\%)} = \frac{W_i - W_f}{W_i} \times 100 \qquad \longrightarrow (4)$$

Where, MC = moisture content (%, wet basis);

W_i= initial weight of sample (g)

W_f = final weight of sample (g)

3.4.2 Milling

18 samples of dried parboiled rice with two unparboiled samples were kept in an air tight polythene bag. The samples were then taken to Ghana Irrigation Development Authority for milling. Satake rice milling machine was used to mill 500g sample each of the samples to about 100 percent husking ratio. Brown rice was then polished and graded to obtain white rice, head rice and broken rice respectively. The milling yield and degree of milling were done using the following formulas:

$$\text{Milling yield (\%)} = \frac{\text{Weight of milled rice (g)}}{\text{500g of parboiled paddy}} \times 100 \qquad \longrightarrow (5)$$

$$\text{Degree of milling} = \frac{\text{Weight of bran removed (g)}}{\text{Weight of brown rice (g)}} \times 100 \qquad \longrightarrow (6)$$

Figure 3.3. Satake Rice Mill Machine

3.4.3 COLOUR MEASUREMENT

A Minolta Chroma Meter Model CR 310 (Minolta Camera Co. Ltd., Osaka, Japan) was used to measure the lightness and saturation of the colour intensity value of the whole kernel mill rice by utilizing the CIE *L**, *a**, *b** uniform colour space procedure. The value of *L** expresses the psychrometric lightness value, and *a** and *b** are factors expressing hue and saturation of the colour intensity. The instrument was calibrated with a standard white plate having *L**, a* and b* values. Each measurement was replicated five times and the average value was used.

The colour intensity value (*B*) of parboiled grain was calculated using the following formula (Kimura *et al*., 1993):

$$B = \sqrt{(a*)^2 + (b*)^2} \qquad \longrightarrow (7)$$

Figure 3.4. Minolta Chroma Meter Calorimeter

Figure 3.5. Calorimeter Sample Pad

3.4.4 DETERMINATION OF PASTING CHARACTERISTICS

A smooth paste was made of the prepared flours of parboiled rice (40g) in 420ml distilled water (8.8% slurry) for viscoelastic analysis using a Brabender Viscoamylograph (Viskograph-E, Brabender Instrument Inc. Duisburg, Germany) equipped with a 1000cmg^{-1} sensitivity cartridge. The smooth paste was heated at a rate of 1.5°Cmin^{-1} to 95°C and maintained for 15min. It was then cooled at 1.5°Cmin^{-1} to 50°C and maintained for 15min. Viscosity profile indices were recorded for pasting temperature, peak temperature, peak viscosity, viscosity at 95°C, viscosity after 15min hold at 95°C (95°C Hold), viscosity at 50°C, viscosity after 15min hold at 50°C (50°C Hold), breakdown and setback as described by Walker *et al*., (1988).

Figure 3.6. Brabender Viscoamylograph

Figure 3.7. Viscoamylograph Cartridge

3.4.5 DETERMINATION OF TEXTURE CHARACTERISTICS

The hardness texture characteristic was determined by cooking a sample for 20-30 min within which the cooked sample was kept in an insulated container. A texture analyzer was then used to determine the grain hardness. A pair of forceps was used to pick five grains of cooked sample and then placed between auxiliary vertical load and sample platform. The setup was then controlled automatically by software which gives end result hardness graph and values.

Figure 3.8. Texture Analyzer

Figure 3.9. Texture Analyzer Keyboard

Figure 3.10. Computer

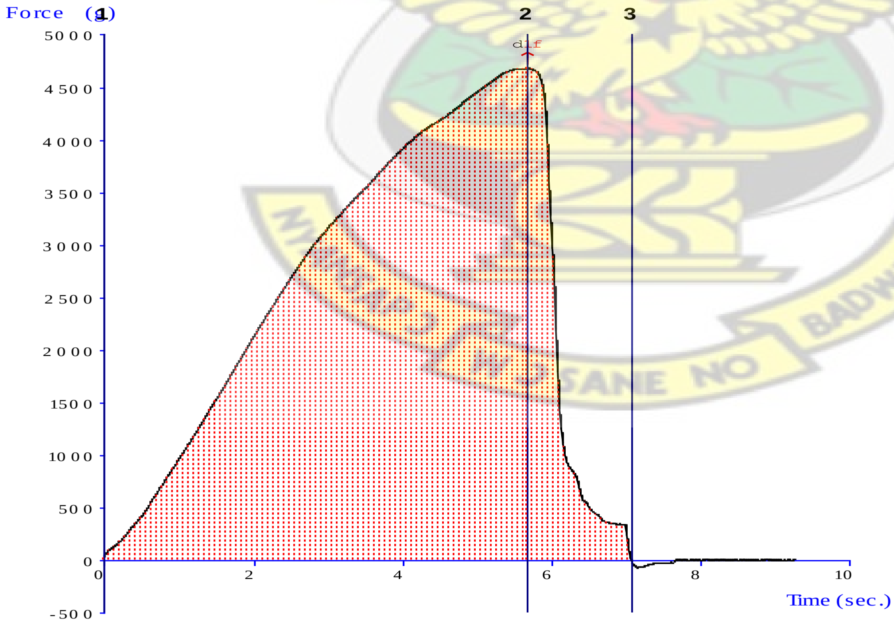

Figure 3.11. A typical rice hardness graph

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Effect of parboiling treatment on physical properties

4.1.1 Lightness

Parboiling treatment discolours grain and decreases the lightness value but the ultimate aim was to produce whiter parboiled rice. Several researchers measured various kinds of lightness value (Jayanarayanan, 1964; Bhattacharya and SubbaRao, 1966; Kawamura *et al*., 1982; Kimura *et al*., 1993). Jayanarayanan (1964) reported that whiteness of parboiled rice was affected by soaking conditions, water temperature and pH value. Others reported that lightness (or whiteness) of parboiled rice was mainly affected by the temperature and period of steaming (Bhattacharya and SubbaRao, 1966; Kimura *et al*., 1993; Bhattacharya, 1996). Table 4.1 and 4.2 show the statistical results of lightness value for Nerica one (N1) and two (N2) respectively. From these tables, it can be observed that steaming temperature and its period had a significant effect ($p<0.01$) on the whiteness of the grain kernel for both varieties as can also be observed from Table 4.33 and Table 4.35 in the appendix showing the mean summary of steaming treatment on physicochemical lightness value of varieties and its LSD.

As the steaming temperature and period increases, the lightness value decreases as shown in Fig 4.1 and Fig 4.2. In Figure 4.1, the lightness value decreases for all the steam samples for 100°C, 110°C and 120°C with highest effect on steam 120°C, 110°C and 100°C respectively at period of 10min. As the steaming period increases to 25min, the most affected were steam at 110°C, 100°C and 120°C respectively. Also for steam period of 15min, steam samples 120°C, 100°C and 110°C respectively were most affected with lightness value. In Figure 4.2, the lightness value decreases for all the steam samples with least value for 120°C, 110°C and 100°C respectively at period

10min while with increase steaming period to 25min, the most affected were steaming at 120°C, 110°C and 100°C respectively. Also at steaming period of 15min, the most affected lightness value was steam sample 120°C, 110°C and 100°C respectively. These figures show a scatter diagram of the effect of steaming on lightness value for Nerica one and Nerica two respectively as temperature and period of steaming increases. These are in agreement with other researchers as mentioned above. The first order kinetic model (Bhattacharya, 1996) was used to analyse the experimental data.

Table 4.3 and 4.4 show the average lightness value and rate of reaction due to steaming for both varieties. As the steaming temperature increases, the final K-value (ie rate of reaction) increases at high steaming temperature and thus decreases in lightness value. Figs 4.3 and 4.4 show the temperature dependence of lightness reaction rate constant for Nerica one and Nerica two. There is significant dependence of K-value on steaming temperature as observed from these figures having significant ($p<0.01$) positive linear correlation between K-value and 1/T. They also have R^2-values of 0.439 and 0.481 for both varieties respectively.

Table 4.1 Statistical results for physical property (ANOVA Table for Lightness L-colour value N1)

SOURCE	**DF**	**SS**	**MS**	**F**	**P**
Steam	3	569.3	189.8	8.88	0.006
Error	8	171.0	21.4		
Total	11	740.3			

Table 4.2 Statistical results for physical property (ANOVA Table for Lightness L-colour value N2)

SOURCE	DF	SS	MS	F	P
Steam	3	624.30	208.10	20.88	0.000
Error	8	79.75	9.97		
Total	11	704.05			

Table 4.3 Average Lightness (L) and rate of reaction value (K) due to steaming temperature for Nerica 1

Treatment		Steaming	
Temperature	100^{o}C	110^{o}C	120^{o}C
Lightness Value N1	62.2825	63.9775	63.0225
K-value, min^{-1}	0.294431	0.205517	0.494314

Table 4.4 Average Lightness (L) and rate of reaction value (K) due to steaming temperature for Nerica 2

Treatment		Steaming	
Temperature	100^{o}C	110^{o}C	120^{o}C
Lightness L-value N2	64.0475	67.3625	64.305
K-value, min^{-1}	0.280277	0.188169	0.530106

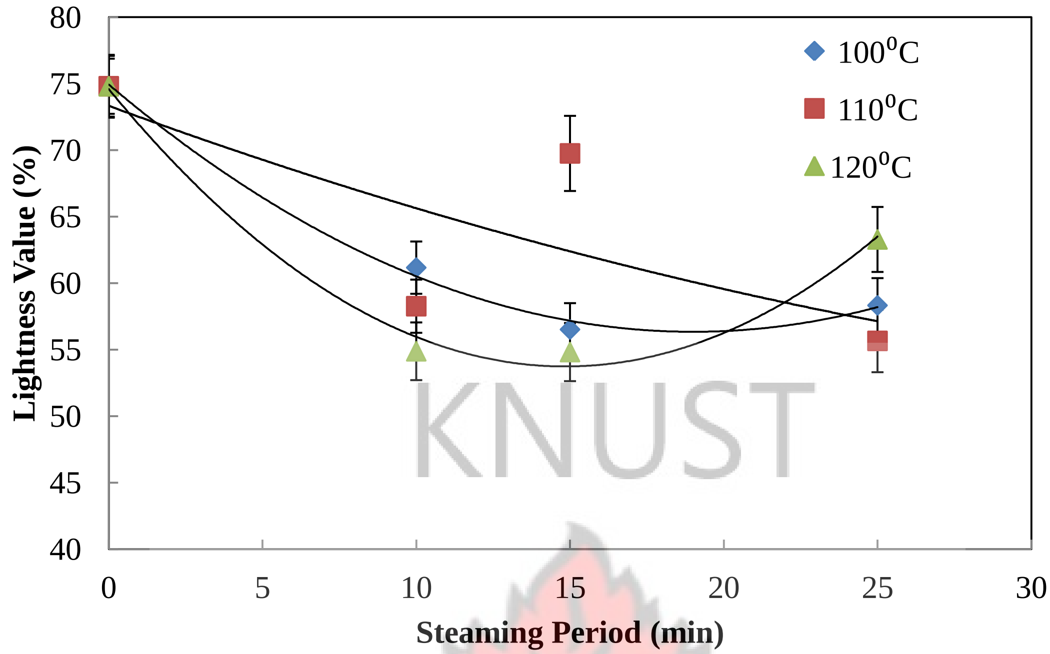

Figure 4.1. Effect of steaming on lightness value for Nerica 1.

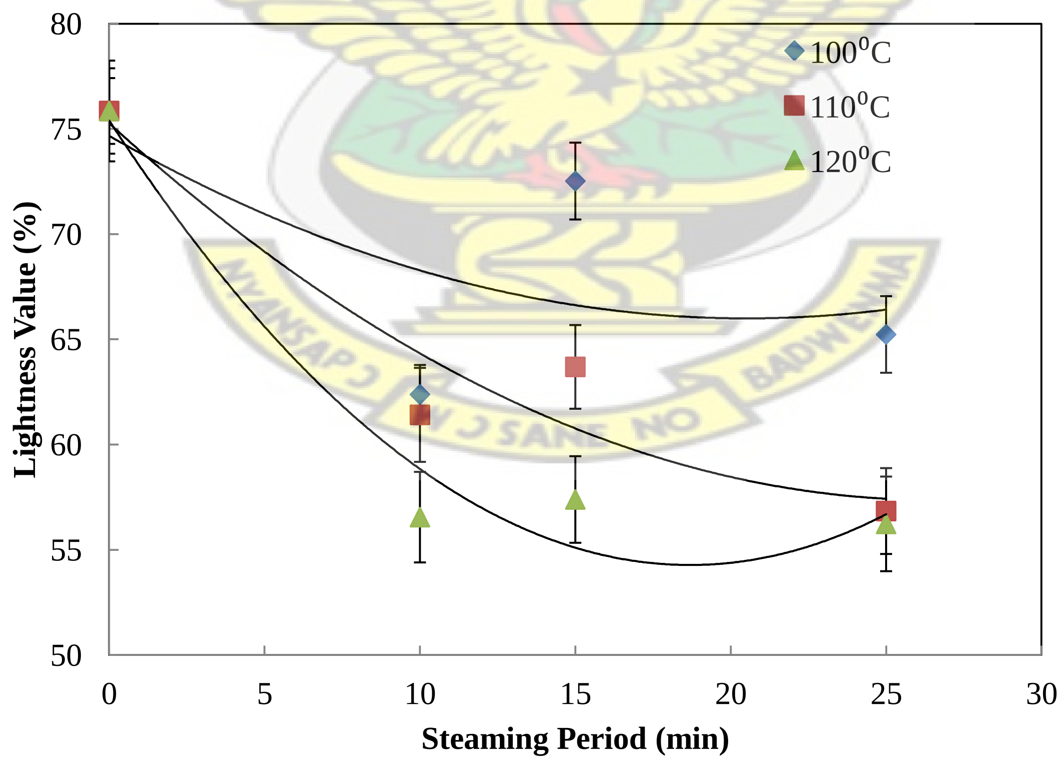

Figure 4.2. Effect of steaming on lightness value for Nerica 2.

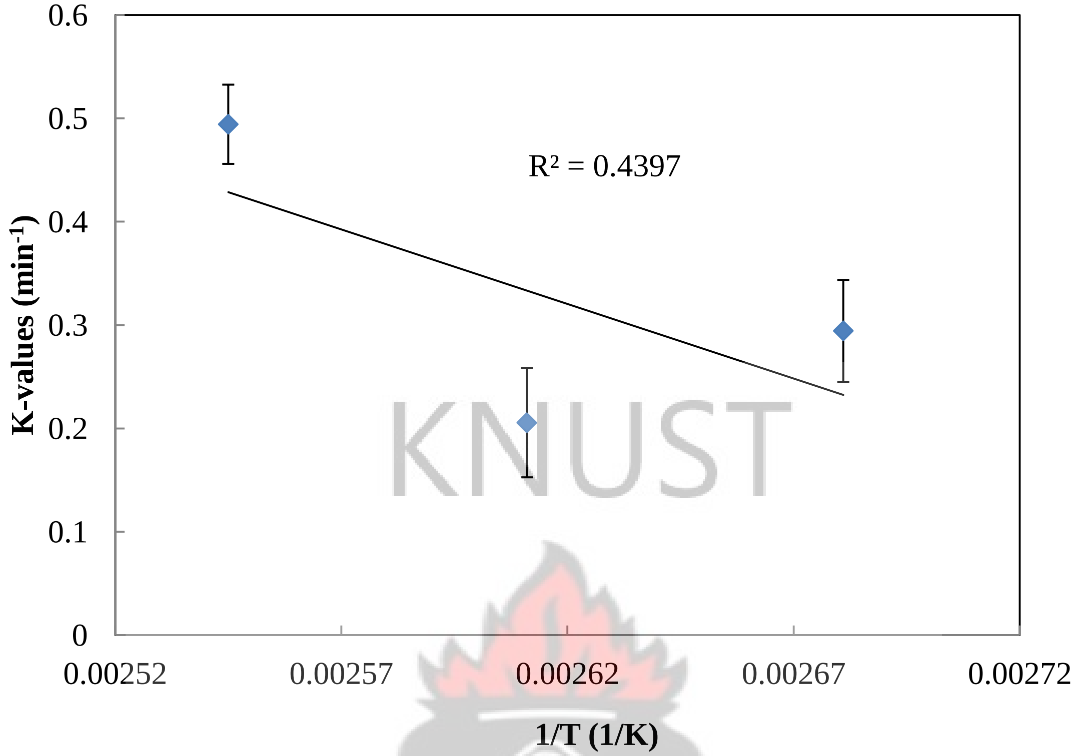

Figure 4.3. Temperature dependence of lightness reaction rate constant for Nerica 1.

