KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

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DEPARTMENT OF FOOD SCIENCE AND TECHNOLOGY

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DEVELOPMENT AND QUALITY CHARACTERISTICS OF YAM BEAN (PACHYRHIZUS EROSUS) FLOUR AND ITS PERFORMANCE IN BREAD

THIS DISSERTATION IS PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF M.Sc. DEGREE IN FOOD SCIENCE AND TECHNOLOGY

BY

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MAY 2013

DECLARATION

I declare that I have wholly undertaken the study reported herein under the supervision of Professor Ibok N. Oduro and that except portions where references have been duly cited, this dissertation is the outcome of my research.

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ACKNOWLEDGEMENT

This study was undertaken at the Department of Food Science and Technology, Kwame Nkrumah University of Science and Technology (KNUST), and the Food Research Institute, Council for Scientific and Industrial Research CSIR-FRI), under the supervision of the Prof. (Mrs.) Ibok N. Oduro (Supervisor), of the Department of Food Science and Technology (KNUST). I wish to thank my supervisor, for all the highly constructive criticisms, contributions and comments, as well as their invaluable direction and help, which have made this study possible.

The work was undertaken with financial assistance by Forum of Agricultural Research in Africa (FARA).I am extremely grateful for the support.

My most heartfelt gratitude goes to my parents, husband, and more particularly to my children for their support and encouragement. My special gratitude also goes to the technical staff of the Chemistry Division, Nutrition Unit and the Processing and Engineering Division of the CSIR – Food Research Institute for their assistance in the product development and quality evaluation phase of the studies. I wish to make special mention of the following technical staff for their assistance: Mr. Amey, Mr. David Ankrah, Mr. Appolonius Nyarko, Frank Mboom, Mrs. Iris Tamakloe and Mrs. Alice Padi and their assistants.

Above all, I am most grateful to the Almighty God who has been with me through it all and has been my help, wisdom and strength.

DEDICATION

This thesis is dedicated to my parents, Mr. and Mrs. Emmanuel Martinson Ayeh, my dear husband, Javiel Sackey Buckman, and my children Bryan Kweku Buckman and Karen Naadu Buckman.

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ABSTRACT

This study was undertaken to develop a standard method for the production of high quality flour from *Pachyrhizus erosus* (*P. erosus*) tubers and to evaluate the quality characteristics of the flour as well as its use in baked products. The experimental design used was a 2 x 3 factorial design with three replicates involving the two factors of peeling (peeling and no-peeling) and three pre-treatments (blanching at 100^{o}C for 3 min; soaking in 0.1% sodium metabisulphite solution for 3 min; and a no-treatment control). Quality determinants used to establish standard process include ease of drying, colour, pH and ease of milling as indicated by the particle size. Blend formulations with *P. erosus* flour at 0, 10, 20 and 30 % replacement levels for wheat flour were used to assess the effect of the *P. erosus* flour in bread making. Peeling with sodium metabisulphite pretreatment produced the whitest *P. erosus* flour as indicated by the highest L*-value of 90.89. Flour samples from unpeeled roots had lower pH (5.96) than those from peeled samples (6.65). The combined effects of peeling and metabisulphite or blanching treatment produced flours with desirable pH values. The standardized flour produced recorded a moisture content of 5.8%**,** which is within the acceptable range for commercial flours. The crude fat content was 0.54% and crude protein was 5.68%. Total carbohydrates content was 85.85% with a crude fiber content of 6.26%. Total sugars and sucrose contents of the flour were 30.46% and 19.12% respectively, with a starch content of 21.0%. The *P. erosus* flour produced and pasting temperature of 70.6°C which is lower than that of sweet potato or taro flour. Peak viscosity was 14.5 BU. The swelling power obtained for the *P. erosus* flour was 752.9g/100g at 85°C with a solubility index of 54%. With regards to the performance of the *P. erosus* flour in bread production with wheat flour, loaf weight of composite bread samples ranged from 521 to 530 g, while loaf volumes ranged from 1,221 to 1,269 cm^3 with significant differences ($p < 0.05$) among the different bread samples. As the level of *P. erosus* flour substitution increased, the loaf volume decreased. Overall acceptability scores of all the bread samples prepared with the flour blends were only slightly lower than that for the traditional bread. It is concluded that the standard procedure established is able to produce flour of high quality grade that could be used in composite flours for bread making to reduce the over dependence on imported wheat flour.

KNUST

TABLE OF CONTENTS

KNUST

KNUST

KNUST

KNUST

KNUST

KNUST

LIST OF TABLES

KNUST

LIST OF FIGURES

KNUST

CHAPTER ONE

1.0 INTRODUCTION

Protein-energy malnutrition and food insecurity are among the most serious problems facing tropical African countries today (Bhat and Karim 2009). It has been estimated that 800 million malnourished people live in some of the least developed countries (Myers, 2002). High prices of available staple foods and policy constraints on food imports are also contributing factors that have been worsening the food situation in developing countries (Weaver, 1994). Also contributing to this problem is the underutilization of most of the crops found in this part of the world. These crops include legumes, root crops and cereals which have been investigated and found to be inexpensive and possess good nutritive value for the solution of protein-energy malnutrition (Bhat *et al*., 2009). The potential of roots and tubers for addressing the food insecurity situation in West African countries comes only next to cereals, but the utilization of these crops remains under exploited. Although several legumes are available on the market, in most cases production rate compared with consumption has mostly remained unmet (Ali *and* Kumar 2000).

Pachyrhizus erosus is a legume plant belonging to the genus *Pachyrhizus* which has been defined to be a close relative of soybean and phaseolus bean (Ingham, 1990). The genus comprises five species (Sorensen, 1988). Three of these are cultivated for their edible tuber and the remaining two are found growing wild. The three cultivated species include, *Pachyrhizus ahipa*, from Bolivia and Northern Argentina, *Pachyrhizus erosus* from the Semi-arid tropics of Central

America, Philippines, West Africa and *Pachyrhizus tuberosus* from the tropical lowlands of the Adean mountain range. Among the cultivated species, only the *P. erosus*, which is commonly called Mexican yam bean, has been introduced more or less tropically. The yam bean (*P. erosus*) is a legume root crop whose tuber is consumed raw by the local people who consider it to be energy-rich and easily digestible food. It is widely used as cheap carbohydrate source for human and livestock and it has been adjudged to be of good nutritional value (Nielsen 1995). With an average yield of 60t/ha, the production capacity of yam bean is reported to be the highest among the tuber-bearing legumes (Juarez-Garcia *et al*., 1994). The tuber of the yam bean has on dry matter basis high starch content with interesting physicochemical properties for the food industry (Bergthaller *et al*., 2001). It is a good source of inulin, which is a form of sugar with low caloric value with immense benefits to diabetics. Its high phyto-nutritional profile comprises of dietary fiber, and antioxidants, in addition to traces of minerals and vitamins (Slavin 2011). Fresh yam bean tubers are rich in Vitamin C and contain small amounts of valuable B-complex groups such as folates, riboflavins, pyridoxine, panthothenic acid and thiamin. Studies by Alvavez *et al*. (1998) on the characterization of the phytochemical content in yam bean revealed that, rotenone and its derivatives are the major active ingredients responsible for its biological activity. The rotenone content of yam bean seeds is quite high (nearly 1% of seed weight) thus making it toxic for human consumption. However, the rotenone has been widely explored to be used as a potential insecticide (Duke, 1981). The matured seeds contain high amounts of good quality oil, and,

KNUST

according to literature, the oil quality is comparable to groundnut and cottonseed oil if the rotenone is removed (Sorensen *et al.,* 1994). Thus this is an area where researchers should focus their attention to help improve its use through the removal of the rotenone. This will lead to food security. In terms of agronomic importance, Marcarian (1978) recognized this crop as a symbiotic legume and considers the crop as a potential to fix nitrogen in the field to reduce cost of farming. Yam bean is also characterized by optimal time to harvest, high yield potential and high nutritive quality which make it a high agricultural export commodity.

KNUST

1.1 Statement of the problem

Although yam bean has been demonstrated to have the potential to be integrated into the marginal, drought-prone farming systems of Sub-Saharan Africa, where malnutrition is prevalent, it has never succeeded in becoming an established crop. The yam bean crop still remains an underutilized commodity because of limited information on its wider food uses. To date, the main source of flour in the baking industry is wheat flour, which is not produced in Ghana. This has become a challenge to most bakers due to the rising cost. However the physicochemical properties of yam bean flour and its potential application as composite flour in the baking industry need an exploration. Although several common edible flours have been developed from cereals, legumes and root and tuber crops, and are available on the Ghanaian market, in most instances, their food uses are limited. In addition preservation and processing methods for yam bean flour production have not been

extensively investigated to develop an intermediate product with desirable characteristics that will help broaden its utilization base.

1.2 Justification

The present level of food insecurity facing developing countries, especially African countries, requires that maximum research and development efforts should be made to exploit and promote the food uses of all available food crops that can easily be produced under the local climatic conditions. The yam bean has been found to grow well in Ghana, but despite its commercial potential the crop still remains underutilized. Developing and establishing the quality characteristics of shelf-stable flours from the yam bean will facilitate the development of acceptable recipes. Development of food products from yam bean roots provides a means of enhancing the crop's commercial potential. This will lead to increased utilization of the crop and for improved food and nutrition security as well as more income to families engaged in the production of the yam bean in response to increase in demand. Enhancing the utilization of the yam bean through product development and quality characterization is essential in promoting food security, meeting nutritional needs and increasing the revenue margin of farmers. The results obtained from this study will enhance the understanding and knowledge about yam bean flour production, its physicochemical and functional as well as sensory properties in substituting it in wheat flour.

KNUST

1.3 Main objective

The main purpose of this study is to develop a standard method for the production of yam bean flour and to establish its quality characteristics.

Specific objectives

The specific objectives of the study were:

- To determine the effect of sodium metabisulphite and blanching on the colour and moisture content of yam bean flour and its particle size distribution.
- To determine the physicochemical and functional characteristics of the standard flour developed from *P. erosus*
- To determine the functionality of the *P. erosus* flour as a composite of wheat flour in bread

KNUST

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Geographical Distribution of Pachyrhizus. erosus

Pachyrhizus erosus (*P. erosus)* originated in Mexico and Central America, as far south as Costa Rica, and the crop has been known in cultivation in this region from approximately 1000 BC. (Globinmed, 2011). It was said to be originally introduced to the Far East by the Spanish through the Acapulco-Manila route, reaching Amboina prior to the end of the 17thCentury. *P. erosus* is presently found in cultivation throughout the tropics. Even though there are no major growing centers the plant is known to grow well in tropical and sub-tropical regions,acid and sodic soils and has high potential in nitrogen fixation (Bhat *et al*., 2009).The plant is found growing wild throughout tropical Africa, most commonly in Central and Western Africa (Wokoma and Aduagba 2001).

According to Sorensen (1990) *P. erosus* has been introduced into several African countries including Tanzania, Senegal, Sierra Leone, Cameroon and DR Congo. In an effort to promote and increase the utilization of the crop, several experiments have been undertaken to evaluate the legume root crop under West African conditions using different species of yam bean from different ecological origins. These were tested in field trials at different locations. For West Africa, the only data available are yield estimates from ten *P. erosus* accessions in Senegal (Annerose and Diouf, 1998). Currently in Ghana it is being cultivated by the CSIR –Crops Research Institute in Kumasi on experimental basis.

2.2. Agronomic Characteristics and Cultivation of Pachyrhizus erosus

Pachyrhizus erosus or the Mexican yam bean is a small genus of five species of tropical and subtropical plants growing from large, often edible taproot. Scientifically, it can be classified into the Plantae kingdom and belonging to the genus *Pachyrhizus*. The species are *Pachyrhizus ahipa*, *Pachyrhizus erosus*, *Pachyrhizus ferrugineus*, *Pachyrhizus panamensis*, and *Pachyrhizus tuberous* (Vietmeyer, 1992). Among the five species within the genus the two species commonly cultivated are *P. erosus* and *P. Ahipa* both of South America origin. The yam bean or jicama or *Pachyrhizus erosus* is a brown coloured root vegetable which is very similar to a turnip. It is described as a climbing plant with a long and tuberous root that may grow in five months with an average length of 6 – 8 feet and an average weight of 50 pounds or more (Stephens 2007).

KNUST

P. erosus is said to be quite tolerant of differences in climatic conditions, but is generally associated with regions having moderate precipitation or high precipitation with well drained soils (Globinmed, 2011). A well-drained soil is preferable, as the crop does not tolerate water-logging. According to Orting *et al* (1996), August to October is the planting period with productive pruning in November to March, and it takes 4 – 7 months to mature as a legume. Its propagation strategy is mainly self-pollination where the most vigorous plants are selected for seed production. The plant is pruned in order to improve yield and tuber growth. The seed for the next harvest is selected during harvest on the basis of seed size and quality (Orting *et al.,* 1996).

The Mexican yam bean is traditionally grown as intercrop with maize. Sorensen (1996) reported that the flowering period takes 87 days after sowing. *P. erosus* thrives well in cool tropical valley with altitude 1800 – 2900m and average temperature of 16 – 18 ºC. It is normally grown along river banks in loamy soil with pH of 6 – 8 (Orting *et al.*, 1996).

2.3 Post-harvest Storage of P. erosus

Post-harvest storage is a problem of concern in exporting, distribution, and marketing of farm produce. Most crops suffer the improper post-harvest treatment such as chilling injury, poor handling and extreme temperatures. In the case *P. erosus* like other crops low temperature storage (below 20^{o}C) is found to reduce storage life with the optimal storage temperature ranging between 12.5 – 17.5 ºC. Washing, trimming and dipping in high concentration of chlorine solution helps to reduce the microbial load prior to usage (Cantwell *et al*., 1992). Another factor is prolonged storage which has been found to alter the starch /sugar ratio (Sorensen, 1996). Chen (1988) reported that after three months of storage at 25.5ºC the sucrose content tripped and only one-sixth of the starch is retained. In Bolivia, some producers leave the tubers in the open sun for close to 2 weeks prior to marketing to obtain sweeter tubers (Orting *et al.*, 1996). Splitting or cracking of tubers prior to harvest may be a serious problem under certain climatic conditions. The crop should be irrigated for some weeks before harvest. Tubers that are physically damaged during harvest are susceptible to attack by common fungi and increased dehydration when stored (Cantwell *et al*., 1992). Wounded yam bean

tubers suffer greatly from textural changes, decay and internal browning caused by the fungi *Rhizopus stolonifer and Penicillium sp.* when stored at low temperatures (<10°C) and high relative humidity (>80%) (Bruton, 1983). Temperatures below 10°C result in chilled-induced changes in colour and texture, and prolonged storage converts starch to sugar (Orting *et al.*, 1996).

