Comparative Study on the Properties of Yam (*Dioscorea Rotundata*) Varieties in Ghana: A Case Study in Asante Mampong

By

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CERTIFICATION

This is to certify that this thesis is the candidate's own account of his research

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ABSTRACT

Four local varieties of *Dioscorea rotundata* namely *Pona, Labreko, Asobayere* and *Muchumudu* were compared by analyzing for their organoleptic, physicochemical and functional properties to ascertain whether these varieties have unique characteristics for particular food products. A survey was initially conducted in Asante Mampong (a yam farming community) and results revealed a high preference for *Labreko* in terms of eating quality (mealiness, taste and softness). This was confirmed in a sensory analysis test which revealed high scores for mealiness and taste for *Labreko*; hence *Labreko* may be promoted for export and local consumption. Significant differences existed in moisture, ash and carbohydrates. *Muchumudu* had the highest moisture content (74.43%) and may be used for mashed products such as yam pottage. *Asobayere* had the lowest moisture content (58.91%) and may be exploited for export because of its potential high keeping quality. Carbohydrate contents ranged from 34.24% (*Asobayere*) to 14.78% (*Muchumudu*). Mineral analysis showed that *Pona* was relatively high in iron (4.45 mg/100 g). High calcium (91.60 mg/100 g) and phosphorus (114.50 mg/100 g) contents were recorded in *Muchumudu*, which is reflective of its high ash content (3.46%). Thus, *Muchumudu* may be a good source of calcium and phosphorus for growing children. *Asobayere* had the highest starch yield (20.89%) and may be exploited for starch production. Flours and starches from the yam varieties showed similar trends in amylose contents, swelling power, water binding capacity and some pasting properties. For the starches, amylose content ranged from 27.48 to 31.55%; swelling power ranged from 10.57 to 12.48; solubility index ranged from 8.52 to 9.32% and water binding capacity ranged from 175.25 to 182.69%. There were significant differences ($P<0.05$) in the pasting properties of the starch samples. The pasting temperature ranged from 75.10 (*Asobayere*) to 77.30°C (*Muchumudu*). *Labreko* and *Asobayere* may also be used for foods that require shorter processing time such as instant foods because of their low pasting temperatures. The peak viscosity ranged from 614 (*Pona*) to 726 BU (*Asobayere*). *Asobayere* may thus be used for foods that require thick and cohesive paste, gel strength and elasticity. The final viscosity ranged from 385 (*Pona*) to 817 BU (*Muchumudu*). The breakdown viscosity ranged from 25 (*Muchumudu*) to 385 BU (*Asobayere*). *Muchumudu* may be used in products that require low viscosity and paste stability at low temperatures. Pasting properties of the flours also followed a similar trend. The results of the study show that *Labreko, Asobayere* and *Muchumudu* have unique characteristics which can be used as a basis for their promotion to increase the range of options for consumers on the local and export markets.

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DEDICATION

I dedicate this work to my parents, Lovelace and Eunice Addy, and siblings, Roland and Richael Addy for their support, encouragement and prayers.

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CHAPTER ONE

1.0 INTRODUCTION

Yams (*Dioscorea* spp.) are important source of carbohydrate for many people of the Sub-Saharan region, especially in the yam zone of West Africa (Akissoe *et al*., 2003), and are the third most important tropical root crop after cassava and sweet potato (Onyeka *et al*., 2006). Yams contribute more than 200 dietary calories per capita daily for more than 150 million people in West Africa and serve as an important source of income (Babaleye, 2003). There are some 600 species (Amani *et al*., 2004) of yam, but only six are mostly grown as staple foods. These are *Dioscorea rotundata* (white yam), *D. alata* (water yam), *D. cayenensis* (yellow yam), *D. esculenta* (Chinese yam), *D. bulbifera* (aerial yam) and *D. dumetorum* (trifoliate yam) (Otegbayo *et al.,* 2001).

Varietal differences influence the quality of various traditional yam products (Akissoe *et al.,* 2001). The nutritional value of yam varies greatly between different species and amongst varieties of the same species. Variations are also subject to such other factors, as cultivation methods, climatic and soil characteristics, age of maturity reached by the tuber at harvest, length of storage and the processing techniques (Osagie, 1992). The value of the yam as a basic food has been attributed to the high digestibility of its starch, which is present in the form of small granules (Sebio and Chang, 2000). The cooking and processing characteristics of yams, the eating and storage quality of yam-containing products will be greatly dependent on starch properties since starch makes up about 70-82% of yam tubers (Wang *et al.*, 2006a).

