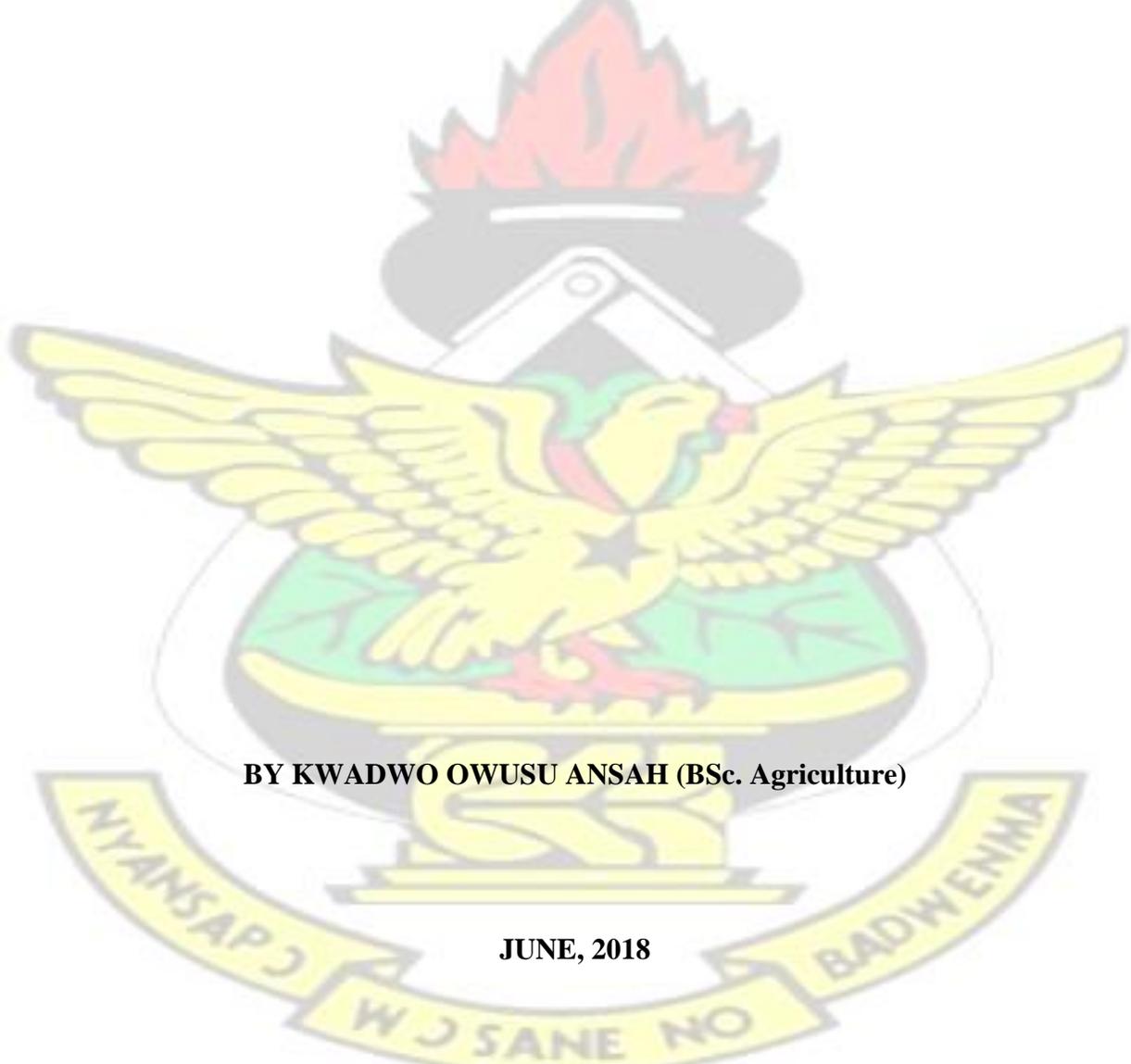


KNUST

**EVALUATION OF SOME QUALITY ATTRIBUTES OF CASSAVA ACCESSIONS
AT**

VARYING MATURITY



BY KWADWO OWUSU ANSAH (BSc. Agriculture)

JUNE, 2018

KWAME NKURUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF SCIENCE

EVALUATION OF SOME QUALITY ATTRIBUTES OF CASSAVA ACCESSIONS AT
VARYING MATURITY

A THESIS SUBMITTED TO THE DEPARTMENT OF FOOD SCIENCE AND
TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE
AWARD OF
MASTER OF SCIENCE IN FOOD QUALITY MANAGEMENT

BY

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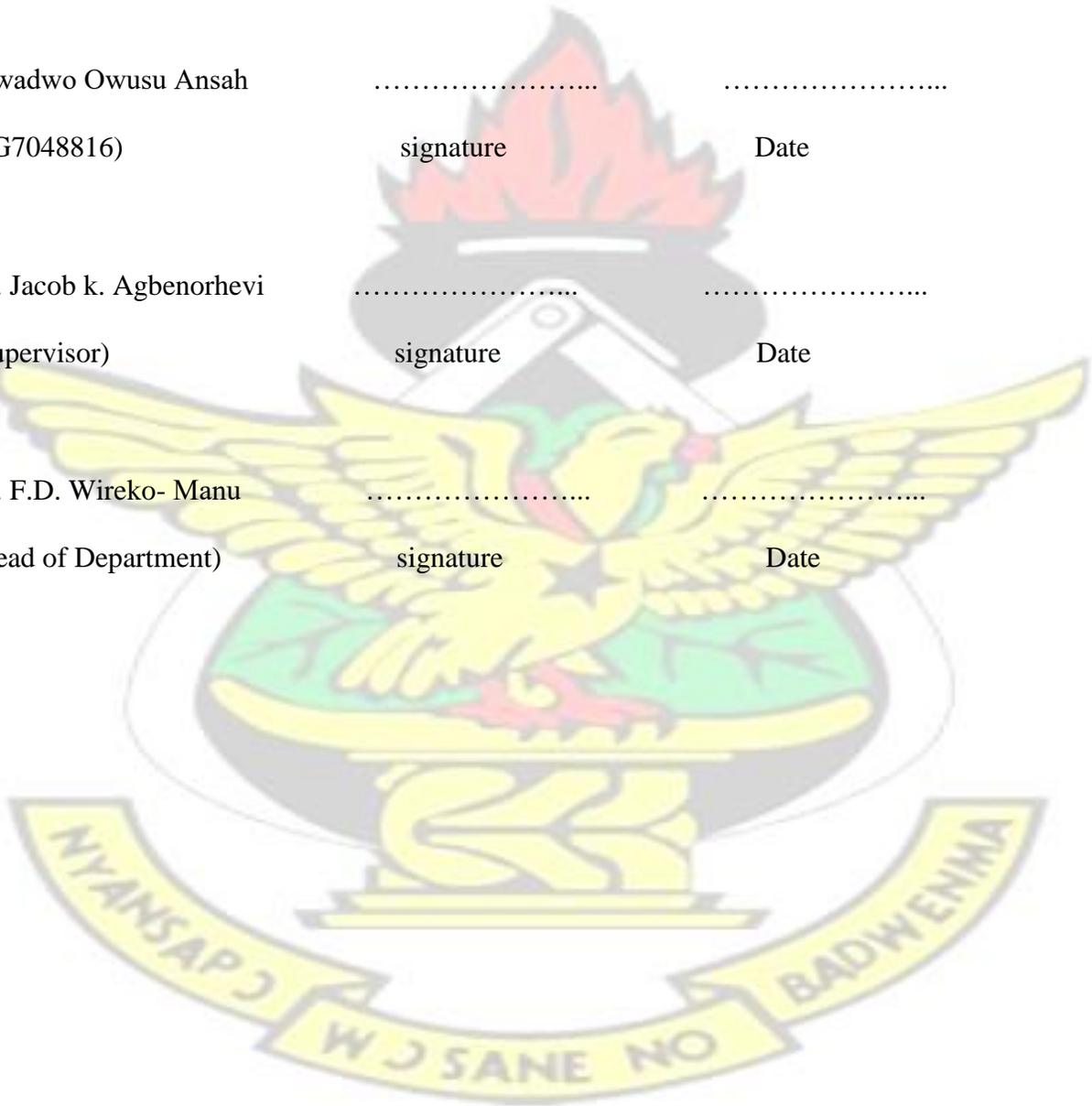
DECLARATION

I hereby declare that this thesis has been composed by myself, and has not been accepted in full or in part in any previous application for higher degree. The work of this thesis is a work of my own accord; any collaborative work has been specifically acknowledged as has all sources of information.

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ABSTRACT

Cassava (*Manihot esculenta*) is a root crop which has been used widely in the production of many products and also as an important source of starch on a global proportion. The aim of this work was to investigate the characteristics of starch from new cassava accessions at different stages of maturity. Three new cassava accessions (*Abrabopa*, *Amansen* and *Duadekpakpa*) were harvested at four consecutive months (from April – July 2017; 7-10th month) after planting. Starch was extracted from these cassava accessions using the conventional method of starch extraction and their yield calculated. The amylose content and presence were determined by means of spectrophotometry whereas pasting properties of the starches were analyzed using Rapid Visco Analyzer. Average starch yield ranged from 18-29% and was at its highest yield in the 10th month for all the accessions studied. There were no significant differences ($p > 0.05$) in the peak viscosity, final viscosity, peak time and pasting temperature but significant difference was recorded for setback, trough and breakdown of the starch samples. The amylose (14-25%) and amylopectin (76-85%) content of the varieties differed significantly ($p < 0.05$). The results show that maturity affects the starch yield, composition and pasting properties of the new cassava accessions and this should be considered in deciding the time to harvest each accession for specific food and non-food industrial applications.

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To my friend and course mate, Gabriel Annobil Bisiw for the synergy that edged me on. I would like to express my heartfelt gratitude to my dear wife Safia Adams for all the sacrifices, the love and the encouragement. I am forever grateful.



DEDICATION

This work is dedicated to my late father, Kwame Asante Amoateng for his love, support and adventurous spirit which has brought me this far.

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CHAPTER ONE

Introduction

1.0 Background to the study

Starch forms a major component of cassava (*Manihot esculenta Crantz*) and it is an essential raw material for food and non-food industries worldwide (Mweta, 2009). According to report by Tewe and Lutaladio (2004), the dry weights of cassava tubers contain 80 to 90% carbohydrate, out of which 60-80% is starch and the rest constitute sugars such as glucose, fructose and maltose. Starch contributes greatly to the texture of many foods and is widely used in the food industry and others for applications including thickeners, colloidal stabilizers, gelling agents, bulking agents, and adhesives (Goel *et al.*, 1999). It is also known for its use in several African diets, textiles and plywood, paperboard, pharmaceuticals, petroleum and brewery manufacturing. This diverse usage of cassava starch is due to its many characteristics, such as high paste viscosity, high paste clarity, and high freeze-thaw stability, which are advantageous for industrial purposes (Sriroth *et al.*, 2002).

The extraction of starch is done in several countries using common food crops such as maize, wheat, rice and sweet potatoes. The by-products depending on the source demonstrate different functionality as a result of the variance in their granular structure, that is amylose and amylopectin ratio and branch chain length distribution, which affects their physical and chemical properties.

Literature is replete with data on physicochemical properties of cassava such as granule structure, pasting properties, swelling power and solubility (Charles *et al.*, 2004; Gomes *et al.*, 2005; Zaidul *et al.*, 2007).

Food and Agricultural Organization (2000) reported that, global demand for cassava starch could increase at an annual rate of 3.1%, with regional growth rates expected to be 2.3% for Africa,

4.2% for Asia and 3.4% for Latin America. This resulted in an increase in research on cassava starch production. Cassava varieties such as ‘Abasafitaa’ (clone-TMS(4)1425), ‘Afiiafi’ (clone TMS 30572), Tek bankye (coded *Isu-White (Isu-W)*), ‘Glemoduade’ (clone TMS 50395) and ‘Doku duade’ are among the locally bred and selected varieties that have been endorsed by the Ghana Ministry of Food and Agriculture (MOFA) and the Crop Research Institute (RTIP Fact sheet, 2002) as high starch yielding varieties.

A comparative evaluation of physiochemical and functional properties of cassava flour from different fertilizer protocols by Mensah (2013) revealed that the physiochemical properties of the flour were significantly affected by different cassava varieties and different fertilizer protocols.

It is important to note that starch characteristics and yield from cassava is dependent but not limited to variety, maturity, cultivation practices and extraction methods. A study conducted on extraction of cassava starch with the aid of pectolytic enzymes from *Saccharomyces cerevisiae* and the effect of cassava variety difference on the process and found out that, optimization of starch extraction from cassava using crude pectolytic enzymes from *S. cerevisiae* was dependent on variety as well as the treatment combinations adopted during extraction.

Research on cassava is centered on improving the quality of starch and incorporating it into other flour to make composite flour and weaning foods (Annor-Frimpong *et al.*, 1996; Bokanga 1998). Genetic modifications for starch crops have in most cases led to the development of starches with improved and targeted functionality (Jobling and Mittal, 2004).

1.1 Problem statement

The increasing demand for cassava starch due to numerous industrial applications has led to a rise in the cultivation of cassava and the production of its starch. The yield and the quality characteristics of cassava give an indication of the possible industrial application. Yield and the quality of the starch are dependent on the cassava accessions and the maturity at which cassava is harvested. New cassava accessions have been cultivated by the department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology. However, the suitable maturity/ harvesting time to achieve optimum starch yield and the desired quality have not been studied.

1.2 Justification

Findings from this work would provide the suitable maturity at which to harvest cassava for optimum starch yield and desired quality in relation to the different accessions. Ultimately, the economic value for cassava cultivation will improve.

This study will detail the different quality attributes of different cassava accessions that can be exploited for a number of emerging starch industries.

1.3 Main Objective

The main objective of the study is to evaluate quality attributes of starch from three cassava accessions namely; *Amansen*, *Abrabopa* and *Duadekpakpa* at varying maturity.

1.3.1 Specific objectives

The specific objectives of this study are to:

1. To determine the yield of starch from the different accessions of cassava at varying maturity.

2. To determine the pasting properties of starch from these different accessions at varying maturity.
3. To determine the amylose and amylopectin content of starch from the accessions at varying maturity.



CHAPTER TWO

LITERATURE REVIEW

2.1 Taxonomy of Cassava

Cassava (*Manihot esculenta* Crantz) is a Dicotyledonous plant that belongs to the family; Euphorbiaceae, class Manihoteae, genus Manihot. Genus Manihot has about 100 species with *Manihot esculenta* Crantz being the only commercially cultivated species (Alves, 2002).