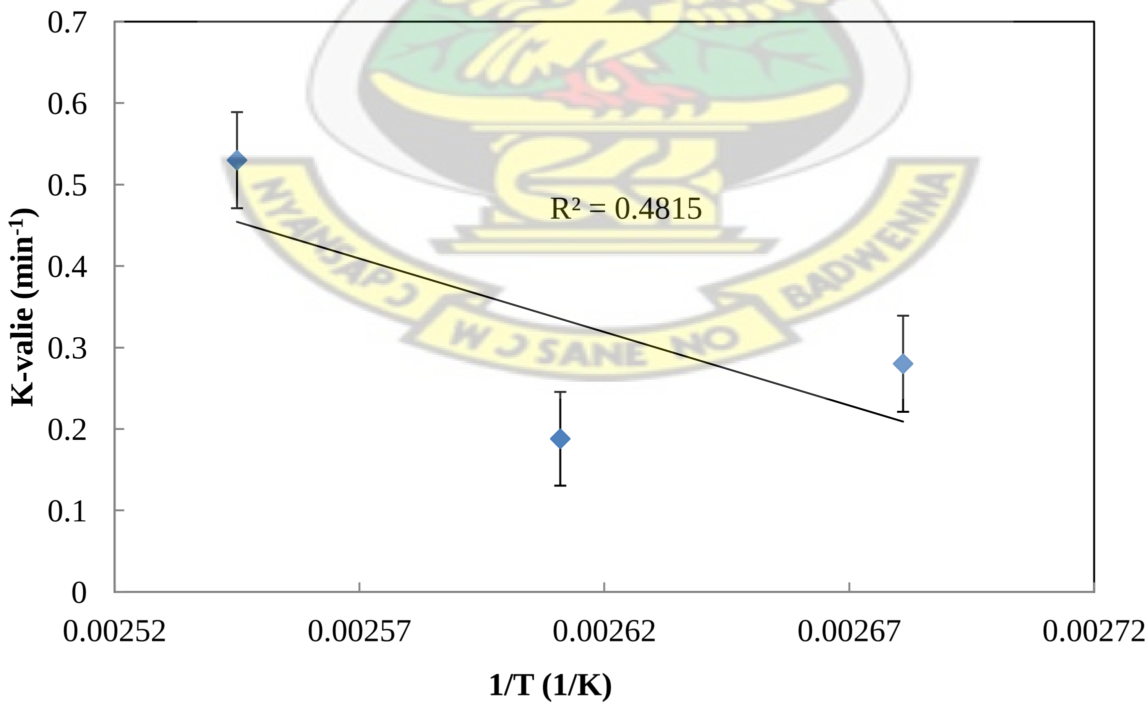

Figure 4.4. Temperature dependence of lightness reaction rate constant for Nerica 2.

4.1.2 Colour Intensity

High temperature and long steaming time generally produce a dark colour and harder product (Bhattacharya, 1985; Kimura *et al*., 1993). These products fetch lower price in the market. In addition, parboiled rice has a peculiar smell and taste. Discoloration of rice due to parboiling treatment is another important quality indicator. It is a negative effect of the parboiling process, because dark coloured parboiled rice loses market value and lowers consumer acceptability in most countries (Bhattacharya, 1985). Many researchers measured the colour intensity value following parboiling treatment (Jayanarayanan, 1964; Bhattacharya and SubbaRao, 1966; Pillai-yar and Mohandoss, 1981; Kimura *et al*., 1993; Bhattacharya, 1996), and reported that discoloration was mainly caused by the Maillard type of non-enzymatic browning reaction, and that the processing conditions determine the intensity of colour during parboiling.

Tables 4.5 and 4.6 show the statistical results for B-colour intensity for both Nerica (1) and Nerica (2) varieties. From Tables 4.5 and 4.6, it can be observed that the steaming treatment had significant effect ($p<0.01$) on colour intensity. As the temperature increases, their mean and standard deviation value increase as compared to their control value (i.e. steam 0^oC) for both varieties. Nerica (2) was darker in colour than Nerica (1) after milling. Parboiled rice takes longer time to polish compared to raw rice during polishing. In the appendix, Tables 4.34 and 4.36 show the mean summary of steaming treatment on physicochemical properties on paddy rice and their LSD. From Table 4.34 it is observed that at the highest steam temperature (120^oC), the highest mean colour value was obtained (i.e. very dark colour of grain) as compared to the other temperatures. This might be the reason why parboiled rice loses market value and lowers consumer acceptability as compared to raw rice. Steaming temperature and period must be controlled during parboiling treatment. Figs 4.5 and 4.6 show the effect of steaming treatment on the colour intensity value for Nerica (1) and Nerica (2) respectively. From Fig 4.5 with steam period 10min, the darker rice was at steam 100^{o}C, 120^{o}C and 110^{o}C respectively and 25min period shows most affected colour at steam 120^{o}C, 110^{o}C and 100^{o}C respectively. While 15min indicate highly affected colour pattern on steam sample 110^{o}C, 120^{o}C respectively with no effect on steam sample 100^{o}C.

From Fig 4.6 with steam period of 10min, steam sample 100^{o}C shows significant effect of colour intensity as compared to steam sample 120^{o}C and 110^{o}C. At steam period 25min, the most affected colour intensity was steam sample 120^{o}C, 100^{o}C and 110^{o}C respectively. The colour intensity increased with increase in steaming temperature and period, and the increased pattern was severe at higher temperatures. To understand the reaction kinetics of colour intensity, experimental data were fitted to a first-order kinetic model to calculate the kinetic parameter which shows the kinetic parameters of colour intensity value for different temperatures. The final colour intensity value increased with increase in steaming temperature, while k-value also showed changes in pattern as shown in Tables 4.11 and 4.12 titled Average colour intensity and reaction rate constant value due to steaming for Nerica (1) and Nerica (2) respectively.

Figs 4.7 and 4.8 show the temperature dependence of colour intensity reaction rate constant. They also have a significant dependence of K-value on steaming temperature as observed from these figures having significant ($p<0.01$) positive linear correlation between K-value and 1/T. They have R^2-values of 0.307 and 0.794 for Nerica (1) and Nerica (2) varieties respectively. It was established that the change of yellowish component was faster than the reddish component (Kimura, 1989) of parboiled rice due to parboiling. Tables 4.7, 4.8, 4.9 and 4.10 show the Anova results for physical property for a*(hue or red) and b*(saturation or yellow) values on the effects of steaming of Nerica (1) and Nerica (2) respectively. From these tables, there exist significant effect ($p<0.01$) of steaming on both a* and b* values for both varieties which affected their colour intensity during parboiling.

These results indicated that the effect of parboiling treatment was greater on the lightness value; therefore, this value can be seen to be a more important quality indicator than colour intensity value. The change in final colour intensity value was found to be greater for higher temperatures of 110^{o}C and 120°C and longer durations. To produce a less coloured product, steaming temperature and period should be controlled, as higher temperature affects colour quality of parboiled rice. It was also reported that colour intensity due to parboiling treatment was controllable at lower temperature (Bhattacharya, 1985; Kimura, *et al*., 1993). Considering the visual observations and the change of the parboiled rice with temperatures in this study, parboiled rice at high temperatures and longer periods should be avoided.

Table 4.5 Statistical results for physical property (ANOVA Table for colour intensity value for Nerica 1)

SOURCE	DF	SS	MS	F	P
Steam	3	0.611	0.204	1.59	0.267
Error	8	1.026	0.128		
Total	11	1.637			

Table 4.6 Statistical results for physical property (ANOVA Table for colour intensity for Nerica 2)

SOURCE	DF	SS	MS	F	P
Steam	3	182.3726	60.7909	824.05	0.000
Error	8	0.5902	0.0738		
Total	11	182.9627			

Table 4.7 Statistical results for physical property (ANOVA Table for hue value thus a-value N1)

SOURCE	DF	SS	MS	F	P
Steam	3	2.235	0.745	5.86	0.020
Error	8	1.016	0.127		
Total	11	3.251			

Table 4.8 Statistical results for physical property (ANOVA Table for hue value thus a-value N2)

SOURCE	DF	SS	MS	F	P
Steam	3	209.2311	69.7437	844.44	0.000
Error	8	0.6607	0.0826		
Total	11	209.8913			

Table 4.9 Statistical results for physical property (ANOVA Table for b-value N1)

SOURCE	DF	SS	MS	F	P
Steam	3	3.73	1.24	0.54	0.670
Error	8	18.51	2.31		
Total	11	22.24			

Table 4.10 Statistical results for physical property (ANOVA Table for colour b-value N2)

SOURCE	DF	SS	MS	F	P
Steam	3	16.8069	5.6023	109.69	0.000
Error	8	0.4086	0.0511		
Total	11	17.2155			

Table 4.11 Average Colour intensity and reaction rate constant value due to steaming for Nerica 1

Treatment	Steaming		
Temperature	100^oC	110^oC	120^oC
Colour intensity(B-value)	6.971828	6.734731	7.067151
K-value, min^{-1}	0.290443	0.367204	0.188671

Table 4.12 Average Colour intensity and reaction rate constant value due to steaming for Nerica 2

Treatment	Steaming		
Temperature	100^oC	110^oC	120^oC
Colour intensity(B-value)	9.488492	9.620844	9.568959
K-value, min^{-1}	0.358254	0.335653	0.334684

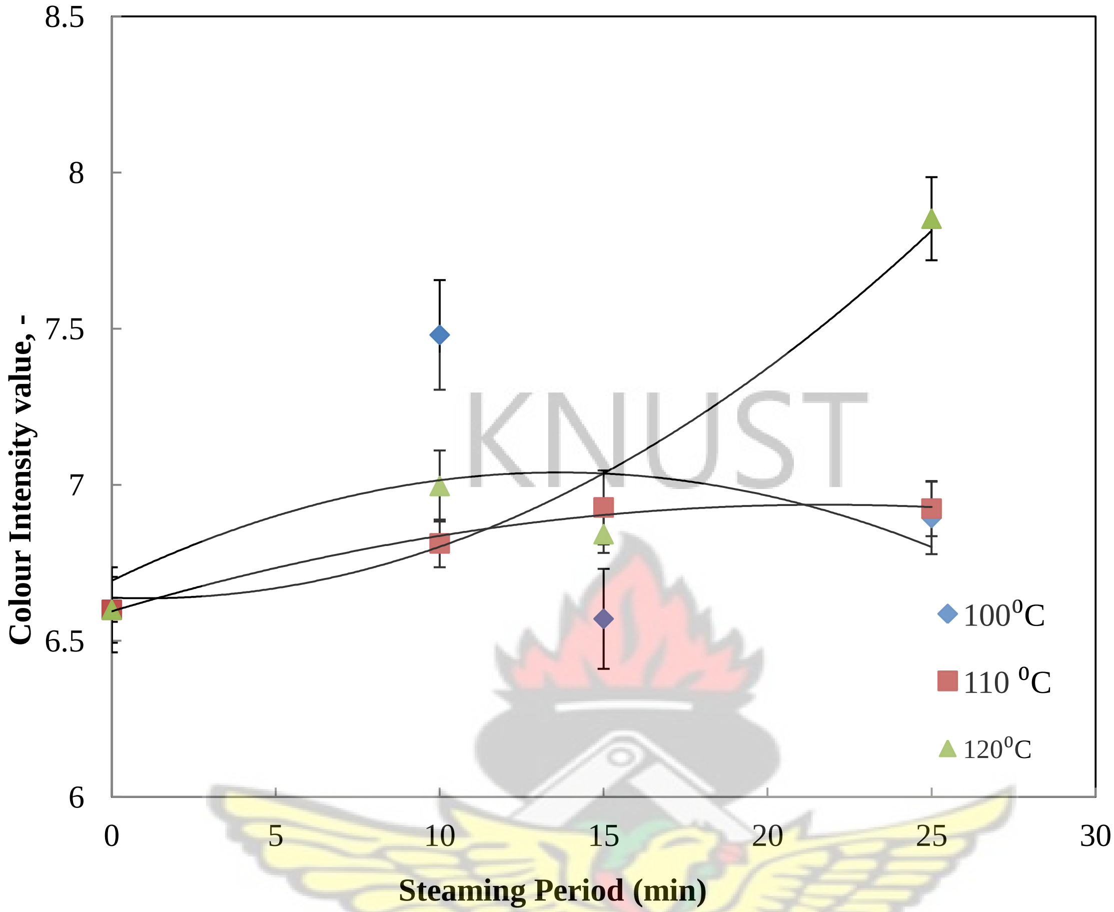

Figure 4.5. Effect of steaming period on colour intensity value of Nerica 1

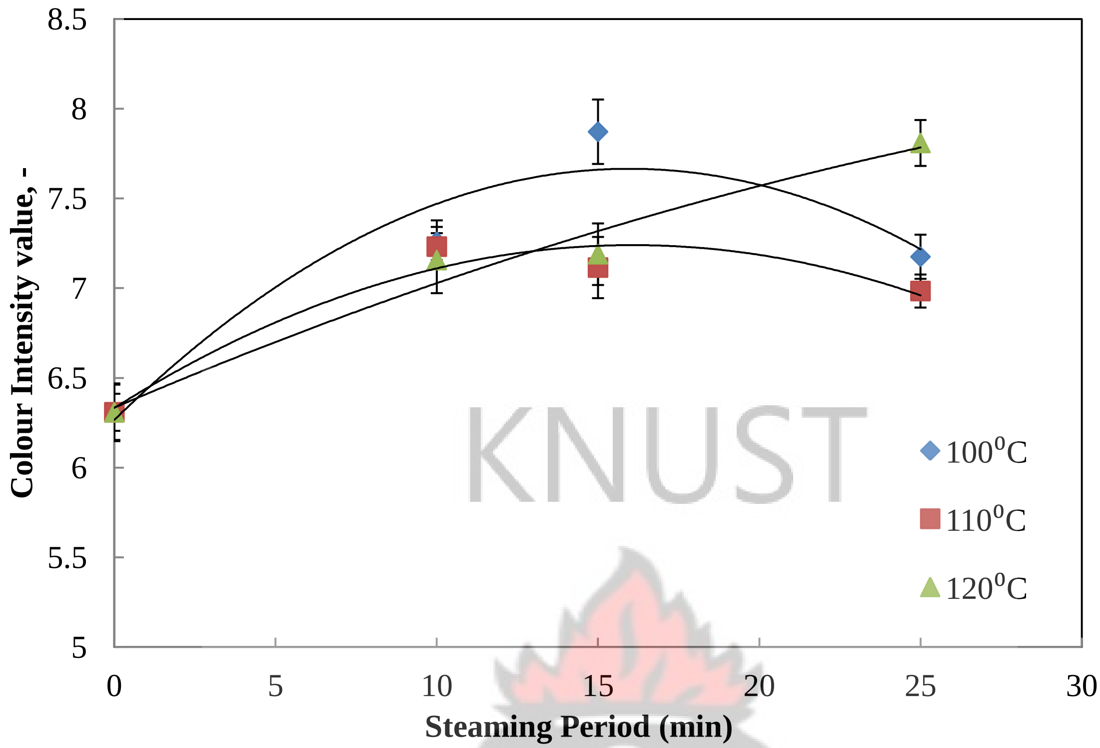

Figure 4.6. Effect of steaming period on colour intensity value of Erica 2.

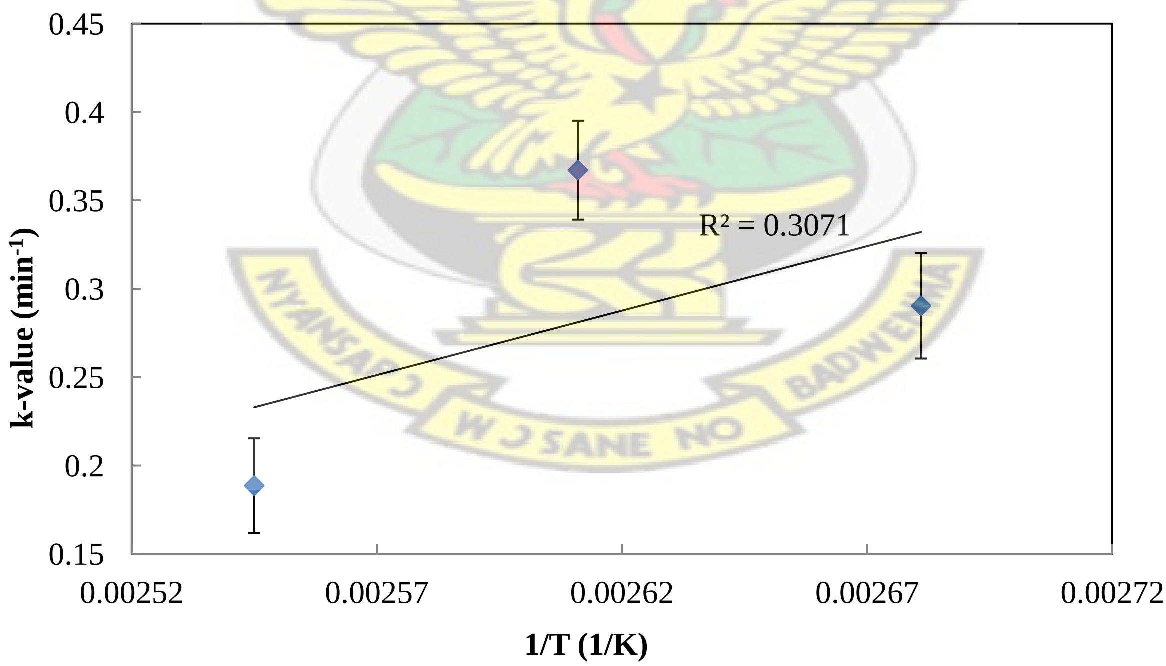

Figure 4.7. Temperature dependence of colour intensity reaction rate constant for Nerica 1.