In many parts of West Africa including Ghana, yam is processed into various food forms, which include pounded yam, boiled yam, roasted yam, or grilled yam, yam balls, mashed yam, yam chips and flakes (Orkwor *et al*., 1997) and are usually accompanied by protein rich soups and sauces. Yams may also be prepared for food simply by frying slices usually in vegetable oil without preliminary boiling to soften the tissue. The processing of yams traditionally depends on the species; *D. rotundata* is preferred for use in preparing boiled yam and pounded yam (Ajibola *et al*., 1988).

Out of the six species commonly found in West Africa, *D. rotundata* is the most widely grown and generally considered to be the best in terms of food quality, thus commanding the highest market value (Markson *et al.*, 2010; Otegbayo *et al.*, 2001). In Ghana, within *D. rotundata* species, there is a class of cultivars commonly known as *Pona* yam and is rated superior to other white yam varieties such as *Labreko*, *Asobayere* and *Muchumudu,* in terms of its cooking quality and thus commands a high price than other yams in the market. *Pona* and *Labreko* have sweet, floury and fragrant tuber flesh and are the most preferred cultivars by consumers in Ghana (Otoo *et al.,* 2009). *Asobayere* is also preferred by some consumers and is also gaining some amount of popularity. *Muchumudu* is the least preferred among these varieties and even unknown to most yam consumers.

Ghana is the third largest producer of yam in the world (MiDA, 2009), but most of the yam produced get into domestic utilization for various food preparations while little or none get into industrial processing. There is a need to expand utilization of yam through industrial processing. The potential of yam to be processed into value-added products would be influenced by their physical and chemical properties.

1.1 Problem statement

Many of the developing world's poorest farmers and food insecure people are highly dependent on root and tuber crops as a contributing, if not the principal, source of food, nutrition, and cash income (Scott *et al.*, 2000). Yams belong to a group of crops labeled "orphaned crops", which have not received research attention for a long period of time and very little improvement, has been made to these crops (Otoo, 2007). Yam ranks second after pineapple in terms of volume and value of non-traditional export crops in Ghana (Asuming-Brempong, 1994). Owing to its importance on the international market as an export crop, most research work is centered on *Pona*. On the other hand, little information is available on the physicochemical, pasting and sensory properties of *Labreko, Asobayere* and *Muchumudu*, probably leading to the underutilization of these varieties.

Pona also has the potential of becoming increasingly expensive on the domestic market due to the preference by the export market. Low income households therefore find it relatively unaffordable compared to other roots and tubers like cassava, cocoyam, and taro. The cost of calories from cassava is low as compared to the cost of calories from yam, which is considerably expensive (Aidoo *et al.,* 2009). Farmers of the less preferred varieties tend to earn less.

1.2 Justification

Ghana is a leading yam exporter, having exported 20,841 metric tons of yams in 2008, but with increasing global demand for yams coming from Europe, the U.S. and neighboring African countries (MiDA, 2009), there is potential for higher production and export volumes if other lesser known varieties of white yam are studied, and their unique properties are brought out and promoted for export. Thus improving food security and increasing farmers' incomes. This will ensure sustainable and cost effective yam production.

Knowledge on the physicochemical and functional properties of *Labreko*, *Asobayere* and *Muchumudu* would lead to a better understanding of their characteristics providing information for their end use quality. This may lead to increase utilization, both domestically and industrially, such as the production of flour for compositing with wheat flour in bread making. This can lead to reduction in the amount of foreign exchange lost in importing wheat flour.

Furthermore, knowledge on the physicochemical and functional properties of *Pona* is also necessary for the development of protocols or processes that may lead to the improvement of other lesser known varieties. This can lead to the reduction of prices because of the availability of more yams on the market. Availability of a wide range of yam varieties with known properties peculiar to specific products would give consumers from the local and export markets options to choose from.