Cassava cultivars have also been classified according to morphology e.g. leaf shape and size, plant height, stem and petiole colour, inflorescence and flower colour, root shape and colour, and content of cyanogenic glucoside in the roots (Onwueme, 1978; Mkumbira, 2002; Nasar, 2005).

Early literature classified cassava genus as having two edible species; *Manihot utilissima* Phol and *Manihot aipi* indicating cultivars with low and high cyanogenic concentrations respectively. The flesh of sweet/cool cultivars is therefore relatively free of cyanogenic glycoside (Mkumbira, 2002, 2005).

2.2 Morphology and Description of Cassava

The cassava plant is a perennial woody shrub, short-lived and growing to a height of three meters or more with an erect glabrous stem noticeable by protruding knobs of leaf scars with varying degrees of branching (Kochhar, 1981). The plant is made up of the shoot system and the root system. The shoot system consists of stem, leaves, and flowers while the root system consists of feeder roots and tubers (IITA, 1990). The root is not tuberous in structure but a true root. The size

and shape of cassava root is dependent on the variety and the prevailing environmental conditions (Wheatley and Chuzel, 1993). Roots are the primary storage organ of the plant (Ricardo *et al.*, 2007).

The development of a tuber is mainly in the diameter of the root. The tubers are 50cm long and 10cm in diameter and commonly not branched, but branching may occur if they are more meters long (Cobley, 1976). A mature tuber consists of three distinct anatomical regions; the outer skin or periderm which seals off the surface of the tuber as the bark, a thin rind or cortex usually white, but may be tinged pink or brown, and the core or pith (flesh) which consist mainly of parenchyma rich in starch with few xylem bundles and latex tubes usually white but may be yellow or tinged red; this is the edible portion (IITA, 1990).

Three percent (3%) of the total root weight is the periderm, which is a thin layer with only a few cells thick. The cortex is made up of sclerenchyma and phloem, forming 11- 20% of the root weight (Alves, 2002). The parenchyma regions are the edible portion of the root and constitute about 85% of the total weight with xylem vessels distributed in the matrix where starchcontaining cells are found (Wheatley and Chuzel, 1993).

Cassava plants can be distinguished by their morphological characteristics such as leaf size, colour and sharply branching habit, plant height, colour of stem and petiole, tuber shape and colour, maturity period and yield (IITA, 1990).

The older part of the stem consists of prominent knoblike scars, which are the nodal positions where leaves were originally attached. Each nodal unit consists of a node, which subtends a leaf and an inter-node. There are two types of branching. In fork branching, the main stem grows for a while before producing (usually) three branches at the apex of the stem while in lateral branching,

after a certain period of growth lateral branching sets in and branching occurs on any part of the main stem at some distance from the apex (IITA, 1990).

Cassava also contain cyanogenic glucosides, mainly linamarin, and in a small proportion, lotaustralin which may be hydrolyzed by the endogenous enzyme linamarse to liberate hydrogen cyanide (HCN) (Mahungu *et al.*, 1994).

2.3 Origin and Distribution of Cassava

Cassava is native to South America but is now grown in tropical and sub-tropical areas worldwide for the edible starchy roots (tubers), which are a major food source in the developing world, including Africa.

There seem to be several opinions about the origin of cassava. The crop is said to have been cultivated in Peru and Mexico about 4000 and 2000 years ago, respectively. However, majority of botanists and ecologists consider the northeast of Brazil to be the most probable center of origin. Cassava is believed to have originated in North East Brazil but there is the likelihood of other origins in Central America, Western and Southern Mexico and part of Guatemala (Rogers, 1963). The Portuguese took it from Brazil to western coast of Africa in the 15th century; later at the end of the 18th century, it was introduced to Madagascar and then onto the east coast of Africa. Pursigolve (1987) reported that, Western and Southern Mexico and parts of Guatemala and North-Eastern Brazil are the two geographical locations of phylogeny of the genus *Manihot*. Doku (1969) also expressed that the crop was first introduced to Congo in Africa from South America about 400 years ago. Cultivation of the crop has spread to about 40 African countries from Madagascar in the South-east to Senegal in the West and to Cape Verde in the North-west (Nweke, 2004). According to MOFA (2003), the crop was introduced to the Volta region of Ghana, where it spread to the Brong-Ahafo and Ashanti regions. It was also grown in all the

Regions except the Upper East. The crop became a major food crop in the coastal belts at the beginning of the 19th century, and then to Ashanti and Northern regions in the 1930s (Doku, 1969).

2.4 Cultivation

The worldwide cassava production increased to about 230 million tons from 2009-2010 (Zhu *et al.*, 2015). In 2013, the cassava production increased to 276.7 million tons and it is expected to increase to 291 million tons by 2020 (Scott *et al.*, 2000). Africa contributes to about 51.3%, Asia 29.4%, and Latin America 19.3% (Mombo *et al.*, 2016). In Africa, Nigeria is the largest producer of cassava and its starch and production is strongly increasing with the years Oduwaye *et al.*, 2014). This production value is expected to increase due to the rising prices of traded food staples of cereals like rice, farmers would turn to indigenous crops as an alternative source. Among these crops cassava has seen the most development in cultivation because the root can be left in the ground for well over a year and harvested when food shortages arise. This attribute could lead to marked expansion in cassava output in Africa where access to storage facilities is a challenge.

2.4.1 Cultivation of Cassava in Ghana

In the early 1960s, Ghana was the seventh largest producer of Cassava in Africa with an annual production of 1.2 million tons. It increased its output to 7.2 million tons annually as the third largest producer in Africa after Nigeria and Congo (Nweke, 2004). Cassava cultivation is practiced in all the agro-ecological zones in Ghana. According to MOFA (2005), the average yield of cassava in Ghana is 12.42 metric tons per hectare with a potential yield of 28.0 metric tons per hectare. The chunk of the nation's cassava is produced in the southern and the middle belt (MOFA, 1997). This constitutes barely 80% of the gross cassava production in Ghana with 20% granted to production in the Northern region.

The crop contributes 16% of Ghana's Agricultural Gross Domestic Product (AGDP) (SafoKantanka, 2004). In Ghana, it is estimated that 70% of farmers grow cassava and is consumed by more than 80% of the population (Parkes, 2009). The yield may be enhanced by the application of fertilizer by farmers to provide the requisite nutrients for optimum development of the crop. Cassava is used directly as food or as a raw material for production of starch.

2.5 Cassava Starch

Cassava starch is a white or cream-colored powder obtained from cassava roots (Dufour *et al.*, 1996). Processing cassava into starch is one form through which the produce can have assured longevity. IITA (1990) recognized that cassava starch makes 45% of the essential cassava products in Africa, Abass *et al.* (1998) also stated that cassava starch is the easiest and the cheapest to make among the root crops as flour as well as the highest income generator.

Shittu *et al.* (2008) reported that selection of cassava root variety and application of fertilizer are essential factors when considering optimizing composites of cassava-wheat flour for quality bakery products.

2.5.1 Yield of Starch

The starch yield from cassava roots is dependent but not limited to: cultivar type, maturity, extraction method and cultivation practices. Starch composition in cassava root rises with an increase in the dry matter accumulation (Henry *et al.*, 1998). The starch content usually declines at the beginning of raining season due to insufficient sunlight and hence the hydrolysis of starch to sugar (Henry *et al.*, 1998). Production of starch and sugar increases in cassava root when the soil has higher potassium levels, as potassium helps in the formation of more starch vacuoles (Addo-Quaye *et al.*, 1993). According to IITA (2005), starch contents of cassava obtained from different varieties of cassava ranged from 61.8-66.4%. However, there is substantial loss in starch

content of roots when left in the soil after maturity. It is therefore for this reason that early maturing varieties are harvested at nine months after planting if only the starch component is of economic importance (Ketiku and Oyenuga, 1972). A field trial by Vichukit *et al.* (1994) indicated that starch content surges from 7-9 months of maturity, after which this content will depend on rainfall conditions.

2.6 Uses and Application of Cassava Starch

Cassava starch is popularly known in world trade as tapioca. It can be used directly as coating for textile, made into collections of baked or gelatinized products and manufactured into glucose, maltose and dextrin. The use of starch was recorded as far back as the 4th century among the Egyptians which was acquired most probably from wheat and used as a binder for fibers and in the production of papyrus (Mensah, 2013)

When cassava is milled into fine powder it can be used in making salad dressing, biscuit, composite bread, ice cream powder, custard powder and flakes. Cassava flour is also employed in the making of delicacies such as cassava fruit cake and cassava dumplings (Balagopalan *et al.*, 1988). Researchers at IITA have indicated that cassava can be used to make bakery products such as cakes, cookies and doughnuts (Onabolu and Bokanga, 1995). The fine powder has also seen use in the production of cereal as industrial starch adhesive (Balagoplan, 1988).

Unmodified starch, modified starch and glucose are used in the food industry for one or more of the following purposes

- a. Directly as cooked food, such as custard, tapioca.
- b. Thickener: Using the paste properties of starch in soups, baby foods sauces and gravies

- c. Filler: Contributing to the solid content of potages, pills, tablets and other pharmaceutical products
- d. Binder: To consolidate mass and prevent it from drying out during cooking in sausages and processed meats
- e. Stabilizer: Owing to the high-holding capacity of starch it is used as a voltage stabilizer. In many developing countries bread consumption is continually expanding and there is growing dependence on exported wheat. In Ghana, cassava contributes about 46% of the total food production. This makes cassava the next best option to wheat as an alternative for making bread. It would therefore be economically advantageous if imports of wheat flour is gradually reduced and replaced with cassava flour. The applications of starch in food industries depend on the functional properties such as pasting, gelatinization, retrogradation, water absorption capacity, swelling power and solubility which vary based on the botanical source and variety (Amani *et al.*, 2004; Peroni *et al.*, 2006; Yuan *et al.*, 2007).

2.6.1 Bakery products

Although starch is the major constituent of flours, the art of bread making depends to a large extent on the selection of flour with the proper gluten characteristics. Starch is used in biscuits and in cream sandwiches in a range of 5-10 percent in order to soften its texture and add taste as well as render the biscuit non sticky (Abdel-Aal, 2009). The use of dextrose in some kinds of yeast-raised bread and bakery products has certain advantages as it is readily available to the yeast and the resulting fermentation is quick and complete. It also imparts a golden brown colour to the crust and permits longer conservation (Mensah, 2013)

2.6.2 Confectionaries

Unmodified starch and modified starches has been widely used for making dextrose and glucose syrup as sweetening agents in confectionaries. They are also used in the manufacture of many types of candies such as toffee, hard and soft gums. Dextrose prevents crystallization in boiled sweets and reduces hydrophobicity in the finished product.

2.6.3 Monosodium Glutamate (MSG)

This product is used extensively in many parts of the world in powder or crystal form as a flavoring agent in foods such as sweet meat, vegetables, sauces and gravies. Cassava starch and molasses are the major raw materials used in the manufacture of MSG in the Far East and Latin American countries.

2.6.4 The Production of Dextrose

At present most of the dextrose in commerce is prepared in the form of pure dextrose monohydrate by a combined acid-enzyme process on glucose. Dextrose is used in pharmaceutical grade-sugar.

There is an increasing interest in manufacture of glucose syrup directly from starchy roots or grains than from the separated starch in order to save on capital investment for the production and purification of starch from such raw materials. The starch conversion industry (glucose and dextrose) is the largest single consumer of starch, utilizing about 60% of total starch production. Glucose syrup and crystalline dextrose compete with sucrose sugar and are used in large quantities in fruit canning, confectionaries, jams, jellies, preserves, ice cream, bakery products, pharmaceuticals, beverages and alcohol fermentation. Glucose and dextrose in the confectionary industry is to prevent crystallization of the sucrose. In the baking industry, they serve as fermentable carbohydrate and in the ice cream, fruit-preserves and similar industries it is to

increase the solids without causing an undue upturn in the total sweetness, thus emphasizing the natural flavor of the fruit, and also to prevent the formation of large ice crystals which mar the smooth texture. Glucose and dextrose are used as partial or complete substitute for sucrose.

2.7 Starch Structure and Composition

Starch is a polysaccharide made up of repeating glucose units (Cho and Proky, 1999). According to Vaclavik and Christian (2008), starch is the main storage form of carbohydrate in plants. The starch molecule occurs within an organelle called amyloplast which is found in the cytoplasm. Starch consists of two molecules; a linear structure known as amylose and a branched structure known as amylopectin (Fennema, 1997). Starch molecules are formed when amylose and amylopectin molecules associate themselves through hydrogen bonding. The ratios of amylose and amylopectin in starch granules make starches from different sources differ from one another (Mensah, 2013)

The granules normally contain 70 to 80 percent amylopectin and 20 to 30 percent amylose (Vorweg *et al.*, 2002). The structure and relative amounts of both molecules play an important role in determining starch properties and purity. High amylose cornstarch (amylo-maize) for example contains over 50 percent amylose whereas 'waxy' maize has almost none or less than 3 percent (Singh *et al.*, 2003). Amylose and amylopectin are inherently incompatible molecules; amylose having lower molecular weight ($\sim 10^6$ Daltons) with a relatively extended shape whereas amylopectin has huge but compact molecular weight ($\sim 10^8$ Dalton). The presence of amylose tends to reduce the crystal nature of the amylopectin and influence the ease of water penetration into the granules (Mensah, 2013).

2.7.1 Amylose

Normal starch contains 20-30% amylose and 80-70% amylopectin. High amylose starches contain more than 40% amylose and waxy starch less than 15% amylose (Tester *et al.*, 2004; Van Hung *et al.*, 2006). Nonetheless, the relative amylose to amylopectin content may change with crop variety (Jane *et al.*, 1992; Shujun *et al.*, 2006). Peroni *et al.* (2006) reported amylose content of 19.8%, 32.6% and 22.6% for cassava, yam and sweet potato starch, respectively.

Amylose is primarily a linear chain of 500-20,000 D-glucose units linked by α -1 \rightarrow 4 linkages. However, some amylose molecules have a few (about 0.3-0.5 %) α -1 \rightarrow 6 branches (Hoover, 2001). When starch granules are heated to gelatinization, released amylose goes into solution. However, upon cooling of the starch paste or suspension, amylose chains coil into double helices and become insoluble in cold water. Hydrogen bonding between aligned chains causes retrogradation and release of bound water (syneresis) (Mensah, 2013). The double stranded crystallites are resistant to amylases and have a fairly hydrophobic structure of low solubility. Amylose forms a characteristic dark blue colour complex with iodine. It also forms complexes with various organic compounds such as butanol and fatty acids. These complexes are essentially insoluble in water. The amylose content and degree of polymerization (DP) are important for the physical, chemical and functional properties of starch. The higher the amylose content, the lower is the swelling power and the smaller is the gel strength for the same starch concentration (Mensah, 2013). Hegenbart (2009) reported that longer amylose molecules tend to make a product's texture fibrous because of their colligating tendencies. The molecular weight of the amylose also affects the elasticity of a starch gel.