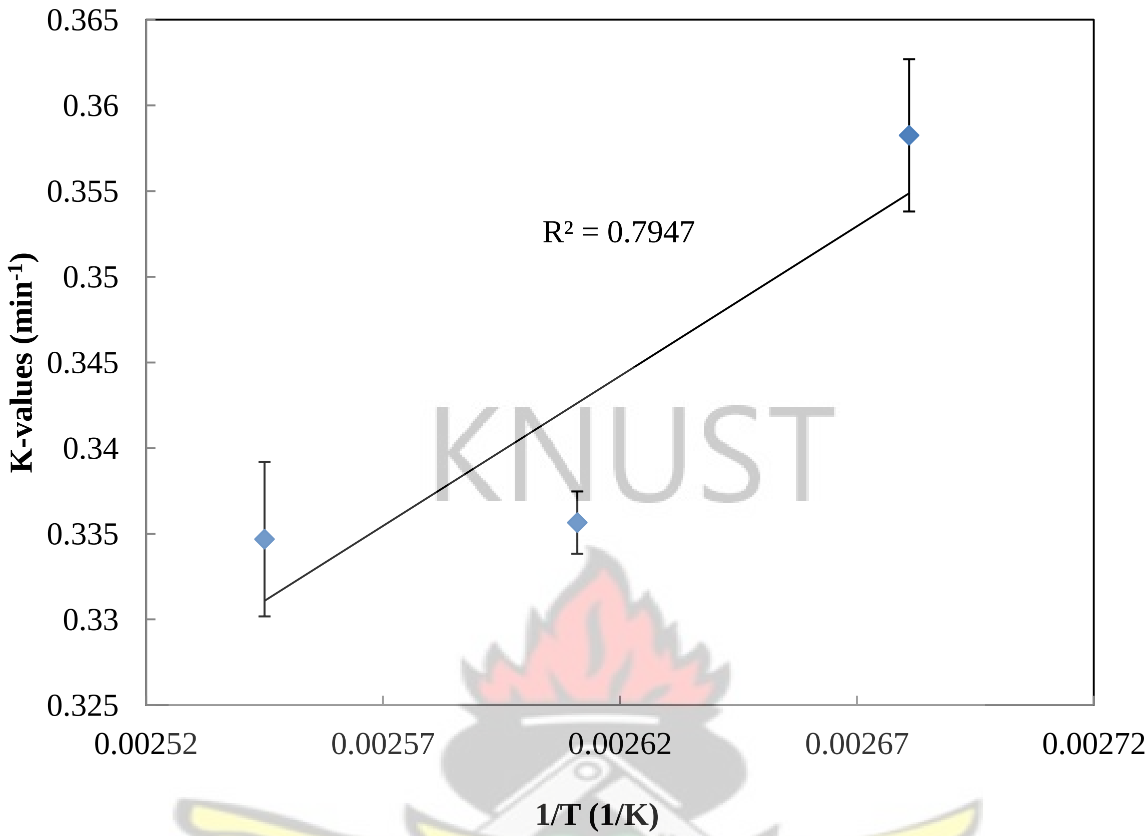

Figure 4.8. Temperature dependence of colour intensity reaction rate constant for Nerica 2.

4.1.3 Milling Yield

The parboiled product exhibits several advantages over unparboiled product such as the strengthening of kernel integrity, increased milling recovery, prevention of the loss of nutrients during milling and improved shelf life as well as prevention of the proliferation of fungus and insects (Rao and Juliano, 1970a, Bhattacharya, 1985). Tables 4.13 and 4.14 show the statistical results for milling yield. From the tables, it can be observed that steaming treatment had a significant effect ($p<0.01$) on milling yield for both varieties. In the appendix, Tables 4.33 and 4.35 shows a significant increase in mean yield as compared to the control but decreases at high temperature and thus shows a significant difference as to its LSD. Parboiling treatment brought about a striking improvement in the milling quality of paddy rice (Bhattacharya and SubbaRao, 1966). The parboiling imparts hardness to the grains so that they resist breakage during milling, minimizing breakage loss and increasing milling yield (Garibaldi, 1972).

Figures 4.9 and 4.10 show the effect of parboiling treatment on the milling yield of both varieties. From Fig 4.9 with steam period 10min, steam samples at 120^{o}C, 110^{o}C and 100^{o}C show greater milling yield respectively while at steaming period of 15min, the highest milling yield was steam at sample 120^{o}C followed by 100^{o}C and 110^{o}C respectively. Also at steam period 25min, steam sample 100^{o}C, 120^{o}C and 110^{o}C shows greater milling yield respectively. From Fig 4.10, at steam period of 10min, higher milling yield occurred for steam sample 100^{o}C, 120^{o}C and 110^{o}C respectively. It was also high for steam sample 120^{o}C, 110^{o}C and 100^{o}C respectively at steam period of 15min. When the steaming period was increased to 25min, steam samples 110^{o}C, 100^{o}C and 120^{o}C also increases respectively but decreases comparatively to the milling yield period of 15min and 10min respectively. It can be seen that as steaming temperature and period increase, there was an increase in the milling yield until the highest steaming temperature and period, and then decreased rapidly.

During parboiling of paddy rice at higher temperatures, severe deformation of the grain occurs along with exudation of endosperm due to husk splitting and absorption of excessive moisture. The deformed grain loses the exuded part of the endosperm during milling. Thus, with parboiling of paddy rice at higher temperatures for a longer steaming period milling yield decreases, depending on the severity of processing conditions. Since higher steaming temperature is most favourable for grain deformation, which reduces the milling yield, it might be the cause for getting almost the same or less milling yield due to steaming temperature and period increases for both figures of the varieties.

Tables 4.15 and 4.16 show the average milling yield (%) and rate of reaction value (K) due to steaming temperature for both varieties. It can be seen from Table 4.16 that milling yield and reaction rate increase at 110°C while they decrease at 120°C for Nerica (2). For Table 4.15, rate of reaction and milling yield at 100°C is higher than 110°C but less than values at 120°C. Figs 4.11and 4.12 show the temperature dependence of milling yield (%) on reaction rate constant for Nerica (1) and (2). From these figures the rate of reaction decreases as parboiling temperature increases. These figures show a significant ($p<0.01$) negative linear correlation between K-value and 1/T for steaming as observed with coefficient of correlation (R^2) values of 0.994 and 0.605 respectively. It also shows a significant difference on the temperature dependence of the rate of reaction.

Table 4.13Statistical results for physical property (ANOVA Table for milling yield (%) N1)

SOURCE	DF	SS	MS	F	P
Steam	3	133.05	44.35	13.63	0.002
Error	8	26.04	3.25		
Total	11	159.09			

Table 4.14Statistical results for physical property (ANOVA Table for milling yield (%) N2)

SOURCE	**DF**	**SS**	**MS**	**F**	**P**
Steam	3	59.41	19.80	13.29	0.002
Error	8	11.92	1.49		
Total	11	71.34			

Table 4.15 Average milling yield (%) and rate of reaction value (K) due to steaming temperature for Nerica 1

Treatment	Steaming		
Temperature	100^{o}C	110^{o}C	120^{o}C
Milling yield N1	78.035	76.905	78.235
K-value, min^{-1}	0.333475	0.199296	0.336551

Table 4.16 Average milling yield (%) and rate of reaction value (K) due to steaming temperature for Nerica 2

Treatment	Steaming		
Temperature	100^{o}C	110^{o}C	120^{o}C
Milling yield N2	76.435	77.935	77.12
K-value, min^{-1}	0.214248	0.338254	0.315604

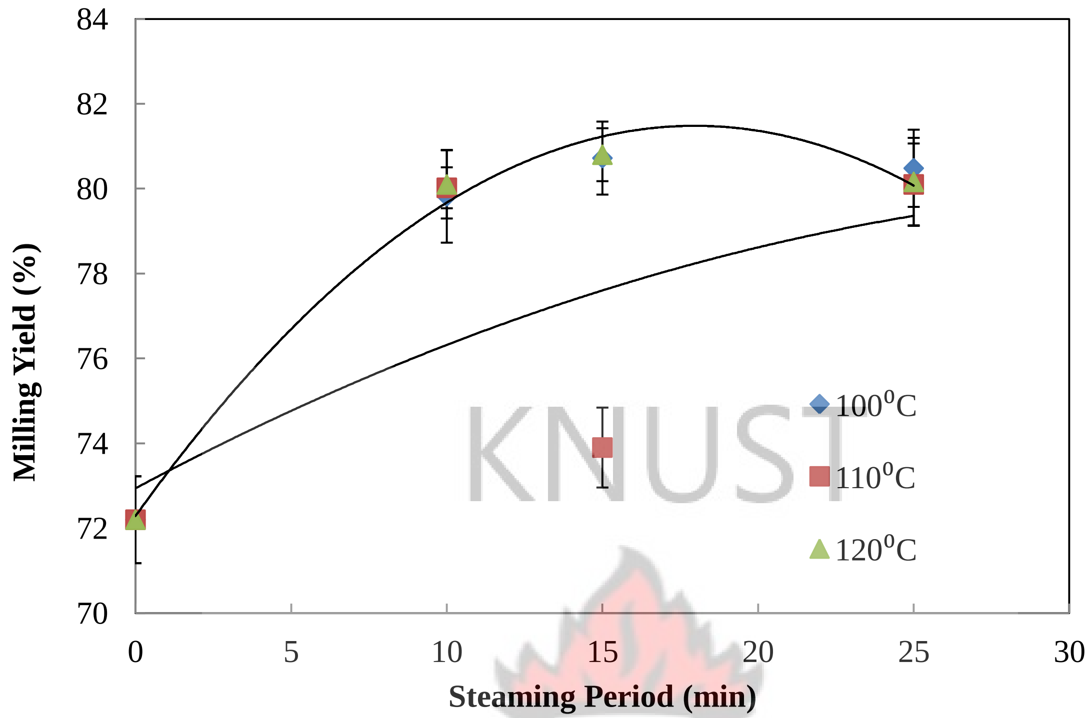

Figure 4.9. Effect of steaming on milling yield (%) for Nerica 1.

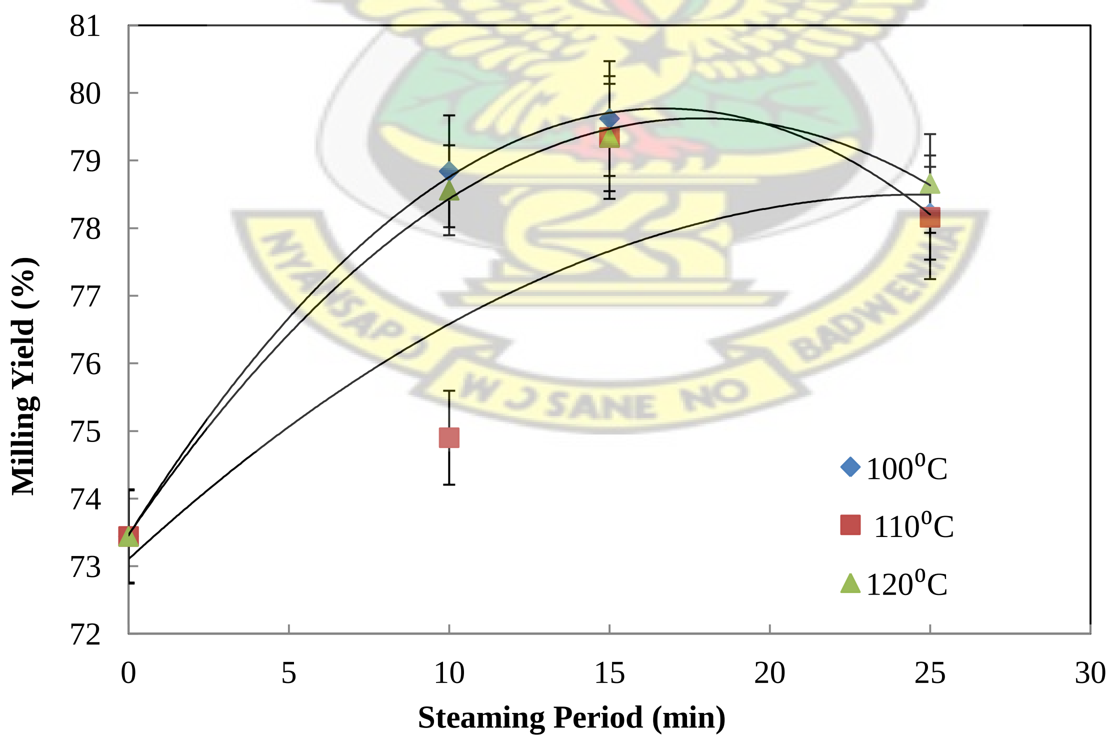

Figure 4.10. Effect of steaming on milling yield (%) for Nerica 2.

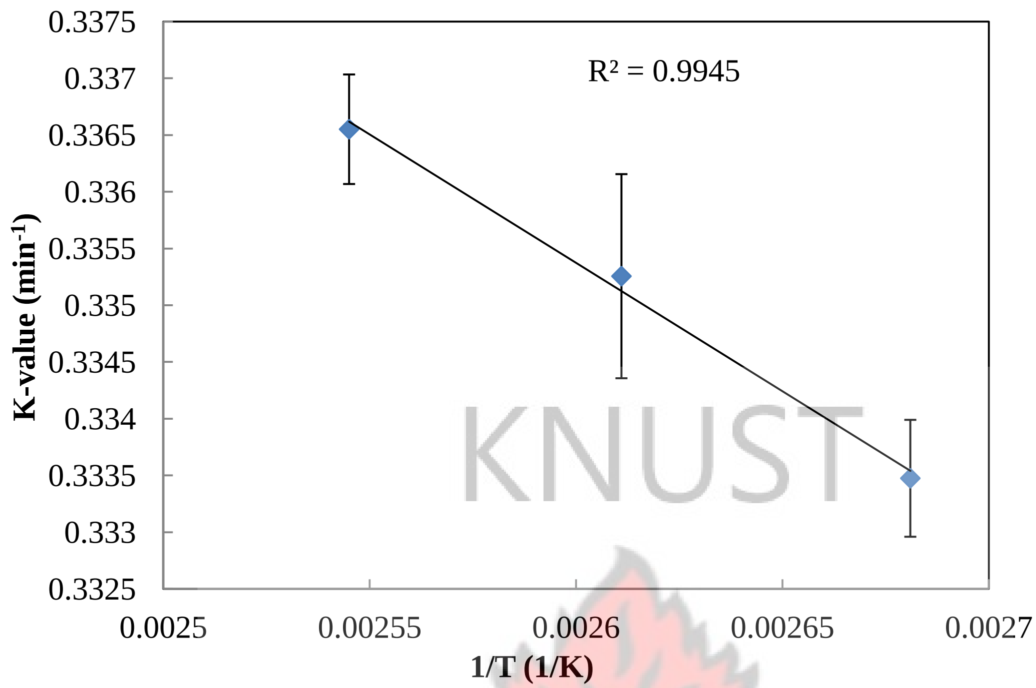

Figure 4.11. Temperature dependence of milling yield (%) reaction rate constant for Nerica1.