1.3 Objective

The main objective of the study is to compare the organoleptic, physicochemical and functional properties of four yam varieties, namely *Pona*, *Labreko*, *Asobayere* and *Muchumudu.*

1.3.1 Specific Objectives

1. To determine the desired quality of yam through a market survey.
2. To determine the sensory properties of boiled yam from the four varieties.
3. To determine the physicochemical and functional properties of flour and starch from the four yam varieties.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Roots and tubers

Roots and tubers belong to the class of crops that provide energy in the human diet in the form of carbohydrates. Root and tuber refer to any growing plant that stores edible material in subterranean root, corm, or tuber (Aidoo *et al.*, 2009).

Wide range of tuber crops are grown worldwide, but only five species account for almost 99% of the total world production. These are potato (*Solanum tuberosum*, 46%), cassava (*Manihot esculenta*, 28%), sweet potato (*Ipomea batatas*, 18%), yams (*Dioscorea* spp., 6%) and taro (*Colocassia*, *Cytosperma*, *Xanthosoma* spp., 1%) (Jayakody *et al.,* 2007).

Root crops, especially cassava and yam are important commodities in the diet in many parts of Africa. Their processing involves treatment that converts them into finished products with acceptable taste, colour, flavour and texture (Sefa-Dedeh, 1995). Root crops are the primary staple foods of the tropics, with yams being the most prized crop among them. Although cassava and sweet potato have overtaken yams in range and volume, yams remain the dominant crop in the regions where they are best adapted (O' Sullivan, 2010). Where they have become subdominant, their cultural significance exceeds their dietary contribution. In the Pacific region, yams are grown throughout the lowlands, but are the dominant staple in relatively few areas (Bourke and Vlassak, 2004).

2.2 Botanical and agronomic characteristics of yams

The term 'yam' refers to all members of the genus *Dioscorea*. Yams are climbing plants with glaborous leaves and twining stems, which coil readily around a stake. They include some 600 species (Amani *et al*., 2004) including *D. alata*, *D. abyssinia*, *D. batatas*, *D. cayenensis*, *D. esculenta*, *D. japonica*, *D. rotundata* (Hoover, 2001), *D. opposite* (Wang *et al*., 2006b) and *D. dumetorum* (Afoakwa and Sefa-Dedeh, 2001). About 10 species are commonly cultivated for food, while a number of others are harvested from the wild in times of food scarcity (Bhandari *et al*., 2003). Many wild yam species contain toxic or bioactive chemicals, and some of these are cultivated for pharmaceutical products (Coursey, 1967).

Although highly variable in appearance both between and within species, all yams share a common growth habit of thin, twining vines and a shallow, widely radiating root system, both of which die and are renewed each year. All economically important species are tuberous, producing one or more underground tubers, which are starch storage organs derived from stem tissue. The tubers provide a means of vegetative propagation from one season to the next. In most cases the tubers are annual—they shrivel at the start of the new growing season and are replaced by new tubers (O'Sullivan, 2010).

However, some genotypes of several species produce perennial tubers, which may continue to grow over several years. Many species produce aerial tubers, or bulbils, as a means of vegetative dispersal. Vegetative propagation is much more common than propagation by true seed, even among most wild yam species. Cultivated yams are mostly vegetatively propagated. Yams are dioecious, with male and female flowers borne on separate plants (O'Sullivan, 2010).

2.3 *Dioscorea rotundata* (The white yam)

Dioscorea rotundata remains the principal yam cultivated in West Africa. Its cultivation has also spread to other parts of the world. It is grown extensively in the West Indies, and to some extent in East Africa. There are very large numbers of cultivars of *D. rotundata* that are grown, especially in West Africa. Unfortunately, the taxonomic position of most of these cultivars, and of cultivars of yam generally, is somewhat confused, partly because there are no universally accepted names for the cultivars, and partly because detailed descriptions of the distinguishing features of each cultivars are lacking, making referencing to cultivars ambiguous and unreliable (Onwueme, 1978; Otoo *et al.*, 2009).

The situation, therefore, is one in which each locality has its own unique series of names for the different cultivars (Onwueme, 1978). The various cultivars can be identified by their tubers during storage or by their shoot characteristics while they are growing on the field. Identification may be based on tuber shape, tuber-skin colour and structure, tuber-flesh colour and tuber-flesh texture; or on the colour of sprout and shoot tips, quantity and distribution of spines and bloom on the stem, and leaf shape, size, and colour (Onwueme, 1978).