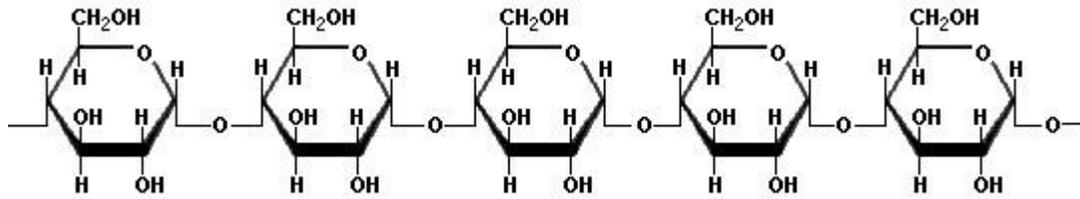


Fig. 2.1: Structure of amylose

Source : (<http://www.sciencetificpsysic.com/fitness/carbohydratesI.html>)

2.7.2 Amylopectin

In Amylopectin, linear α -(1 \rightarrow 4)-linked chains are interconnected through α -(1 \rightarrow 6) glycosidic bond to form irregular branches occurring approximately one per twenty-five glucose units (Sajilata *et al.*, 2006). The glucose polymers are arranged in three dimensional semi-crystalline structures called a granule, having different shapes and sizes. The quality of amylopectin molecules in starch ranges between 50 to 100 percent and starch with 100 percent amylopectin are called waxy starches (Mensah, 2013). They form soft parts rather than rigid gels when gelatinized. The comparative proportions of amylose and amylopectin present in starches are accountable for the difference in cooking characteristics exhibited in foods.

The structure of amylopectin is more complex since 4 – 5 % of the total linkages form branches. This branching is determined by enzymes and makes amylopectin more water soluble with higher bonding capacity. This structure consists of three types of chains: The C chain carries the sole reducing group in the molecule to which the B - chains are attached, while the terminal A - chain is attached to the B - chain (Manners, 1989). In its native form, amylopectin is of a semicrystalline assembly oriented radially in the starch granule to form concentric regions of alternating amorphous and crystalline lamellae. In the crystalline lamellae, amylopectin linear branches form double helices arranged in parallel with each other, while the amorphous lamellae regroup the

molecule's branching points (Figure 2.2). Amylose molecules are found in the amorphous lamellae between the amylopectin crystallites. Typically, the crystalline and amorphous lamellae are 6nm and 4nm thick, respectively (Robin *et al.*, 1974). Some amylopectin (for example, from potato) has phosphate groups attached to hydroxyl groups, which increase starch hydrophilicity and swelling power.

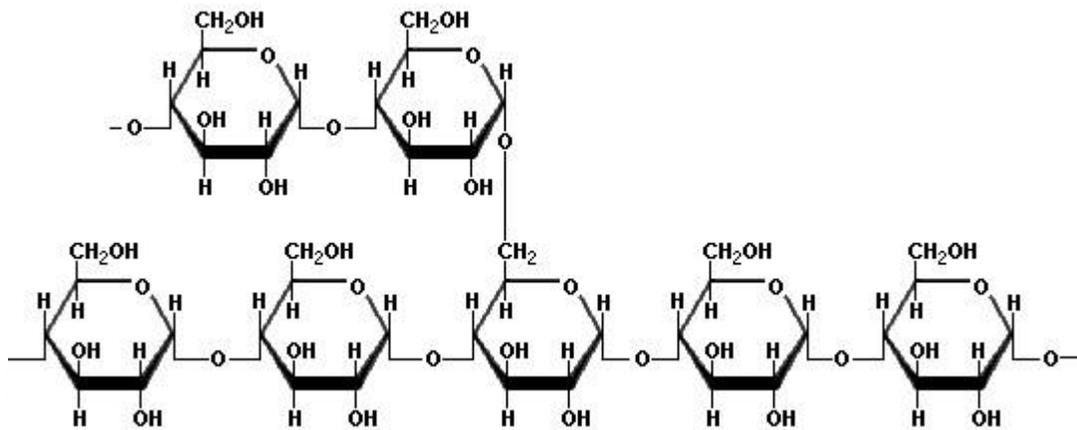


Figure 2.2: Structure of amylopectin:

Source: :(<http://www.sciencetificpsysic.com/fitness/carbohydratesI.html>)

2.8 Functional Properties of Cassava starch

The application of cassava starch in the food industries is influenced by its functional properties. These include; water binding capacity, pasting characteristics, solubility and swelling power. The functional properties exhibited are dependent on the structural characteristics of the starch; such as molecular weight of amylose and amylopectin as well as the chain length distribution of the amylopectin (Mweta, 2009).

For example; functional properties such as viscosity of flour is important when used as gum replacers (Hong and Nip, 1990). The ability of starch to form paste or gel also determines the

texture and the quality of that food product (Lii *et al.*, 1995). The water binding capacity and Solubility are also indispensable in deciding the quality of carbohydrate-based fat substitutes (Ju and Mittal, 1995). All of these attributes have been testified to influence gelling ability, water and fat binding ability and hence the textual quality of food products that have their substitute

2.8.1 Swelling Power

The Swelling power of starch demonstrates the occurrence of non-covalent bonding between starch molecules. Swelling power is defined as the swollen sediment weight per weight of flour (Baah, 2009). The amylose-amylopectin ratio and chain length affect the swelling power of starch. Molecular weight distribution, degree of branching and conformation impacts the degree of swelling and solubility of flour (Rickard *et al.*, 1991). Sanni *et al.* (2005) reported that the swelling power of starch granules reflect the magnitude of the associative forces within the granules, thus the higher the swelling ability the lower the associative forces. Swelling power is reduced by high amylose content and the presence of stronger or higher number of intermolecular bonds (Sanni *et al.*, 2005). Apea-Bah *et al.* (2011) observed that the swelling power of cassava flour ranges from 17.15-31.97%. It has been reported that starches with high swelling percent are less resistance to break down.

Swelling is reversible to a level that the molecular structure inside the granules is disrupted and birefringence is lost. Above a relatively narrow temperature range, all the starch granules swell irreversibly and is said to have undergone gelatinization. Preceded heating of the gelatinized starch granules allows swelling and softening, forming a viscous paste. When the paste is fluid, it is called a sol and when it is solid it is called a gel. The principal effect of starch granule swelling occurs when the starch is gelatinized in an aqueous medium. While the temperature of an aqueous suspension of starch is set up above the gelatinization or pasting range, hydrogen bonds go on to

be disrupted, water molecules become attached to the liberated hydrogen groups and the granules swell (Mat-Hashim *et al.*,1992). Increase in viscosity of the starch paste with heating is conceived to be the cause of starch being extruded out of the starch grain into the surrounding medium. The starch molecules entrap the free water and inhibit its free flowing. The power of the starch to expand and produce a viscous paste once heated in water or with certain chemical is its most significant practical use in the food industry as it affects the texture and digestibility of starchy foods.

2.8.2 Gelatinization of Starch

Gelatinization of starch is a technique that breaks down the intermolecular bonds of starch molecules in the presence of water and heat, permitting the hydrogen bonding site to employ more water (Freeland-Graves and Peckham, 1987). Whenever starch granules come into contact with cold water, a small quantity of it is absorbed inducing a reversible swelling. A temporary suspension in which the granules do not dissolve is also formed. The starch liable to settle out of the mixture as soon as the mixture is permitted to stand (Freeland-Graves and Peckham, 1987). Once the starch mixture is heated, the water starts to penetrate the starch granules, resulting in swelling and loss of birefringence.

Penetration of water molecules increase the randomness in the general structure and decrease the number and size of the crystalline regions of the starch molecule. However, water entry is not allowed into the crystalline regions. Heat induces such regions to be diffused, so that the chains begin to separate into amorphous form (Hegenbart, 2012)

2.8.3 Solubility

Solubility is expressed as the percentage by weight of flour dissolved molecularly after heating in water (Baah, 2009). Solubility of flour depends on inter-associative forces, swelling power and the

presence of other components such as minerals. Cassava flour and starches have higher solubility than other tuber crop starches and this can be assigned partly to the high swelling power cassava starches experience during gelatinization (Moorthy, 2002). Different cassava varieties have their starch solubility varying from 17.2 to 27.6%. However, Moorthy (2002) observed no direct correlation between the swelling power and solubility. The solubility of cassava flour has been found to range from 7.81-18.80% (Apea-Bah *et al.*, 2011). Flour with lower solubility is very important in preparation of pasta product and baked foods. High solubility flour may concede soggy dough with less cohesiveness.

2.8.4 Pasting and Viscosity Properties of Starch

One essential property of starch is its ability to give viscous paste when heated in water. This property defines the use of starch in paper, textile and food industries. In a study by Moorthy (1994), using Brabender Visco-amylograph, on cassava starch from different varieties, three peak patterns were noted: Single stage gelatinization with high peak viscosity and high viscosity breakdown, two-stage gelatinization with high peak viscosity and breakdown, and Broad twostage gelatinization with medium viscosity breakdown. Starch viscosity is largely influenced by the granule shape and swelling power, amylopectin-amylose entanglement and amylose/amylopectin interactions. Influence of amylopectin structure and amylose content on the gelling properties of five cultivars of cassava starches was determined.

Waxy starches (high amylopectin contents) give high viscosity because amylopectin molecules do not align as easily and thus give weaker hydrogen bonding. High amylose starches give low viscosity.

High viscosity is an indication of good quality native starch while low viscosity implies that the starch has undergone some degree of degradation during processing (Dzogbefia *et al.*, 2008).

Peak viscosity is the maximum viscosity attained during the heating phase. At peak viscosity, the bulk of the starch granules are fully swollen. On high temperature hold phase of 95C, starch granules start to breakdown and solubilisation extends leading to a drop in viscosity and a trough viscosity is registered. The viscosities at 95C and peak viscosity value are measures of the ability of starch to form paste upon cooking and higher value suggest thicker paste. Kim *et al.* (1995) remarked that high viscosity is suitable in the food industry where high thickening is expected.

The difference between the peak and trough viscosities is called breakdown. During cooling, the solubilized starch molecules set out to re-associate and viscosity start to increase again towards the cold paste or final viscosity. When in sufficient concentration, there is formation of a gel. The deviation between the cold paste and the hot paste viscosity is known as setback or retrogradation. Amylose is the major molecule that retrograde. It can re-associate to form a harder and firmer gel again (Thomas and Atwell, 1998). Starches with higher amylopectin to amylose ratios are inclined to retrograde very much slower than starches with a high proportion of amylose. This is because of the extended period of time it takes the highly branched amylopectin molecule to re-associate in a rigorous manner (Moorthy, 2002). Retrogradation is often an undesirable side effect of starch gels and influence the overall quality and shelf life stability of food products. This constitute staling in bread and other baked products (Katayama *et al.*, 2002). Graves and Peckham (1987) reported that when a cold starch gel stands for some time, there is outflow of liquid from the gel. This outflow of liquid from the gel is known as syneresis or weeping. According to Oduro *et al.* (2000), high setback value is useful when the starch or flour is to be used for domestic product such as fufu, where high viscosity and paste stability at low temperature is required. Low setback value

depicts that the starch or flour contributes a non-cohesive paste which is essential in many industrial application (Kim *et al.*, 1995)

Starch viscosity changes with temperature, it is low in cold water, but upon heating, a thick paste with increased viscosity is formed. The high gelatinization starches have high pasting temperatures than the low gelatinization starches. These high pasting temperatures are attributed in part to the high amylose contents.

2.8.5 Pasting Temperature and Gelatinization

Gelatinization of starch occurs over a distinct range of temperatures known as gelatinization temperature. This indicates the temperature at which part of the amylose breaks from amylopectin and leaches out of the starch granules during heating. Again, the peak gelatinization or pasting temperature is the temperature at which irreversible swelling of the starch granules occur contributing to peak viscosity. Gelatinization temperature is invariably lower than the pasting temperature (Moorthy, 2002). Bainbridge *et al.* (1996) observed that an increase in viscosity indicates the tendency of starch to retrograde or associate. They also found that starches with high pasting temperature and high peak viscosity have weak associative forces. Boakye *et al.* (2001) established that the pasting temperature of four cassava varieties usually grown in Ghana to range from 64-67°C. Oduro *et al.* (2000) also discovered that a related root and tuber crop, sweet potato had pasting temperatures comparatively higher and ranged from 72-73.3°C. According to Bainbridge *et al.* (1996), lower pasting temperature starches are easier to cook, nevertheless, lower pasting temperature starches are as well associated with low paste stability and regarded as an undesirable property of flour. Low paste stability and low pasting temperature suggest less associative force and cross-links within the starch granules of flour. Higher amylose indicates higher gelatinization temperature. This is as a result of the wide hydrogen bonds in the

linear amylose molecules which necessitate more energy to break and gelatinize the starch (Hegenbart, 2009).

2.9 Starch Market and Production in Ghana

The Ayensu starch factory was established in 2002 by the Ex-President of Ghana, John Agyekum Kufuor with the aim of cutting down the rate of spoilage of cassava in the country and also create jobs for the people and encourage the youth to take up farming and move the country to its former glorious days of agro economic high. However, in the early years of its operation the starch factory encountered various problems including broken parts and insufficient funds to pay suppliers which lead to minimal output and consequentially the loss of their customers such as pastry companies and crop research institutes.

2.10 Starch Market and Consumption in Ghana

The consumption of starch although common in various forms in the country, the population is still unable to consume everything that is produced in the country. This is what lead to the formation of the president's special initiative PSI by the former president of the republic John Agyekum Kufuor to promote the agro-food industry counting on a collaboration from the Danish side Danida to export the starch to Europe on license. Approximately 36,000tonnes of cassava was processed into starch by the Ayensu Starch Factory on a weekly basis and this was in the year 2002 and the factory has since broken down several times until the partnership with Tiberias Ghana Limited with 70% ownership and the government of Ghana 30%.

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 Raw materials (cassava tubers)

About 1kg of fresh root tubers of three (3) cassava accessions were obtained from Department of Agriculture Engineering, KNUST. They were; *Abrabopa*, *Duadekpakpa* and *Amansen*. The tubers were harvested at different maturity (7th, 8th, 9th and 10th months).