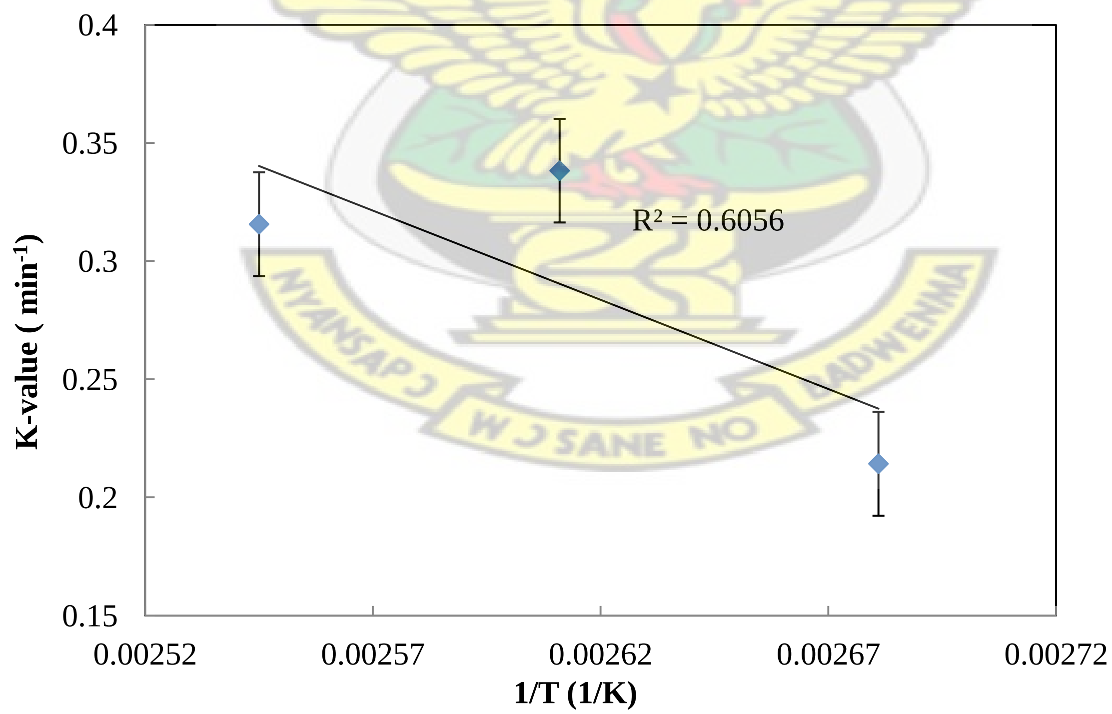

Figure 4.12.Temperature dependence of milling yield (%) reaction rate constant for Nerica 2.

4.1.4 Head Rice Yield

Tables 4.17 and 4.18 show the statistical results for head rice of Nerica (1) and (2) respectively. From these tables, it was observed that there was a significant effect ($p<0.01$) for both varieties due to parboiling treatment. From these tables, as the steaming temperature and period increases, the mean value increases from raw rice to steam at 100°C. At higher temperature and period, the mean value decreases at steam of 110°C and then rises at steam of 120°C. As steaming temperature increases, it decreases degree of milling which improves head rice yield as observed in this study. Thus excessive steaming increases the starch gelatinization which causes exuding of the endosperm from the husk which might be the cause of this effect as reduced head rice yield after milling of parboiled rice steamed at higher steaming temperature and period. Tables 4.34 and 4.36 show the summary of steaming treatment on physicochemical properties of both varieties and their least significant difference (LSD) respectively. From these tables, it was observed that there was a significant difference ($p<0.01$) between the mean summary values and their least significant difference (LSD) for both varieties.

Tables 4.19 and 4.20 show Average head rice and reaction rate constant value due to steaming for both varieties. From Table 4.19, there was a fluctuation for the head rice values and reaction rate constant (k-values) as the steaming temperature and period increase but the k-values for Table 4.20 show an increase in values as the steaming temperature and period increase. At highest steaming temperature (120°C), the rate of reaction was highest for both varieties. It was observed that head rice yield can be improved by controlling steaming temperature and period as excessive parboiling treatment affects head rice yield. Figs.4.13 and 4.14 show the effect of steaming on head rice for both varieties respectively. From Fig 4.13, head rice increases as steaming period increases. At steam period 10min, steam samples 100°C, 110°C, and 120°C increase respectively. For steam period 15min, there was a slight increase in head rice for steam sample 110^{o}C while a greater increase occurred for steam sample 120^{o}C, and 100^{o}C respectively. Also steam period 25min shows an increase in head rice for steam sample 120^{o}C, 100^{o}C and 110^{o}C respectively but comparatively lower head rice for steam period 15min and 10min. Fig 4.14 also shows a similar behaviour as Fig 4.13 for steam sample 100^{o}C, 110^{o}C and 120^{o}C as steaming period increases from 10min, 15min and 25min. From these figures, it shows an increase in head rice as at steam 100^{o}C for 10min. Steam 110^{o}C for 15mins shows a decrease in head rice whilst slightly higher increase in head rice for steam 120^{o}C for 25min. Figs.4.15 and 4.16 show temperature dependence of head rice reaction rate constant for Nerica (1) and (2) respectively. It shows a negative linear correlation between k-values and 1/T with R^2 values of 0.420 and 0.989 respectively.

However, it was found that the steaming of rice variety at the suitable conditions increased the head rice yield of parboiled rice which further caused gelatinization process that brings stronger structure and the denaturation of protein by diffusing into inter-granular space of starch which further increases the binding effect, and is better for milling process (Gariboldi, 1972). In addition, the moisture was removed slowly from parboiled rice in the shade, although it takes longer and gives an excellent milling quality. In addition, head rice yield values decreased with a longer time and a higher temperature of steaming. It might be that soaking and steaming low amylose content at higher temperature cause severe deformation of the grain that loses the exuded part of the endosperm while absorbing excessive moisture which led to reduced milled yield (Islam *et al*., 2004; Bello *et al*., 2006). Therefore, a longer duration of steaming is not suitable for parboiled rice.

Table 4.17 Statistical results for physical property (ANOVA Table for head rice (g) Nerica (1)

SOURCE	**DF**	**SS**	**MS**	**F**	**P**
Steam	3	146969	48990	6.04	0.019
Error	8	64924	8115		
Total	11	211893			

Table 4.18 Statistical results for physical property (ANOVA Table for head rice (g) Nerica (2)

SOURCE	**DF**	**SS**	**MS**	**F**	**P**
Steam	3	86387	28796	8.97	0.006
Error	8	25686	3211		
Total	11	112073			

Table 4.19 Average head rice and reaction rate constant value due to steaming for Nerica 1

Treatment		Steaming	
Temperature	100^oC	110^oC	120^oC
Head rice N1	284.3	229.725	263.275
K-value, min^{-1}	0.316438	0.183397	0.592530

Table 4.20 Average head rice and reaction rate constant value due to steaming for Nerica 2

Treatment		Steaming	
Temperature	100^oC	110^oC	120^oC
Head rice N2	251.825	295.3	280.225
K-value, min^{-1}	0.196624	0.316537	0.478591

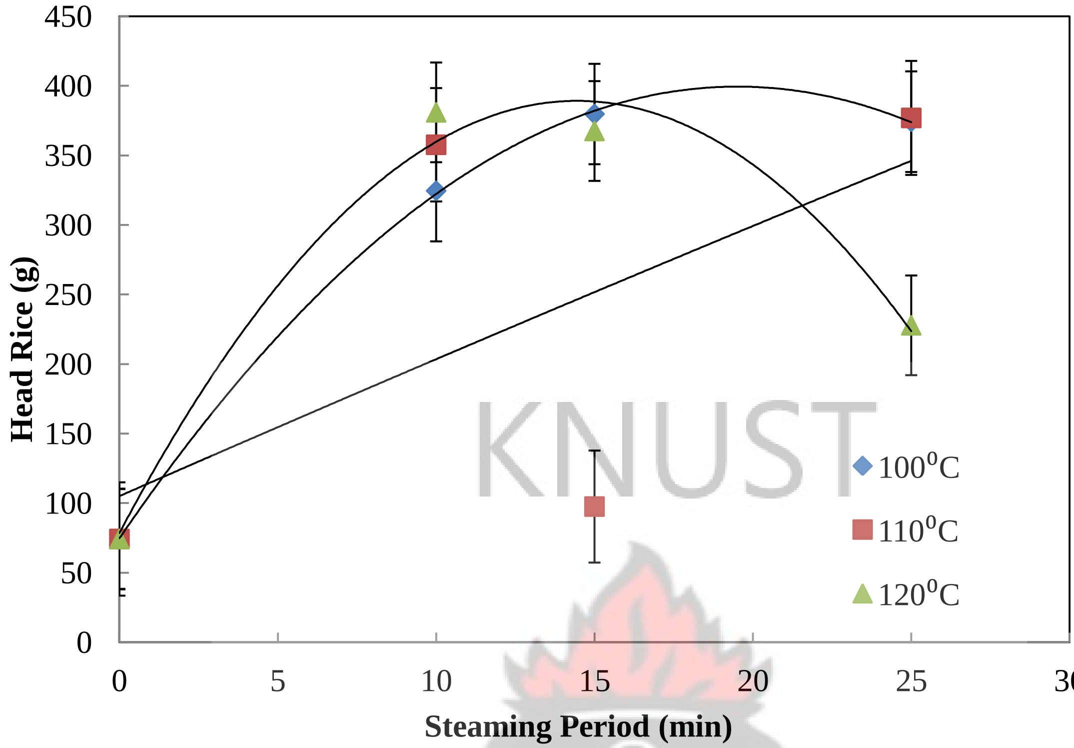

Figure 4.13. Effect of steaming on head rice (g) for Nerica 1.

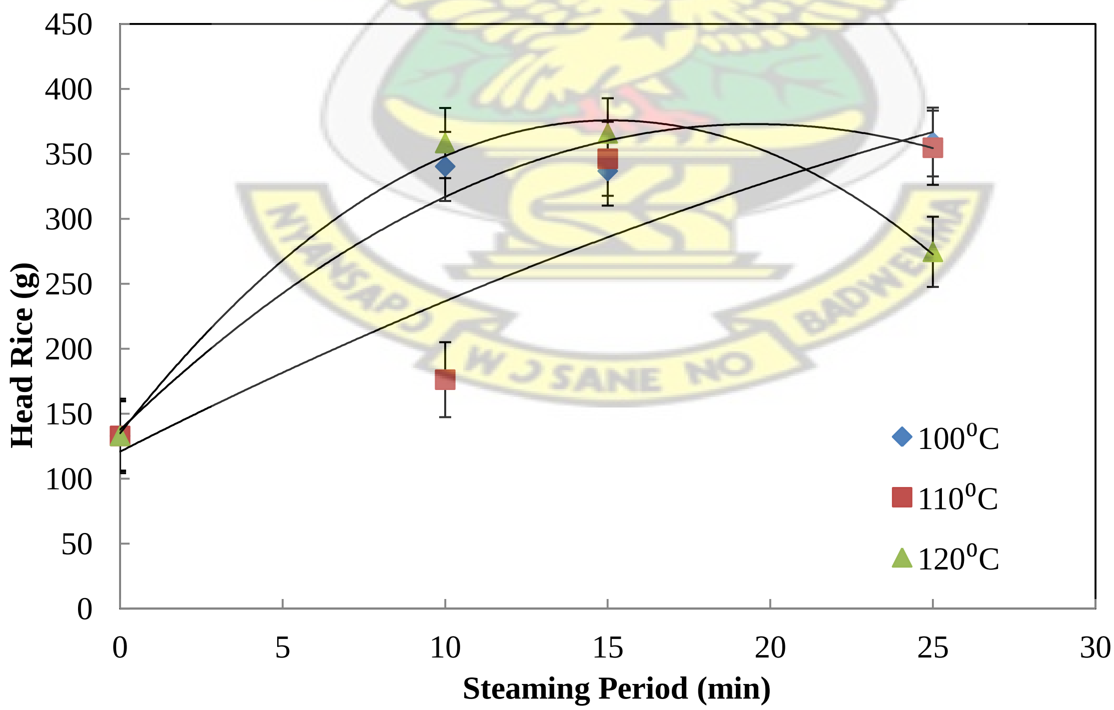

Figure 4.14. Effect of steaming on head rice (g) for Nerica 2.

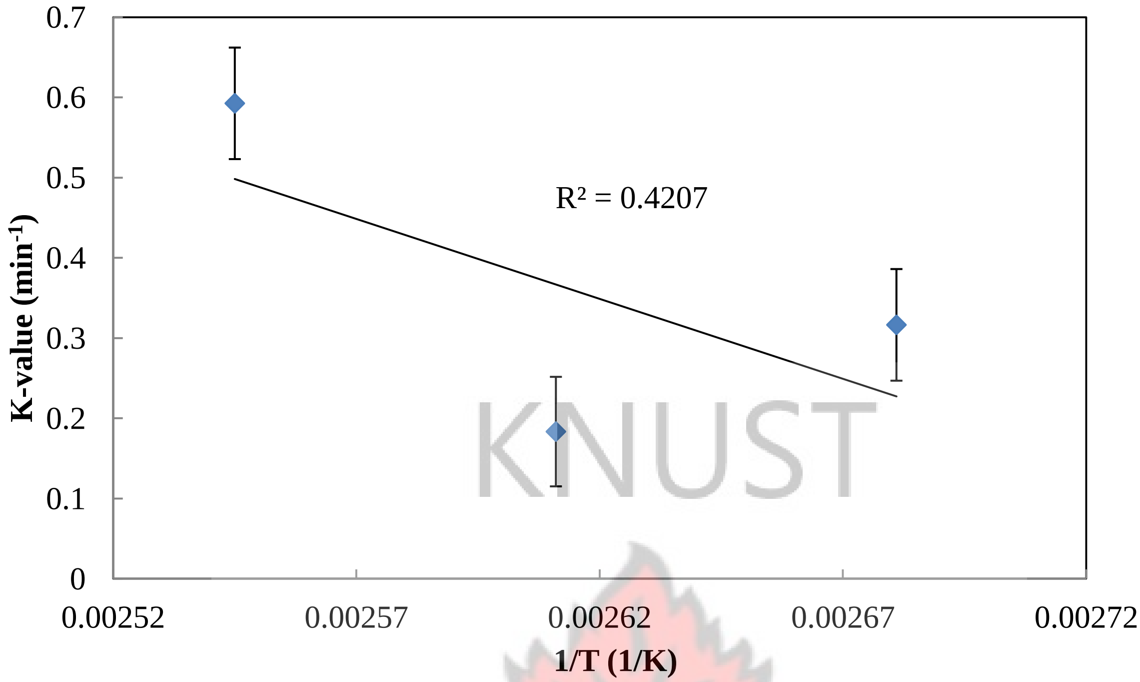

Figure 4.15. Temperature dependence of head rice (g) reaction rate constant for Nerica 1.

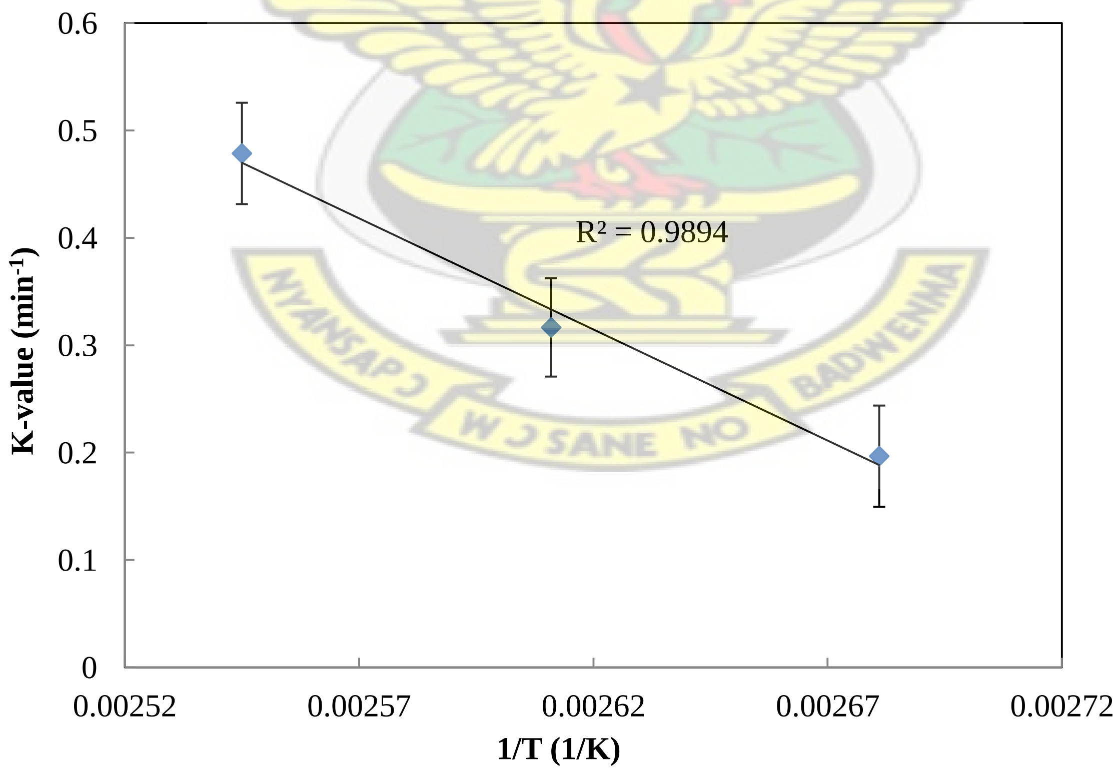

Figure 4.16. Temperature dependence of head rice (g) reaction rate constant for Nerica 2.