2.4 Economic Importance and Utilization of Root and Tubers in Africa

2.4.1. Economic importance

KNUST

Root and Tubers are important primary food crops, playing a critical role in the global food system, particularly in the developing world, where they are ranked among the top ten food crops (Scott *et al.*, 2000). The production of roots and tubers in developing countries has an estimated annual value of more than 41 billion U.S. dollars or nearly one fourth the values of the major cereals (Scott *et al.*, 2000). Root and tubers contribute to the energy and nutrition requirement of more than two billion people and constitute an important source of income in rural and marginal areas. They have multiple uses, most notably as food security crops, regular food crops, cash crops and are increasingly used as livestock feed and raw materials for industrial purposes (Scott *et al.*, 2000).Root and tuber crops contribute more than 600 calories per day in the following countries: including Angola, DRC, Congo-Brazzaville, Central African Republic, Mozambique, Ghana, Cote d'Ivoire, Rwanda, Togo and Benin (FAO, 2000). Nigeria produces approximately 40% of the entire root and tuber crops in Africa, being the largest

producer of cassava and yam which are approximately 35% and 70% respectively, of the total production in South Sahara Africa (SSA).

2.4.2 Utilization of root and tuber crops

Root and tubers are important sources of carbohydrate and energy and are used as staple foods in tropical and sub-tropical countries (Liu *et al*., 2006). The fresh roots and tubers cannot be stored for long because of the high moisture content, and transportation of these crops to urban market centers is difficult and expensive. Fresh tubers like cassava contain varying amounts of cyanide which is toxic to humans and animals. It is therefore important to process them into various forms in order to increase the shelf life, facilitate transportation, marketing and increase their utilization base. Processing reduces and stabilizes seasonal fluctuations of supply of the crop. Because roots and tubers are versatile, they offer many opportunities for product development.

Although some of these crops are relatively rich in protein or certain vitamins, they are mainly used as carbohydrate sources in a wide range of products. Many industries that could use root and tuber crops maintain rigid standards for specific raw material qualities such as purity, hygiene, physicochemical composition, and functional properties. Products of root and tuber crops are manufactured through a wide range of processes. For each product there are generally different technological processes. Starch for example, can be extracted either manually with rustic equipment or by automated equipment. The type of technology depends on factors such as raw material characteristics, raw material cost, cost of

KNUST

labour, product quality and many others. Basically, root and tuber crops are transformed into flour by a series of processes which include: selecting /grading and cleaning; peeling (manual, mechanical, chemical, or steam); sulphating to prevent browning; reduction of size by slicing , chipping /rag , or grating/grasping; blanching to prevent enzyme action; drying (solar or artificial) using batch or continuous processes; milling (in hammer, pin, or roller mills; Grading by mesh size according to the end use; and packaging for storage or future use.

KNUST

2.4.3 Utilization of P. erosus

The yam bean tuber is consumed raw by the local people who consider it as an energy-rich and easily digestible food (Sorensen, 1996). The plant produces large roots like potato and cassava which can be consumed cooked or processed. The tuberous root qualities range from forms with a low dry matter content (less than 10%) consumed fresh to forms that are only consumed when cooked, because of their high dry matter content (25-30%) (Sorensen 1996). On the other hand the seeds have high oil content but are not edible because they contain toxic rotenone. This is one reason why people shun away from the consumption of yam bean seed. However, if the rotenone could be removed the seed would provide a good protein source which could be used in the food industry as an alternative to both ground nut and cotton seed oil (Santos *et al* 1996).

Dorpoto *et al*, (2011) developed a detailed procedure for yam bean flour production, involving the effects of grating without pressing, slicing as well as grating and pressing. The pressing step was recommended to avoid the marked off-flavours, limiting its conservation and use. Kale *et al*., (2007) in their work used sun-drying in the production of yam bean flour. There is, however, a dearth of literature on the effect of peeling and blanching in addition to sodium metabisulphite pre-treatment on P. *erosus* flour which this study seeks to find.

KNUST

2.5 Nutritional Value of P. erosus

There have been several studies conducted on the nutritional composition of the tuber of yam bean. (USDA,1984;Taderal *et al*., 1984; Hoof and Sorensen,1989; Ratanadilok and Wanyangukura, 1994). It is reported that the protein content in *P. erosus* and for all yam bean varieties is estimated to be almost half that in potato but double the protein content of sweet potato (Velacasco and Gruneberg, 1999; Noman *et al*., 2007). The carbohydrate content was found to be lower than in potato but was half in sweetpotato. It also contains less than 1% lipids on dry matter basis, and in terms of crude fiber *P. erosus* tuber has a value of 1.4% which is almost 14 times higher than that in potato and 4 times higher than in sweetpotato. The total reducing sugars was 1.83% with total soluble sugars being 2.13 % (Norman *et al.*, 2007). When consumed fresh the plant is high in moisture. The moisture content is about 82.01% which is significantly higher than that of sweetpotato, cassava and other tubers. Duke (1981) has reported the presence of adenine and choline in the tuber. In an experiment to study the adverse effects of

the consumption of *P. erosus* tubers Noman *et al.*,(2007) reported that there is very low level of anti–nutritional factors in the tuber unlike the seed and this may not affect its nutritional value. The consumption of the tubers is therefore recommended for both human and livestock. Some of the anti-nutritional factors are phytin, phytin-pectin, and tannic acid.

2.6 Proximate Composition of the *Pachyrhizus* species

It is reported that the flour from *Ahipa* root which is one of the *pachyrhizus species* can be considered an alternative food source of gluten-free products, with some considerable amount of protein, fiber and minerals such as potassium, calcium and iron (Doporto *et al.*, 2010). In terms of crude protein, Zaklan *et al*. (2007) reported that *P. ahipa* root flour has more protein than that of other root and tuber crops like cassava, sweetpotato and yam. Compared to values reported by Sabanis and Tzia (2009) the *P. ahipa* root flour is lower in protein at a value of 8.61% than that of wheat flour which is 11.8%, but similar to values found in corn which is 7.5% and rice 7.0%.Yam bean flour has similar starch content to that of sweetpotato flour (Doporto *et al.*, 2010; Lebot *et al.*, 2009). Noman *et al.*, (2007) reported that *P. erosus* has a lower value of ash of than sweetpotato and potato.

2.7 Starch and Amylose Content of Yam Bean (*P. erosus*)

The starch content of *P. erosus* is reported to be between 45 – 55% with sugars between 8 – 24%. The yam bean starch has similar properties to those of cassava starch, and contains about 23% amylose. This makes the yam bean a potential

new source of starch (Melo *et al.*, 1994). They are usually small size granules (≤10μm) present in different geometric forms (Melo *et al.*, 1994). Current efforts are geared towards the substitution of wheat flour with flours from root and tuber crops to reduce cost of bread production. The yam bean has additional advantages in its colour, flavour and high content of sugar for a better composite with wheat flour for products like bread and pastries.

2.8 Effects of Dehydration

KNUST

The most commonly used drying method include sun drying, convectional air drying, vacuum drying and osmotic drying (Krokida and Maroulis, 2001). Each drying method has some characteristic drying parameters which can be regulated; changing the moisture transport mechanism and the drying rate. The two processes that occur during drying include the addition of heat and the removal of moisture from the food. Nutritional losses occur more during drying due to the application of heat than to the removal of moisture. Generally, except for thiamine (vitamin B1), removal of moisture results in increased concentration of nutrients. The changes that occur during concentration will depend on the content of the mixture and the temperature at which the process takes place. Generally, there is a decrease in water content and corresponding increase in other components (Morris *et al*., 2006). Losses during the drying process will depend on: preparation procedures before drying, e.g. slicing, blanching, drying temperature, drying time storage conditions.

According to Fellows (2000) all products undergo changes during drying and storage that result in the reduction in their quality compared to the fresh material. The physical and chemical changes occurring during drying or processing will improve certain characteristics of the final product, but in most cases, a loss of nutrients and organoleptic properties has been reported (Karel and Young, 1989; Nykanen and Nykanen, 1987; Garcia *et al.,* 1988; Paakkonen *et al.*, 1989)

KNUST

The proper handling of these reactions ensures that the product has a high nutritional value as well as significant extended shelf life. According to reports by various workers, drying method and the physiochemical changes that occur during drying seem to affect the quality properties of the dehydrated product. More specifically, drying method and processing conditions affect significantly the color, texture, nutritional content, density and porosity and sorption characteristics of the material. So the raw material may end up as a completely different product depending on the type of drying method and conditions applied (Krokida and Maroulis, 2001). Heating does not generally change the total dietary fibre content (Jones *et al.,* 1990), however, heat treatment cause insoluble dietary fibre content to increase as a result of the complexing of its components with protein and amino acids (Matalas *et al*., 2001).

Blanching involves subjecting raw commodities to boiling or near boiling temperature for short periods. The principal function of blanching is to inactivate enzymes but the operation also partially cooks the tissue and renders the cell

membranes more permeable to moisture (Lee, 1983). The process can either be carried out in water or steam. Water blanching is basically the immersion of the commodity in a container of boiling or near boiling water temperature for the necessary time, while in steam blanching the product is exposed to steam. Steam blanching is often preferred to water blanching because there is a smaller loss of nutrients by leaching and, in some vegetables the dried product has an extended shelf life (Steve 2011).

KNUST

2.9. Functional Characteristics

Functional properties are the intrinsic physicochemical characteristics which may affect the behavior of food systems during processing and storage. In other words, functional properties are the properties that give information on how a food ingredient will behave in a food system. These properties include pasting characteristics, swelling power, and solubility, water holding capacity, and swelling volume. Adequate knowledge of these physicochemical properties indicates the usefulness and acceptability of the food product for industrial and consumption purposes.

2.9.1. Pasting Properties

Pasting viscosity characteristics are among the most important parameters used to ascertain the suitability of flours and starches for certain end uses. They have been used to predict the quality of some end products like bread and pastries (Bha-Hachary, *et al.*, 1999; Champegre, *et al.*, 1999). Pasting is the state that is observed after starch passes the gelatinization stage during heating. Continuous

heating results in more starch granules becoming swollen, accompanied by increase in leaching of amylose and amylopectin from the granules as well as the increase of viscosity. When most of the granules have passed through this process, the starch is considered to be pasting and peak viscosity is reached (Thomas and Atwell, 1997). Thus a starch paste is defined as a two phase system composed of a dispersed phase swollen granules and a continuous phase of leached amylose. During cooling, aggregation of amylose phase with linear segments of amylopectin will result in the formation of a strong gel.

KNUST

The ability of starch to form paste is said to be useful for starch as ingredient in food systems to improve food texture during processing. According to Katayama (2002), rheological properties of starch play important roles in food and industrial processing application. Heating and shearing treatments that are usually applied during processing might cause rheological changes of the paste and subsequently might affect the final product (Katayama, *et al.*, 2002). In Ghana, several weaning food formulations developed had to be subjected to hot paste viscosity measurements in order to establish their pasting characteristics during cooking and the effects of various ingredients (Plahar, *et al*., 1983; Annan and Plahar, 1995; Nti and Plahar, 1995).

Melo *et al*. (2003) also reported that the gelatinization temperature of yam bean starch paste ranges from 53 – 63ºC, which is similar to that of cassava. In general pasting temperature of tuber starches is lower than that of cereal starches. The

high lipid and amylose content of cereals probably may be responsible for different pasting behaviour.

2.9.2. Water Holding Capacity

The term water holding capacity WHC) is frequently employed to describe the ability of a matrix of molecule, usually macromolecules present at low concentrations to physically entrap large amounts of water in a manner that inhibits exudation (Fennema, 1996). Food matrices that entrap water in this way include gels of pectin starch and cells of tissues of both plant and animals. The concept of free and bound water within a food is of great practical significance. The status of water has an influence on the structural and textural properties of the food as well as its microbiological stability. Knowledge of WHC is extremely useful in explaining and predicting flour behaviour in food products (Wooton and Bamunuarachi, 1978).

2.9.3 Swelling Power

The swelling power or swelling index is the measure of the ability of starch to imbibe water and swell. It can also be defined as the swollen sediment weight (g) per gram of dry starch. Swelling can also be positively related to the amount of soluble solids leached outside the granules during heating. The initial granule size also influences the swelling and determines the onset of gelatinization. Starch with higher amylose content has significantly lower swelling power. Leach *et al.*, (1959) reported that the amylose acts both as diluent and inhibitor of swelling.

Sanni *et al.,* (2005) reported the swelling of granules reflect the extent of associative forces with the granule, therefore the higher the swelling index, the lower the associative forces. Values for swelling powers at higher temperatures should represent progressive relaxation of the bonding forces within the granules. Dengate (1984) explained that, differences in swelling behavior appeared to be caused by differences in lipid and amylose content as well as granules organization. Li and Yeh (2001) studied various starches and concluded that the thermal and dynamic rheological characteristics are essential to investigate the swelling phenomenon. Temperature has a significant impact on the swelling power. Swinkels (1985) reported yam bean starch has a lower swelling power than that of cassava starch. The high swelling power of potato would be due, among others, to the high phosphate content because the negative charges allowed easier water entrance into the granules.

KNUST

2.9.4. Solubility

The solubility values of starch ranged from 4.25 to 5.96%. Ikegwu (2005) observed a range of water absorption capacity (59.75 – 68.02%) of different starches analyzed. The ability of food materials to absorb water is sometimes attributed to their protein content (Kinsella, 1976). Solubility of starch depends on the type and origin of the starch. Solubility of the starch provides evidence of non-covalent bonding between molecules within the starch granules. Many factors may influence the degree and kind of association at the molecular level. These factors include the ratio of amylose to amylopectin, the characteristics of each

fraction in terms of molecular weight/distribution, degree and length of branching, and conformation (Hoover, 2001; Leach *et al.,* 1959). Rickard *et al*. (1991) reported that temperature of an aqueous suspension of starch is raised above the gelatinization range, hydrogen bonds holding the starch granules continue to be disrupted. Water molecules become attached to the liberated hydroxyl groups and the granules continue to swell, and as a direct result of swelling, there is a parallel increase in starch solubility.

KNUST

2.9.5. Swelling volume

Swelling volume (volume of gel) is used to measure flour or starch swelling properties. Rickard *et al*., 1991). It is the volume of the un-dissolved sediment obtained after centrifugation. The flour swelling volume test measures the cumulative effects of starch quality, specifically amylose/amylopectin ratio as reflected by the volume of gel produced when flour is heated with an excess of water (AACC 2001). Swelling volume of starch is not affected by mild to moderate pre-harvest sprouting. It helps to monitor the impact of starch additive as well.