3.2 Method

3.2.1 Starch Extraction

About 1kg Fresh cassava tubers were peeled and washed (right after harvest) with water into a bowl. They were then grated and 100g from each sample was weighed using a mass balance (Model: ML204/01, Mettler Toledo, Switzerland) for extraction of starch using conventional method for starch extraction. The 100g collected from each sample was blended with 100ml of deionized water in a blender (Model: ACGM-TD 71, Crompton Mixer Grinder) for one minute to aid the release of starch. The slurry was then transferred into an Erlenmeyer flask and about 350ml of distilled water was used to wash the slurry into a sieve lined with cheese cloth to filter. The filtrate was allowed to stand for five hours for the starch to settle and the supernatant was decanted and discarded. The starch was air dried at room temperature for 2 days and collected. The dried starch was weighed and the yield was calculated by dividing the weight of dried starch over the weight of grated cassava (100g) in the formula below;

$$\text{Starch yield} = \frac{\text{Weight of dried starch}}{\text{Weight of grated cassava}} * 100$$

The dried starch from each sample was packed and stored in high density zip lock bags.

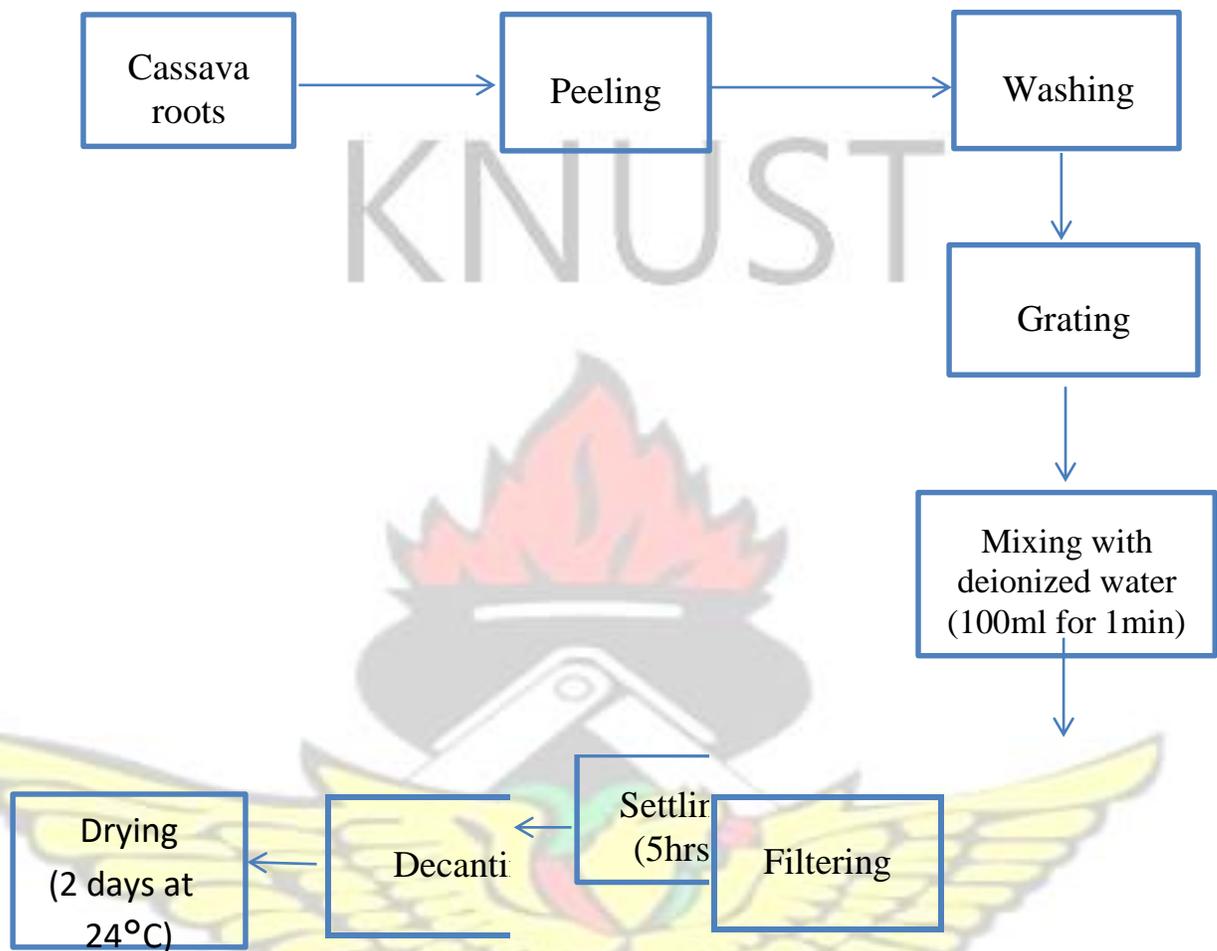


Fig. 3.1: Flow chart for starch extraction from cassava roots

3.2.2 Determination of pasting properties

The moisture content of each starch sample was determined with an electronic moisture analyzer (Sartorius MA 45) by heating 5g of sample at 105°C for 5 h. Heating was repeated until a constant weight of the sample was recorded. Percentage moisture was determined by subtracting the final weight of starch after drying from the initial weight before drying.

The moisture value obtained was input into the software of the Rapid Visco Analyzer (RVA,

Model RVA 4500), which automatically indicates the weight of starch sample to be used and the amount of distilled water to be added to make slurry. The slurry was then set into a stainless steel canister of the instrument as recommended and heated at a rate of 1.5°C/min by means of thermostat at a speed of 75rpm. The start temperature was 50°C and when the suspension attained 95°C, the suspension was held constant for 15 min (first holding period) as stirring continuous.

The paste was then cooled down to 50°C at a rate of 1.5°C/min and held for another 15min (second holding period).

Peak viscosity (cP), Setback viscosity (cP), Breakdown viscosity (cP) Pasting temperature (°C), Pasting time (min), Peak temperature (°C), Peak time (min), Viscosity at 95°C (cP), Viscosity after 15 minutes at 95°C (cP), Viscosity at 50°C (cP), Viscosity after 15 min at 50°C (cP) were measured and recorded.

Paste stability at 95°C was calculated as the difference between viscosity at 95°C and viscosity after 15 min at 95°C and paste stability at 50°C was also calculated as the difference between viscosity at 50°C and viscosity after 15 min at 50°C.

3.2.3 Determination of Amylose and Amylopectin

3.2.3.1 Preparations of Reaction Mixtures

About 40g of NaOH was dissolved in 1000ml distilled water to get 1N NaOH solution. About 1L of distilled water was added to 57.5ml acetic acid to get a 1N Acetic acid solution. Iodine (Potassium iodide, KI) solution was prepared by dissolving 0.26 g of Iodine into 10ml of Potassium iodide solution containing 2.6g of KI. The amylose content of the starch samples was determined based on the iodine colorimetric method described by McCready and Hassid (1943).

3.2.3.2 Standard Amylose Preparation

A weight of 0.04g of amylose (pure potato starch) was measured into a 100 ml volumetric flask.

About 1ml of 95% ethanol and 9.0ml of 1N NaOH were pipetted into the solution and shaken. The solution was heated in a water bath for 10 minutes to gelatinize and allowed to cool to room temperature. The solution was topped to 100 ml using distilled water.

A series of standard amylose solution was prepared by pipetting 1, 2, 3, 4 and 5ml of amylose solution into 5 different volumetric flasks and adding 2ml of iodine to each flask. Acetic acid was added to each flask. Volumes of acetic acid 0.2, 0.4, 0.6, 0.8 and 1.0ml were added to flasks containing 1ml, 2ml, 3ml, 4ml, and 5ml of standard amylose solutions respectively. Distilled water was added to 100ml mark and allowed to stand for 20 mins. The absorbance of the solution was determined at 620nm with a spectrophotometer (Shimadzu Spectrophotometer UV-1800).

A standard curve was plotted using the absorbance of the different standard amylose solutions. The amylose content of the sample was determined in reference to a standard curve and expressed on percentage basis.

3.2.3.3 Estimation of Amylose and Amylopectin Content

As described by Juliano (1971), the formation of helical complex between amylose and iodine results in a typical deep blue colour of starch dispersion discolored with iodine and this forms the basis for quantitative determination of amylose content. The formation of these complexes is determined by calorimetry.

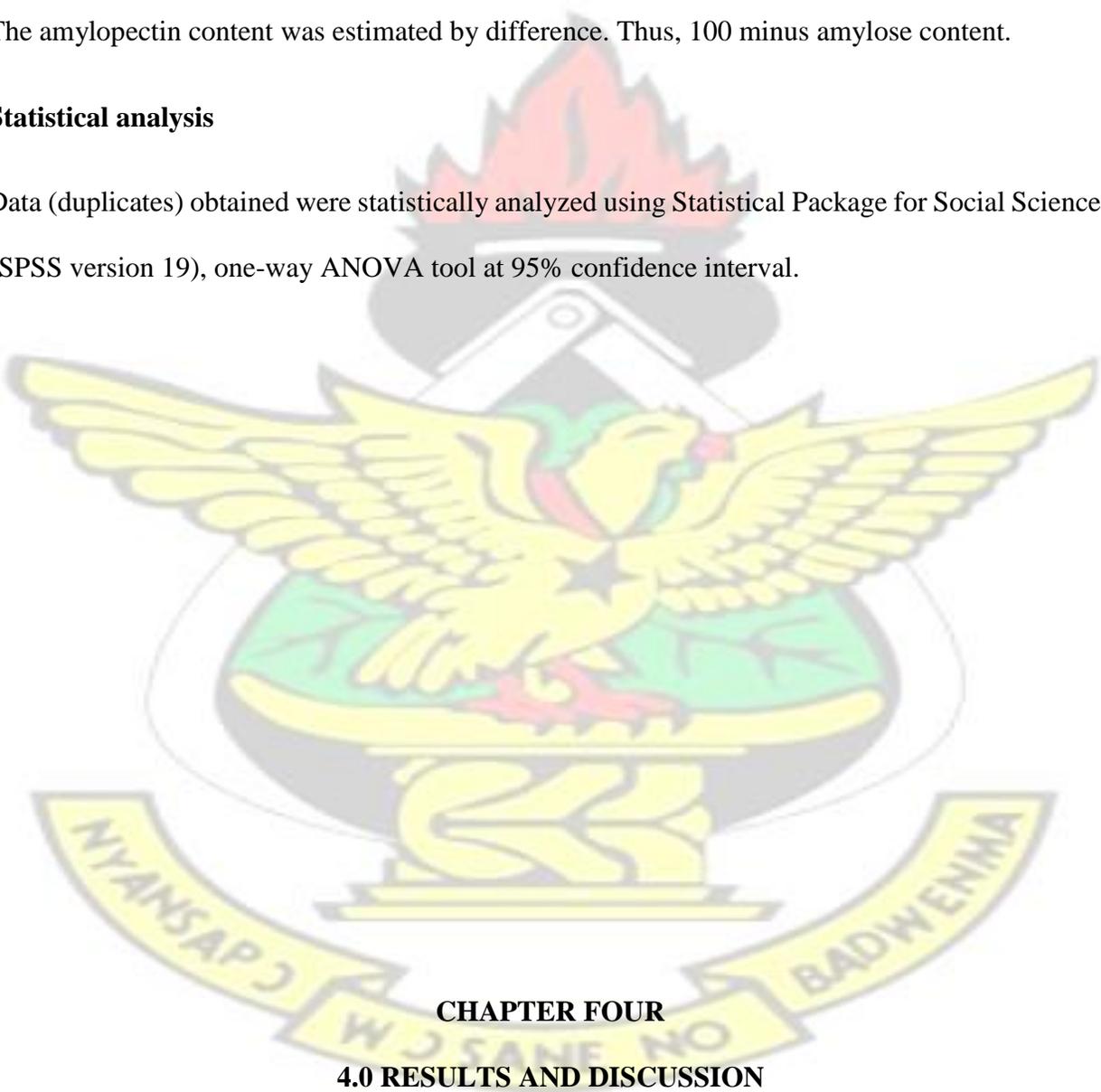
Approximately 0.1 g of the starch sample was weighed into a 100 ml volumetric flask. The sample was solubilized with 1 ml of 95% ethanol and 9 ml of 1 N sodium hydroxide. The resulting solution was heated for 10 min in boiling water to gelatinize and cooled to 28°C. The solution was topped

with distilled water to 100 ml mark. Using a Pipette, 5 ml of the 100ml solution was taken into another 100 ml volumetric flask in three replications. About 1 ml of 1N acetic acid and then 2ml iodide solution were added to the solution and made up to 100 ml. The solution was vortexed and allowed to stand for 20 minutes. The absorbance of the solution was determined using a spectrophotometer (Shimadzu Spectrophotometer UV-1800) at 620nm for each sample.

The amylopectin content was estimated by difference. Thus, 100 minus amylose content.

Statistical analysis

Data (duplicates) obtained were statistically analyzed using Statistical Package for Social Sciences (SPSS version 19), one-way ANOVA tool at 95% confidence interval.



CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Starch Yield and Amylose and Amylopectin content

The table shows the yield, amylose and amylopectin content of the three cassava accessions in study. The starch yield ranged from; (19.33% ± 0.58 -25.00% ± 1.00) for *Duadekpakpa*, (18.00% -29.33%) for *Abrabopa* and *Amansen* had starch yield between (19.00% - 26.66 %).

Table 4.1: Yield, Amylose and Amylopectin of Three Accessions of Cassava at Different Maturity

Maturity/Variety	Yield (%)	Amylose (%)	Amylopectin (%)
Month 7			
DK	19.33 ± 0.58 ^a	21.23 ± 1.58 ^a	78.77 ± 1.58 ^a
AN	19.00 ± 0.00 ^a	15.95 ± 1.46 ^a	84.05 ± 1.46 ^a
AP	18.00 ± 1.00 ^{ab}	23.89 ± 1.65 ^a	76.10 ± 1.65 ^a
Month 8			
DK	20.00 ± 1.73 ^a	25.14 ± 2.20 ^a	74.86 ± 2.20 ^a
AN	23.33 ± 2.08 ^{abc}	19.83 ± 0.15 ^a	80.17 ± 0.15 ^a
AP	18.33 ± 1.00 ^{abc}	17.85 ± 3.15 ^a	82.15 ± 3.15 ^a
Month 9			
DK	24.67 ± 1.15 ^{bcd}	17.95 ± 1.09 ^a	82.05 ± 1.09 ^a
AN	25.67 ± 1.53 ^{cd}	16.40 ± 2.19 ^a	83.60 ± 2.19 ^a
AP	25.00 ± 0.00 ^{cd}	17.68 ± 0.04 ^a	82.32 ± 0.04 ^a
Month 10			
DK	25.00 ± 1.00 ^{cd}	20.08 ± 0.40 ^a	79.92 ± 0.40 ^a
AN	26.66 ± 2.31 ^d	19.62 ± 0.38 ^a	80.38 ± 0.38 ^a
AP	29.33 ± 2.08 ^{cd}	20.12 ± 2.76 ^a	79.88 ± 2.76 ^a

DK = *Duadekpakpa*, AN = *Amansen* and AP = *Abrabopa*. Values are Mean ±SD. Experiment was conducted in duplicates.