4.1.5 Hardness

Hardness is the most important physical property of parboiled rice among all the physical properties, as it reduces breakage during milling which further makes significant influences in increasing the market value and consumer acceptability. It is generally understood that cooked parboiled rice is harder and less sticky than raw cooked rice (Islam *et al.*, 2001). Hardness value is greatly affected by parboiling condition such as starch gelatinization and amylose content. Tables 4.21 and 4.22 show the statistical results of hardness for both Nerica (1) and Nerica (2) which were the local varieties used for the study. From the tables, it can be seen that steaming treatment had significant effect ($p<0.01$) on hardness in both varieties. Several researchers reported that hardness is greatly affected by parboiling conditions, moisture content after drying, elapsed time, the balance of starch gelatinization and retrogradation and other factors (Ali and Bhattacharya, 1976; Pillaiyar and Mohandoss, 1981; Bhattacharya, 1985; Itoh and Kawamura, 1985; Kimura, 1991; Islam *et al*., 2001).

Also Tables 4.33 and 4.35 in the appendix show the summary of steaming treatment on physicochemical properties and its least significant difference. From these tables, it was observed that increase in steaming treatment had a significant effect on hardness in both varieties. Figs 4.17 and 4.18 show the effect of steaming treatment on paddy rice varieties and steaming periods on hardness value. Fig 4.17 shows an increase in hardness value as the steaming temperature and period increase. From Fig 4.17, hardness increases as steaming period increases. At steam period of 10min, 15min and 25min, hardness increases for steam sample 100^{o}C, 110^{o}C and 120^{o}C respectively as steam temperature increases for the samples. Comparatively, steam period of 25min, 15min and 10min show greater increase in hardness respectively. Fig 4.18 also shows a similar behaviour of hardness as steam period increases and steam temperature increases. But for long steaming period and high temperature, it was observed that the husks of paddy were splitting due to expansion of the endosperm. Fig 4.18 also shows the same trend but as steaming temperature and period increased excessive splitting was observed causing more of the endosperm to exude which affected its hardness value as shown in the graph. The hardness of the parboiled rice was due to gelatinization of starch granules which occurred at high temperature of steaming and its period. This might also be the reason why excessive exuding of endosperm occurred during the steaming process at high temperature and period. Tables 4.23 and 4.24 show the Average hardness and reaction rate constant value for hardening reaction at different steaming processes. From Table 4.23, it can be observed that the steaming process has significant effect on both hardness and rate of reaction. As the temperature increases, hardening of grain kernel and rate of reaction also increases.

Comparatively, hardening of Nerica (1) from Table 4.24 also follows the same trend but its reaction rate constant differs. This might be due to excessive hardening of the kernel leading to more splitting of the husk. There are other factors which affect the hardening of the kernel during parboiling which may include the sizes of Nerica (1) being smaller compared to Nerica (2). Also physical textural hand feeling of the varieties shows more grittiness in Nerica (2) than Nerica (1) which might be the cause of high hardness properties and reaction rate constant values. Hardness of the parboiled rice can depend on temperature of steaming, particle sizes and textural properties of the two varieties as observed in this study. Fig 4.19 and Fig 4.20 show temperature dependence of hardening reaction rate constant for Nerica (1) and Nerica (2). These figures show a significant ($p<0.01$) negative linear correlation between K-value and 1/T for steaming as observed with coefficient of correlation (R^2) values of 0.849 and 0.989 respectively. It also shows a significant difference on the temperature dependence of the rate of reaction.

Table 4.21 Statistical results for physical property (ANOVA Table for hardness N1)

SOURCE	DF	SS	MS	F	P
Steam	3	15598770	5199590	16.51	0.001
Error	8	2519556	314945		
Total	11	18118326			

Table 4.22 Statistical results for physical property (ANOVA Table for Hardness N2)

SOURCE	DF	SS	MS	F	P
Steam	3	26441035	8813678	146.43	0.000
Error	8	481512	60189		
Total	11	26922547			

Table 4.23 Average hardness and reaction rate constant value due to steaming for Nerica 1

Treatment		Steaming	
Temperature	100°C	110°C	120°C
Hardness N1	2258.1025	2734.555	3204.883
K-value, min^{-1}	0.272791	0.314784	0.320369

Table 4.24 Average hardness and reaction rate constant value due to steaming for Nerica 2

Treatment		Steaming	
Temperature	100°C	110°C	120°C
Hardness N2	3178.245	3257.075	3553.405
K-value, min^{-1}	0.327085	0.312507	0.323663

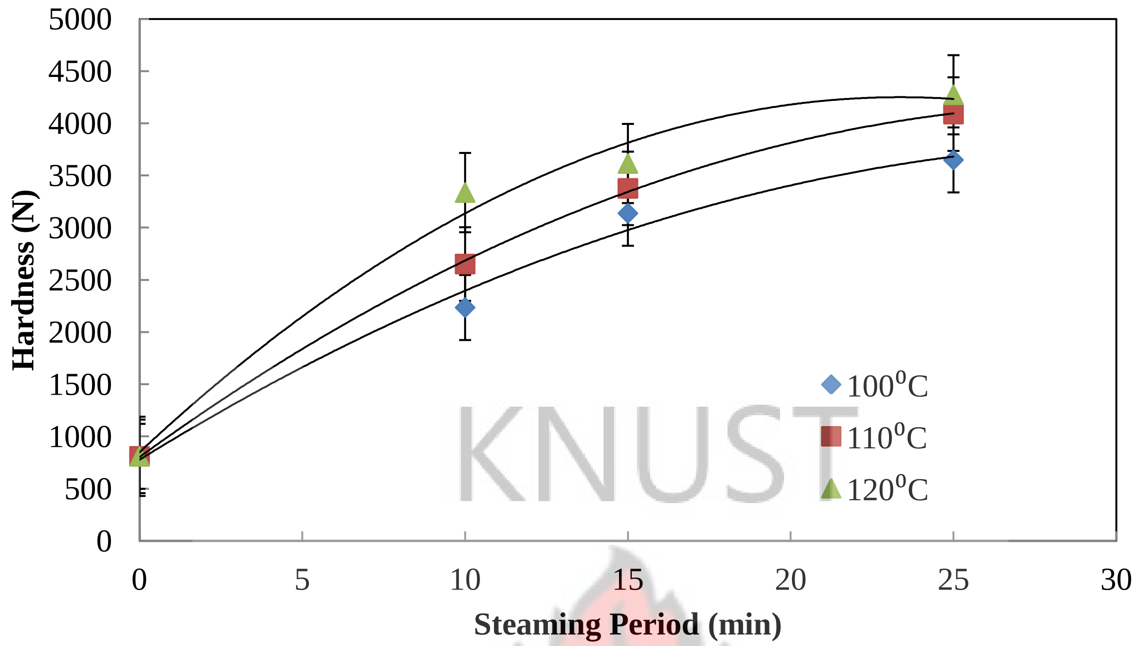

Figure4.17. Effects of steaming on hardness of Nerica 1.

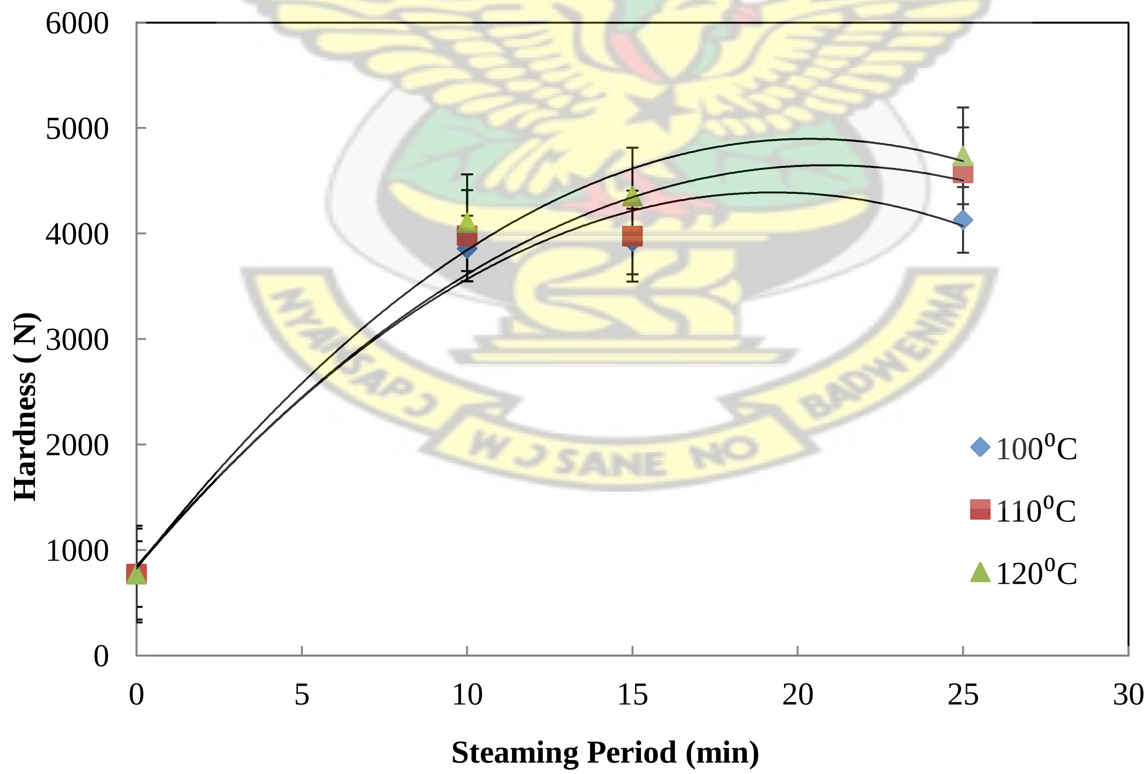

Figure 4.18. Effects of steaming on hardness of Nerica 2.

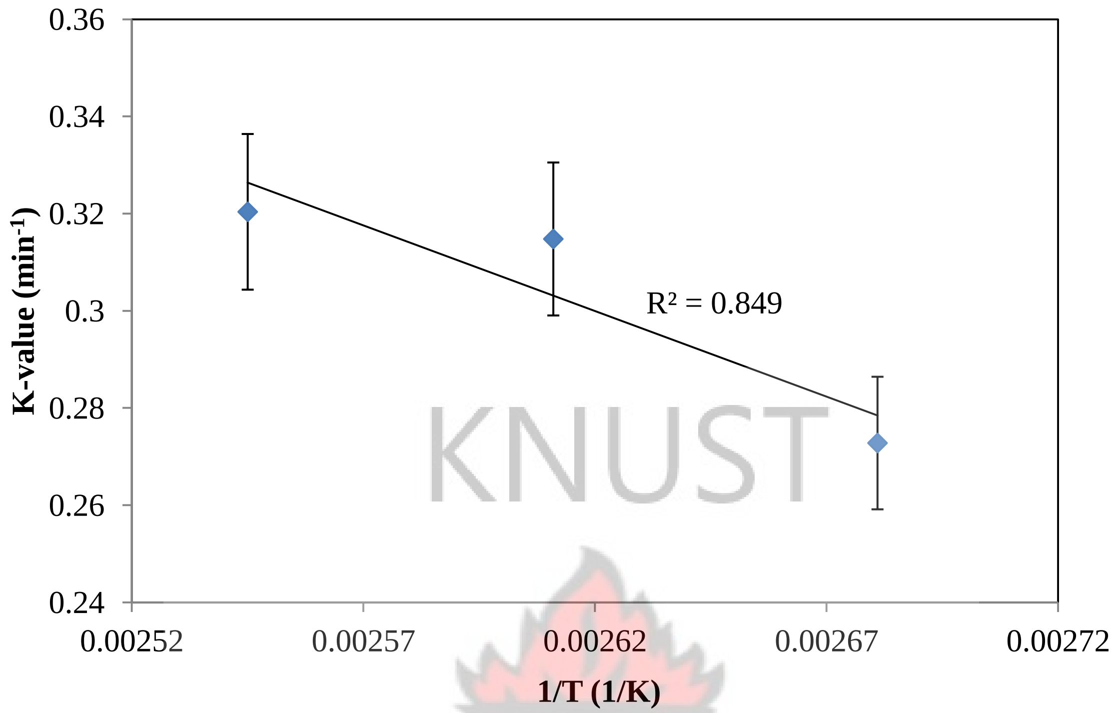

Figure 4.19. Temperature dependence of hardening reaction rate constant for Nerica 1.

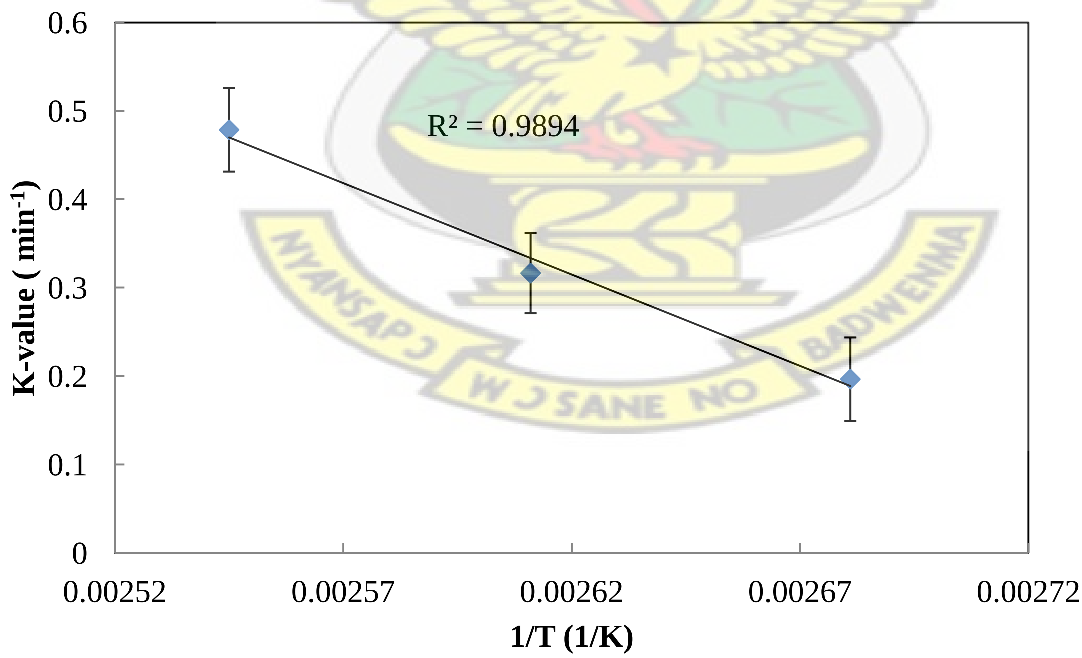

Figure 4.20. Temperature dependence of hardening reaction rate constant for Nerica 2.

4.2 Effect of parboiling treatment on gelatinization properties

4.2.1 Maximum viscosity

The process of starch gelatinisation is called parboiling which depends on the severity of the parboiling process. It was reported that parboiling treatment resulted in a decrease in maximum viscosity and breakdown (Kimura *et al*., 1995) as can be observed by RVA units. In some cases of parboiled rice, distinct peak viscosity was almost identical to final viscosity (Raghavendra Rao and Juliano, 1970). Table 4.25 and 4.26 show the statistical results for maximum viscosity for Nerica (1) and (2) respectively. From Table 4.25, it was observed that maximum viscosity for mean value decreases from raw rice to steam at 120^{o}C as steaming temperature and period increase. There was no significant difference at steaming temperatures of 100^{o}C and 110^{o}C but significant effect existed at steam 120^{o}C. But from Table 4.26, there exists a significant effect ($p<0.01$) for all steaming temperatures as it increases. This might be due to amylase or starch granules content with each variety which affected the gelatinization process of Nerica (1) and (2) as steaming temperature and period increase.