2.10. Wheat Flours and Composite Flours

2.10.1 Wheat Flours

Wheat is a good source of energy for human consumption in the World, and it provides more than 60 percent calories of the total dietary requirement **(**Sims *et al.,* 2009). Other than gluten flour, all types of wheat flour derive 80% of their

calories from carbohydrate. Depending on the flour type, the percent of calories from protein ranges from 9 to 15%, except for gluten flour, which has 45% protein content. Calories from fat are never more than 5%. Wheat flour also contains dietary fiber, B-vitamins (thiamin, riboflavin, niacin and folacin), calcium, iron, sodium and other trace elements. Wheat (*Triticumae sativum* Desf.) flour of both hard and soft wheat classes has been the major ingredient of leavened bread for many years because of its functional proteins. Wheat contains two proteins glutenin and gliadin. Glutenin provides some unique functional properties in leavened breads. Also gluten is responsible for the protein-starch interaction that provides specific visco-elastic properties in bread dough. These properties are responsible for gas cell formation, including stabilization and retention of these gas cells during the proofing and baking process. (Gan *et al.*, 1989)

Wheat flour is the main component for several food products such as noodles, pasta, breads, biscuits cakes and pastry. Each of these food products has specific requirements with regards to flour quality, food processing and consumer preferences. Furthermore each flour type plays an important role in food systems by stabilizing it and creating the structure of food. It also interacts with other components to deliver or maintain nutrient and flavor (Cui, 2005). Wheat has to be imported, since the climatic conditions and soil types do not permit its cultivation locally. As a result of this problem, there has been constant importation of wheat which has adverse effect on balancing trade. For this reason

the FAO and developing countries have the interest of replacing the wheat needed for making baked goods and pasta, wholly or partially with flour from home-grown products. (Seibel, 2011)

2.10.2 Types of Wheat Flour

During milling, the three parts of the wheat kernel (the bran – the outer covering of the grain, the germ – the embryo contained inside the kernel, and the endosperm – the part of the kernel that makes the white flour) are separated and recombined accordingly to achieve different types of flours (Wheat Foods Council Network, 2012). White flour is the finely ground endosperm of the wheat kernel. All-purpose flour is white flour milled from hard wheat or a blend of hard and soft wheat. All-purpose flour when used in baked goods produce superior sensory attributes especially in products like cake, pastries, breads, and noodles. It is usually enriched, bleached or unbleached (Wheat Foods Council Network, 2012).

Bread flour is white and is a blend of hard, high-protein wheat and has greater gluten strength and protein content than all other flour types. It is usually conditioned with ascorbic acid, and the protein content varies from 12 to 14% (Wheat Foods Council Network, 2012). Cake flour is fine soft wheat flour with low protein content. It is used to make cakes, cookies, crackers and some types of pastries. It has a greater percentage of starch and has less protein (7-9 %) which keeps cakes and pastries tender (Wheat Foods Council Network, 2012). Self-

rising flour, also referred to as phosphate flour, is made by adding salt and leavening to all-purpose flour. It is commonly used in biscuits and quick breads but is not recommended for yeast breads. It can be substituted for all-purpose flour by reducing salt and baking powder. Pastry flour is an intermediate flour between those of all-purpose and cake flour. It is usually milled from soft wheat for pastry-making but can be used for cookies, cake, crackers and similar products. It differs from hard wheat flour in that it has a finer texture and lighter consistency. Protein content varies from 8 to 9 % (Wheat Foods Council Network, 2012). Semolina is the coarsely ground endosperm of durum, hard spring wheat with a high-gluten content and golden colour. It is hard, granular and resembles sugar (Wheat Foods Council Network, 2012).

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2.11. Wheat Proteins

2.11.1. Classification and functions

Protein is considered the most important nutrient for human and animals, as manifested by the origin of its name, *proteios* (Greek), for primary. The protein content of wheat grains may vary between 10%-18% of the total dry matter. Wheat proteins are classified according to their solubility in various solvents. Classification is based on the sequential extraction of ground wheat grain which results in the following fractions:

- albumins, which are soluble in water;
- globulins , which are insoluble in pure water , but soluble in dilute NaCl solutions, and insoluble at high NaCl concentrations;

- gladins, which are soluble in 70% ethyl alcohol, and;
- glutenins, which are soluble in dilute acid or sodium hydroxide solutions (Sramkova *et al.*, 2009).

Gladins and glutenins are storage proteins and cover about 75% of the total protein content. The wheat stores proteins in this form for future use by the seedling. Gladins and glutenins are mainly located in the endosperm and are neither found in the seed coat layers nor in the germ. Storage proteins in wheat are unique because they are technologically active. The gliadin fraction controls bread loaf volume and varies in flours that differ in bread making potential (Horsney1969). The factor responsible for mixing time and dough development is the glutenin fraction. During dough mixing, the protein mass is converted from granular protein bodies into homogeneous network in which starch granules are embedded (Belderok *et al.*, 2000).

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1.11.2. Wheat Flour Gluten

Gluten plays a critical role in the development of the cellular structures that characterize bread and fermented wheat flour products. The two key factors that contribute to the formation of a gluten structure from wheat flour are hydration of the proteins with water and the input of energy to the flour-water mixture. Thereafter the physical movement of the flour-water mixture imparts energy which results in some cross-linking of flour proteins through the formation of S-S bonds at the terminal ends of the protein chains (Wieser, 2003). The result of the cross-linking is an increase in the resistance of dough to further mixing, that is,

more energy is required in order to continue the mixing process. Eventually the point is reached at which the mixture is fully hydrated and later smooth, developed dough is obtained. Continuing mixing beyond this point leads to the breakdown of the gluten structure and considerable changes in the rheological characteristics of the dough. In reviewing the principles of bread-dough formation, Stauffer (1998) discussed the chemical and physical changes that occurred from when wheat flour was hydrated through to the development of a gluten structure capable of trapping gas in the dough matrix.

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During the gas production and expansion phase the gluten network is gradually stretched thinner and thinner. After some time the expansion of individual gas bubbles brings them into close proximity with others and coalescence of bubbles may occur. This coalescence is encouraged by foam drainage in the lamellae between the gas cells (Wilde, 2003). As a consequence of coalescence, the size of many of the gas bubbles increases, but this is not necessarily the case for many of the smaller ones. The internal pressure of some of the smaller gas bubbles is such that the carbon dioxide cannot diffuse into them and they do not increase in size. In the case of very small gas bubbles the internal pressure may be so great that they cease to exist, and the air/ nitrogen gas contained within them diffuses into the aqueous phase of the dough. Once formed, the visco-elastic nature of gluten plays a critical role in the development of the cellular structures that characterize bread and fermented products. (Wilde, 2003).

2.12. Properties of P. *erosus* flour

Processing of horticultural produce increases its economic value and increases grower returns thus improving the socio economic status of farmers (Karuniawan, 2004). Developing a standard method for production of flour from *P. erosus* will increase its economic potential. *P. erosus* flour like other tuber flours have been known to lack gluten and gelatinize at relative low temperature with rapid and uniform swelling of granules. They also exhibit a high viscosity profile and high paste clarity compared to cereal starches. The flour shows weaker associative intra granular forces and these properties may not be desirable for application in most food systems. Wheat flour has higher phospholipids and produces a starch paste with lower transmittance than those of most tuber flours whose starch has a lower content of phospholipids (Singh, 2003). But the characteristic flavor and colour of *P. erosus* will make an alternative source for new product development in substitution to wheat flour which has the potential of reducing over-reliance on wheat flour (Zaidul, 2007).

2.13. Composite flours

In most developing countries wheat flour is mainly used in making bread, buns, noodles, biscuit and others. Although it is well known that no other crop can achieve the baking properties of wheat, composite flours became the subject of numerous studies. Composite flour may be considered firstly as blends of wheat and other flours for the production of many products like snacks, porridges, pastries, pasta and many other products (Dendy 1993). Composite flours are quite

different from the ready mixed flours in the sense that ready-mixed flour may contain non-perishable constituents of the recipe for a certain baked product, whereas composite flour may contain mixture of different tubers rich in starch, protein sources or cereals (Annon, 2000). Possible sources are cassava, yam, maize, millet, soy, peanut, sorghum and flours from other sources which substitute wheat to form composite flour. The composite flours from cereals such as maize are known to be rich in protein (Abdel-Kader, 2000).

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2.13.1. Uses of composite flours

Although it is well known that no other crop flour can be used to achieve the baking properties of wheat, composite flours have become the subject for many studies. For developing countries the use of composite flours have the following advantages (a) saving of hard currency,(b) promotion of high-yielding, native plant species (c) better supply of protein for human nutrition, and (d) better overall use of domestic agricultural production (Berghofer, 2000; Bugusu *et al*., 2010). Several trials have been carried out using composite flours especially in Africa because of continually growing population in areas like Senegal, Niger and Sudan (Berghofer, 2000).In these trials the bread sector was to produce typical French bread with composite flour. The proportion of wheat in the different mixtures varied greatly, the maximum being 70%.This is due the technical problems of kneading and keeping fresh bread (Seibel, 2011) So far there are no reports that bread and biscuit have been produced from composite flours to any appreciable extent in African. In spite of the lower price, the population is often

disinclined to buy such bread because of its unfamiliar flavor and its textural properties, which differ from those of ordinary white bread. For developing countries, the use of composite flours could have numerous advantages as stated earlier, and the efforts must persist.

2.14. Wheat Flour Bread

Bakery products are the most important type of processed food world- wide and the most popular in terms of consumption is bread (Azizi and Rao 2004). Bread, a staple food prepared by baking dough is a product priced for its taste, aroma and texture. (Osuji 2006). The product is basically made of hard wheat flour, yeast, fat sugar and water. Bread is a good source of nutrients required by the body for metabolic processes. It is one of the food products that are known to have no social stratification, and as such, it is consumed by all and sundry irrespective of their per capita income (Ikpeme, 2010). FAO (1973) reports that there has been continuous increases in bread consumption in many of the developing countries due to the following these reasons: (a) a steadily growing population,(b) change in eating habits and (c) an overall increase in income.

2.14.1. Bread consumption in Ghana

In Ghana consumption of bread has been on the increase as the years go by and therefore has been an integral part of the daily meals of many Ghanaians (Ellis *et al.*, 1997). Among the eight selected foods that are imported into Ghana, between the year 1984 and 1988, wheat and wheat flour mainly used for bread production,

formed an average 33% (Oti-Boateng, 1993). In Ghana there are different types of bread. The names are based upon the composition of the flour and the ingredient used (Ellis *et al.*, 1997).These include tea bread which is made from wheat flour, salt, sugar, fat, eggs, and water; butter bread as white bread which is made from the same ingredients as tea bread with the main difference in the amount of fat and less salt. Other types of bread are the sugar bread which contains the same basic ingredients with reduced fat of about (14%), and brown bread which is made up of the patent and whole flour mixture with or without additives (Fox and Cameron, 1989).

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2.14.2. Assessment of Composite Bread Quality

Different levels of successes have been recorded with the composite use of flours from legumes, cereals, roots and tubers in baked goods (Dhingra and Jood, 2002). Studies by Kale *et al.* (2007) revealed the possibility of replacing sun dried materials of yam bean storage roots with wheat flour in bread baking and reported that replacement up to 20% of wheat flour is possible to obtain bread with desirable sensory attributes. The results however show that 10% substitutions seem to be better for all sensorial quality attributes. It was also shown that the higher the substitution the sweeter the product as indicated by the sweetness perception of the panelist. Ikpeme *et al.*, (2010) evaluated the functional and sensory properties of unblanched and blanched taro and wheat composite flour based bread. The result revealed that acceptable bread could be produce from addition of un-blanched taro flour to wheat flour at 10% level. Ndife *et al.*,

studied the use of wheat and soy bean flour blends in the production of functional bread and reported there was decrease in bread volume and dough expansion with progressive inclusion of soy flour. Abdelghafor *et al*., (2011) evaluated the baking properties of whole decorticated sorghum-wheat composite flour and determined the physical characteristics and organoleptic quality of the bread. The sensory evaluation result revealed that up to 20% wheat replacement with whole decorticated sorghum flour produced acceptable bread. In assessing the quality of bread produced from breadfruit and breadnut with wheat flour composite bread Malomo *et al.,* (2011) reported that wheat flour cold be substituted with bread fruit and bread nut up to 15% level. The bread loaf weight ranged from 550-600g with the volume ranging from 1229.01 – 1886.03 cm^3 and specific loaf volume 2.08 – 3.39 cm^3/g. Khalil *et al*. (2000) demonstrated that inclusion of cassava flour into wheat flour up to about 30% could still give an acceptable fresh loaf depending on the source of flour. It is quite obvious that varying replacement levels of different flours in wheat give different bread quality. There is therefore the need to establish the appropriate wheat flour replacement level for the *P. erosus* flour.

2.14.3. Flour and starch properties that influence the quality of Bread

The influence of wheat flour on baked-product character is more commonly expressed on the basis of its composition; mainly the protein, starch, and fibre content as well as other important physicochemical properties, such as particle size and protein quality. It is therefore possible to consider the influence of flour

on bread structure formation using such properties. During baking, myriad chemical and biochemical interaction among lipids, starches and proteins occur which result in the physical transformation of the dough (Goesaert *et al.*, 2005). Starch, the most abundant constituent of plants, occurs as semi-crystalline granules. It has some unique properties, which determine its functionality in many food applications, in particular bread making (Goesaert *et al.,* 2005). The major components of starch are the glucose polymers amylose and amylopectin. Amylose is an essentially linear molecule consisting of α-(1-4) –linked D-glucopyranosyl units with a degree of polymerization (DP) in the range of 500-6000 glucose residues. It is now well recognized that a fraction of the amylose molecule is slightly branched by α-(1,6)- linkages (Hizukuri, *et al.,1981;* Shibanuma *et al.*,1994). In contrast, amylopectin is a very large, highly branched polysaccharide with DP ranging from $3x10^6$ glucose units (Zobel, 1988).The amylose /amylopectin ratio differs between starches but typical levels of amylose and amylopectin are 25-28% and 72-75% respectively (Coloma *et al.*,1992).

Other studies reported that rheological behavior of wheat dough is influenced by the specific properties of the starch granule surface and by the presence of amylolytic enzymes (Martinzez-Anaya, 1997).

The key role of wheat-flour protein is the formation of the gluten structures essential for bread making. An increase in the protein content leads to an increase in the gas-retention properties of the dough and therefore an increase in bread volume. When the total protein content of a wheat grain increases, the total

amount of gluten proteins also increases, but the amount of the non-gluten forming proteins (i.e. albumins and globulins) changes very slightly. For this reason, there is a positive relationship between the total protein content and gluten content of wheat flours. Thus, wheat of high-protein content usually has a higher proportion of gluten proteins compared with flours with lower protein contents. It has long been established that the rheological properties and bread making performance of wheat flours are related to the quantity and quality of their proteins. Gluten has gained wide acceptance in the food processing industries because of its unique physical properties, such as visco-elasticity, film-forming ability, thermosetting properties and high water absorption capacity. Its visco-elastic properties improve dough strength, mixing tolerance and handling properties in a bread making process. Eggleston *et al.* (1993) reported that variation in bread samples which are produced from the same formulation, proofing time, dough size and loaf volume could be attributed mainly to different rate of gas evolution and the extent of starch gelatinization. Akobundu (1988) suggested that the reduction in wheat structure forming proteins and a lower ability of the dough to enclose air during proofing might have a volume depressing effect on bread.

2.15. Colour Determination

Colour is one of the most important attributes of food, both for its aesthetic value and for quality judgment. A consumer frequently considers the overall appearance of the flour including the colour before making purchasing decision. Generally

speaking bright white colour flour is more desirable for many products. It affects the overall judgment on the worth of food from both an aesthetic and safety point of view. It plays an important role in the taste threshold, flavor identification, food preferences pleasantness, acceptability and finally food choice. (Clydesdale, 1984). Thus color determination was one of the criteria used for the optimization of the flour production method in this work. The colour value for typical white flour as adapted by the Approved Methods of the AACC (2000) was used for the optimization process. L* is a parameter that measures the extent of lightness. When L* is zero it indicates black, when 100, it indicates white. The*-value indicates red colour when positive and green colour when negative. Positive b*-value indicates yellow while negative indicates blue colour.