2.4 World production of yam

Worldwide yam production in 2008 amounted to 53 million tons (Table 2.1), of which Africa produced 96.5%. Most of the world's production comes from West Africa representing 93%, with Nigeria alone producing 66%. In 2008, Nigeria (the leading producer of yam) produced 35 million tonnes followed by Côte d'Ivoire (6.9 million tonnes), Ghana (4.8 million tonnes), and Benin (1.8 million tonnes) (FAOSTAT, 2010).

During the past decade, total world production has increased from 39.6 million tonnes in 2000 to 54 million tonnes in 2009 (Table 2.2). During the period of 1975 to 1990, total yam cultivated area increased by about 38.8% globally, with total production also increasing by 45.8%. However, the importance of yam in the economy of the main producing areas appears be declining due partly to competition with other crops like cassava in Nigeria, and taro in the South Pacific (Opara, 1999).

Table 2.1 World production of yam from 2000 to 2009 (million tonnes).

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Production	39.5	39.9	42.2	44.2	46.9	49.1	52.5	47.4	53.1	54.1

Source: FAOSTAT (2010)

Table 2.2 Area harvested, yield and production of yam in the world (2008).

		Area harvested (Ha)	Yield (Hg/Ha)	Production(Tonnes)
World		4,983,396	106,525	53,085,709
Africa	East Africa	36,238	71,786	260,141
	Middle Africa	187,800	73,730	1,384,650
	North Africa	57,000	24,035	137,000
	West Africa	4,491,538	110,088	49,446,481
Americas	Cent America	4,925	100,290	49,393
	Caribbean	104,223	60,512	630,682
	South America	61,613	97,671	601,781
Asia	East Asia	8,050	225,093	181,200
	SouthEast Asia	5,212	46,402	24,185
Europe	South Europe	165	163,636	2,700
Oceania	Melanesia	25,222	142,150	358,531
	Polynesia	1,410	63,581	8,965

Source: FAOSTAT (2010).

2.5 The chemical composition of yam

2.5.1 Nutritional value of yam

Yam is considered to be the most nutritious of the tropical root crops (Wanasundera and Ravindran, 1994). It contains approximately four times as much protein as cassava, and is the only major root crop that exceeds rice in protein content in proportion to digestible energy (Bradbury and Holloway, 1988).

Table 2.3 Nutrient content of yam species (*Dioscorea* spp.).

Nutrient	*D. rotundata*	*D. alata*	*D. cayenensis*	*D. esculenta*	*D. dumetorum*
Moisture (%)	50.0-80.0	65-78.6	60-84	67-81	67-79
Carbohydrate (%)	15-40.61	22-31	16	17-25	17-28
Starch (%)	26.8-30.2	16.7-28	16.0	25	18-25
Free sugar (%)	0.3-5.57	0.5-1.4	0.4	0.6	0.2
Protein (%)	0.087 -4.30	1.1-8.7	1.1-1.5	1.3-1.9	2.8
Crude fat (%)	0.05-2.70	0.1-0.6	0.06-0.02	0.04-0.3	0.3
Crude fibre (%)	0.70-1.80	1.4-3.8	0.4	0.2-1.5	0.3
Ash (%)	0.7-2.6	0.7-4.1	0.5	0.5-1.5	0.7
Phosphorus (mg/100g)	17-110.27	28-52	17	35-53	45
Calcium (mg/100g)	36	28-38	36	12-62	52
Iron (mg/100g)	5.2	5.5-11.6	5.2	0.8	

Sources: Alinnor and Akalezi (2010); Asiedu *et al.* (1997); Baah *et al*. (2009a); Bradbury and Holloway (1988); Coursey (1967); Eka (1985); Muzac-Tucker *et al.* (1993); Ojokoh and Gabriel (2010); Opara (1999); Osagie (1992); Akomeah-Adjei (2004) and Otegbayo *et al*. (2001).

2.6 Starch

Starch is a polysaccharide constructed from glucose as the basic building block (John, 1992). They are long complex chains of simple sugars joined together by glycosidic bonds and are the most important carbohydrate in the human diet contained in many staple foods (Rickard *et al.*, 1991). Starches of various origins have individual characteristic properties which go back to the shape, size, size distribution, composition and crystallinity of the granules.