Values in column under the same month with different superscript letter are significantly different at 95% Confidence Interval

The yield of starch was found to be lower at the 7th month for all the varieties. Starch yield increased steadily and was greater in the 10th month for all the varieties as seen in Table 4.1. This result agrees with the findings of Vichukit *et al.* (1994) which stated that starch yield of cassava increases from the 7-9th month after which the yield depends heavily on rainfall. The starch yield

ranged from 18-29%. These values are lower than the values obtained by IITA (1990) which stated that the starch yield is between 61.8-66.4%. Stage of harvest or maturity had significant difference on starch yield at $p < 0.05$. There was no significant difference between the yields of starch for the various accessions at the same confidence level according to table 4.1. Variety had no significant effect on the amylose and amylopectin concentrations of the cassava at ($p < 0.05$). Amylose content is an important parameter in almost all starch properties. Low contents of amylose lead to an increase in the relative crystallinity of starch as a result of reduced amorphous regions located in the granule of the starch (Tukomane *et al.*, 2007). There was no particular trend in the amylose and amylopectin concentrations in table 4.1 as shown above. Amylose and amylopectin ratio ranged from 16-25% to 75- 84% respectively. *Amansan* recorded the lowest amylose concentration with the corresponding high amylopectin concentration. A high amylopectin concentration is an indication of a good quality native starch. Starch from the *amansan* accession therefore has the ability to forms a more viscous soft gel rather than a rigid paste when gelatinized. This would make starch from *amansan* more useful in foods to be frozen since it would not retrograde easily due to its low amylose content.

4.4 PASTING PROPERTIES

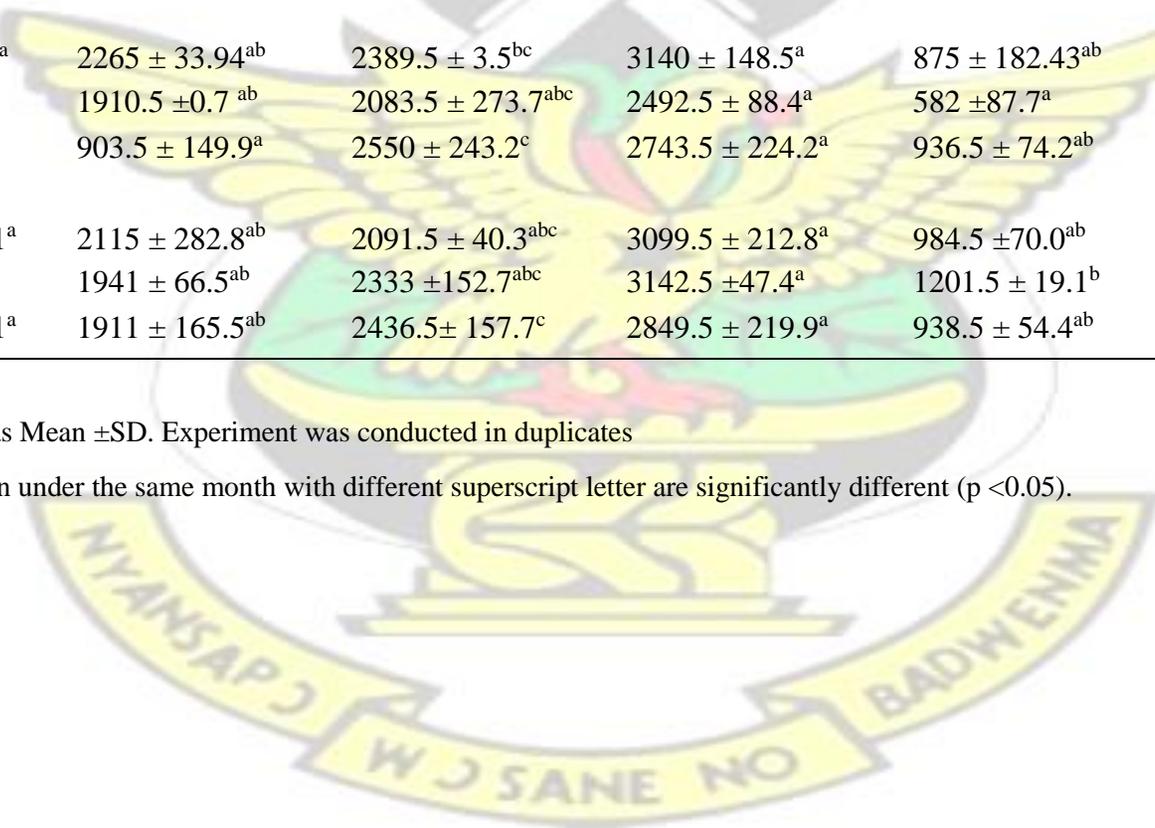
The peak viscosity ranged from 3853.5 - 4859 cP. The results for trough were between 903.5 – 2432 cP. Break down viscosity were 1734 - 2436.5 cP while the final viscosity ranged from 2492.5 – 3263 cP

Table 4.2: Pasting Properties of Three Varieties of Cassava at Different Maturity

Varieties	Peak Viscosity (cP)	Trough (cP)	Breakdown (cP)	Final viscosity (cP)	Setback (cP)	Peak time (min)	Pasting temp(°C)
Month 7							
<i>Duadepakpa</i>	4139.0 ± 265.9 ^a	2227.5 ± 137.9 ^{ab}	1911.5 ± 128.0 ^{abc}	3048.5 ± 159.1 ^a	821 ± 21.2 ^{ab}	4.17 ± 0.14 ^a	77.20 ± 0.57 ^a
<i>Abrabopa</i>	4080.0 ± 181.0 ^a	2304 ± 69.3 ^{ab}	1773 ± 107.5 ^{ab}	2885 ± 9.9 ^a	666 ± 60.8 ^a	4.19 ± 0.12 ^a	77.30 ± 1.48 ^a
<i>Amansen</i>	3853.5 ± 16.3 ^a	2119.5 ± 118.1 ^{ab}	1734 ± 101.8 ^a	2816 ± 19.8 ^a	696.5 ± 74.2 ^a	4.27 ± 0.00 ^a	76.53 ± 0.46 ^a
Month 8							
<i>Duadepakpa</i>	4540.5 ± 610.2 ^a	2351 ± 274.4 ^{ab}	2189.5 ± 335.9 ^{abc}	3229 ± 342.2 ^a	878 ± 67.88 ^{ab}	4.30 ± 0.14 ^a	74.45 ± 0.07 ^a
<i>Abrabopa</i>	4725.5 ± 201.5 ^a	2301 ± 77.8 ^{ab}	2424.5 ± 123.7 ^c	3263 ± 14.1 ^a	962 ± 63.6 ^{ab}	4.07 ± 0.19 ^a	76.00 ± 0.14 ^a
<i>Amansen</i>	4859 ± 55.2 ^a	2432 ± 72.1 ^b	2427 ± 17.0 ^c	3158 ± 176.8 ^a	726 ± 248.9 ^a	3.90 ± 0.04 ^a	74.48 ± 0.03 ^a
Month 9							
<i>Duadepakpa</i>	4654.5 ± 30.4 ^a	2265 ± 33.94 ^{ab}	2389.5 ± 3.5 ^{bc}	3140 ± 148.5 ^a	875 ± 182.43 ^{ab}	4.165 ± 0.23 ^a	74.80 ± 0.57 ^a
<i>Abrabopa</i>	3994 ± 274.4 ^a	1910.5 ± 0.7 ^{ab}	2083.5 ± 273.7 ^{abc}	2492.5 ± 88.4 ^a	582 ± 87.7 ^a	4.37 ± 0.05 ^a	74.86 ± 0.60 ^a
<i>Amansen</i>	4357 ± 393.2 ^a	903.5 ± 149.9 ^a	2550 ± 243.2 ^c	2743.5 ± 224.2 ^a	936.5 ± 74.2 ^{ab}	3.9 ± 0.42 ^a	74.48 ± 0.12 ^a
Month 10							
<i>Duadepakpa</i>	4206.5 ± 323.1 ^a	2115 ± 282.8 ^{ab}	2091.5 ± 40.3 ^{abc}	3099.5 ± 212.8 ^a	984.5 ± 70.0 ^{ab}	4.34 ± 0.47 ^a	74.90 ± 0.57 ^a
<i>Abrabopa</i>	4274 ± 219.2 ^a	1941 ± 66.5 ^{ab}	2333 ± 152.7 ^{abc}	3142.5 ± 47.4 ^a	1201.5 ± 19.1 ^b	4.44 ± 0.05 ^a	74.55 ± 0.07 ^a
<i>Amansen</i>	4347.5 ± 323.1 ^a	1911 ± 165.5 ^{ab}	2436.5 ± 157.7 ^c	2849.5 ± 219.9 ^a	938.5 ± 54.4 ^{ab}	3.94 ± 0.47 ^a	62.73 ± 17.78 ^a

Values are presented as Mean ±SD. Experiment was conducted in duplicates

Mean values in column under the same month with different superscript letter are significantly different (p < 0.05).



KNUST



Viscosity of starch is important in starch characterization. The variances observed in viscosity helps in cultivar selection for food and other industrial purposes. Results for the pasting properties for the cassava starch from the various varieties are shown in Table 4.2.

The final viscosities observed were low compared to the peak viscosities. This indicates the low susceptibility of cassava starch to retrogradation (Moorthy, 2002). Set back viscosity also ranged from 582 ± 87.7 - 1201.5 ± 19.1 Cp while the peak time were between 3.90 - 4.44 Cp. Low peak time of starch from *Amansen* at the 10th month and its low pasting temperature at the same month indicates its low resistance to swelling and easy formation of paste which makes it more suitable for both food and non-food industrial processes because of decrease in energy costs during production. Cassava starch has low pasting temperature of 68°C averagely and that it easily forms paste as compared to other starches like potato which has an average of 72°C (Moorthy, 2002) and an average of 69.5°C for rice (Cameron *et al.*, 2007). The pasting temperature of starch from the three different varieties ranged from 74.48 ± 0.03 - 77.30 ± 1.48 °C. This was contrary to an observation by (Moorthy, 2002) which reported that the average pasting temperature of cassava starch is 68°C. The high pasting temperature of starch indicates that it has a higher resistance towards swelling. There were no significant differences observed at $p < 0.05$ for peak viscosity, trough, breakdown, final viscosity and setback but peak time and pasting temperature had significant differences at the same confidence level.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The yield of starch for the three accessions was between 18%-29%. Yield is an important parameter in starch characterization in order to determine which accession is most suitable for commercial starch production. The amylose concentrations were observed to be between 16%-25% with amylopectin ranging from 75%-84%. The significant difference in the pasting properties of the different cassava accessions suggests the different utilization properties of the accessions for industrial and food use. High breakdown viscosity indicates the low tendency of the starch to withstand heating and shear stress during cooling. The low breakdown and low final viscosity of *Amansen* at the 9th month indicates its high stability. Differences amongst varieties in the final viscosity on the other hand could be as result of variances in amylose concentrations.

Maturity had no effect on the peak time and pasting temperature at $p < 0.05$.

5.2 RECOMMENDATION

The present work shows that maturity affects the starch yield, composition and pasting properties of the new cassava accessions. This should be considered in deciding the time to harvest each accession for specific food and non-food industrial applications.

Further studies should be done to assess any possible changes in yield, pasting properties and amylose and amylopectin structure at full maturity of the accessions.

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APPENDIX

Appendix 1.0: Output from RVA for starch from Abrabopa at 7th month maturity

TCW3 Report

8/3/2017 2:23:02AM User Food Analysis Lab

Security ID = 140864545001537

Test Details Samples

01

Lab\Documents\TCW3 Data\abrabo pa 1

Configuration file

Analysis Lab\Documents\TCW3 Data\TCW3 Config

C:\Users\Food Files\flour.rvc

Date 2017/07/13

Time 03:40:42

Tester Food Analysis Lab

Instrument 2163573

Sample Weight 3.56

Moisture Basis 14.00 (%)

(g)

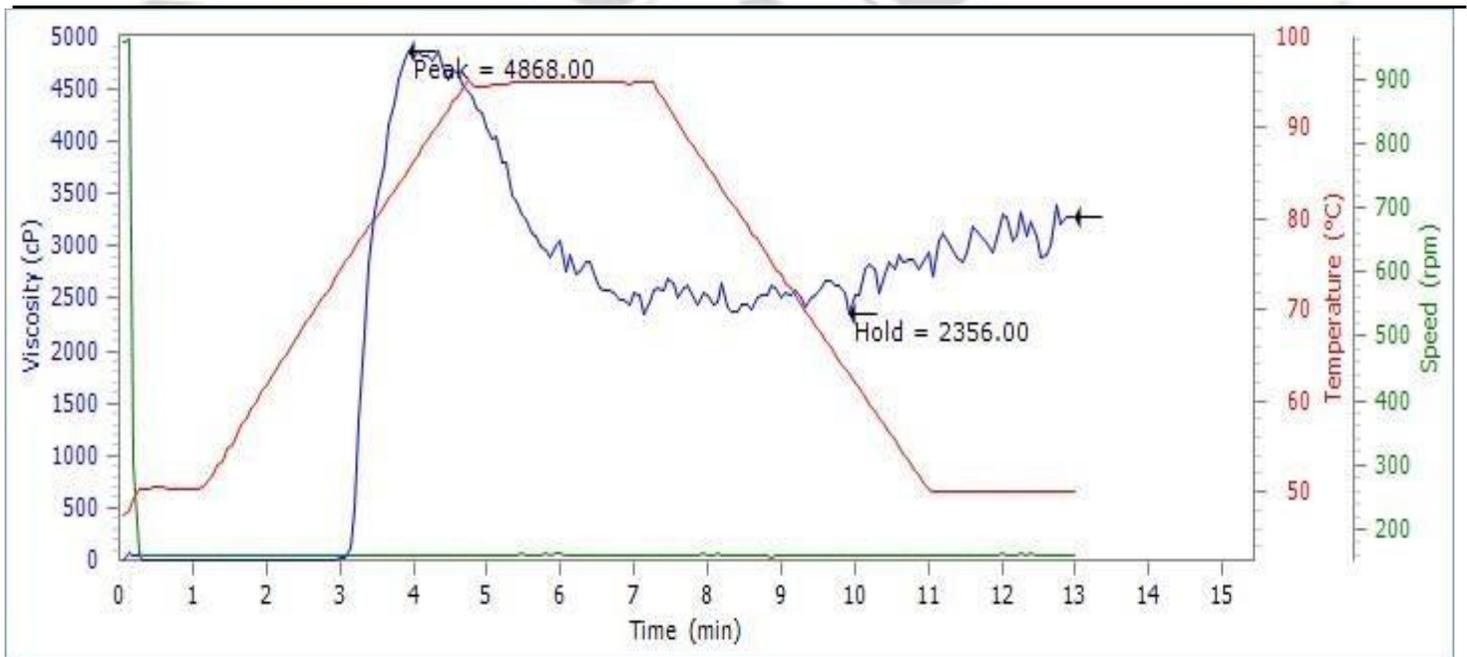
Water Weight 24.94 (g) Sample Moisture 15.40 (%)