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2.16. Particle size distribution

Particle size distribution of flour is an important factor in achieving desired product qualities. It is important during mixing of dried powders. If the particle size is too small, the flour becomes too fine and reconstitution becomes a problem. Hunt *et al*. (2000) observed that pasting viscosity increased with reduced particle size. Small particles sizes (<132μm) were more viscous on pasting, whilst medium (132 – 365μm) and large (365 – 1,047μm) sized particles were more difficult to hydrate and had higher setback viscosity.

2.17. Sensory Evaluation

Sensory evaluation is a scientific discipline used to evoke measure, analyze and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch and hearing (Stone and Sidel, 1993). The qualities of a food identified by these senses are called sensory characteristics of the food. These include the food's taste, odor, appearance, mouth feel and sound. Sensory evaluation is normally carried out by designed experiments under proper environmental conditions by both trained and untrained panels. Panels with different degree of training are required for different types of sensory analysis. The degree of training required depends on a number of considerations, such as degree of differences to be detected, number of panelists required for the tests and time and value of the analysis to the product type.

There are several reasons for conducting sensory evaluation in the food industry. These include new product development, product matching, product improvement, process change, cost reduction, selection of a new source of raw material supply, quality control, consumer acceptance and opinions, product grading and rating, consumer preference, sensory panel selection and training, and correlation of sensory properties (IFT, 1981)..

There are two major types of sensory evaluation. These are the Product-Oriented or Analytical tests and the Consumer-Oriented or Affective tests (Watts, *et al.*, 1989). Analytical Tests (or Product-Oriented Tests) are used to discriminate between products (Discriminative tests) or to describe sensory characteristics of

the product (Descriptive tests). Here the use of trained and/or experienced panellists is required. A trained panel of about 5 – 15 is usually used. Examples of discriminative and descriptive tests are: Difference Tests such as triangle test, paired comparison test, and duo-trio test; Ranking for intensity Tests where samples are placed in order of perceived intensity of a sensory characteristic, Scoring for Intensity Tests where samples are scored on line scales or category scales for the perceived intensity of a sensory characteristic; and Descriptive Tests where trained panellists provide a total sensory description of the sample. Affective Tests (or Consumer-Oriented Tests) are used to evaluate consumer preference for, and/or acceptance of the product. Large numbers of untrained panellists are required here. Examples are: Preference Tests which allow consumers to express a choice between samples; Acceptance Tests used to determine consumer acceptance of a product; and Hedonic Tests designed to measure degree of liking for a product.

KNUST

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Source of raw materials

Pachyrhizus erosus roots were obtained from the experimental farms of the CSIR-Crops Research Institute in Kumasi, Ghana. All other ingredients (wheat flour, sugar, salt, margarine and yeast) used in this study for the preparation of dough were obtained from local markets in Accra. Sodium metabisulphite used to condition the yam bean roots during processing was obtained from Micrite Group, Gh. Ltd., Accra, Ghana.

KNUST

3.2 Methods

3.2.1 Experimental Design

The experimental design used in the study was a 2 x 3 factorial design with three replicates involving the two factors of peeling (peeling and no-peeling) and three pre-treatments (blanching, soaking in sodium metabisulphite and a no-treatment control).

3.2.2 Development of P. erosus flour

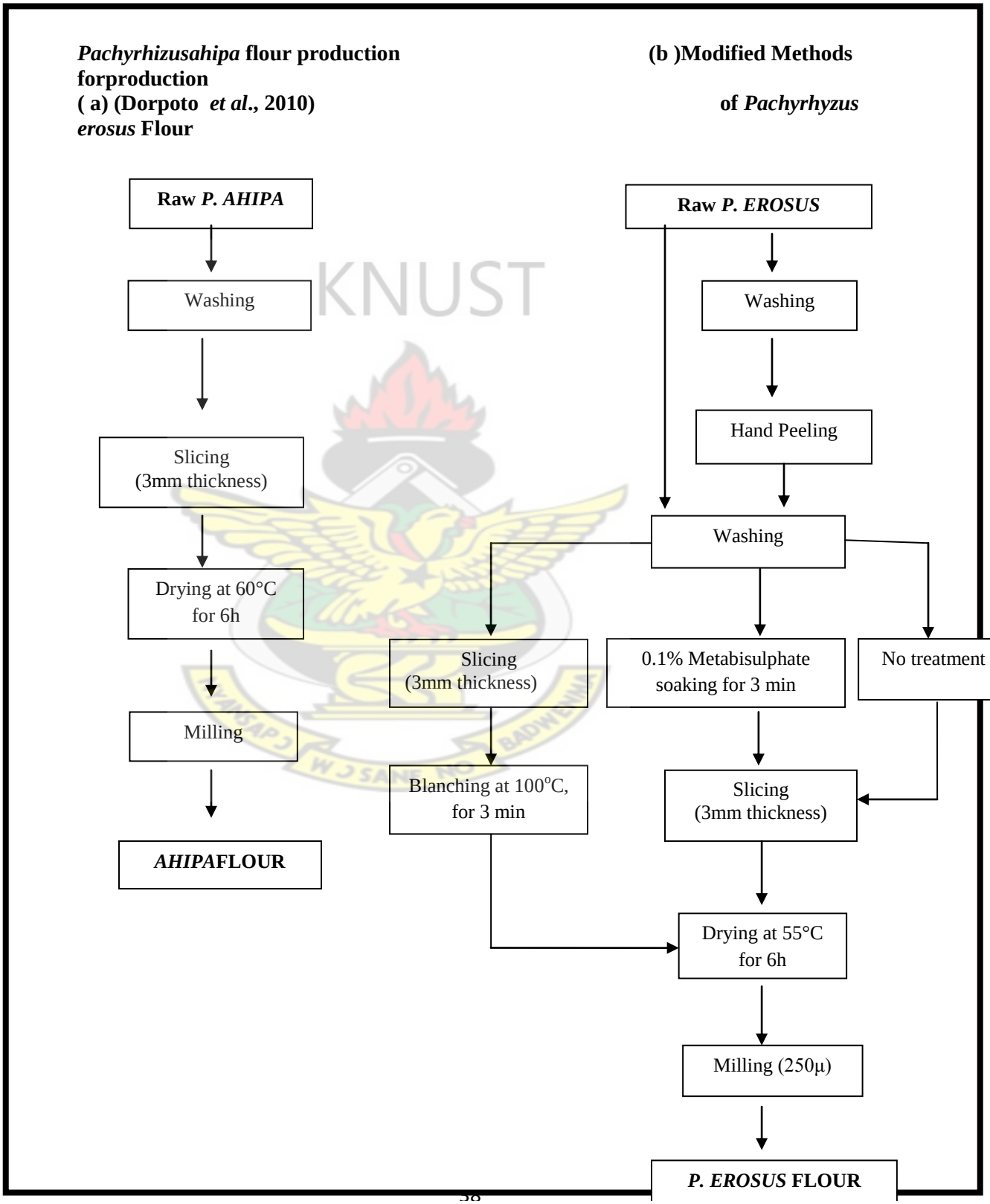
Figure 3.1 shows the process flow diagram for the development of the yam bean (*P. erosus*) flour. This process was based on modifications of the method described by Doporto *et al., (*2010) for the production of *P. Ahipa* flour. In the present study, the normal product development phases involving idea generation, screening of ideas, technical development processes for optimization and

prototype refining by sensory techniques were considered. Based on the experimental design used, peeled and unpeeled samples were subjected to the following three pre-treatment options: soaking in 0.1% sodium metabisulphite solution for 3 min, blanching at 100^{o}C, for 3min and a control sample which had no treatment with sodium metabisulphite or blanching. These pre-treatment options were applied to each of the two portions of peeled and unpeeled tubers.

Selected fresh tubers of *P. erosus* were divided into portions which were randomly assigned to the various treatments of peeling and no-peeling with each of the three pre-treatments. For the peeled samples, the tubers were washed thoroughly in water, peeled with knife, washed again in clean water and portions of the peeled tubers subjected to the appropriate pre-treatment. That is, soaking in 0.1% sodium metabisulphite solution for 3 min, blanching at 100^{o}C for 3min, or no-treatment. The unpeeled samples were only washed thoroughly and the appropriate pre-treatment applied. After the appropriate pre-treatment, the samples were then sliced to about 3.0mm thickness using One-Touch automatic deluxe vegetable Slicer (Model KC25, Daka Res. Inc., China) and weighed. The weighed samples were spread thinly on separate drying trays and dried in a mechanical dryer (Apex, Royce Ross Ltd) maintained at 5 .5 hours. The dried slices were weighed again and milled using a hammer mill (Jacobson Machine Works INC., Minneapolis, Minn, 55427, USA) to an average particle size of 250 um. The resulting *P. erosus* flour samples were sealed in double laminated

KNUST

sealable polyethylene bags and stored in a freezer for further analysis (Badrie and Mellowes, 1992).



KNUST

Figure 3.1 Flow charts for production of yam bean flour (a) Ahipa flour (b) P erosus flour

3.2.3 Colour

The colour of flour samples were measured using the L*, a* and b* colour space (CIELAB space) with Colorimeter CR-200 (Minolta, Model CR310, Minolta Camera Company Ltd., Osaka, Japan). The L* value indicates lightness, where L* = 0 is completely black and L* = 100 is completely white. The* values represents red-green with positive a* and negative a* depicting red and green, respectively. The b* values on the other hand represent yellow-blue, with positive b* representing yellow and negative b* representing blue. The meter was calibrated with white tile (L* = 93.30, a* = 0.32 and b* 0.33). The samples were poured into a transparent petri dish and the measuring head of the meter was carefully placed on three different locations on the petri dish. The measurements were determined in triplicates and mean and standard deviations determined.

3.2.4. pH

The pH of flour samples was measured using the Genway pH meter (Model 300030, England). Ten percent slurry of the sample was prepared by mixing 10g sample in 100 ml of distilled water. The meter was calibrated and used to obtain pH readings of the slurry. The determination was done in triplicate.

3.2.5 Chemical Analysis of P. erosus Tubers and Flour Samples

Both raw *P. erosus* tuber and the flour samples produced were analyzed for their proximate composition. Moisture (AOAC 925.10), protein (AOAC 984.13), fat (AOAC 920.39) and ash (AOAC 923.03) were determined by the AOAC (1990; 2000) standard methods. Carbohydrates were calculated by difference. Energy

values were obtained using the Atwater factors 3.47, 8.37 and 4.00 for protein, fat and carbohydrates, respectively (Eyeson and Ankrah, 1975).

3.2.5.1 Determination of moisture

Moisture content was determined in accordance with the method of AOAC.925.10 (1990). Approximately 2 – 5 g well mixed test samples were accurately weighed and transferred into previously dried and weighed metal moisture dishes. The dishes were dried with the contents for 4 h in a thermostatically controlled moisture oven provided with an opening for ventilation and maintained at 103± 2°C. After the drying period, the dishes were covered, removed and cooled in desiccators and re-weighed. The moisture content of the sample was determined as the loss sample weight after drying to a constant weight, expressed as a percentage.

$$\% \text{ Moisture} = \frac{(\text{Weight of dish + fresh sample}) - (\text{Weight of dish + dry sample})}{(\text{Weight of dish + fresh sample}) - (\text{Weight of dish})} \times 100$$

3.2.5.2 Determination of protein

Protein content of samples was determined based on the A.O.A.C. 984.13 (2000) Kjedahl procedure. The method follows the use of the Tecator Kjeltec Systems (Foss Tecator AB, Sweden) for nitrogen determination. Determinations were done in triplicates allowing for a variance of ± 0.2 %. A weight of 0.50g of the homogenous sample was taken on a piece of filter paper and placed into a 250 ml

digestion tube. One kjeltab and 15 ml of concentrated H_2SO_4 were added to the digestion tube and shaken gently to wet the sample with the acid. Digestion was carried out at 400°C with the Kjeltec digestor 1007 (Foss Tecator AB, Sweden) till digest turned bright green. The rack with exhaust was removed and digestion tubes and contents left to cool. Twenty five milliliters (25 ml) of 4% boric acid (receiver solution) was measured out into a conical flask and positioned in the distillation unit so that the distillate outlet is submerged in the receiver solution. The digestion tube was fixed into the distillation unit and the safety door closed. The kjeltec auto distillation 2200 unit (Foss Tecator AB, Sweden) was programmed to discharge 80 ml distilled water and NaOH and distil samples in four minutes. Titration was done with standardized 0.1N HCl. A blank was carried out and control sample (ammonium sulphate) was used to check the distillation and digestion efficiency at a recovery of 98% - 102%. The nitrogen and protein content of the sample was calculated as follows:

$$\% \text{ Nitrogen (w/w)} = \frac{\text{Sample titre} - \text{Blank titre}) \times \text{Normality of acid} \times 14.007}{10 \times \text{Weight of sample}}$$

% Crude protein (w/w) = % Nitrogen x 5.17, expressed to the nearest 0.1%

3.2.5.3 Determination of crude fat

Crude fat was determined in accordance with the AOAC 920.39C (2000) method, using the Soxhlet Extractor. Accurately weighed 2 – 5 g of homogenous sample was placed into a filter paper, folded and placed in a thimble and stuffed with

grease-free glass wool. About 240 ml of petroleum ether was added to the round bottom flask which was previously weighed, and the apparatus assembled. The extraction was done for a period of 15h at a condensation rate of 6 – 8 drops per second avoiding bumping. The flask with the extracted fat was heated in a water bath to evaporate the solvent. It was then heated in an oven at 103±2°C for 1h to dry the extracted fat, and cooled to room temperature in a desiccator and weighed. The crude fat content was calculated as follows:

$$\% \text{ Crude fat} = \frac{(\text{Wt of flask+ fat}) - (\text{Wt of empty flask- blank})}{\text{Wt. of sample}} \times 100$$

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3.2.5.4 Determination of Ash

The ash content of samples was determined using the method as outlined in the AOAC 923.03 (2000). Crucibles were placed in a furnace and ignited at 550◦c ±10◦c for about 20 minutes and cooled in a desiccator at room temperature and weighed. Accurately weighed 3 – 5 g well mixed test portions were transferred into the pre-weighed crucibles and ignited in a muffle furnace at approximately 550°C ± 10°C for 8 h. Furnace was allowed to drop to below 250°C and the crucibles transferred to desiccators to cool. The crucibles with the contents were weighed and the total ash content calculated and expressed as a percentage as follows:

$$\% \text{ Ash} = \frac{(\text{Weight of crucible + Ash}) - (\text{Weight of empty crucible})}{\text{Weight of sample}} \times 100$$

3.2.5.5Determination of crude fibre

The crude fibre content of the samples was determined using the method described by Pearson (1970). The samples were analyzed by taking a weight between 2.7 to 3.0 g. The samples were defatted through extraction with petroleum spirit by stirring, settling and decanting three times. They were then air dried and transferred to a 1000 ml conical flask. A 200 ml of 0.255N Sulphuric acid (H_2SO_4), measured at ordinary temperature, was added and brought to boiling point. Boiling was done for exactly 30min. A circular piece of filter paper was placed in a Buchner funnel and boiling water poured onto it to cover the holes in the funnel. Care was taken to ensure that the filter paper used is of such a quality not to release any paper fibre during this procedure and other washings. The hot water was drained by applying suction by the aid of a Buchner flask. After boiling for 30 minutes, the acid mixture was then filtered. Filtration of the bulk of the 200ml was completed within 10 minutes. The insoluble matter was washed with boiling water until the washings were free from acid. The filtrate was washed back into the original flask by means of a wash bottle containing 200ml of 0.313N Sodium hydroxide (NaOH) solution measured at ordinary temperature and brought to boiling point. The mixture was boiled for 30 min. It was filtered immediately through a pre-weighed ash-less filter paper and washed first with boiling water, then with 1% hydrochloric acid (HCl), and finally with boiling water until free from acid. The filter paper was then washed twice with alcohol and then three times with diethyl ether and dried at 100°C to a constant weight.