Starch granules are composed of a mixture of two polymers: an essentially linear polysaccharide called amylose and a highly branched polysaccharide called amylopectin, primarily forming the crystalline regions (BeMiller and Huber, 2008). The large size and highly branched structure of amylopectin are responsible for the high viscosity of amylopectin dispersions (Manners, 1989). Amylopectin constitutes about 75% of most common starches. Most starches contain about 25% amylose (BeMiller and Huber, 2008). Otegbayo *et al.* (2001) reported 35.80 and 33.1% for *Pona* and other *D. rotundata* varieties respectively. An amylose content of 26.6% for *D. rotundata* was also reported by Baah *et al.* (2009b).

Variability in shape exists among yam starches, ranging from round, triangular, oval and to elliptical (Moorthy, 1994). The shape and size of these granules are characteristic of the starch's botanical source, growing and harvest conditions. It is assumed that starches with a range of granular structures behave uniquely, leading to the provision of a range of functional attributes (Baah, 2009). Moorthy (2002) reported the granule size of yam starch from *D. rotundata/cayenensis* to be 10 to 70 μm. Granule sizes ranging from 19 to 50 μm for *D. cayenensis-rotundata* complex and 10 to 56 μm for *D. rotundata* were also reported by Brunnschweiler *et al*. (2004) and Malomo and Jayeola (2010) respectively.

2.6.1 Properties of starch

2.6.1.1 Water binding capacity

Water molecules which are closely contingent to macromolecules are restricted in motion. Such water molecules are loosely termed "bound water" and reflect the ability of a molecular surface to form weak, non-covalent bonds in water. Where extensive hydrogen bonding occurs between the macromolecules, there is reduction in the molecular surfaces available for such 'binding' of water molecules (Rickard *et al.*, 1991). A range between 159.7 and 202.0%, and 163.3% was reported by Baah (2009) for *D. alata* and *D. rotundata* respectively.

2.6.1.2 Swelling power and solubility

When starch is heated in excess water, the crystalline structure is disrupted (due to breakage of hydrogen bonds) and water molecules become linked by hydrogen bonding to the exposed hydroxyl groups of amylose and amylopectin. This causes an increase in granule swelling and solubility. Swelling and solubility provide evidence of the magnitude of interaction between starch chains within the amorphous and crystalline domains and also evidence of association bonding within the granules of yam starches. The higher the swelling index, the lower the associative forces (Jimoh *et al.*, 2009; Ikegwu *et al.*, 2009). The extent of this interaction is influenced by the amylose/amylopectin ratio, and by the characteristics of amylose and amylopectin in terms of molecular weight/distribution, degree and length of branching, and conformation (Hoover, 2001). The formation of amylose – lipid complexes can restrict swelling and solubilisation (Swinkels, 1985).

The swelling power was defined by Balagopalan *et al.* (1988) as the maximum increase in volume and weight which the starch undergoes when allowed to swell freely in water. The swelling power and solubility of yam are dependent on varietal differences, environmental factors, and the age of the crop. Values of 11.0 and 8.6% were reported by Baah *et al*. (2009b) for swelling power and solubility of *D. rotundata* respectively.

2.6.1.3 Pasting characteristics

Pasting properties are important functional characteristics of flours and starches. When an aqueous suspension of starch is heated above a critical temperature, granules swell irreversibly and amylose leaches out into the aqueous phase, resulting in increased viscosity (pasting) (Brabet *et al.*, 1998). This leads to the granules being highly susceptible to thermal and mechanical breakdown (Tsakama *et al.,* 2010).

The pasting temperature provide an indication of the minimum temperature required for sample cooking, energy cost involved and other components stability (Ikegwu *et al.*, 2009). It also gives an indication of the gelatinization time during processing (Odedeji and Adeleke, 2010). It is the temperature at which the first detectable increase in viscosity is measured and it is an index characterized by the initial change due to the swelling of starch (Eniola and Delarosa, 1981). Ogutunde (1987) reported that the associative bonding of the amylose fraction is responsible for the structure and pasting behaviour of starch granule.