KNUST

Test Results

Test	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time
01 abrabo pa 1	4868.00	2356.00	2512.00	3273.00	917.00	3.93

Test	Pasting Temp
01 abrabo pa 1	76.10



Appendix 1.1: Viscograph of Abrabo pa at 7th month maturity Appendix 2.0: Output from RVA for starch from Abrabopa at 8th month maturity

8/3/2017 2:34:47AM User Food Analysis Lab

Security ID = 140864545001537

Test Details Samples

01

Lab\Documents\TCW3 Data\abrabo pa22

Configuration file Analysis Lab\Documents\TCW3 Data\TCW3 Config
C:\Users\Food Files\flour.rvc

Date 2017/08/02

Time 04:17:55 Tester Food Analysis Lab

Sample Weight 3.51

Water Weight 24.99 (g) Sample Moisture 14.36 (%)

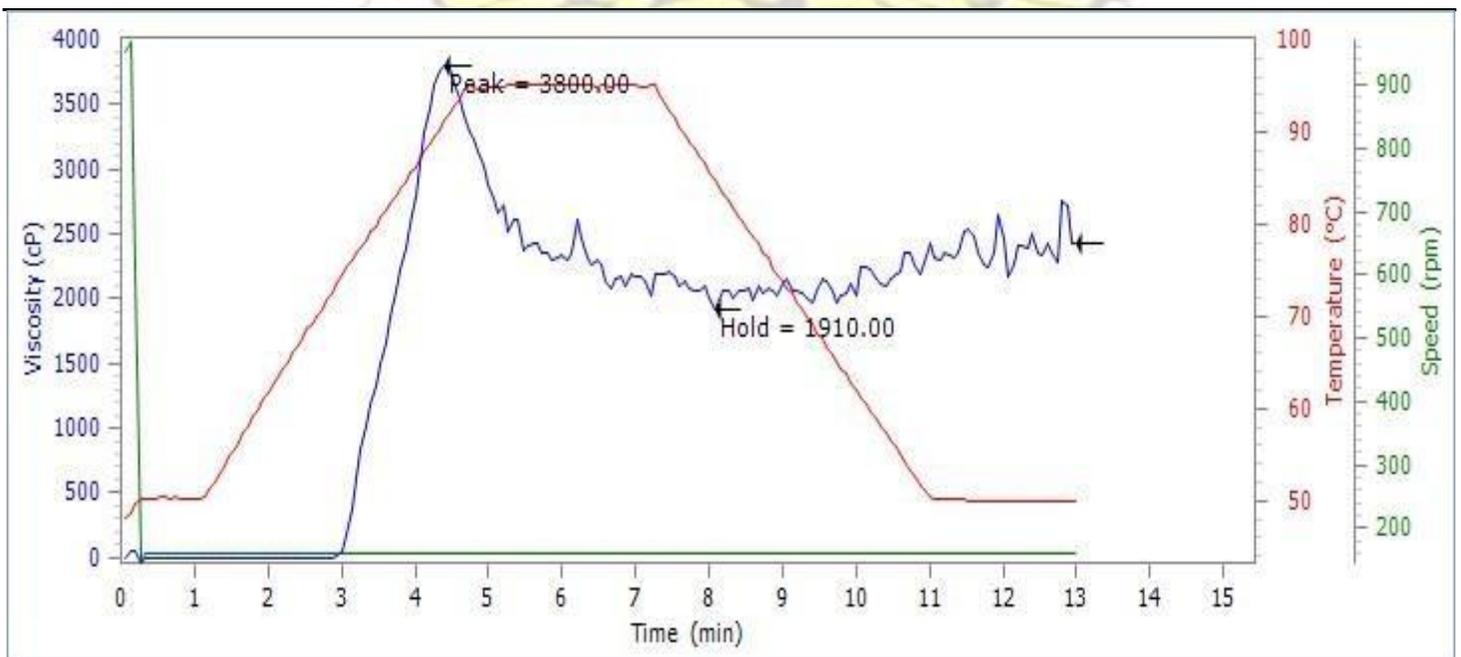
Instrument 2163573

(g)

Moisture Basis 14.00 (%)

Test Results

Test	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time
01 abrabo pa22	3800.00	1910.00	1890.00	2430.00	520.00	4.40
Test	Pasting Temp					
01 abrabo pa22	74.45					



Appendix 2.1 Viscograph of Abrabopa at 8th month maturity

Appendix 3.0: Output from RVA for starch from Abrabopa at 9th month maturity

TCW3 Report

8/3/2017 2:27:27AM User Food Analysis Lab

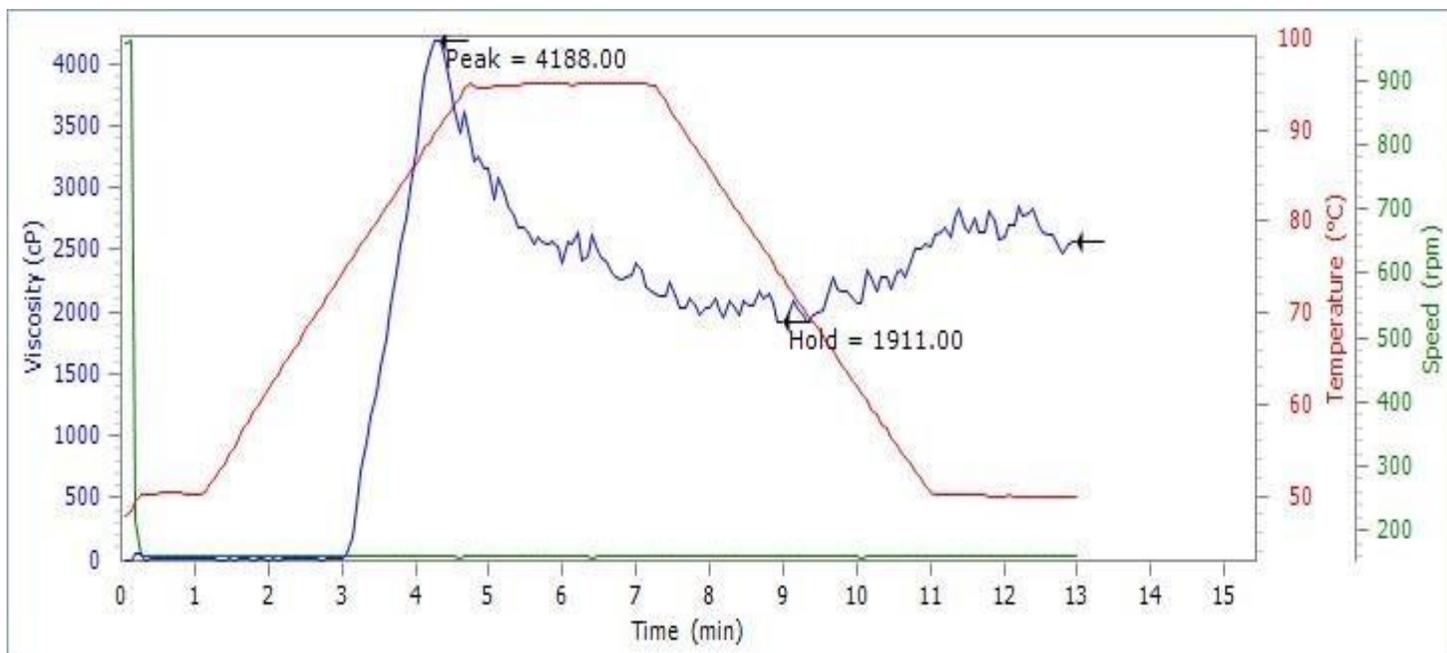
Security ID = 140864545001537

Test Details Samples

01 C:\Users\Food Analysis Lab\Documents\TCW3
Data\ABRABO PA 2
Configuration file Analysis Lab\Documents\TCW3 Data\TCW3 Config
C:\Users\Food
Files\flour.rvc
Date 2017/07/14
Sample Weight 3.54 (g) Time 03:53:47 Tester Food Analysis Lab Instrument 2163573
Water Weight 24.96 (g) Sample Moisture 14.87 (%) Moisture Basis 14.00 (%)

Test Results

Test	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time
01 ABRABO PA 2	4188.00	1911.00	2277.00	2555.00	644.00	4.33
Test	Pasting Temp					
01 ABRABO PA 2	75.30					



Appendix 3.1: Viscograph of Abrabopa at 9th month maturity

Appendix 4.0: Output from RVA for starch from Abrabopa at 10th month maturity

TCW3 Report

8/3/2017 2:42:05AM User Food Analysis Lab

Security ID = 140864545001537

Test Details Samples

01C:\Users\Food Analysis L

Configuration file

C:\Users\Food Analysis Lab\Documents\TCW3 Data\TCW3 Config Files\flour.rvc

Date 2017/08/02

Sample Weight 3.66

Time 02:40:10

Tester Food Analysis Lab

Instrument 2163573

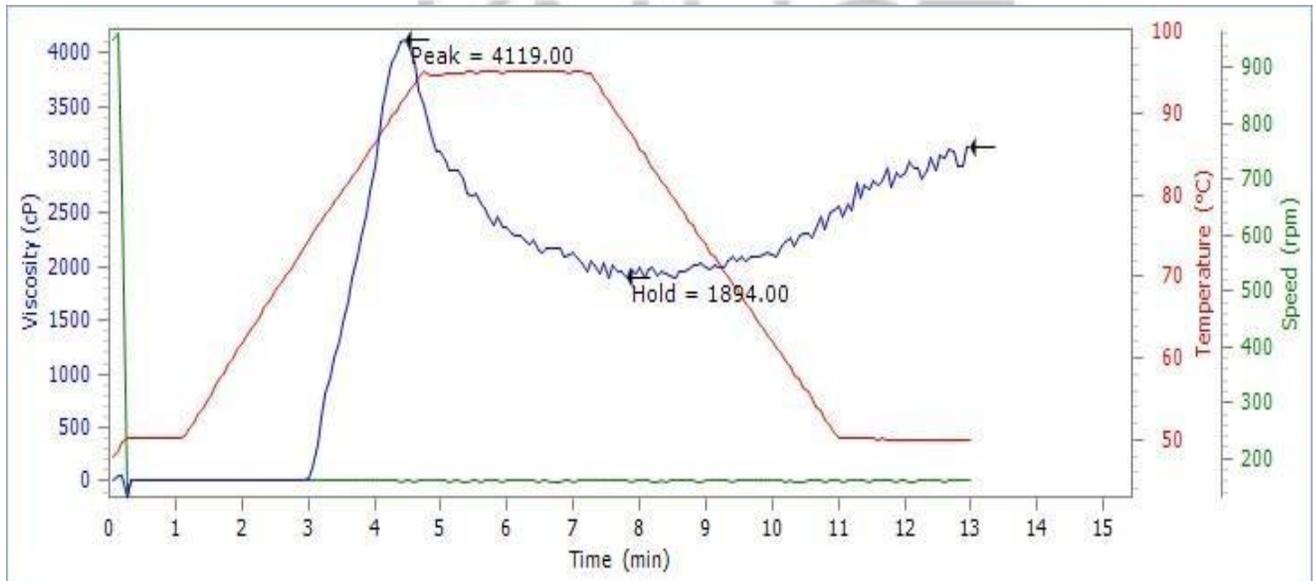
(g)

Water Weight 24.84 (g) Sample Moisture 17.68 (%)

Moisture Basis 14.00 (%)

Test Results

Test	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time
01 abrasopa 3	4119.00	1894.00	2225.00	3109.00	1215.00	4.47
Test	Pasting Temp					



Appendix 4.1: Viscograph of Abrabo pa at 10th month maturity

Appendix 5.0: Output from RVA for Asansen at 7th month

TCW3 Report

8/3/2017 3:03:17AM User Food Analysis Lab

Security ID = 140864545001537

Test Details Samples

01C:\Users\Food Analys

Configuration file

C:\Users\Food Analysis Lab\Documents\TCW3 Data\TCW3 Config
Files\flour.rvc

Date 2017/07/12

Instrument 2163573

Sample Weight 3.44 Time 03:35:40

Tester Food Analysis Lab

Moisture Basis 14.00

(g)

Water Weight 25.06 (g) Sample Moisture 12.60 (%) (%)

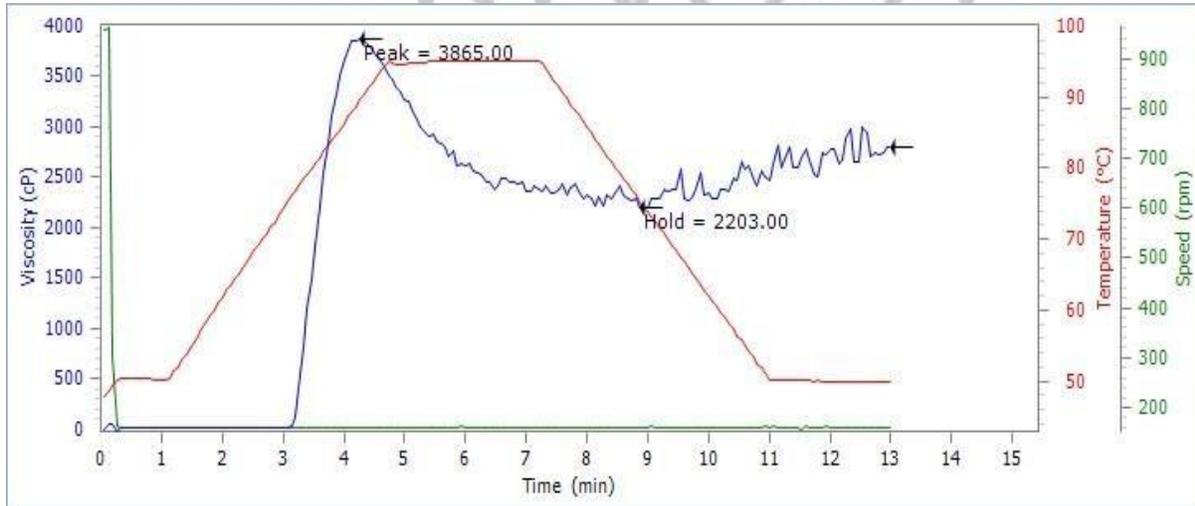
Test Results

Test	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time
01 amasen	3865.00	2203.00	1662.00	2802.00	599.00	4.27