KNUST

The ash-less filter and its content were incinerated in a muffle furnace, cooled in desiccators and weighed again.

$$\% \text{ Crude fiber} = \frac{(\text{Weight of paper + residue}) - (\text{Weight of ash})}{\text{Weight of sample}} \times 100$$

3.2.5.6 Determination of Sugars

Sugars were determined on clarified solutions before and after inversion at 68 – 70 °C using the Lane and Eynon volumetric method as described by Pearson (1970). Thirty five grams of sample was weighed into a wide-necked 250 ml volumetric flask. Extraction of water-soluble matter was done by shaking the weighed sample with 150 ml of distilled water. The solution was clarified by the addition of 5 ml of zinc acetate followed by 5 ml of potassium ferrocynide solution. Content was made to the mark and filtered after 10 min. The specific sugars determined included total sugars, reducing sugars and sucrose.

The sucrose level of the flour samples were determined in the absence of reducing sugars by inverting a portion of the test solution with acid followed by neutralization with alkali and titration by the Lane and Eynon (1970) method. The percent sugar was multiplied by 0.95 to get the percent sucrose content in the flour sample. For the determination of reducing sugars, a burette was filled with a quantity of the filtrate and this was used to titrate against 10 ml of equal volumes of Fehling's solutions A & B. Total sugars were determined by inversion. A 20 ml portion of the filtrate was quantitatively transferred into a 100 ml volumetric flask

and distilled water added to produce a volume of 60 ml. Five milliliters of concentrated HCl was added and the flask swirled around and immersed in 68 – 70 °C water bath for 10 min. The flask was cooled quickly and the solution neutralized with N NaOH, cooled and made up to 100 ml. This solution was used to titrate against 10 ml. equal volumes of Fehling's solution A & B as before.

3.2.5.9 Determination of starch content

The starch was determined using the Lintner's method (Pearson, 1970). About 0.5g of the sample was titrated with 20ml of water and 40ml of hydrochloric acid added in small portions at a time. The mixture was then washed into a 200 ml flask with 12% (w/w) HCl, and 10 ml of 5% phosphotungstic acid added to precipitate proteins. The volume was made up to 200ml with 12% more hydrochloric acid. The mixture was well shaken, filtered and the optical rotation of the filtrate was measured in 200mm tube. The mean specific rotation of *P. erosus* starch was taken as+185.7°.

The starch percentage in the flour was calculated as follows:

$$\% \text{ starch} = \frac{4000 \times \text{observed optical rotation}}{\text{Length of tube in decimeters} \times \text{specific rotation}} = \frac{4000 \times a}{2 \times 185.7}$$

3.2.6 Functional Properties

Functional properties are the properties that give information on how a food ingredient will behave in a food system. In the present study functional properties

determined include hot paste viscosity properties, swelling power, swelling volume and solubility and water holding capacity.

3.2.6.1 Determination of Pasting Properties of P. erosus Flour

The pasting properties of the flour were determined using the Brabender Viscograph (No.802525, Duisburg, Germany) equipped with a 10 cm-g sensitivity cartridge. Ten percent slurry of the flour sample was prepared with distilled water and the slurry was heated uniformly (1.5°C per min) from 25°C to 95°C, held at 95°C for 15 min, and cooled at the same rate to 50°C (Shuey and Tipples, 1982). The resulting amylograms provided pasting temperatures, peak viscosities, viscosity at 95°C, stability, cooking times and setback viscosities.

3.2.6.2 Determination of Swelling power, Swelling Volume and Solubility

The swelling power, swelling volume and solubility of the flour were determined based on a modification of the method of Leach *et al.,* (1959). One gram of the sample was transferred into a weighed graduated 50 ml centrifuge tube. Distilled water was added to give a total volume of 40 ml. The suspension was stirred uniformly with a stirrer avoiding excessive speed, in other not to cause fragmentation of the starch granules. The sample was heated at 85°C in a thermostatically regulated temperature bath (Grant instruments, England Ltd.) for 30min with constant stirring. The tube was removed, wiped dry on the outside and cooled to room temperature. It was then centrifuged for 15min at 2,200 rpm (Mistral 3000i, UK). The solubility was determined by evaporating the

supernatant in a hot air oven (BS Gallenkamp, England) and the residue weighed. The swelling volume was obtained by directly reading the volume of the swollen sediment in the tube. The sediment paste was weighed. Determinations were done in triplicate. The % solubility and swelling power were then calculated as follows:

$$\text{Swelling power (g hydrated flour/100g dry flour)} = \frac{\text{Wt. of sedimented paste}}{\text{Wt. of initial sample (dry basis)}} \times 100$$

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$$\%\ \text{Solubility} = \frac{\text{Weight of soluble sample}}{\text{Weight of sample dry basis}} \times 100$$

3.2.6.3 Water-Binding Capacity (WBC)

The Water-Binding capacity of the flour was determined in triplicate according to the method of Yamazaki (1953) as modified by Medcalf and Gilles (1965). An aqueous suspension was made by dissolving 2g of the sample in 40ml of water. The suspension was agitated for 1 h on Griffin Flask Shaker (Model hs501, digital, Janke 7 Kinkel GMBH &Co. KG) after which it was centrifuged for 10 min at 220rpm with a centrifuge (Mistral 3000i, UK). The free water was decanted from wet starch and drained for 10min. The WBC of the sample was then calculated as follows:

$$\text{Water binding capacity} = \frac{\text{Bound water}}{\text{Weight of sample}} \times 100$$

3.2.7 Particle size determination

Particle size distribution of samples was determined using the method described by Ngoddy *et al*. (1986) with a slight modification. One hundred grams of sample was weighed into the topmost sieve of a set of sieves (Meinzer II mains Sieve Shaker) with a mesh range of 250μm to 100 μm, arranged in a decreasing order of mesh size. It was covered and mounted on a shaker. The samples were subjected to shaking for 20 min. The proportions of the various fractions of flour retained on the sieves were calculated as follows:

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$$\% \text{ fraction X} = \frac{\text{Weight of fraction X retained}}{\text{Total weight of sample}} \times 100$$

3.2.8 Determination of Baking Characteristics of P. erosus Flour

3.2.8.1 Formulation of Wheat flour/P. erosus flour Blends

The *P. erosus* flour and wheat flour were blended at varied ratios to give six blends at 0%, 5%, 10%, 15%, 20% and 30% replacement levels of *P. erosus* in wheat flour. The blends were thoroughly mixed with a wooden spoon.

3.2.8.2 Preparation of P. erosus bread samples

Table 3.2.1 gives the ingredient composition of the *P. erosus* and control unfortified bread samples. Bread was prepared using the straight dough process. Baking trials were carried out under laboratory conditions to optimize baking conditions prior to the actual runs. Dough was prepared by mixing all dry ingredients and water of lukewarm temperature was added. The dough was kneaded for about 30 – 45 min

depending on the composition. The dough was allowed to proof for 15 mins and was divided into 500 g portions. These were then molded and placed in a greased baking pan and allowed to proof for 50 – 60 min at about 30°C. The samples were then baked in a pre-heated electric oven at 220°C for about 20 – 30 min until golden brown. The bread samples were allowed to cool at room temperature of about 30°C for 30 – 45 min and stored in sealed polyethylene pouches for further analyses.

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Table 3.1 Ingredient composition of *P. erosus* bread samples

Ingredient	Wheat flour/*P. erosus* flour Blend					
	Control	70:30	80:20	85:15	90:10	95:5
Wheat flour (g)	1,000	700	800	850	900	950
P. erosus Flour (g)	0	300	200	150	100	50
Water (mL)	500	500	500	500	500	500
Salt (g)	15	15	15	15	15	15
Sugar (g)	20	20	20	20	20	20
Margarine (g)	20	20	20	20	20	20
Yeast (g)	10	10	10	10	10	10

3.2.8.3 Determination of quality characteristics of bread samples

Quality characteristics of bread samples determined included loaf weight, loaf volume, texture, water activity, moisture content, crumb colour, microbiological quality and sensory evaluation. Details of the analysis are as follows:

3.2.8.3a Loaf weight

Loaf weight was obtained by weighing samples after cooling using a laboratory scale (KERN 510 Gott. Kern and Sohm GmbH, D-72458 Albstatdt, Germany)

and readings recorded in grams. Mean weight values were recorded for each sample (Malomo *et al*., 2011).

3.2.8.3b Loaf Volume

The loaf volume was measured using the Rapeseed displacement method (AACC, 2000, Standard 10-05). A calibrated empty container was filled to the mark with sorghum grains. The container was then emptied and the bread sample placed inside and filled again with the grains. The displaced sorghum was weighed in a measuring cylinder and used as a measure of the loaf volume. The specific volume was calculated by dividing the volume obtained by its weight.

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3.2.8.3c Sensory evaluation of bread samples

Preference tests were conducted with 60 untrained panellists in a large-scale consumer acceptability testto determine relative preferences for the various sensory attributes of bread samples using the nine-point hedonic scale as described by Larmond (1977). A score of 9 represented like extremely with 1 indicating dislike extremely. Taste, aroma, texture, crust colour, mouth feel and overall acceptability were the attributes considered in the preference test. The test was carried out by administering a semi-structured questionnaire to randomly selected and willing respondents at the CSIR-Food Research Institute and the Ghana Broadcasting Corporation premises in Accra in order to make the data fairly representative of the population in Accra. The samples were served in disposable plates to panelists in a systematic order to eliminate positional biases in assessment (i.e., were

presented to consumers using a complete random design). The panelists were provided with disposable cups with water to rinse their mouths between samples. The questionnaire was explained to the panelists to orient them on what was expected of them. In situations where the respondent could not fill out the questionnaire independently, sensory assistants were available to help them write out their responses in a language of mutual understanding as accurately as possible.

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3.3 Statistical Analysis

All determinations from the laboratory experiments were done in replication. The statistical analyses were conducted using ANOVA procedures depending on the experimental design. Significant statistical differences in samples were tested at $p < 0.05$, and least significant differences (LSD) method was used for the post-hoc multi comparison test. All the analyses were done with Statistical Package for Social Scientist (16.0) software.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 OPTIMIZATION OF STANDARD METHOD FOR *P. EROSUS* FLOUR

4.1.1. Effect of peeling on Colour, Particle size and pH

The results obtained using the L*a*b* colour values are shown in Table 4.1. Peeling significantly affected the brightness of the flour as indicated by the higher L* value for the peeled samples.

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Table 4.1. Effect of peeling on colour (L* a* b*), particle size and pH of P. *erosus* flour[1]

Quality Characteristics	Treatment	
	Peeled	**Unpeeled**
Colour value		
L*	85.01±0.25[a]	81.86±0.43[b]
a*	-1.01±0.01[b]	-0.67±0.02[a]
b*	11.30±0.37[a]	11.04±0.05[a]
ΔE	15.61[b]	18.12[a]
Particle size (%)		
>300µm	0.75±0.07[a]	0.08±0.00[b]
250 - 300µm	0.08±0.04[a]	0.60±0.28[b]
150 - 250µm	16.40±0.28[a]	14.40±0.98[b]
100 - 150µm	11.90±0.14[a]	13.10±0.12[b]
< 100 µm	70.00±0.28[a]	70.60±1.53[a]
pH	6.65±0.00[a]	5.96±0.01[b]
Moisture content (%)	2.89±0.08[a]	2.24±0.18[a]

[1]Values with the same superscript letter in a row are not significantly different (p >0.05)

The negative a* values obtained for flours from both peeled and unpeeled samples indicated that the colour is slightly on the greener side than reddish. However

unpeeled samples tend to have a higher intensity of the greenness compared to the peeled samples. This may be due to the presence of slightly coloured peels. The b* values for the two flours were not significantly different ($p< 0.05$). The positive values indicate slight yellow colour for both samples. However, the yellowness was more intense (about 11.30) compared to reported intensities for commercial white flour (6.90). The estimation of ΔE, indicate the extent of deviation of colour of samples from the standard tile colour used (L*=97.63, a*=-0.48, and b*=+2.12). From the results the unpeeled samples had a greater deviation (ΔE= 18.12) from the standard colour value than the peeled samples (ΔE = 15.6). Peeling, although a tedious unit operation in root crop processing, tend to give a better product as far as colour is concerned.

Particle size distribution of flours prepared from peeled and unpeeled *P. erosus* roots indicated that as much as 70% of the flours were less than 100μm in size. Based on this finding, particle size of <150μm was used as the average ideal particle size of flours in the present study. The results in Table 4.1 show that flours from both peeled and unpeeled roots had over 98% of the sample with particles below 250μm in size. The analysis of variance revealed a non-significant effect of peeling on the particle size distribution.

The results of the present study indicate that unpeeling significantly decreased the pH of flours (Table 4.1). Flour samples from unpeeled roots were significantly lower ($p<0.05$) in pH (5.96±0.01) than those from peeled samples (6.65±0.00).

The presence of peels apparently contributed to the increased acidity of the samples, this may be attributed to the presence of antioxidants in the peels (Guedes *et al*., 2011). According to Pearson (1981) wheat flour usually has a pH between 6.0 and 6.80. Peeling is therefore necessary to obtain flours with pH similar to wheat flour. Lower acidity imparts characteristic sour taste to the flour and makes it less preferred for use in baking (Apea-Bah, *et al*. 2011).

Moisture content is an indicator of flour storability. Moisture content greater than 14.5% supports microbial growth (AACC, 2000). The moisture content for peeled and unpeeled flour samples was 2.89 % for the peeled flour and 2.24 % for the unpeeled flour which could be acceptable for commercial flours. Though there was a variation in the mean percentage of moisture content between the samples, statistically there was no significant difference ($p<0.05$). This demonstrates that, whether the sample is peeled or unpeeled, the moisture content of the sample does not vary unlike the pH.