It was observed that a lower maximum viscosity value due to parboiling is a reflection of the decreased swelling ability of gelatinized starch (Priestley, 1976; Ali and Bhattacharya, 1980). Figs. 4.21 and 4.22 show the effect of steaming on maximum viscosity for both varieties of rice respectively. From Figure 4.21, there is a decrease in maximum viscosity as steaming temperature increases from raw rice to steam (120^{o}C) and period 25mins. From Figure 4.22, as the steaming temperature increases and period increases a scatterly graph representation with an increase in maximum viscosity results. At steam temperature 100^{o}C the maximum viscosity remains unchanged at 94.5 RVA units as the period increases. For steam of 110^{o}C, as period increase to 15mins, it reduced to 90.05 RVA units and then rose again after that time elapsed to

94.5 RVA units. For steam of 120^{o}C, it did not show any significant effect on maximum viscosity as both temperature and period increases. From Figure 4.22, as maximum viscosity increased from 91.05 RVA units to 94.5 RVA units, effect of steaming and period increases had a slight effect on maximum viscosity for Nerica (2) as compared to Nerica (1) which shows decrease in maximum viscosity.

Tables 4.27 and 4.28 show average maximum viscosity and reaction rate constant value due to steaming. Table 4.27 shows a decrease in maximum viscosity and an increase in reaction rate constant with highest at steam (120^{o}C). From Table 4.28, maximum viscosity for steaming temperatures (100^{o}C and 120^{o}C) was the same but different from steam 110^{o}C, as reaction rate constant values were different but highest for steam 120^{o}C. Figs. 4.23 and 4.24 show temperature dependence of k-values, maximum viscosity and reaction rate constant for Nerica (1) and (2) respectively. From these figures, significant ($p<0.01$) negative linear correlation between k-values and 1/T was obtained with R^2 values of 0.723 and 0.839 for steaming both varieties respectively. Also there exists a significant difference of temperature dependence of reaction rate constant (k-values) for both varieties. This decreasing pattern agrees well with other researchers in case of RVA parameter (Kimura *et al.*, 1995), as well as amylograph viscosity (Raghavendra Rao and Juliano, 1970; Priestley, 1976; Ali & Bhattacharya, 1980c).

The change in quality of parboiled rice with respect to maximum viscosity due to parboiling treatment can be understood from the least squares analysis using the first order kinetic model. It was found that the average value of maximum viscosity was lowest for the higher steaming temperature of 120°C compared with 100^{o}c and 110°C temperature, and that of reaction rate constant value was highest at the higher steaming temperature. The average maximum viscosity and reaction rate constant value indicates the quality index and the rate of change of quality for the respective steaming temperature. The maximum viscosity depends on the swelling behaviour of starch granules during heating stage. Formation of amylose complex due to parboiling stabilizes the starch granules (Gray and Schoch, 1962), which restrict swelling and solubilisation of starch. As a result, destruction of starch granules does not occur even at higher temperature, since complexes are thermally stable at temperatures greater than 100^{o}C (Biliaderis *et al*., 1993).

Table 4.25 Statistical results for physical property (ANOVA Table for Maximum viscosity for Nerica 1)

SOURCE	DF	SS	MS	F	P
Steam	3	1079	360	2.85	0.105
Error	8	1010	126		
Total	11	2089			

Table 4.26 Statistical results for physical property (ANOVA Table for Maximum viscosity for Nerica 2)

SOURCE	DF	SS	MS	F	P
Steam	3	25.40	8.47	6.04	0.019
Error	8	11.21	1.40		
Total	11	36.61			

Table 4.27 Average maximum viscosity and reaction rate constant value due to steaming for Nerica 1

Treatment	Steaming		
Temperature	100°C	110°C	120°C
Maximum viscosity	88.775	89.425	72.3625
K-value, min^{-1}	0.135600	0.133783	0.253024

Table 4.28 Average maximum viscosity and reaction rate constant value due to steaming for Nerica 2

Treatment	Steaming		
Temperature	100°C	110°C	120°C
Maximum viscosity	93.7125	92.7	93.7125
K-value, min^{-1}	0.236635	0.250531	0.336635

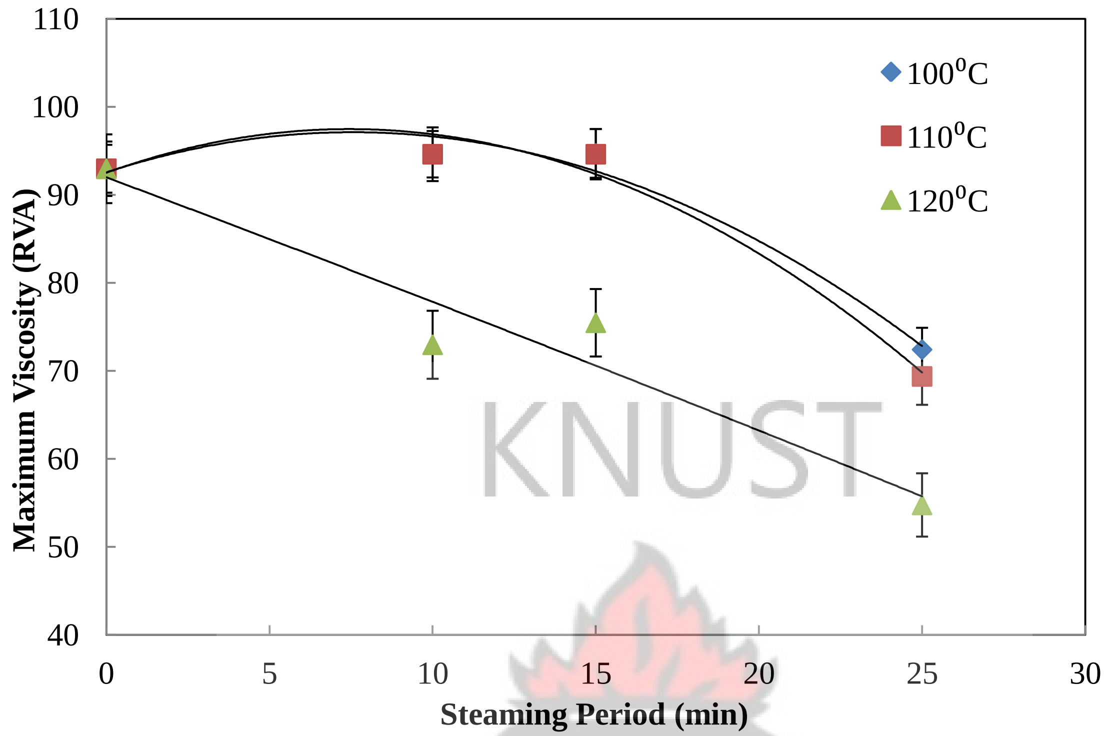

Figure.4.21. Effect of steaming on maximum viscosity of Nerica 1.

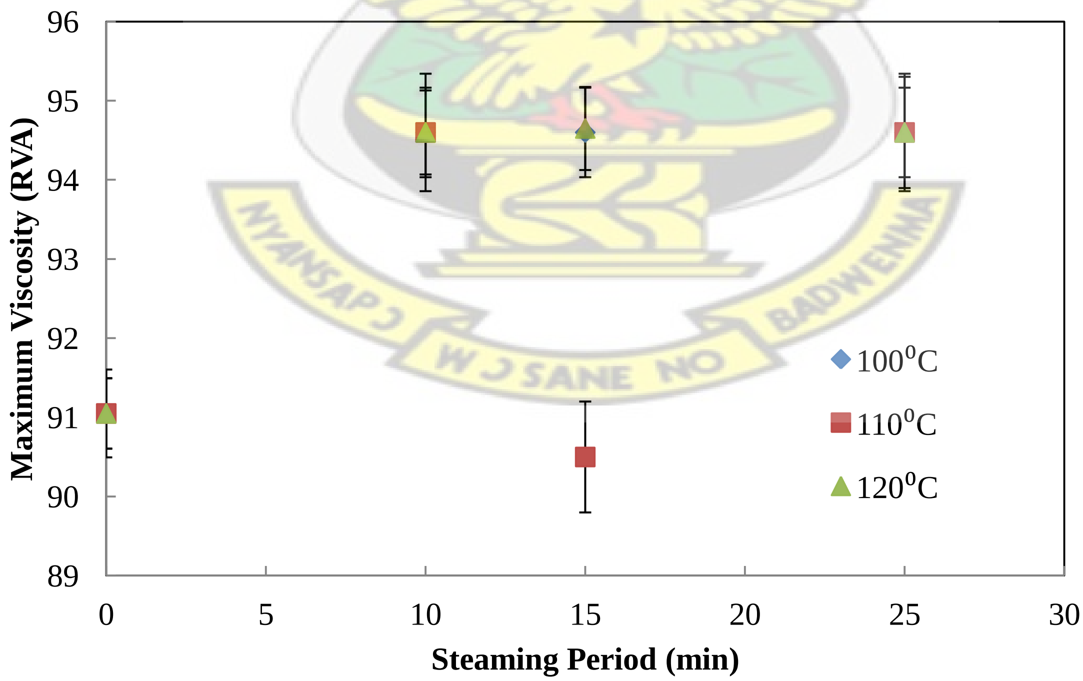

Figure.4.22. Effect of steaming on maximum viscosity of Nerica 2.

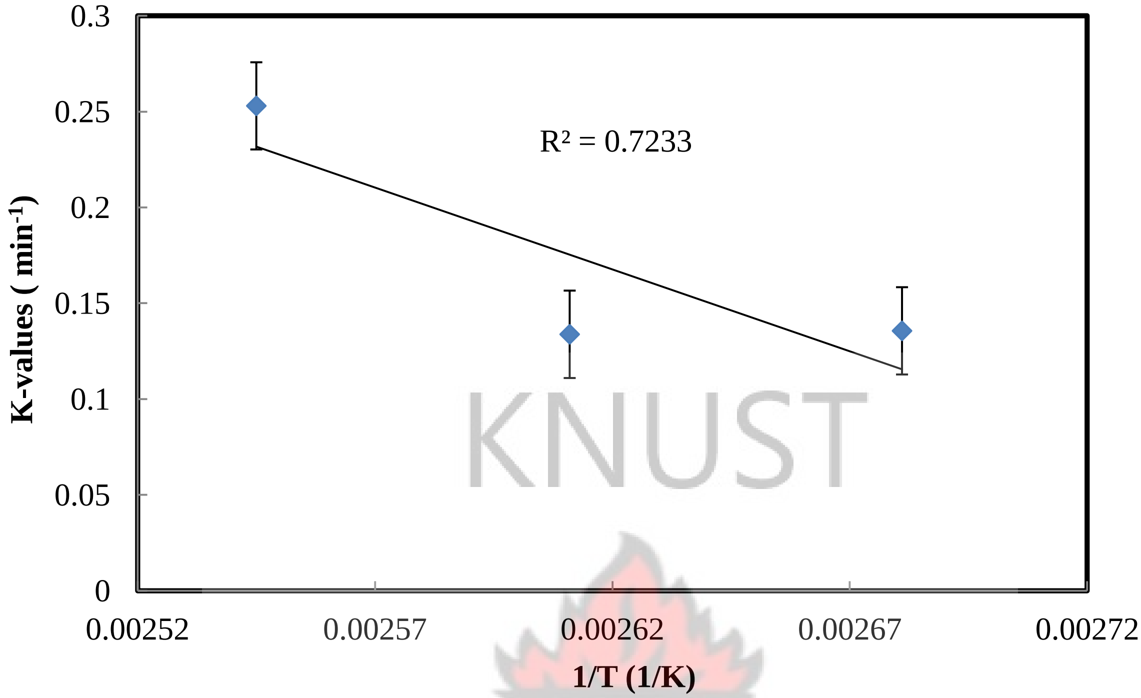

Figure.4.23. Temperature dependence of maximum viscosity reaction rate constant for Nerica 1.

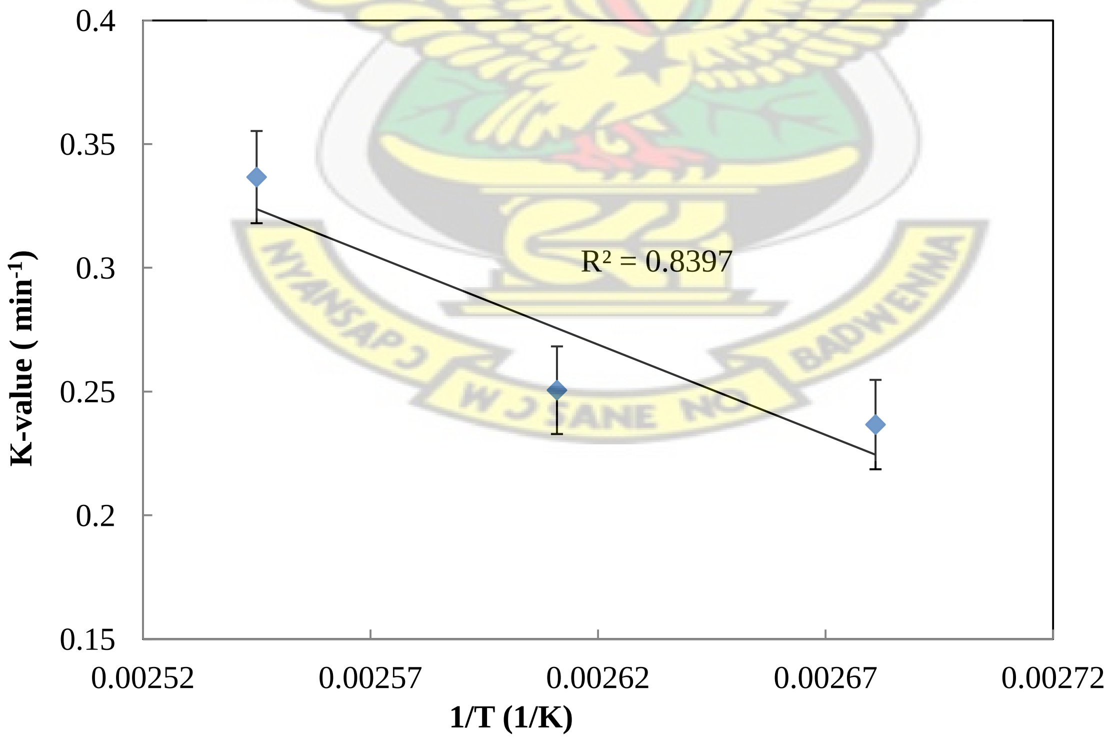

Figure.4.24. Temperature dependence of maximum viscosity reaction rate constant for Nerica 2.

4.2.2 Breakdown value

Tables 4.29 and 4.30 show the statistical results for breakdown value for both varieties Nerica (1) and (2) respectively. From these tables, steaming treatment had a significant effect ($p<0.01$) on break down values of both varieties. As steaming temperature and period increase, it has a higher effect on the parboiled rice at steam temperature of 120^oC for both varieties. The mean summary for both varieties at Tables 4.29 and 4.30 also show a higher effect of steaming on maximum viscosity. It was reported by Kimura *et al*. (1995), that parboiling treatment also resulted in decrease in breakdown as those of maximum viscosity. Figs 4.25 and 4.26 show the effect of steaming treatment on the breakdown value in this study as already reported by other researchers. These figures also show a scatter graph with a decrease in breakdown value from positive values to negative values as parboiling treatment increases.

Tables 4.31 and 4.32 show average breakdown value and reaction rate constant value for Nerica one and two respectively. From these tables, it can be seen that rate of reaction increases at higher temperature (120^oC) which implies steaming treatment had a significant effect on the parboiled rice. From this result, breakdown of parboiled rice can be controlled with steaming temperature. Higher effect of steaming on maximum viscosity was also observed. From these tables it can be seen that steaming temperature has significantly affected the rate constant value of breakdown. In case of maximum viscosity, the steaming temperature affected the reaction rate constant value. As mentioned earlier, in some cases maximum viscosity of parboiled rice was almost identical (Raghavendra Rao and Juliano, 1970), but in this case minus breakdown value clearly indicated that in some cases viscosity of parboiled rice gradually increased, which did not follow the pattern of raw rice. In this study, for the parboiled rice obtained from longer period and higher temperature of steaming, no pasting time was achieved.

It was also reported that ultimate peak viscosity was not reached even after constant heating at 95°c for 30 min (Priestly, 1976). Figs 4.27 and 4.28 show the temperature dependence of k-values for breakdown rate constant for both varieties. As in the case of maximum viscosity, also significant difference of temperature dependence of k-value was observed for both varieties. Although, significant ($p<0.01$) negative linear correlation between k-values and 1/T was obtained for steaming with R^2-values of 0.814 and 0.588 for Nerica (1) and (2) respectively.