Test Pasting Temp

01 amasen

76.20



Appendix 5.1 Viscograph of Amansen at 7th month maturity

Appendix 6.0: Output from RVA for starch from Asamsen at 8th month maturity TCW3

Report

8/3/2017 3:00:09AM User Food Analysis Lab

Security ID = 140864545001537

Test Details Samples

01C:\Users\Food Analyssi
Configuration file

C:\Users\Food Analysis Lab\Documents\TCW3 Data\TCW3 Config Files\flour.rvc

Date 2017/07/13

Instrument 2163573

Sample Weight 3.60

Time 02:01:51

Tester Food Analysis Lab

Moisture Basis 14.00

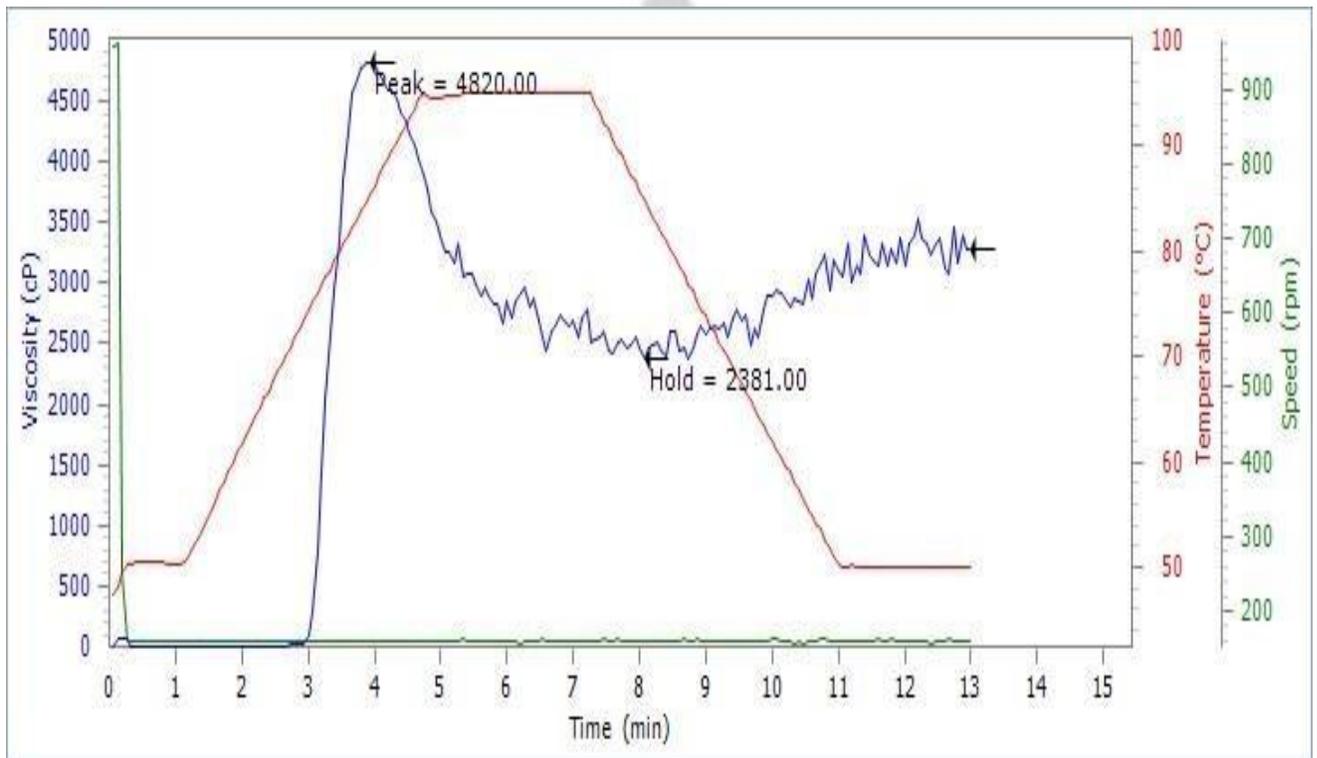
(g)

Water Weight 24.90 (g) Sample Moisture 16.40 (%) (%)

Test Results

Test	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time
01 amasen 1	4820.00	2381.00	2439.00	3283.00	902.00	3.93

Test	Pasting Temp
01 amasen 1	74.50



Appendix 6.1: Viscograph of Amasen at 8th month maturity

KNUST

Appendix 7.0: Output from RVA for starch from Asamsen at 9th month maturity

TCW3 Report

8/3/2017 3:01:40AM User Food Analysis Lab

Security ID = 140864545001537

Test Details Samples

01C:\Users\Food Analysis

Configuration file

C:\Users\Food Analysis Lab\Documents\TCW3 Data\TCW3 Config
Files\flour.rvc

Date 2017/07/14

Sample Weight 3.52 Time 02:51:56

Tester Food Analysis Lab

Instrument 2163573

Moisture Basis 14.00

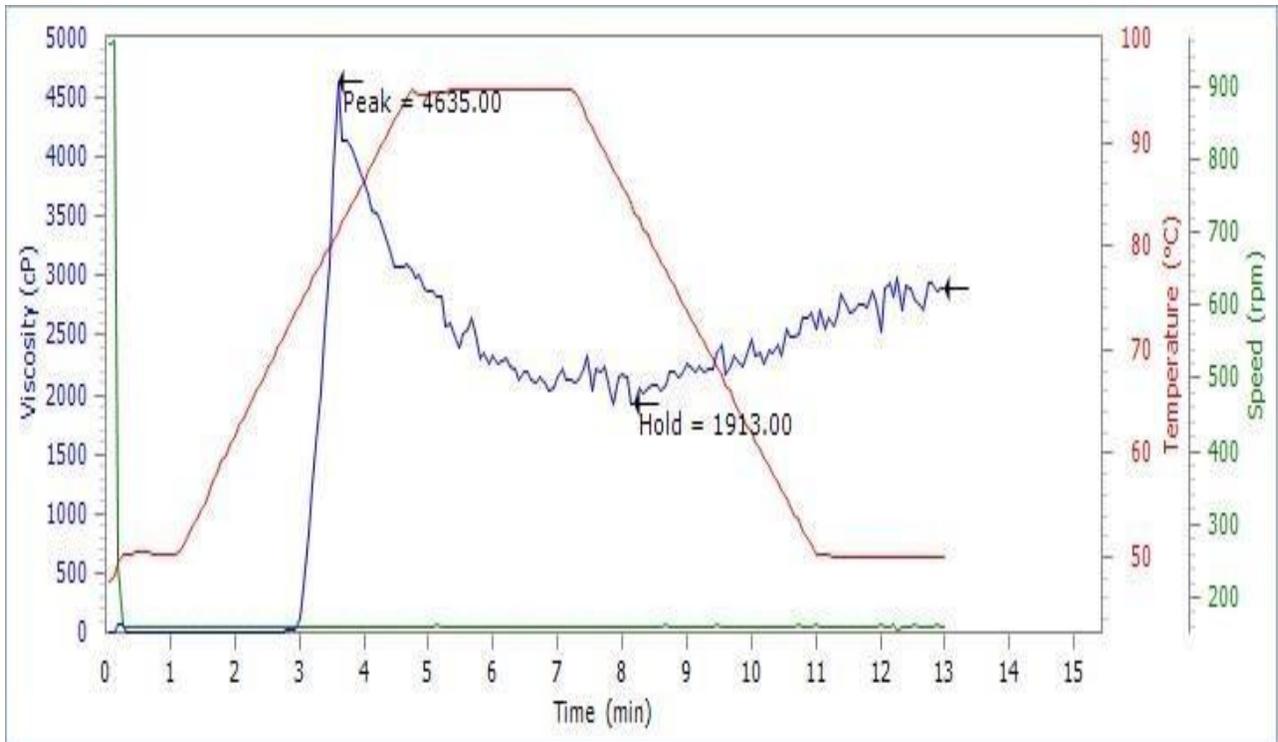
(g)

Water Weight 24.98 (g) Sample Moisture 14.46 (%)

(%)

Test Results

Test	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time
01 AMASEN 2	4635.00	1913.00	2722.00	2902.00	989.00	3.60
Test	Pasting Temp					
01 AMASEN 2	74.40					



Appendix 7.1: Viscograph of Amansen at 9th month maturity



Appendix 8.0: Output from RVA for starch from Asamsen at 10th month maturity

TCW3 Report

8/3/2017 3:06:28AM User Food Analysis Lab

Security ID = 140864545001537

Test Details Samples

01C:\Users\Food Analysis

Configuration file

C:\Users\Food Analysis Lab\Documents\TCW3 Data\TCW3 Config
Files\flour.rvc

Date 2017/08/01

Instrument 2163573

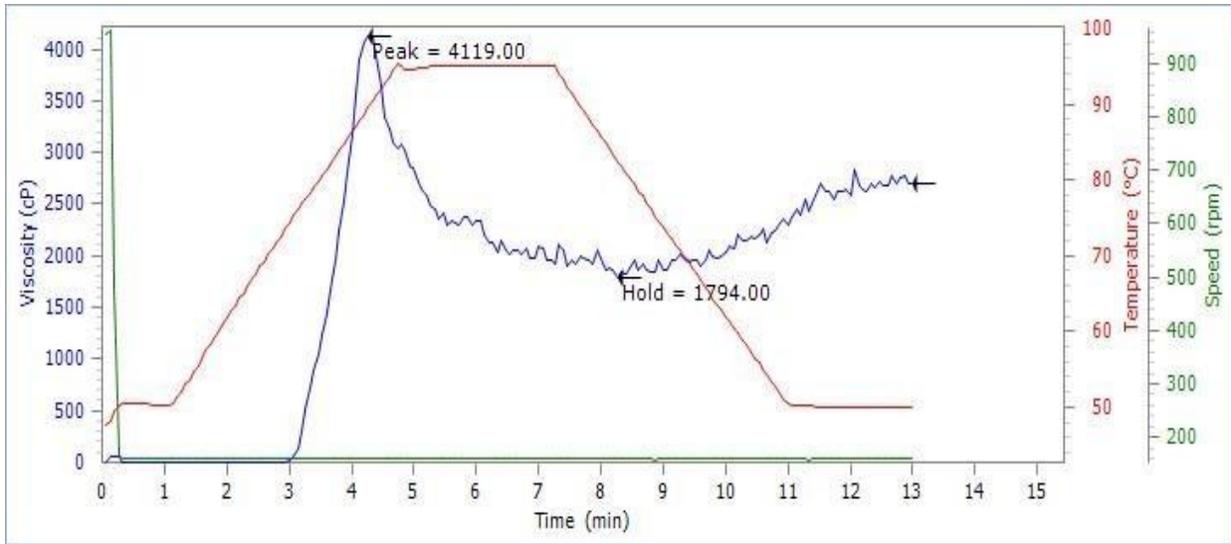
Sample Weight 3.50 (g) Time 03:09:29 Tester Food Analysis Lab

Moisture Basis 14.00 (%)

Water Weight 25.00 (g) Sample Moisture 14.08 (%)

Test Results

Test	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time
01 amasen3	4119.00	1794.00	2325.00	2694.00	900.00	4.27
Test	Pasting Temp					
01 amasen3	75.30					



Appendix 10.1 Viscograph of Amansen at 10th month maturity

Appendix 11.0: Output from RVA for starch from Duadekpkpa at 7th month maturity

TCW3 Report

8/3/2017 3:58:46AM User Food Analysis Lab

Security ID = 140864545001537

Test Details Samples

01

Lab\Documents\TCW3 Data\duadekpkpa

Configuration file Analysis Lab\Documents\TCW3 Data\TCW3 Config

C:\Users\FoodFiles \flour.rvc

Date 2017/07/12

Time 11:38:28

Tester Food Analysis Lab

Instrument 2163573

Sample Weight 3.41

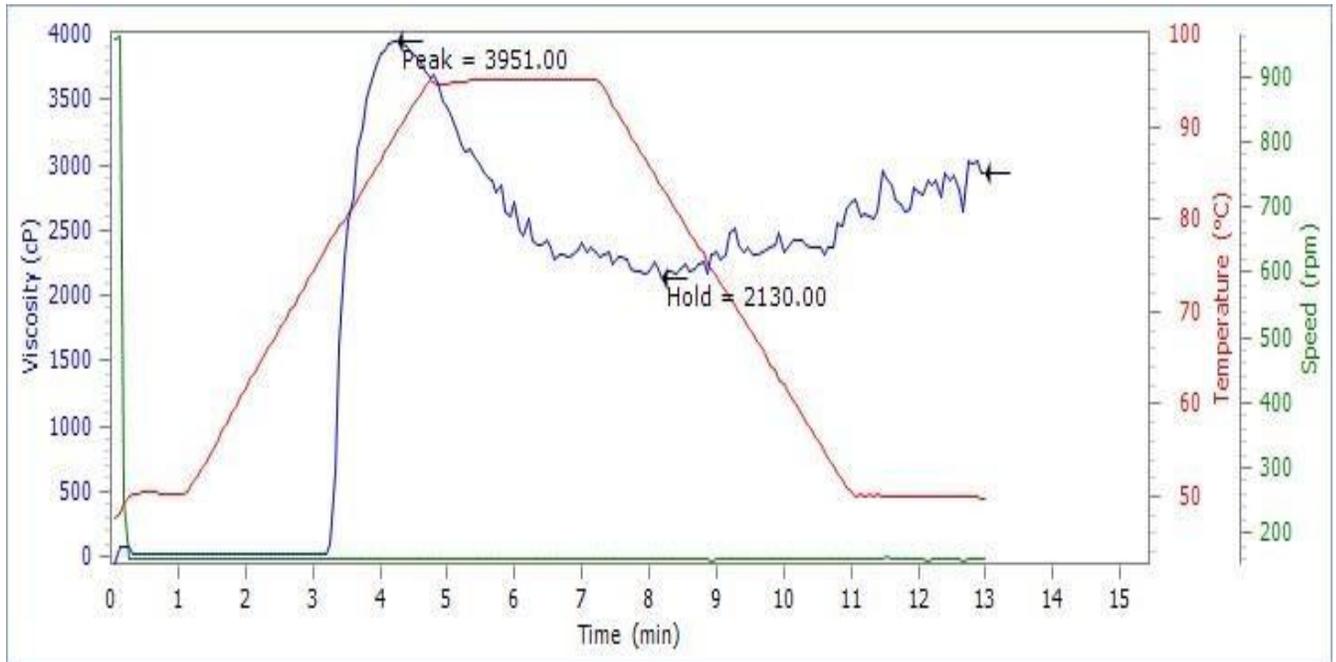
Moisture Basis 14.00

(g)