4.1.2. Effects of Pre-treatment on the Colour, Particle size, pH and Moisture content of P. erosus Flour

The effects of sodium metabisulphite and blanching treatments on the colour, particle size, pH and moisture content of *P. erosus* flour samples are shown in Table 4.2. The sodium metabisulphite pre-treated *P. erosus* flour recorded the highest L*-value of 90.89 with the blanching pre-treatment giving the lowest L*-value (87.57). This implies that the sodium metabisulphite pre-treated *P. erosus*

flour had a higher white intensity compared to the other samples. The whiteness of the sodium metabisulphite pre-treated flour made it the only one that was comparable to commercial flours (L* value of 92.5). Again the sodium metabisulphite pre-treated *P. erosus* flour recorded the lowest b*-value among the three treatments. The implication is that the sodium metabisulphite pre-treated *P. erosus* flour was less yellow than the rest of the samples. However, its yellowness was higher (8.84) than reported for commercial white flour (6.90). The various pre-treatment methods had significant ($p < 0.05$) differences on the colour of the flour samples.

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There were significant differences ($p<0.05$) in the particle size distribution of all the samples with the blanched produced flour having relatively higher particle sizes distribution compared to the control and sodium metabisulphite treated flour (Table 4.2). Approximately 50% of the blanched flour particles were less than 100μm whiles 70% and 69 % of the control and sodium metabisulphite treated samples were below 100 μm (Table 4.2). Blanching apparently caused pre-gelatinization of the starch granules, which upon drying hardened and became more difficult to break into finer particles during milling (Fennema, 1996). pH values for the flours ranged between 6.0 and 6.4. Although there were significant differences ($p<0.05$) in the pH values, all treatments produced flour with pH in the acceptable wheat flour pH range (6.0 to 6.80). The slight differences could be attributed to some degree of fermentation of the sugars during drying. Moisture

content of the flour samples ranged between 5.20 and 5.50%, indicating good flour storability.

4.1.3. Effect of Interaction of Peeling and Pre-treatments on the Quality Characteristics of P. erosus Flour

The combined effect of peeling and sodium metabisulphite treatment produced the best quality *P. erosus* flour as far as the whiteness (L* of 90.89) of flour which is a key quality attribute is concerned (Table 4.3). It is interesting to note that, sodium metabisulphite treatment without peeling produced flour with second best in lightness (with L* value of about 88). This may be due to the effect of the sodium metabisulphite in preventing enzymatic browning (Sgroppa *et al*., 2010). Peeling without pretreatment produced a flour whose whiteness was next to peeled and sodium metabisulphite treated flour as well as only sodium metabisulphite treated flour, while blanching with peeling gave the fourth best flour in whiteness with L* value of about 83.0. Unpeeling with or without blanching was the least in terms of lightness. The blanched and control unpeeled *P. erosus* flour recorded the same lowest L- value of 81.86. This means that when unpeeled only sodium metabisulphite treatment can improve the colour. The deviation from the standard white tile colour values as indicated by ΔE also showed the same trend where peeled samples treated with sodium metabisulphite had the least deviation of 10.90, followed by sodium metabisulphite treatment without peeling (12.72) and peeling with no pretreatment (15.61). Peeling with sodium metabisulphite treatment is therefore necessary as a combined treatment of the *P. erosus* roots in the production of high quality flour in terms of colour.

Table 4.2 Effect of Interaction of Peeling and Pre-treatments on the Quality Characteristics of *P. erosus* Flour

Quality Characteristics	Treatment					
	Peeled			Unpeeled		
	Control	M'bisulphite	Blanching	Control	M'bisulphite	Blanching
Colour value						
L*	85.01±0.25^{c}	90.89±0.25^{a}	83.10±0.23^{d}	81.86±0.43^{e}	87.76±0.51^{b}	81.86±0.36^{e}
a*	-1.01±0.01^{c}	-1.45±0.03^{d}	-1.46±0.03^{d}	-0.67±0.02^{a}	-0.87±0.01^{b}	-1.62±0.08^{e}
b*	11.30±0.37^{c}	10.63±0.09^{d}	14.18±0.19^{b}	11.04±0.05^{c}	10.13±0.02^{d}	18.02±0.23^{a}
ΔE	15.61^{d}	10.90^{f}	18.91^{b}	18.12^{c}	12.72^{e}	22.24^{a}
Particle size (%)						
>300µm	0.75±0.07^{b}	0.70±0.14^{c}	0.65±0.07^{d}	0.08±0.00^{e}	1.30±0.14^{a}	0.60±0.28^{d}
250 - 300µm	0.08±0.04^{d}	0.40±0.02^{c}	0.73±0.11^{a}	0.60±0.28^{b}	0.60±0.07^{b}	0.60±0.00^{b}
150 - 250µm	16.40±0.28^{d}	18.60±1.28^{c}	29.60±1.85^{b}	14.40±0.98^{e}	14.80±0.85^{e}	31.90±0.42^{a}
100 - 150µm	11.90±0.14^{e}	11.20±0.57^{e}	19.60±1.57^{a}	13.10±0.12^{c}	12.20±1.41^{d}	18.40±0.57^{b}
< 100 µm	70.00±0.28^{b}	68.90±1.17^{c}	49.20±1.07^{d}	70.60±1.53^{a}	70.70±2.69^{a}	48.20±1.13^{d}
pH	6.65±0.00^{a}	6.13±0.01^{c}	6.42±0.00^{b}	5.96±0.01^{c}	6.48±0.01^{b}	6.73±0.01^{a}
Moisture (%)	2.89±0.08^{b}	5.42±0.036^{a}	5.54±1.62^{a}	2.24±0.18^{b}	1.94±0.04^{c}	2.39±0.14^{b}

[1]Values with the same superscript letter in a row are not significantly different (p > 0.05)

With regards to ease of milling, both sodium metabisulphite treated and untreated control samples produced finest flour from peeled and unpeeled roots (Table 4.3). Blanching with or without peeling resulted in relatively coarse flour products. The

combined effects of peeling and sodium metabisulphite or blanching treatment produced flours with desirable pH values. Lowest moisture values were observed in flours produced from unpeeled roots, irrespective of the pretreatment applied. High initial moisture absorption by peeled roots during soaking in sodium metabisulphite or blanching may be responsible for the high final moisture content of the flours.

4.1.4. The Optimized method for the production of Standard P. erosus Flour

From the above findings, the standard procedure for the production of high quality *P. erosus* flour is as follows: Selected roots of *P. erosus* are washed thoroughly in water and peeled with knife. The peeled roots are washed again in clean water and cut into thin slices of about 3 mm thickness. The slices are dipped into a 0.1% sodium metabisulphite solution and soaked for 3 min. The treated samples are then spread thinly on drying trays and dried in a mechanical dryer (Apex, Royce Ross Ltd) maintained at 55°C for five and a half hours. The dried slices are milled in a hammer mill. The resulting *P. erosus* flour is then sealed in a double laminated sealable polyethylene bags and stored. The optimized procedure for the production of the standardized *P erosus* flour is represented in a flow diagram in Fig. 4.1.

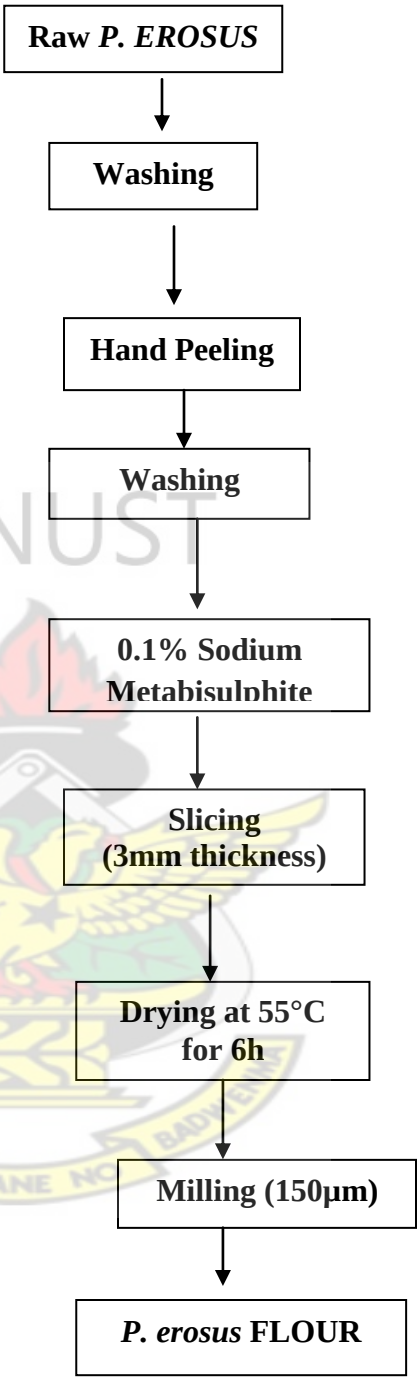

Figure 4.1. Flow chart for production of standardized *P. erosus* flour

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4.2. QUALITY CHARACTERISTICS OF STANDARD *P. EROSUS* FLOUR

4.2.1 Chemical Properties

P. erosus flour samples were evaluated for their chemical properties in terms of the proximate composition, pH value, starch content, sucrose, total sugars and reducing sugars. The results are shown in Table 4.3 with values obtained for the raw tuber for comparison to get the effect of processing on some of the components.

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Table 4.3 Chemical compositions of *P. erosus* roots and flour samples[1]

	Raw *P. erosus* Tuber		*P. erosus* Flour	
Parameter	**As-is Basis**	**DMB[2]**	**As-is Basis**	**DMB[2]**
Moisture (%)	83.71±0.13	-	5.79 ± 0.04	-
Fat (%)	0.12±0.03	0.74±0.18	0.54±0.01	0.57±0.01
Ash (%)	0.53±0.02	3.25±0.12	2.14±0.04	2.27±0.04
Protein (%)	1.57±0.01	9.64±0.06	5.68±0.06	6.03±0.06
Crude fiber (%)	1.48±0.12	9.08 ±0.74	6.26±0.01	6.64±0.01
Carbohydrate by difference (%)	14.11±0.05	86.37±1.16	85.85±0.15	91.12±0.16
Reducing sugars (%)	2.00±0.01	12.28±0.06	11.34±0.03	12.04±0.03
Sucrose (%)	3.62±0.01	22.22±0.06	19.12±0.01	20.29±0.01
Total Sugars (%)	5.63±0.02	34.56±0.12	30.46±0.40	32.33±0.40
Starch (%)	5.18±0.01	31.80±0.06	21.00±0.76	22.29±0.81
Energy (kcal/100g)	62.12±0.16	381.06±0.98	366.29±0.14	388.79±0.15

[1]Values are means ± standard deviation for triplicate determinations
[2]DMB = Dry matter basis

4.2.1.1. Proximate composition of P. erosus flour

The proximate composition of the *P. erosus* tuber and flour are shown in Table 4.4. Moisture content is very important regarding shelf life. The lower the flour moisture content, the better its storage stability. Flours with moisture content greater than 14.5% supports microbial growth and cause deterioration. The moisture content the *P. erosus* flour samples developed in this study was about 5.8 **%,** which is within the acceptable range for commercial flours. The average moisture content for the raw tuber was 83.71%. Noman *et al.* (2007) also reported similar moisture values for raw *P. erosus* (82.01%). This implies that the geographical location may have little effect on the moisture content on the *P. erosus*. Comparing the root (83.7 %) and flour (5.8 %) moisture values, it is obvious that the drying procedure used was quite effective in causing a drastic reduction of the moisture content of the product to very low levels to ensure long shelf-life. This is therefore a way of preservation of the *P. erosus* to help reduce post-harvest losses and enhance food security. The moisture content recorded for P. *erosus* flour is lower than that reported by Ukpabi (2010), who stated that, yam flour has a moisture content of 9.4 %. Other research on the proximate composition of cocoyam revealed a range of 5.01 to 15.20 % of moisture content.

The results indicated that the crude fat content of the P. *erosus* raw tuber was 0.12% and after processing the flour recorded a fat value 0.54%. When the crude fat content was expressed on dry-weight basis, there was significant difference between the tuber and flour with respect to their fat content and this could be

attributed to the processing procedure (Table 4.3). For example, leaching during sodium metabisulphite treatment could reduce the fat content. Studies by McGill *et al*. (1974) reported decreases in fat contents of samples dried in the sun and attributed this to oxidation of fat during the period of drying. Dorpoto *et al.* (2011) reported the crude fat content of *P. ahipa* to be 0.65% on dry-weight basis which is similar to the value obtained for *P. erosus*. The slight difference could be due to varietal differences and/or differences in the geographical locations of their cultivation. The value obtained is also comparable to that reported by (Padonou *et al.*, 2005) for the lipids content of cassava roots**.** The relatively lower fat content recorded in the current study makes the P. *erosus* flour desirable as the risk of oxidation is reduced thus preventing the development of off flavours resulting from rancidity. Also, the low fat content of the flour makes it a suitable substitute for health conscious individual as well as over weights who want to reduce their caloric and fat intake.

In terms of crude protein, the *P. erosus* raw tuber recorded 1.57% while the value obtained for the flour was 5.68%, both on as-is basis. The apparent increase in the protein content could be due to the lower moisture content of the flour as compared to that of the raw tuber. On dry weight basis, the protein content for the *P. erosus* tuber was about 9.6%. Zaklan *et al*. (2007) reported the protein content of *P. ahipa* (a pachyrhizus species*)* root flour to be about 9.0%, which is similar to the value obtained for the dried *P. erosus* tubers used in the present study. This value is more than that of other root crops like cassava, sweet potato and yam.

Sabanis and Tzia (2009) also reported that *P. ahipa* root flour protein content which they found to be 8.61% was lower than that of wheat flour (11.8%) but similar to values found in corn (7.5%) and rice (7.0%). Similarly, the *P. erosus* flour due to its relatively high protein content can be composited with cereal flours and used as weaning foods for children to help resolve the issues Protein Energy Malnutrition (PEM). This can serve as a cost saving exercise since the current over-reliance of soya bean is becoming financially unbearable for most malnourished care givers.

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Total carbohydrates, calculated by difference, were 85.85% for the flour, and 14.07% for the raw tuber. This is not different from values reported in literature (Noman *et al*, 2007; Ukpabi, 2010; Adegunwa *et al*., 2011). Carbohydrates supply quick source of energy and assist in fat metabolism. The crude fiber content of the *P. erosus* flour was 6.26% (and 6.64% on dry-weight basis). The fiber content of the raw tuber was 1.48% on as-is basis, and 9.08% on dry-weight basis (Table 4.3). The difference could be attributed to the processing method used which involved peeling of the relatively high fiber skins. The value obtained in the present study is also similar to the crude fiber content of 1.4% on as-is basis (82.01% mc) for *P. erosus* tuber reported by Noman *et al*. (2007). The crude fiber content of *P. erosus* is said to be almost fourteen times higher than that in potato and four times higher than in sweetpotato. Crude fiber measures the cellulose, hemicelluloses and lignin contents of food.

4.2.1.2. Sugar content of P. erosus flours

Sugars are carbohydrates component of starchy roots and they play an important role in the behaviour of starchy staples in food systems. Reducing sugars, total sugars and sucrose in *P. erosus* raw tuber and the flour developed were determined to show how processing pre–treatments will affect its performance in food systems. The results obtained (Table 4.4) showed that the raw tuber had a reducing sugar value of 2.0% but the flour recorded a value of about 11% due to the lower moisture content. Similarly, total sugars and sucrose contents of the raw tuber showed apparent increases from 5.63 to 30.46% and from 3.62 to 19.12% in flour respectively (Table 4.3). The loss of moisture from the roots led to an increase in total dry solids of the *P. erosus* flour which had high concentration of total and reducing sugar content as shown in table 4.4 (Morris 2004). It can be inferred that processing significantly increased the content of sugars. High reducing sugars content in the tuber can cause darkening as a consequence of Maillard reaction between reducing sugars and amino acids, and are therefore undesirable. Low content of reducing sugars is preferred as they result in lighter colours of desirable quality (Abong *et al.*, 2009). However, incorporation of P. *erosus* flour in the formulation of infant foods has an advantage of already having enough sugar thus the need for external or commercial sugar addition is mitigated.