Table 4.29 Statistical results for physical property (ANOVA Table for breakdown value for Nerica 1)

SOURCE	DF	SS	MS	F	P
Steam	3	22003	7334	27.73	0.000
Error	8	2116	164		
Total	11	24119			

Table 4.30 Statistical results for physical property (ANOVA Table for breakdown value for Nerica 2)

SOURCE	DF	SS	MS	F	P
Steam	3	27897	9299	5.68	0.022
Error	8	13107	1638		
Total	11	41003			

Table 4.31 Average breakdown value and reaction rate constant value due to steaming for Nerica1

Treatment	Steaming		
Temperature	100°C	110°C	120°C
Breakdown value , RVA	38.75	42.5	29.25
K-value, min^{-1}	0.240786	0.250889	0.337533

Table 4.32 Average breakdown value and reaction rate constant value due to steaming for Nerica 2

Treatment	Steaming		
Temperature	100°C	110°C	120°C
Breakdown value, RVA	51.75	69.25	64.125
K-value, min^{-1}	0.319159	0.211965	0.856640

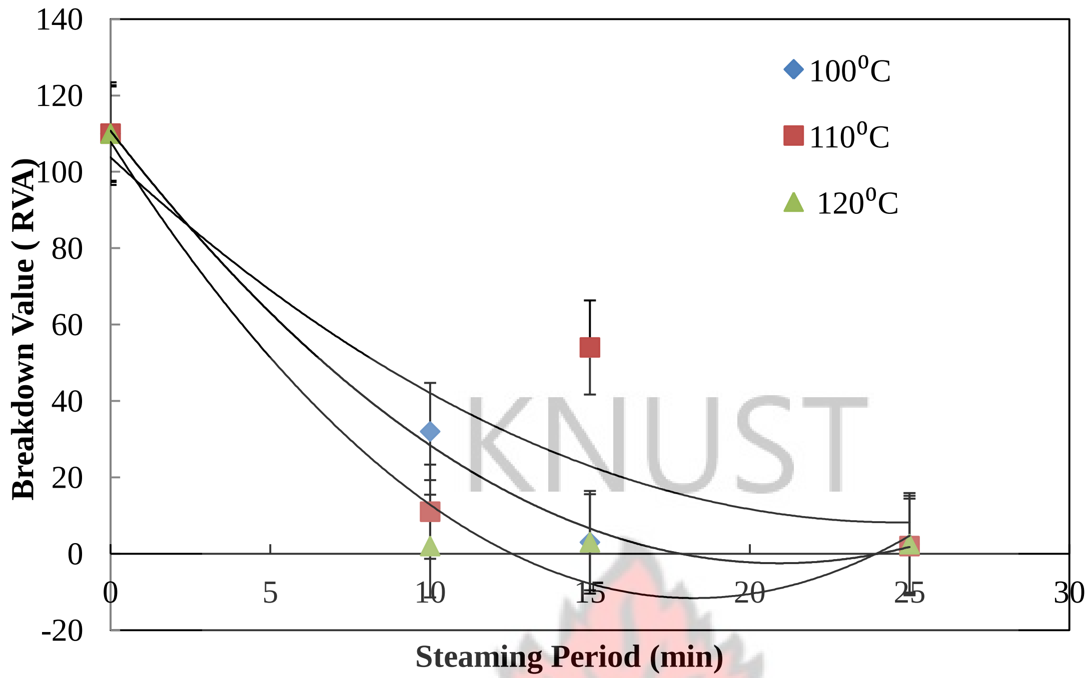

Figure 4.25. Effect of steaming on breakdown value of Nerica 1.

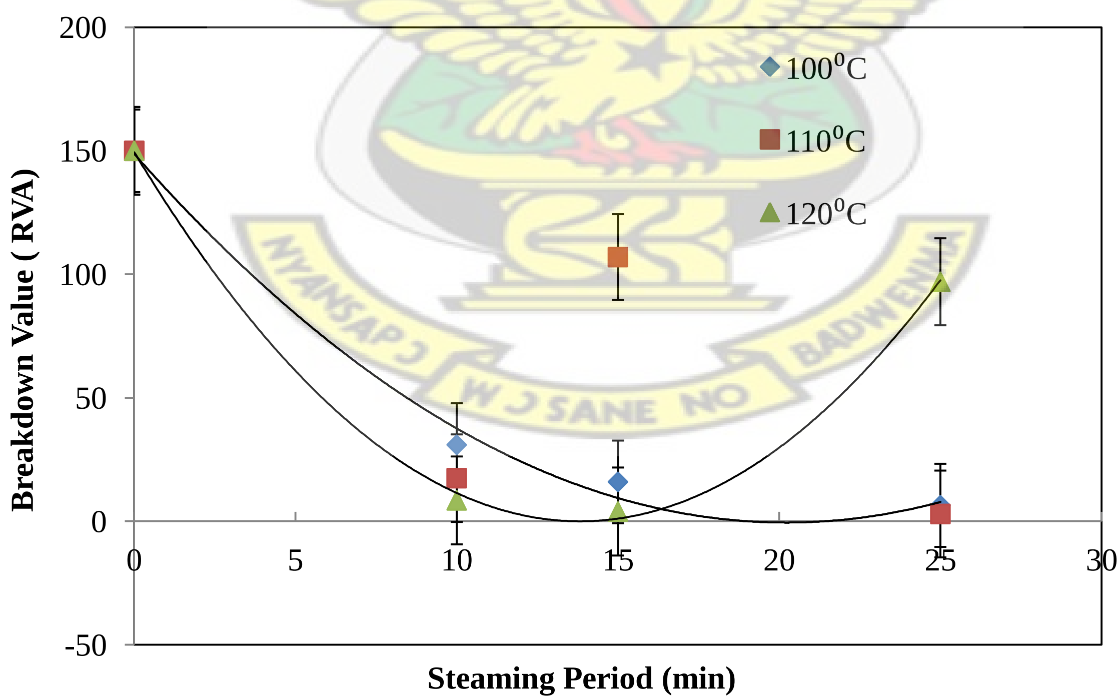

Figure 4.26. Effect of steaming on breakdown value of Nerica 2.

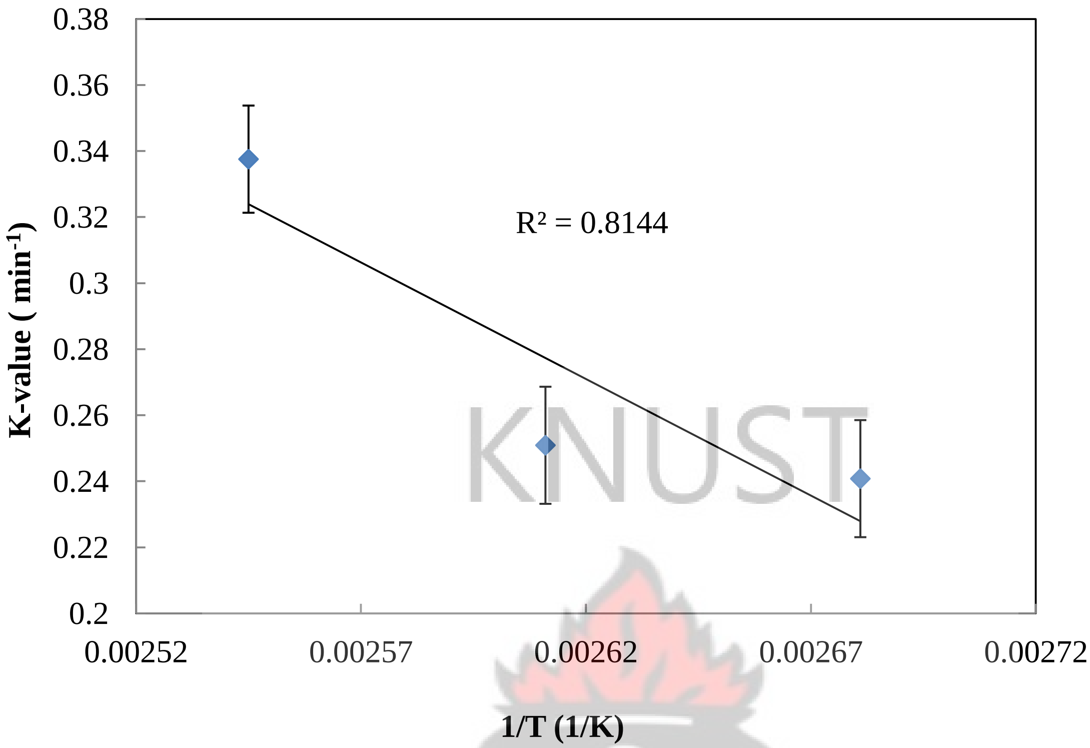

Figure 4.27. Temperature dependence of breakdown rate constant for Nerica 1.

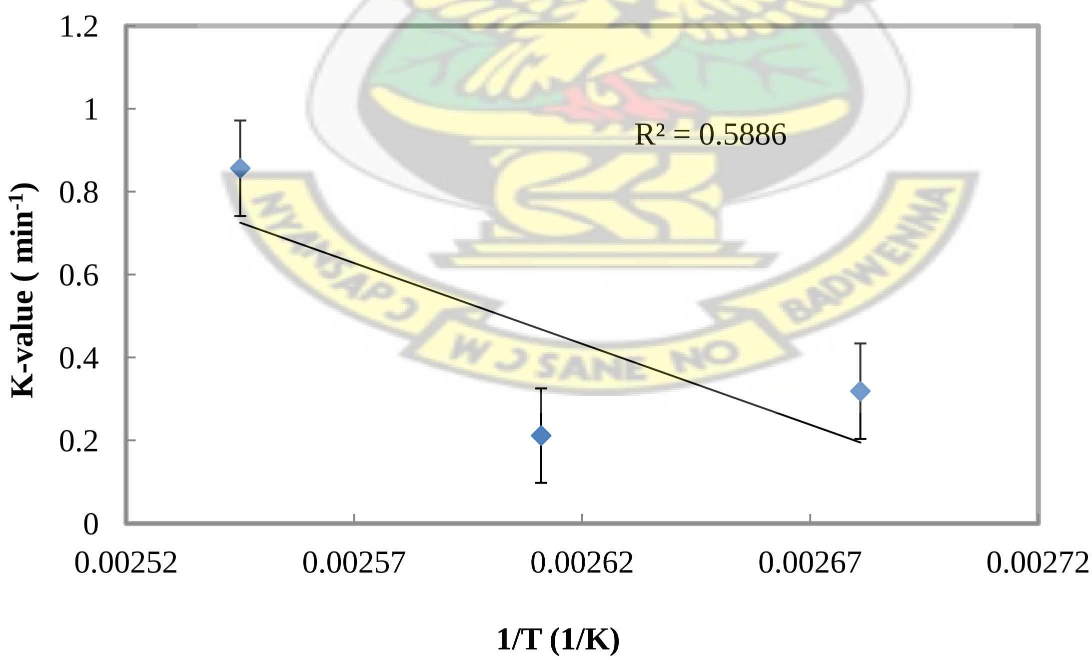

Figure 4.28. Temperature dependence of breakdown rate constant for Nerica 2.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This study was conducted to generate useful data regarding parboiling process, together with some physicochemical properties with steaming quality of parboiled locally grown rice. This data will be helpful in the parboiling industry in developing countries such as Ghana, where small scale production of parboiled rice is produced utilizing traditional parboiling equipment and process. Experiments were conducted to study parboiling effect on the physicochemical properties of two locally grown varieties of rice Nerica (1) and Nerica (2). Data were analysed by the non-linear regression method using a first order kinetic model. Efforts were made to know the effect of parboiling and steaming process on the kinetic parameters of some physicochemical properties of parboiled rice.

The following conclusions can be made from this study:

- The First order kinetic model successfully simulated the parboiling process on the quality indicators through the parboiling process.
- The reaction constant value for lightness, colour intensity and milling yield is controllable with steaming period.
- The final value of head rice yield, hardness, maximum viscosity and breakdown value and their reaction rate constant value are controllable with steaming temperature.
- Both varieties of locally grown rice showed a similar behaviour during the steaming process.

5.2 RECOMMENDATIONS

Further studies should be done for other varieties of local rice to obtain optimum parboiling processing conditions.

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APPENDENCES

Table (i) Parboiling treatment of milling yield for Nerica (1).

Unparboiled sample:

Milling yield (%) = 72.20

Degree of milling (%) = 26.15

Soaking temperature (^{o}C)	Steaming temperature (^{o}C)	Milling yield (%)
26	100	79.82
26	110	80.02
26	120	80.10
50	100	80.72
50	110	73.90
50	120	80.80
70	100	80.48
70	110	80.10
70	120	80.16

Table (ii) Parboiling treatment of degree of milling for Nerica (1)

Soaking temperature (^{o}C)	Steaming temperature (^{o}C)	Degree of milling (%)
26	100	9.32
26	11	5.59
26	120	3.57
50	100	3.49
50	110	26.19

50	120	5.82
70	100	3.53
70	110	4.19
70	120	15.72

Table (iii) Parboiling treatment of milling yield for Nerica (2)

Unparboiled sample:

Milling yield (%) = 73.44

Degree of milling (%) = 17.81

Soaking temperature (^oC)	Steaming temperature (^oC)	Milling yield (%)
26	100	78.84
26	110	74.90
26	120	78.56
50	100	79.62
50	110	79.34
50	120	79.34
70	100	78.22
70	110	78.16
70	120	78.66

Table (iv) Parboiling treatment of degree of milling yield for Nerica (2).

Soaking temperature (^oC)	Steaming temperature (^oC)	Degree of milling (%)
26	100	3.15
26	110	10.12
26	120	5.24
50	100	4.95
50	110	8.34
50	120	4.31
70	100	4.53
70	110	5.50
70	120	7.98

Table 4.33: Summary of steaming treatment on physiochemical properties of paddy rice (Nerica 1)

Treatment	Hardness	Lightness	a-value	b-value	Milling yield (%)	Gelatinization (temperature)
Steam 100^oC	3007.2 c	58.673bc	6.56 b	2.227 c	80.34ab	67.83 c
Steam 110^oC	3371.9 b	61.230 b	6.3067 c	2.48 b	78.007 b	78.13 b
Steam 120^oC	3741.3 a	57.663 c	6.85 a	1.843 d	80.353 a	50.73 d

Raw rice	809.6 d	74.841 a	5.68 d	3.36 a	72.20 c	82.20 a
LSD (0.01)	807.56	6.66	0.51	2.19	2.59	37.22

Treatment means having the same letters along the Colum are not significantly different from each other at 1% level

Table 4.34: Summary of steaming treatment on physiochemical properties of paddy rice (Nerica 1)

Treatment	Gelatinization (temp) breakdown	Gelatinization (maximum viscosity)	Gelatinization (maxi viscosity)breakdown	Head rice	Deg of milling	Colour value
Steam 100°C	3.5 c	87.23 b	12.50 c	359.47 a	5.447 d	6.9813 b
Steam 110°C	6.167 b	86.18bc	22.33 b	277.33 c	11.99 b	6.8876bc
Steam 120°C	0.167 c	67.72 c	2.50 d	325.40 b	8.37 c	7.2299 a
Raw rice	10 a	92.95 a	110 a	74.20 d	26.15 a	6.5994 c
LSD (0.01)	5.65	16.15	40.50	129.63	10.30	0.51

Treatment means having the same letters along the Colum are not significantly different from each other at 1% level

Table 4.35: Summary of steaming treatment on physiochemical properties of paddy rice (Nerica 2)

Treatment	Hardness	Lightness	a-value	b-value	Milling yield (%)	Gelatinization (temperature)
Steam 100^oC	3970.9 c	66.71 b	6.363 b	6.0933 c	78.893 a	78.57 a
Steam 110^oC	4177.1 b	60.647 c	6.077 c	6.3267 b	77.467 b	73.03 c
Steam 120^oC	4398.5 a	56.723 d	6.310bc	6.6667 a	78.853ab	68.60d
Raw rice	771.9 d	75.85 a	15.890 a	3.67 d	73.44 c	76.60 b
LSD (0.01)	353.03	45.44	0.4136	0.3253	1.7565	22.6154

Treatment means having the same letters along the Colum are not significantly different from each other at 1% level

Table 4.36: Summary of steaming treatment on physiochemical properties of paddy rice (nerica 2)

Treatment	Gelatinization (temp) breakdown	Gelatinization (maximum viscosity)	Gelatinization(max viscosity) breakdown	Head rice	Deg of milling	Colour value
Steam 100°C	5.50 d	94.6ab	37.33 c	345.30 a	4.21 d	7.435 a
Steam 110°C	6.33 c	93.233 b	42.50 b	292.27 c	7.987 b	7.110 c
Steam 120°C	28.32 a	94.617 a	36.50 cd	332.77 b	5.843 c	7.385 b
Raw rice	10 b	91.05 c	150 a	132.80 d	17.81 a	6.308 d
LSD (0.01)	28.60	1.70	58.24	25.78	2.27	0.39

Treatment means having the same letters along the Colum are not significantly different from each other at 1% level

Table (v) Results of sample colour measurement

Sample code	L	Average	a	Average	b	Average
N2soak50°C	56.92	57.39	+6.56	6.51	+2.39	3.05
steam120°C	57.72		+6.38		+3.39	