Water Weight 25.09 (g) Sample Moisture 11.85 (%) (%)

Test Results

Test	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time
01 duadekpkpa	3951.00	2130.00	1821.00	2936.00	806.00	4.27
Test	Pasting Temp					



Appendix 11.1 Viscograph of Duadekpakpa at 7th month maturity

Appendix 12.0: Output from RVA for starch from Duadekpakpa at 8th month maturity

TCW3 Report

8/3/2017 3:52:35AM User Food Analysis Lab

Security ID = 140864545001537

Test Details Samples

01

Lab\Documents\TCW3 Data\duadekpakpa 1

Configuration file

Analysis Lab\Documents\TCW3 Data\TCW3 Config

C:\Users\Food

Files\flour.rvc

Date 2017/07/13

Time 02:45:43

Tester Food Analysis Lab

Instrument 2163573

Sample Weight 3.57

Moisture Basis 14.00

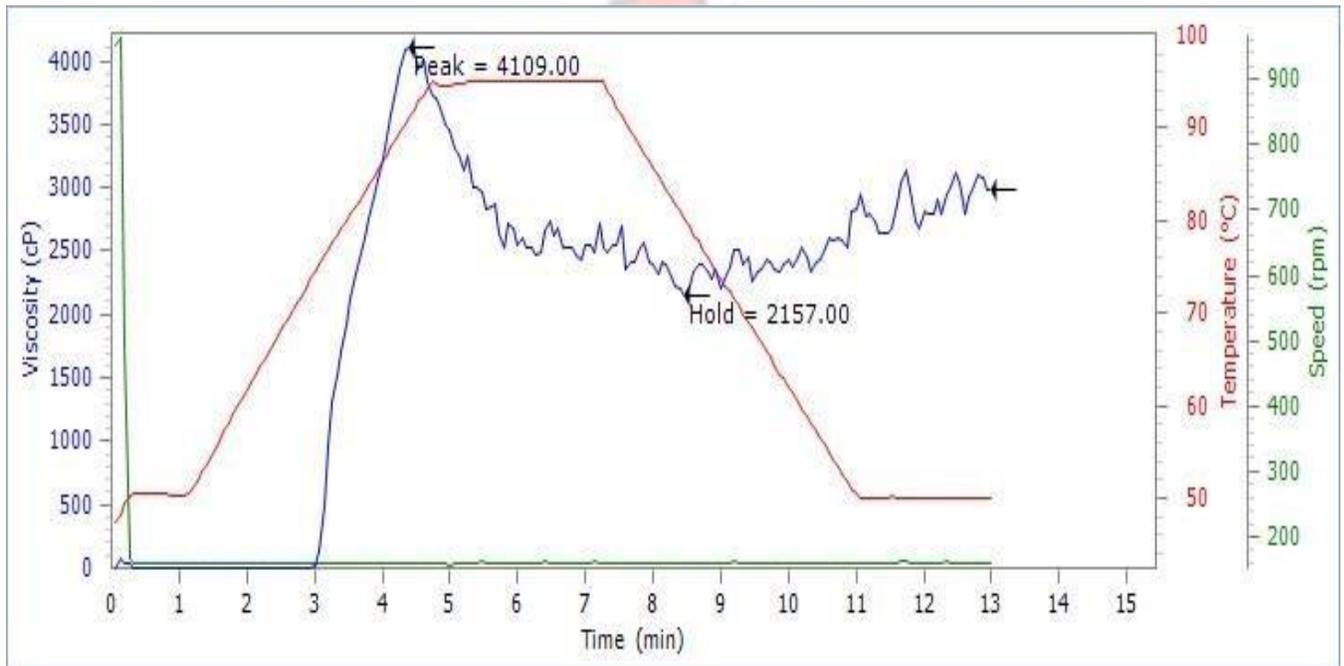
(g)

Water Weight 24.93 (g) Sample Moisture 15.59 (%)

(%)

Test Results

Test	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time
01 duadekpakpa 1	4109.00	2157.00	1952.00	2987.00	830.00	4.40
Test	Pasting Temp					
01 duadekpakpa 1	74.50					



Appendix 11.1 Viscograph of Duadekpakpa at the 8th month

Appendix 12.0: Output from RVA for starch from Duadekpakpa at 9th month maturity

TCW3 Report

8/3/2017 3:54:38AM User Food Analysis Lab

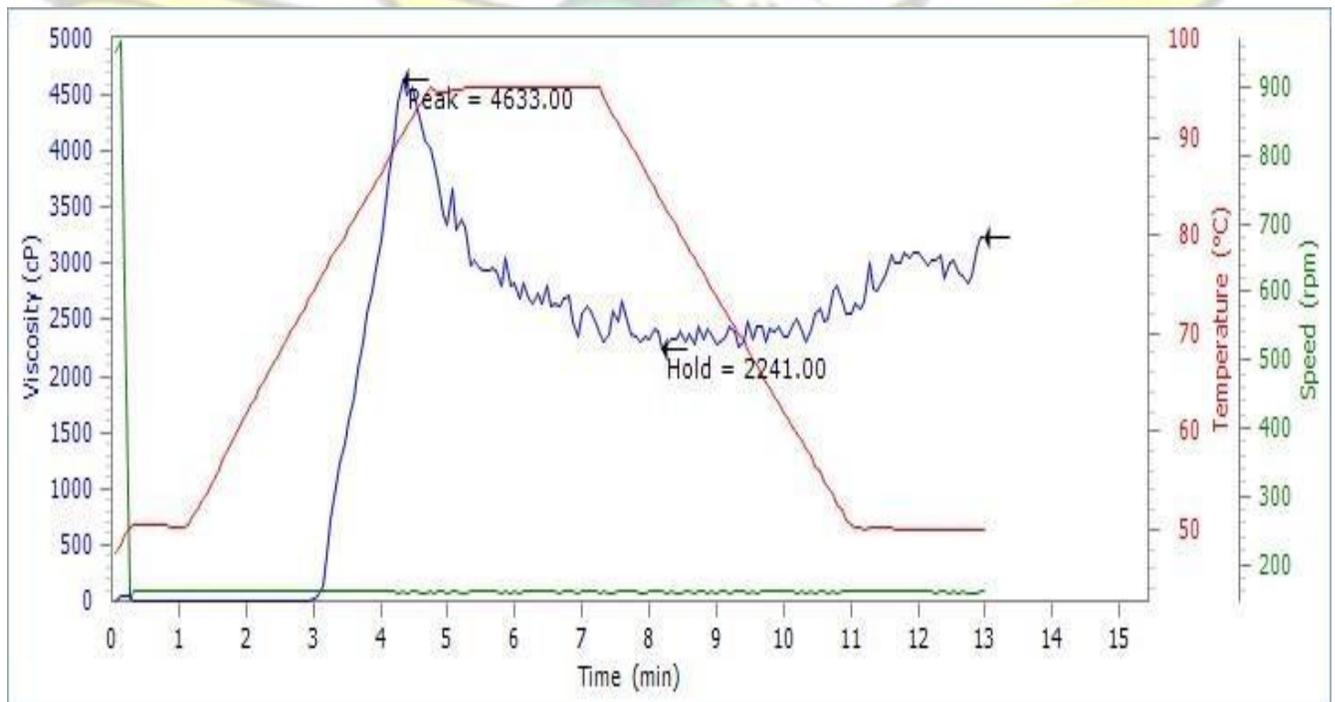
Security ID = 140864545001537

Test Details Samples

01 s Lab\Documents\TCW3
 Configuration file DEKPAKPA 2
 C:\Users\Food Analysis Lab\Documents\TCW3 Data\TCW3 Config
 Files\flour.rvc
 Date 2017/07/14 Instrument 2163573
 Sample Weight 3.53 Time 03:12:44 Tester Food Analysis Lab Moisture Basis 14.00
 (g) Water Weight 24.97 (g) Sample Moisture 14.80 (%) (%)

Test Results

Test	Pasting Temp	Peak Time
01 DUADEKPAKPA 2	75.20	4.33



Appendix 12.1: Viscograph of Duadekpa at the 9th month

KNUST

Appendix 13.0: Output from RVA for starch from Duadekpakpa at 10th month maturity

TCW3 Report

8/3/2017 4:03:24AM User Food Analysis Lab

Security ID = 140864545001537

Test Details Samples

01 Lab\Documents\TCW3 Data\duadekpakpa3
Configuration file Analysis Lab\Documents\TCW3 Data\TCW3 Config
C:\Users\Food
Files\flour.rvc
Date 2017/08/02 Instrument 2163573
Time 01:41:37 Tester Food Analysis Lab
Sample Weight 3.48 Moisture Basis 14.00
(g) Water Weight 25.02 (g) Sample Moisture 13.58 (%) (%)

Test Results

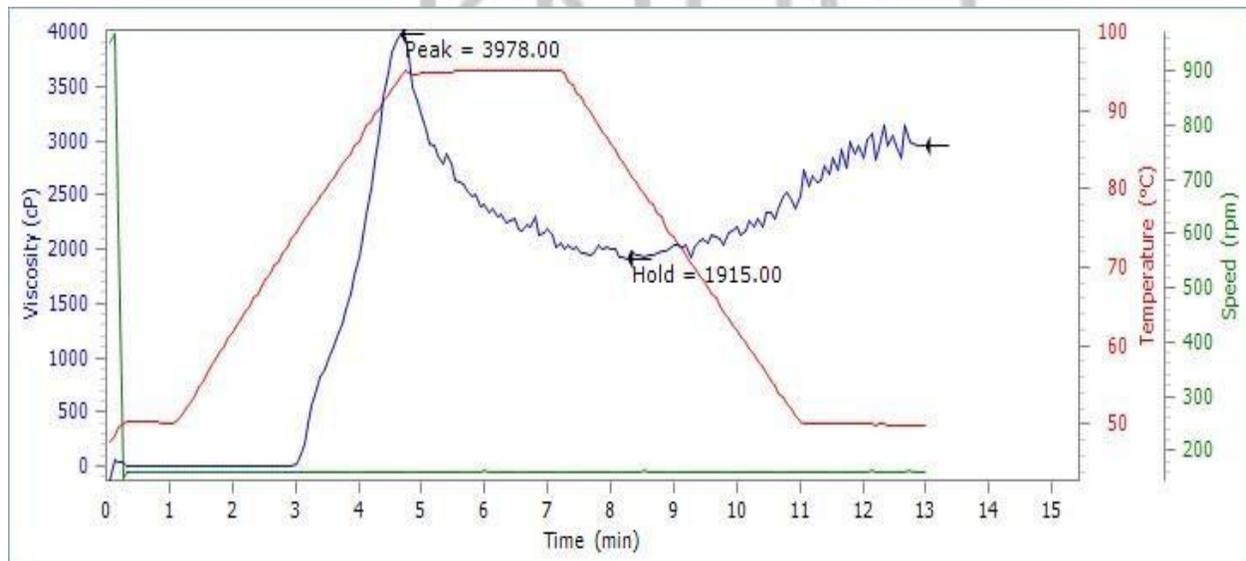
Test	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time
01 duadekpakpa3	3978.00	1915.00	2063.00	2949.00	1034.00	4.67

Test

Pasting Temp

01 duadekpakpa3

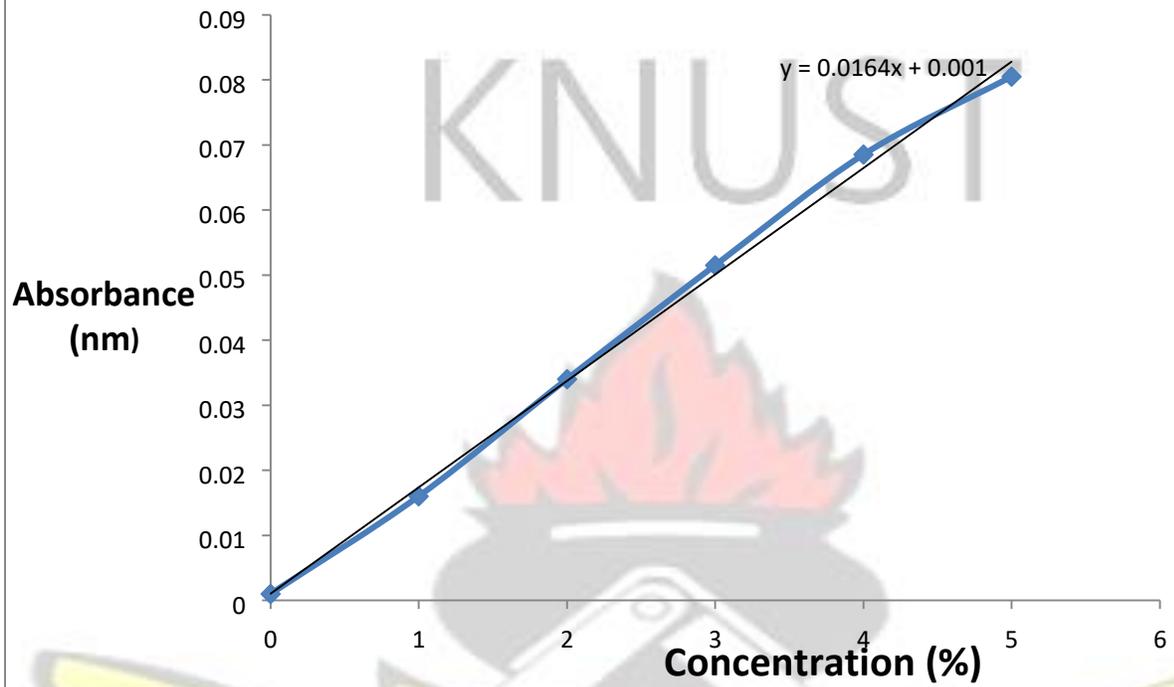
75.30



Appendix 13.1: Viscograph of Duadekpakpa at the 10th month maturity



Calibration curve for standard Amylose Starch



Appendix 14: Standard curve for amylose