4.2.1.3. Starch content of P. erosus flour

The starch content of the *P. erosus* tuber was found to be 5.2% whereas the flour had 21.0%. On dry-weight basis, these values were calculated to be 31.8% and

22.3% for the root and flour respectively. The processing treatments might have caused the reduction in the starch content of the flour through possible hydrolysis. In general however, the starch content of the samples used in this study is less than the amount reported in earlier studies (Adegunwa *et al*., 2011; Perez *et al*., 2012). The starch content of *P. erosus* is reported to be between 45 – 55% with a recent study by Noman *et al*. (2007) reporting a starch content of 9.04% (50.22% on dry-weight basis). The yam bean can be processed into flour that can be used for the production of other food products like bread and pastries.

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4.2.2. Functional Characteristics

4.2.2.1. Pasting Properties

In the present study, the results of the hot paste viscosity measurement of the *P. erosus* flour developed are shown in Table 4.5., alongside literature values for sweetpotato and taro flour for comparison. The amylogram obtained was re-plotted on rectangular coordinates as shown in Fig. 4.2. Details of the viscograph runs and the raw data are also provided in Appendix 2. The *P. erosus* flour produced a pasting temperature of 70.6°C which is lower than that for Sweetpotato

Table 4.4: Pasting properties of *P. erosus* flour, sweetpotato flour and Taro flour

	Flour type		
Pasting characteristics	***P. erosus* flour**	**Sweet potato***	**Taro flour***
Pasting temperature (°C)	70.55±0.07	80.98±0.62	75.12±0.04
Peak viscosity (BU)	14.50±0.71	34.52±3.86	265.87±40.06
Peak time (min)	15.92±0.35	5.21±0.06	8.53±0.00
Viscosity after Holding (BU)	7.00±1.41	11.12±0.65	250.60±37.19
Final viscosity (BU)	16.50±2.12	12.96±0.84	487.04±64.63
Break Down (BU)	7.50±2.12	23.41±3.33	15.27±3.41
Set back (from peak)	2.00±0.71	- 21.55±3.21	221.50±25.34
Setback (from holding at 95°C)	9.50±2.83	1.85±0.19	236.80±27.67

*Source: Aprianita (2010)

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or Taro flour (Aprianita, 2010), but similar to that for cassava mosaic disease resistant cassava found to be between 64.5 to 74.0 °C (Omodamiro *et al.*, 2007). Melo, *et al*. (2003) also reported that the gelatinization temperature of yam bean starch paste ranges from 53 – 63°C, which is similar to that of cassava. In general pasting temperature of tuber starches is said to be lower than that of cereal starches. The pasting temperature is one of the pasting properties which provide an indication of the minimum temperature required for sample cooking, energy cost involved and stability of other components (Shimelis *et al*., 2006). It is clear from the results that the flour sample from the sodium metabisulphite pre-treated *P. erosus* flour will cook faster and less energy consumed, thereby saving cost

and time to because of its lower pasting temperature. Ease of cooking, which is estimated as the time from gelatinization to peak viscosity, is only about 2.0 min. for the *P. erosus* flour. This is far less than over 14 min reported for some legume flours by Plahar *et al.* (1997).

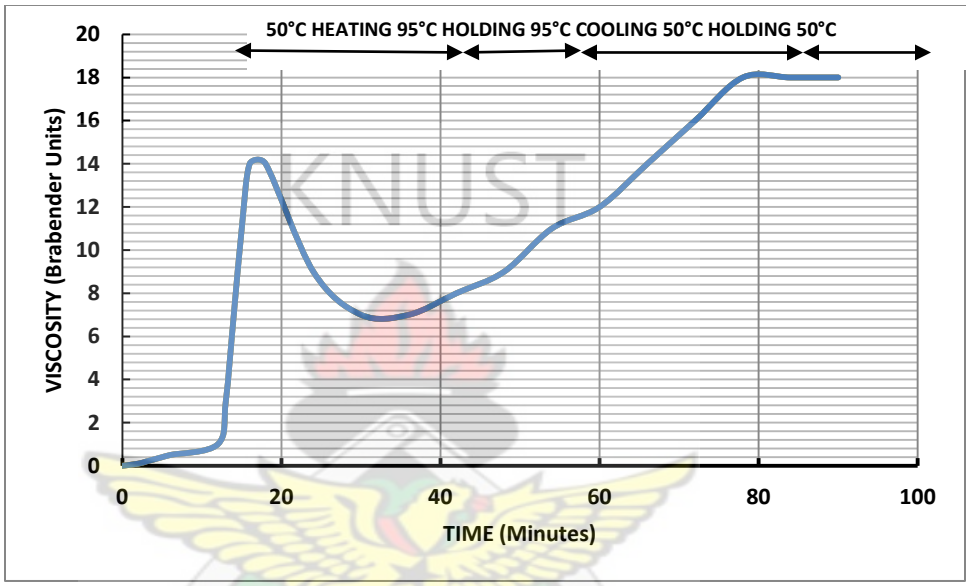

Figure 4.2.Amylograph pasting characteristics of standardized P. erosus flour

The peak viscosity, which is the maximum viscosity developed during or soon after the heating, was 14.5 BU at a peak time of about 16 min. This is about half the peak viscosity value recorded for sweetpotato (34.52 BU) and only a small fraction of the value for Taro flour (267.9 BU) attained at a relatively shorter peak time. Oguntunde (1987) reported that the associative bonding of the amylose fraction is responsible for the structure and pasting behavior of flour-starch granule. The viscosity, or more correctly the consistency of a cooked starch paste simply reflects the resistance to stirring of the swollen mass gel particles.

The breakdown viscosity of the flour sample during prolonged cooking at 95°C was 7.5 BU. This is the difference between the peak viscosity and the viscosity after holding for 15 min at 95°C; and is an indication of the paste stability. Adebowale *et al.* (2005) reported that the higher the breakdown in viscosity, the lower the ability of the sample to withstand heating and shear stress during cooking. Low starch paste stability is therefore commonly accompanied with high value of breakdown in viscosity (Shimelis *et al.,* 2006). From the present results (Table 4.4), it is clear that the *P. erosus* flour produced is able to withstand more heating and shear stress than Taro flour (15.3 BU) and Sweetpotato flour (23.40 BU). The final viscosity was 16.50 BU, producing a setback viscosity of 2.00 BU from peak (and 9.50 BU from holding at 95°C). Final viscosity is used to indicate the ability of starch to form various paste or gel after cooling (Shimelis *et al.,* 2006). Sanni *et al* (2001) reported that lower setback viscosity during the cooling of gari indicates higher resistance to retrogradation. This means that the *P. erosus* flour will exhibit higher resistance to retrogradation due to its low set back value.

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4.2.2.2. Swelling power, Solubility, Water holding capacity and Swelling volume of P. erosus flour

The swelling power, solubility, water holding capacity and swelling volume of the *P. erosus* flour samples are shown in Table 4.5. The swelling power is the measure of the ability of starch to imbibe water and swell, and reflects the extent of associative forces within the granules (Moorthy and Ramanujam, 1986; Sanni *et al,* 2005). The higher the swelling index therefore, the higher the associative

forces. The swelling power obtained for the *P. erosus* flour in the present study was 752.9 g/100g at 85°C with a solubility index of 54%. Swelling power is temperature dependent and is accompanied by solubilization of starch granule constituents (Dorpoto, *et al*., 2011). In earlier studies with Ahipa flour Doporto *et al*. (2011) reported swelling power values of about 800 g/100g sample. Swinkels (1985) reported that yam bean starch has a lower swelling power than that of cassava starch. The high swelling power of potato would be due, among others, to the high phosphate content because the negative charges allowed easier water entrance into the granules. High solubility is associated with high content of amylose, which is believed to leach out easily during the swelling process (Soni *et al*., 1993). Also high amylose content is linked with low swelling power due to greater reinforcement of the amylose molecules (Hoover, 2001). Highly associated starch granules with an extensive and strongly bonded structure also exhibit resistance to swelling (Leech *et al*., 1959). According to Richard *et al.*, (1991) and Singh *et al.*, (2001), pasting viscosities are positively correlated. Thus the higher the swelling power of the sample, the higher the pasting viscosities. The relatively higher swelling power obtained in the current study gives an indication of the high amylose content likely to be present in the starch granules of the *P. erosus* flour.

Water Holding Capacity (WHC) is an important parameter to be considered in the preparation of mashed, snack foods and extruded foods as well as baked products. The water holding capacity (WHC) obtained for the flour sample was 363.88%.

Knowledge of WHC is extremely useful in explaining and predicting the behaviour in food products (Wooton and Bamunuarachi, 1978). In their studies with *P. ahipa*, Dorpoto, *et al*. (2011) reported water holding capacity values of 191% and 132% respectively for Ahipa flour produced by slicing and by grating. Far lower values have been reported by Osundahunsi *et al.*,(2003) for some sweetpotato varieties (24% for red sweetpotato flour and 26% for white sweetpotato flour). The high values obtained in this study might be due to the relatively high protein content of the *P. erosus* root, and is in accordance with report by Ikegwu *et al.* (2009). High water holding capacity will give rise to high swelling power, and high peak viscosity. Root and tuber flours with high level of water absorption capacity will therefore be useful in meeting the needs for root and tuber incorporation into wheat flour for the bakery industry. Increase in WHC in food systems enables bakers to manipulate the functional properties of dough in bakery products (Achinewhu and Orafun, (2000); Iwe and Onadipe, 2001). The higher WHC recorded for *P. erosus* flour makes it suitable for the production of mashed foods because it will ensure product cohesiveness, and also increase the unit yield of the product (Kulkani *et al*., 1996: Pomeranz, 1971).

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Table 4.5 Swelling power, solubility, water holding capacity, and swelling volume of *P. erosus* flour

Functional Property	Mean Value
Swelling power at 85°C (g hydrated flour/100g dry flour)	752.9±18.6
Solubility (%)	54
Water Holding capacity (%)	
Pachyrhizus erosus	368.88
*Red sweet potato	24
*White sweet potato	26
Swelling volume(ml)	14

*Osundahunsi *et al.*, 2003

KNUST

The swelling volume recorded for the *P. erosus* flour was 14.0 ml. Swelling Volume (volume of gel) is used to measure flour or starch swelling properties. It is the volume of the un-dissolved sediment obtained after centrifugation. The flour swelling volume test measures the cumulative effects of starch quality, specifically amylose/amylopectin ratio as reflected by the volume of gel produced when flour is heated with an excess of water (AACC 2001).

4. 3. PRODUCT DEVELOPMENT FROM *P. EROSUS* AND WHEAT FLOUR BLENDS

The performance of the standard *P. erosus* flour developed in bread making was assessed using blends of various levels in wheat flour, as indicated in Table 2.2. Main quality indices examined included the physical properties such as loaf volume, loaf weight and specific volume; and sensory characteristics as determined by consumer acceptability tests.

4.3.1. Physical Properties of P. erosus Bread

The measurement of loaf weight, loaf volume and specific volume provides valuable information about product quality and is an invaluable tool used in making comparisons of ingredient and process effects. The specific volume, which is the ratio of loaf volume to its weight, has been generally adopted in literature as a more reliable measure of the physical property of bread (Shitu *et* al., 2007). The physical properties of the *P. erosus* bread have been shown in Table 4.8. The loaf weight of the composite bread samples ranged from 521 to 530 g. Significant differences (p<0.05) were observed among the different bread samples with respect to their loaf weights. The control sample (100% wheat flour) produced bread with largest loaf weights followed by bread samples from composite blends of 85% wheat flour and 15% *P. erosus* flour. Other blend formulations produced bread samples with relatively lower loaf weights compared to the control sample. There was no significant difference (p >0.05) in the loaf weights of bread from these blend formulations (FMA, FMB, FMD, FME) although have varying percentages of *P. erosus* flour and wheat flour (Table 4.6).

The loaf volume of the composite bread samples ranged from 1,221 to 1,269 cm^3 as shown in Table 4.6. The lowest loaf volume was recorded by the higher *P. erosus* substituted flour (70: 30) while the control sample recorded the highest loaf volume. It was observed that there are significant differences (p<0.05) among the different bread samples with respect to their loaf volume (Table 4.6). This observation is corroborated by Ndife *et al*. (2011) who revealed there a decrease in bread volume and dough expansion with an increase in soya flour.

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Table 4.6 Physical properties of bread samples from blends of wheat and *P. erosus* flours

Sample	Loaf weight (g)	Loaf volume (cm^3)	Specific loaf volume(cm^3 g)
CTL	530.87±1.27[a]	1269.63±9.27[a]	2.39±0.02[b]
FMA	521.53±3.01[c]	1266.28±1.98[b]	2.43±0.01[a]
FMB	521.50±3.01[c]	1255.21±5.84[c]	2.40±0.01[b]
FMC	525.38±2.53[b]	1244.61±13.80[e]	2.36±0.01[c]
FMD	521.53±3.01[c]	1250.76±5.19[d]	2.39±0.01[b]
FME	521.53±3.01[c]	1221.77±8.36[f]	2.34±0.02[d]

Values with the same superscript letter(s) in a column are not significantly different (p > 0.05)

CTL=100% wheat flour, FMA=95% wheat flour: 5% *P. erosus* flour, FMB=90%wheat flour: 10% *P. erosus* flour, FMC=85%wheat flour: 15% *P. erosus* flour, FMD=80wheat flour: 20 % *P. erosus* flour, FME=70wheat flour: 30% *P. erosus* flour.

As the level of *P. erosus* flour substitution increased, the loaf volume also decreased. Malomo *et al.* (2011) also observed a similar trend in loaf volume decreases with increasing substitution of wheat flour with bread fruit flour. This could be attributed to inclusion of the *P. erosus* flour which reduced the wheat

gluten and consequently weakened the gluten network in the dough. This assertion is corroborated by the work of Taha (2000).

The calculated specific loaf volume of the composite bread samples ranged from 2.34 to 2.44 cm^3 /g as shown in Table 4.6. Although the range appears quite small, it was observed from the one-way ANOVA in Table 4.6 that there were significant differences ($p < 0.05$) among some of the bread samples with respect to their specific loaf volume. The specific loaf volume of the composite bread with 95% wheat flour and 5% *P. erosus* flour was significantly different from all the others. The result revealed that as the level of substitution of *P. erosus* flour increased, specific loaf volume tend to decrease. Again this observation follows the trend reported by Malomo *et al*., (2011). However, according to the China Grain Product Research and development Institute, CGPRD (1983), the specific volume of standard bread should be 6 cm^3/g and should not be less than 3.5 cm^3 /g (Liu *et al*., 2009). The result shows that none of the samples had a specific volume that met the Chinese standard level. This situation is due to the same lack of gluten in the *P. erosus* mentioned earlier (Ohm and Chung, 1999; Taha, 2000). It can therefore be concluded that although substituting *P. erosus* flour up to 30% may be feasible, the standard specific volume cannot be met.