	57.74		+6.55		+3.29	
	57.18		+6.53		+3.13	
N2soak26^{o}C	62.28	62.38	+6.26	6.25	+3.31	3.69
Steam100^{o}C	62.19		+6.19		+3.80	
	62.43		+6.33		+3.69	
	62.62		+6.21		+3.94	
N2soak70^{o}C	56.56	56.84	+6.52	6.54	+2.22	2.45
Steam110^{o}C	56.25		+6.60		+2.09	
	57.22		+6.64		+2.65	
	57.32		+6.41		+2.70	
N2soak26^{o}C	56.02	56.55	+6.75	6.72	+1.99	2.32
Steam120^{o}C	56.02		+6.73		+2.25	
	56.87		+6.74		+2.65	
	57.24		+6.67		+2.49	
N2soak50^{o}C	71.85	72.52	+5.79	5.75	+4.05	4.19
Steam110^{o}C	72.18		+5.73		+3.83	
	73.03		+5.65		+4.70	
	73.01		+5.81		+4.18	
N2soak70^{o}C	59.36	59.30	+6.15	6.28	+3.78	3.47
Steam100^{o}C	58.89		+6.17		+3.46	
	59.24		+6.49		+3.17	
	59.62		+6.31		+3.46	
N2unparboil	75.91	75.85	+5.84	5.89	+3.45	3.67

Paddy rice	75.01		+5.87		+3.47	
	76.32		+5.93		+3.91	
	76.17		+5.92		+3.63	
N2soak26°C	61.01	61.41	+6.17	6.07	+3.78	3.93
Steam110°C	60.98		+6.04		+3.71	
	61.62		+6.08		+4.22	
	62.02		+5.98		+4.20	
N2soak50°C	63.62	63.69	+5.81	5.97	+4.84	5.13
Steam100°C	63.76		+5.94		+5.48	
	63.38		+6.13		+5.12	
	63.98		+6.01		+5.08	
N2soak70°C	64.92	65.23	+6.99	6.12	+5.11	4.85
Steam120°C	64.82		+6.19		+4.62	
	65.66		+6.12		+5.17	
	65.53		+6.19		+4.85	
N1soak26°C	61.28	61.17	+6.36	6.94	+2.90	2.79
Steam100°C	61.06		+8.38		+3.25	
	61.34		+6.51		+2.50	
	61.06		+6.50		+2.51	
N1soak70°C	61.95	63.29	+6.41	6.29	+4.25	4.70
Steam120°C	62.23		+6.38		+4.59	
	63.44		+6.13		+5.48	
	63.52		+6.26		+4.88	

N1soak50°C	69.49	69.76	+5.55	5.62	+3.35	4.05
Steam110°C	69.50		+5.58		+4.17	
	69.93		+5.75		+4.10	
	70.10		+5.73		+4.09	
N1soak26°C	54.44	54.88	+6.92	6.99	-0.75	-0.29
Steam120°C	54.37		+7.10		-0.30	
	55.55		+6.97		-0.07	
	55.17		+6.99		-0.02	
N1soak50°C	54.22	54.82	+6.90	6.79	+0.18	0.84
Steam120°C	54.88		+6.71		+0.99	
	54.85		+6.97		+0.81	
	55.36		+6.57		+1.38	
N1soak70°C	57.98	58.33	+6.16	6.24	+2.93	2.93
Steam100°C	57.89		+6.18		+2.72	
	58.99		+6.30		+3.10	
	58.55		+6.32		+2.95	
N1unparboil	74.31	74.81	+5.64	5.68	+3.21	3.36
Paddy rice	74.18		+5.66		+3.00	
	75.29		+5.78		+3/46	
	75.47		+5.62		+3.77	
N1soak50°C	55.88	56.52	+6.57	6.50	+0.65	0.96
Steam100°C	56.63		+6.46		+0.69	
	56.72		+6.46		+1.31	

	56.85		+6.50		+1.17	
N1soak26^{o}C	58.44	58.27	+6.46	6.53	+2.33	1.94
Steam110^{o}C	57.85		+6.55		+1.84	
	58.51		+6.51		+1.98	
	58.28		+6.59		+1.62	
N1soak70^{o}C	55.23	55.66	+6.85	6.77	+1.13	1.45
Steam110^{o}C	55.46		+6.81		+1.47	
	56.19		+6.75		+1.57	
	55.77		+6.65		+1.62	

Table (vi) Summary of colour measurement for Nerica (1) at different soaking and steaming temperatures shown below: unparboil 74.81, 5.68, and 3.36

Soaking temperature (^{o} c)	Steaming temperature (^{o} c)	L	a	b
26	100	61.17	6.94	2.79
26	110	58.27	6.53	1.94
26	120	54.88	6.99	0.29
50	100	56.52	6.50	0.96
50	110	69.76	5.62	4.05
50	120	54.82	6.79	0.84
70	100	58.33	6.24	2.93
70	110	55.66	6.77	1.45
70	120	63.29	6.29	4.70

Table (vii) Summary of colour measurement for Nerica (2) at different soaking and steaming temperatures shown below: unparboil 75.85, 15.89 and 3.67

Soaking temperature (^{o}c)	Steaming temperature (^{o}c)	L	a	b
26	100	62.38	6.25	3.69
26	110	61.41	6.07	3.93
26	120	56.55	6.77	2.32
50	100	63.69	5.97	5.13
50	110	72.52	5.75	4.19
50	120	57.39	6.51	3.05
70	100	59.30	6.28	3.47
70	110	56.84	6.54	2.45
70	120	65.23	6.12	4.85

Table (viii) Statistical results for physical property (ANOVA Table for Lightness L-colour value N1)

```
S = 4.624   R-Sq = 76.90%   R-Sq (adj) = 68.24%

                         Individual 99% CIs for Mean Based on
                         Pooled StDev
Level     N    Mean StDev -+---------+---------+---------+--------
steam100  3  58.673  2.344   (--------*--------)
steam110  3  61.230  7.502     (--------*--------)
steam120  3  57.663  4.873  (--------*--------)
```

steam0   3 74.810 0.000   (--------*--------)

-+---------+---------+---------+--------

50   60   70   80

Pooled StDev = 4.624

Table 4.2 Statistical results for physical property (ANOVA Table for Lightness L-colour value N2)

S = 3.157   R-Sq = 88.67%   R-Sq(adj) = 84.43%

Individual 99% CIs For Mean Based on

Pooled StDev

Level   N   Mean StDev -------+---------+---------+---------+--

steam100 3 66.710 5.230   (------*-------)

steam110 3 60.647 3.488   (-------*------)

steam120 3 56.723 0.599 (-------*-------)

steam0   3 75.850 0.000   (-------*------)

-------+---------+---------+---------+--

56.0   64.0   72.0   80.0

Pooled StDev = 3.157

Table 4.5 Statistical results for physical property (ANOVA Table for colour intensity value for Nerica 1)

S = 0.3581   R-Sq = 37.32%   R-Sq(adj) = 13.81%

Individual 99% CIs For Mean Based on

Pooled StDev

Level   N   Mean   StDev --+---------+---------+---------+-------

steam100 3 6.9813 0.4610   (----------*-----------)

steam110 3 6.8876 0.0654   (-----------*----------)

steam120 3 7.2299 0.5442   (----------*-----------)

steam0   3 6.5994 0.0000 (-----------*-----------)

--+---------+---------+---------+-------

6.00   6.60   7.20   7.80

Pooled StDev = 0.3581

Table (ix) Statistical results for physical property (ANOVA Table for colour intensity for Nerica 2)

S = 0.2716   R-Sq = 99.68%   R-Sq(adj) = 99.56%

Individual 99% CIs For Mean Based on

Pooled StDev

Level   N   Mean StDev --------+---------+---------+---------+-

steam100 3   7.435 0.380   (-*-)

steam110 3   7.110 0.124 (-*)

steam120 3   7.385 0.368   (-*)

steam0   3 16.308 0.000   (*-)

--------+---------+---------+---------+-

9.0   12.0   15.0   18.0

Pooled StDev = 0.272

Table (x) Statistical results for physical property (ANOVA Table for hue value thus a-value N1)

S = 0.3564   R-Sq = 68.74%   R-Sq(adj) = 57.02%

Individual 99% CIs For Mean Based on

```
                    Pooled StDev
Level     N    Mean   StDev  ---------+---------+---------+---------+
steam100  3  6.5600  0.3538            (---------*---------)
steam110  3  6.3067  0.6067         (---------*---------)
steam120  3  6.8500  0.1217               (---------*---------)
steam0    3  5.6800  0.0000  (---------*---------)
                    ---------+---------+---------+---------+
                         5.60      6.30      7.00      7.70
```

Pooled StDev = 0.3564

Table (xi) Statistical results for physical property (ANOVA Table for hue value thus a-value N2)

S = 0.2874   R-Sq = 99.69%   R-Sq(adj) = 99.57%

```
                    Individual 99% CIs For Mean Based on
                    Pooled StDev
Level     N    Mean  StDev  --+---------+---------+---------+-------
steam100  3   6.363  0.364  (-*-)
steam110  3   6.077  0.391  (-*-)
steam120  3   6.310  0.213  (-*-)
steam0    3  15.890  0.000                          (-*-)
                    --+---------+---------+---------+-------
                    6.0       9.0      12.0      15.0
```

Pooled StDev = 0.287

Table (xii) Statistical results for physical property (ANOVA Table for b-value N1)

```
S = 1.521   R-Sq = 16.78%   R-Sq(adj) = 0.00%

                        Individual 99% CIs For Mean Based on
                        Pooled StDev
Level     N   Mean  StDev  ------+---------+---------+---------+---
steam100  3  2.227  1.099    (--------------*--------------)
steam110  3  2.480  1.382      (-------------*--------------)
steam120  3  1.843  2.477  (--------------*--------------)
steam0    3  3.360  0.000          (--------------*--------------)
                        ------+---------+---------+---------+---
                            0.0       2.0       4.0       6.0

Pooled StDev = 1.521
```

Table (xiii) Statistical results for physical property (ANOVA Table for colour b-value N2)

```
S = 0.2260   R-Sq = 97.63%   R-Sq(adj) = 96.74%

                          Individual 99% CIs For Mean Based on
                          Pooled StDev
Level     N    Mean   StDev  --------+---------+---------+---------+-
steam100  3  6.0933  0.2977                         (---*---)
steam110  3  6.3267  0.3109                           (---*----)
steam120  3  6.6667  0.1380                              (----*---)
steam0    3  3.6700  0.0000  (----*---)
                          --------+---------+---------+---------+-
                               4.0       5.0       6.0       7.0
```

Pooled StDev = 0.226

Table (xiv) Statistical results for physical property (ANOVA Table for milling yield (%) N1)

S = 1.804   R-Sq = 83.63%   R-Sq(adj) = 77.50%

```
                      Individual 99% CIs For Mean Based on
                      Pooled StDev
Level     N   Mean  StDev  --------+---------+---------+---------+-
steam100  3  80.340  0.466                 (--------*--------)
steam110  3  78.007  3.557            (--------*--------)
steam120  3  80.353  0.388                 (--------*--------)
steam0    3  72.200  0.000  (--------*-------)
                      --------+---------+---------+---------+-
                          72.0      76.0      80.0      84.0
```

Pooled StDev = 1.804

Table (xv) Statistical results for physical property (ANOVA Table for milling yield (%) N2)

S = 1.221   R-Sq = 83.29%   R-Sq(adj) = 77.02%

```
                      Individual 99% CIs For Mean Based on
                      Pooled StDev
Level     N   Mean  StDev  ---+---------+---------+---------+------
steam100  3  78.893  0.702               (-------*-------)
steam110  3  77.467  2.300           (-------*-------)
steam120  3  78.853  0.424               (-------*-------)
```

steam0   3 73.440 0.000 (-------*-------)

---+---------+---------+---------+------

72.0   75.0   78.0   81.0

Pooled StDev = 1.221

Table (xvi) Statistical results for physical property (ANOVA Table for head rice (g) N1)

S = 90.09   R-Sq = 69.36%   R-Sq(adj) = 57.87%

Individual 99% CIs For Mean Based on

Pooled StDev

Level   N   Mean   StDev ------+---------+---------+---------+---

steam100 3 359.47   30.41   (---------*----------)

steam110 3 277.33 156.04   (----------*----------)

steam120 3 325.40   84.79   (----------*----------)

steam0   3   74.20   0.00 (----------*----------)

------+---------+---------+---------+---

0   160   320   480

Pooled StDev = 90.09

Table (xvii) Statistical results for physical property(ANOVA Table for headrice N2)

S = 56.66   R-Sq = 77.08%   R-Sq(adj) = 68.49%

Individual 99% CIs For Mean Based on

Pooled StDev

Level   N   Mean   StDev --------+---------+---------+---------+-

steam100 3 345.30   11.99   (--------*--------)

steam110 3 292.27 100.69   (--------*---------)

steam120 3 332.77   50.60   (--------*--------)

steam0   3 132.80   0.00 (--------*--------)

--------+---------+---------+---------+-

120   240   360   480

Pooled StDev = 56.66

Tablee (xviii) Statistical results for physical property (ANOVA Table for hardness N1)

S = 561.2   R-Sq = 86.09%   R-Sq(adj) = 80.88%

Individual 99% CIs For Mean Based on

Pooled StDev

Level   N   Mean StDev --+---------+---------+---------+-------

steam100 3 3007.2 715.8   (------*------)

steam110 3 3371.9 718.2   (------*-------)

steam120 3 3741.3 481.1   (------*------)

steam0   3   809.6   0.0 (------*-------)

--+---------+---------+---------+-------

0   1500   3000   4500

Pooled StDev = 561.2

Table (xiv) Statistical results for physical property (ANOVA Table for Hardness N2)

S = 245.3   R-Sq = 98.21%   R-Sq(adj) = 97.54%

Individual 99% CIs For Mean Based on

Pooled StDev

Level   N   Mean StDev --------+---------+---------+---------+-

steam100 3 3970.9 141.7   (---*---)

steam110 3 4177.1 344.8   (---*---)

steam120 3 4398.5 319.1   (---*---)

steam0   3   771.9   0.0 (---*---)

--------+---------+---------+---------+-

1200   2400   3600   4800

Pooled StDev = 245.3

Table (xx) Statistical results for physical property (ANOVA Table for Maximum viscosity for Nerica 1)

S = 11.24   R-Sq = 51.63%   R-Sq(adj) = 33.50%

Individual 99% CIs For Mean Based on

Pooled StDev

Level   N   Mean StDev -------+---------+---------+---------+--

steam100 3 87.23 12.85   (----------*----------)

steam110 3 86.18 14.58   (----------*----------)

steam120 3 67.72 11.30 (----------*----------)

steam0   3 92.95   0.00   (---------*----------)

-------+---------+---------+---------+--

60   80   100   120

Pooled StDev = 11.24

Table (xxi) Statistical results for physical property (ANOVA Table for Maximum viscosity for Nerica 2)

S = 1.184   R-Sq = 69.39%   R-Sq(adj) = 57.91%

Individual 99% CIs For Mean Based on

```
                 Pooled StDev
Level     N    Mean  StDev  -----+---------+---------+---------+----
steam100  3  94.600  0.000             (--------*---------)
steam110  3  93.233  2.367         (--------*--------)
steam120  3  94.617  0.029             (--------*---------)
steam0    3  91.050  0.000  (--------*--------)
                            -----+---------+---------+---------+----
                               90.0      92.5      95.0      97.5
Pooled StDev = 1.184
```

Table (xxii) Statistical results for physical property (ANOVA Table for breakdown value for Nerica 1)

```
S = 16.26   R-Sq = 91.23%   R-Sq(adj) = 87.94%
                 Individual 99% CIs For Mean Based on
                 Pooled StDev
Level     N    Mean  StDev  ------+---------+---------+---------+---
steam100  3   12.50  16.89    (------*-----)
steam110  3   22.33  27.79     (-----*------)
steam120  3    2.50   0.50  (------*-----)
steam0    3  110.00   0.00                   (-----*-----)
                            ------+---------+---------+---------+---
                                  0        50       100       150
Pooled StDev = 16.26
```

Table (xxiii) Statistical results for physical property (ANOVA Table for breakdown value for Nerica 2)

```
S = 40.48   R-Sq = 68.04%   R-Sq(adj) = 56.05%

                        Individual 99% CIs For Mean Based on
                        Pooled StDev
Level     N    Mean  StDev  ------+---------+---------+---------+---
steam100  3   37.33  25.11  (----------*-----------)
steam110  3   42.50  56.33   (----------*----------)
steam120  3   36.50  52.44  (----------*----------)
steam0    3  150.00   0.00              (----------*-----------)
                        ------+---------+---------+---------+---
                              0        70       140       210

Pooled StDev = 40.48
```