4.3.2. Sensory Characteristics of P. erosus Bread

Consumer sensory scores for the bread samples are shown in Table 4.8. Samples were scored in terms of colour, aroma, taste, texture/sponginess, crust, mouth feel and overall acceptability using the nine-point hedonic scale (Larmond, 1977).

With respect to the sensory attributes evaluated, the control (100% wheat flour) sample was significantly different ($p<0.05$) from all the composite samples. Colour was rated 'like very much' (mean score of about 8.0) for the control bread, while 5, 10, and 15% *P. erosus*-fortified bread samples were rated 'like moderately' (mean score of about 7.00), and were not significantly different from each other at $p<0.05$. Blends containing higher concentrations of *P. erosus* flour (i.e. 20 – 30%) were scored around 6.00 indicating 'slight liking' for colour. Aroma mean scores indicated moderate liking for the traditional wheat flour bread and mostly slight liking for bread samples containing up to 30% *P. erosus* flour. Caramelization of sugars and products of Maillard reactions contribute significantly to aroma of baked goods.

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Table 4.7 Mean values of sensory scores of bread samples[1]

Sample Code[2]	Colour	Aroma	Taste	Texture	Crust	Mouthfeel	Overall acceptbility
CTL	7.83±0.11^{a}	7.28±0.04^{a}	7.12±0.75^{a}	6.97±0.41^{a}	6.85±1.02^{a}	7.17±0.42^{a}	6.98±0.85^{a}
FMA	7.13±021^{b}	6.08±0.12^{b}	5.98±0.62^{c}	5.87±0.41^{b}	5.58±0.41^{b}	5.67±0.31^{b}	5.72±0.84^{b}
FMB	6.98±0.45^{b}	6.03±0.58^{b}	6.57±0.15^{b}	5.98±0.54^{b}	6.12±0.20^{b}	6.07±0.46^{b}	6.02±0.54^{b}
FMC	6.88±054^{b}	6.40±0.41^{b}	6.28±0.11^{c}	5.98±0.05^{b}	5.27±0.46^{c}	6.02±0.48^{b}	5.70±0.24^{b}
FMD	6.13±0.78^{c}	5.43±0.45^{c}	5.43±0.36^{d}	5.27±0.98^{c}	5.03±0.87^{c}	5.32±0.08^{c}	5.13±0.05^{c}
FME	6.27±1.01^{c}	5.90±0.89^{b}	6.12±0.18^{b}	5.70±0.87^{b}	5.22±0.96^{c}	5.25±0.21^{c}	5.43±0.08^{c}

[1]Values with different superscript in the same column are significantly different. ($p<0.05$)
Interpretation of scores: 1= dislike extremely; 2=dislike v. much, 3=dislike moderately, 4= dislike slightly, 5=neither like nor dislike, 6=like slightly, 7=like moderately, 8=like v. much, 9=like extremely.

[2]CTL=100%wheat flour; FMA=95% wheat flour and 5% *P. erosus* flour; FMB=90%wheat flour and 10% *P. erosus* flour; FMC=85%wheat flour and 15% *P. erosus* flour; FMD=80% wheat flour and 20 % *P. erosus* flour; FME=70% wheat flour and 30% *P. erosus* flour.

The mean scores for taste of the bread samples did not show any clear-cut trend with regards to increasing concentration of *P. erosus* flour in the blend. Taste perception by panelists was apparently enhanced by the high sugar content of *P. erosus* flour. Most of the blends were scored between 'like slightly' and 'like moderately'. Mean scores for texture, crust and mouthfeel again showed moderate liking for the 100% wheat flour bread while blends containing up to 15% *P. erosus* flour were scored slightly lower (like slightly). This means that lack of gluten in the *P. erosus* flour influenced the dough characteristics and hence the textural quality of the final product.

KNUST

Overall acceptability scores of all the bread samples prepared with the flour blends were only slightly lower than that for the traditional bread. From the results in Table 4.8, it is observed that up to 20% wheat replacement was accepted and closer to the score for the control. Also addition of P. *erosus* flour at levels up to 30% could be acceptable for bread making in Ghana. Taha (2000) also reported that wheat/sorghum blends were used to produce acceptable bread samples at levels up to 70:30 blend ratios. In a similar work done by Abigdelghafor *et al*., (2010) revealed that up to 20 % wheat replacement with decorticated sorghum produced bread with uncompromised sensory attributes.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

A standard method has been developed for the production of high quality *P. erosus* flour. Peeling and short soaking in 0.1% sodium metabisulphite are necessary pretreatments in the production of the high quality flour from *P. erosus*. Peeling treatment results in a whiter *P. erosus* flour colour, higher pH and lower moisture content than unpeeled treatment. Metabisulphite pretreatment further enhances the white colour of the final product apparently by preventing enzymatic browning. The pasting characteristics, swelling power, water holding capacity, solubility, and swelling volume and chemical analysis of *P. erosus* flour produced by the standard method developed are comparable to available commercial root and tuber flours. Also sensory evaluation conducted on the bread sample revealed that *P. erosus* flour can be substituted up to 30% replacement levels in wheat flour for bread production.

5.2. Recommendations

Based on the findings of this study, the following recommendations are made:

1. There is the need to conduct toxicity and anti-nutritional studies of unpeeled *P. erosus* flour to establish its safety
2. Further studies need to be conducted on the dough properties of P. *erosus* flour to establish procedures that will help overcome some technical problems encountered during kneading.
3. There is the need to conduct further studies to broaden and diversify the utilization base of *P. erosus*, especially in the area of its use in weaning food formulations.

4. As a result of raw material constraints, the pasting properties of the standard *P. erosus* flour developed in the present study were recorded without relating them to those of a control untreated sample. This aspect needs to be done.

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APPENDICES

1. ANOVA for Physical Characteristics of Bread Samples

ANOVA

weight

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	148.527	4	37.132	5.066	.017
Within Groups	73.298	10	7.330		
Total	221.825	14			

KNUST

ANOVA

volume

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4312.987	4	1078.247	24.411	.000
Within Groups	441.700	10	44.170		
Total	4754.687	14			

ANOVA

specificvolume

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.016	4	.004	9.629	.002
Within Groups	.004	10	.000		
Total	.021	14			

2. ANOVA for Sensory Properties of Bread Samples

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
color	Between Groups	115.022	5	23.004	5.905	.000
	Within Groups	1379.100	354	3.896		
	Total	1494.122	359			
aroma	Between Groups	97.489	5	19.498	4.814	.000
	Within Groups	1433.833	354	4.050		
	Total	1531.322	359			
taste	Between Groups	96.500	5	19.300	4.174	.001
	Within Groups	1637.000	354	4.624		
	Total	1733.500	359			
texture	Between Groups	106.822	5	21.364	4.038	.001
	Within Groups	1873.167	354	5.291		
	Total	1979.989	359			
crust	Between Groups	130.189	5	26.038	5.807	.000
	Within Groups	1587.267	354	4.484		
	Total	1717.456	359			
mouth_feel	Between Groups	120.381	5	24.076	5.547	.000
	Within Groups	1536.617	354	4.341		
	Total	1656.997	359			
overall	Between Groups	127.181	5	25.436	5.300	.000
	Within Groups	1699.017	354	4.799		
	Total	1826.197	359			

KNUST

3. ANOVA for Chemical Properties of *P. erosus* Flour Samples

ANOVA

pH

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.148	2	.074	851.292	.000
Within Groups	.000	3	.000		
Total	.148	5			

ANOVA

moisture

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.098	2	.049	.053	.950
Within Groups	2.787	3	.929		
Total	2.885	5			

KNUST

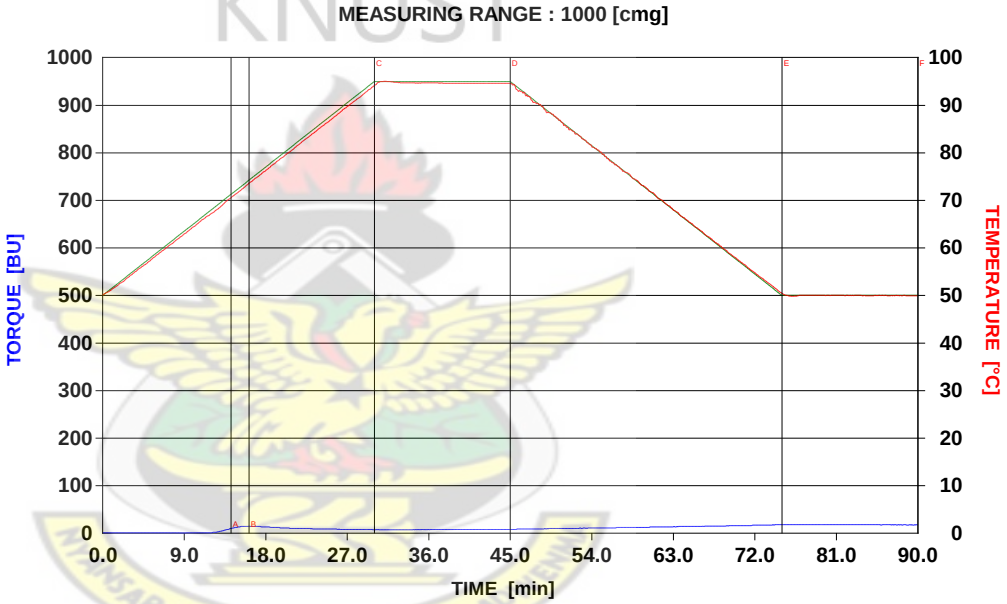
4. Amylogram Data

BRABENDER VISCOGRAPH

Parameter

Operator	:	APOLLONIUS		Date	:	1/30/2012	
Sample	:	MT2 (A)		Method	:	METHOH 1	
Moisture	:	3.80	[%]	Correction	:	14	[%]
Sample weight	:	40	[g]	Corr. to 14%	:	35.7	[g]
Water	:	420	[ml]	Corr. to 14%	:	424.2	[ml]
Note	:						
Note	:						
Speed	:	75	[1/min]	Meas. range	:	1000	[cmg]
Start temperature	:	50	[°C]	Heat./Cool. rate	:	1.5	[°C/min]
Max. temperature	:	95	[°C]	Upp. hold. time	:	15	[min]
End temperature	:	50	[°C]	Fin. hold. time	:	15	[min]

KNUST



Evaluation

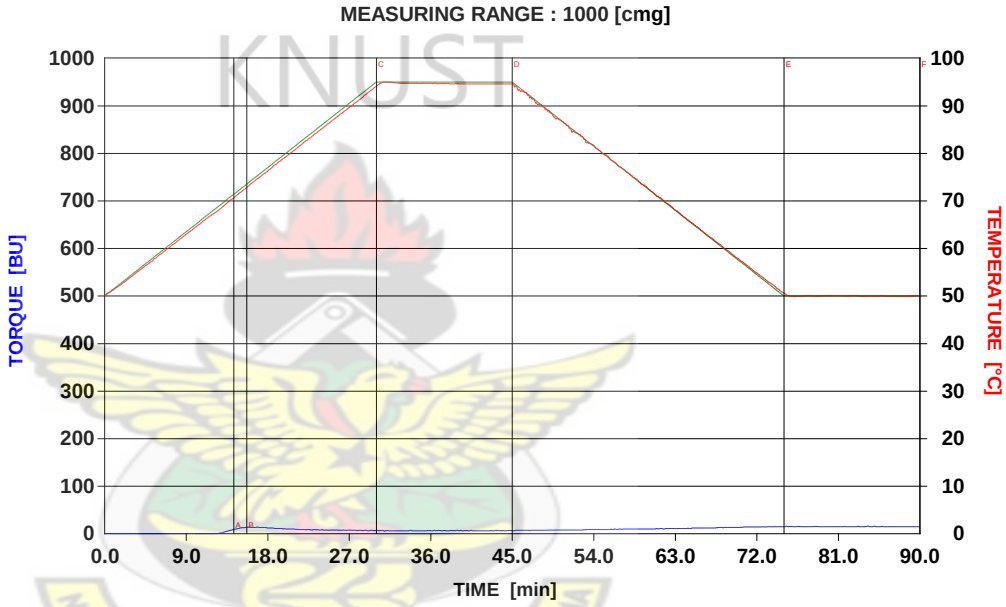
Point	Name	Time [HH:MM:SS]	Torque [BU]	Temperature [°C]
A	Beginning of gelatinization	00:14:10	10	70.5
B	Maximum viscosity	00:16:10	15	73.6
C	Start of holding period	00:30:00	8	94.2
D	Start of cooling period	00:45:00	8	94.6
E	End of cooling period	01:15:00	18	50.4
F	End of final holding period	01:30:00	17	49.9
B-D	Breakdown		7	
E-D	Setback		10	

File : Measurement V: 2.3.16

BRABENDER VISCOGRAPH

Parameter

Operator	:	APOLLONIUS		Date	:	1/30/2012	
Sample	:	MT2 (B)		Method	:	METHOH 1	
Moisture	:	3.80	[%]	Correction	:	14	[%]
Sample weight	:	40	[g]	Corr. to 14%	:	35.7	[g]
Water	:	420	[ml]	Corr. to 14%	:	424.2	[ml]
Note	:						
Note	:						
Speed	:	75	[1/min]	Meas. range	:	1000	[cmg]
Start temperature	:	50	[°C]	Heat./Cool. rate	:	1.5	[°C/min]
Max. temperature	:	95	[°C]	Upp. hold. time	:	15	[min]
End temperature	:	50	[°C]	Fin. hold. time	:	15	[min]



Evaluation

Point	Name	Time [HH:MM:SS]	Torque [BU]	Temperature [°C]
A	Beginning of gelatinization	00:14:15	9	70.6
B	Maximum viscosity	00:15:40	14	72.8
C	Start of holding period	00:30:00	6	94.1
D	Start of cooling period	00:45:00	6	94.6
E	End of cooling period	01:15:00	15	50.6
F	End of final holding period	01:30:00	15	50.0
B-D	Breakdown		7	
E-D	Setback		8	

File : Measurement V: 2.3.16

KNUST
NYANSAPO WO SANE NO BADWENMA

Viscograph Raw Data MT2 (A)

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Viscograph Raw Data MT2 (B)

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5. Consumer Acceptability Test

Name: …… Product: ……..

Sample code: ……

Please assess this bread sample using the scale below. Tick the appropriate column according to the degree of likeness of the sample. Remember to rinse your mouth with the water provided after tasting each sample.

Scale	Interpretation	**Colour**	**Aroma**	**Taste**	**Texture/ Sponginess**	**Crust**	**Mouth feel**	**Overa accep**
9	**Like extremely**							
8	**Like very much**							
7	**Like Moderately**							
6	**Like Slightly**							
5	**Neither like nor dislike**							
4	**Dislike Slightly**							
3	**Dislike Moderately**							
2	**Dislike very much**							
1	**Dislike Extremely**							

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