Viscosity is another property of starch solutions, which makes it useful in many starch industries, example, the role of starch as a thickener in food industries, and as a sizing and finishing agent in textile and paper industries. When an aqueous concentrated suspension of starch is heated above its gelatinization temperature, the individual granules gelatinize and swell rapidly and freely until they consume almost all the available water. As a result of the high swelling, the granules become increasingly susceptible to disintegration by mechanical shear. Pasting properties of various four yam species are shown in Table 2.4.

Table 2.4: Some pasting properties of various yam starches.

Variety	Pasting temp. (°C)	Viscosity at 95°C	Maximum viscosity before cooling
D. rotundata	76-83°C	260-610	470-650
D. alata	81-86°C	25-80	110-200
D. esculenta	82°C	25	55
D. dumetorum	80.2-82°C	25-32	30-55

Sources: Afoakwa and Sefa-Dedeh (2002); Baah *et al*. (2009b); Rasper and Coursey (1967).

(D) Gelatinization

Undamaged starch granules are insoluble in cold water but can imbibe water reversibly, that is, they can swell slightly, and then return to their original size on drying (BeMiller and Huber, 2008). Starch when heated in the presence of excess water, undergoes an order-disorder phase transition called gelatinization over a temperature range characteristic of the starch source. The phase transition is associated with the diffusion of water into the granule, water uptake by the amorphous background region, hydration and radial swelling of the starch granules, loss of optical birefringerence, uptake of heat, loss of crystalline order, uncoiling and dissociation of double helices (in the crystalline regions) and amylose leaching (Stevens and Elton, 1981; BeMiller and Huber, 2008; Jenkins, 1994).

2.7 Other components

Some yams may contain small traces of polyphenolic compounds (Onwueme, 1978). These are significant since they are subject to enzymatic oxidation when the tuber is cut, causing the cut surface to turn brown.

Certain yam species may contain quantities of alkaloids (e.g. dioscorine) and steroid derivatives (e.g. diosgenin). Some *D. bulbifera* are known to be toxic and there may be a contribution of alkaloids from the dioscorine group. Dioscorine triggers fatal paralysis of the nervous system when a fragment of the tuber weighing 100g is ingested. Dioscorine may be extracted for use as a poison, while diosgenin is extracted for pharmaceutical use. Dihydrodioscorine is found in *D. dumetorum* (Degras, 1993; Onwueme, 1978).

2.8 Uses of yam

2.8.1 Culinary uses

Food yam tubers are mostly eaten as a freshly prepared dish or a dish from a processed tuber (Rava *et al.,* 1996). Boiled yam is one of the simplest and most widespread forms in which yam is consumed. Its preparation involves boiling pieces or slices of yam in boiling water for about 10 minutes. Boiled yam is usually eaten with some kind of sauce or soup into which it is dipped before being eaten. In West and Central Africa, boiled yam processed into pounded yam is a very popular food made from yams (Otegbayo *et al.,* 2007). Mashed yam is also prepared by mashing boiled yam. Its texture is less viscous than pounded yam. Frying and roasting are other cooking methods of yam (Achi, 1999; Asiedu et al., 1997). Fried yam-balls are also prepared from the fresh tuber by first grating the peeled tuber, mixing the grated tuber with spices and condiments, and frying portions of it in hot oil to form little balls. Yam can also be baked in an oven before consumption (Onwueme, 1978). Particularly common in Nigeria and Benin, yam is processed into flour and mixed with boiling water to produce a coloured gel-like paste called amala (Akissoe *et al*., 2006). Yam tubers can also be fed to livestock as feed but are not often used because of the availability of much inexpensive substitutes.

For species such as *D. dumetorum,* which contain bitter and toxic substances (e.g. dioscorine), the tuber are detoxified by soaking it in salt water for several hours before it is boiled, or used in any other way. Coloured cultivars of D. alata have been used as colouring and flavouring agent for ice cream (Onwueme, 1978; Salda *et al.*, 1998).

2.8.2 Non-food uses

Many species of yam contain small amounts of sapogenins and alkaloids for which various uses have been found. The main sapogenin present is diosgenin, which serves as a starting point for the pharmaceutical manufacture of corticosteroid drugs (Markson *et al.*, 2010; Onwueme, 1978). Commercial exploitation of yams for diosgenin occurs most prevalently in Mexico, where *D. mexicana, D. floribunda, and D. composita* are grown for that purpose. In South Africa, D. *elephantipes,* and *D. sylvatica* are similarly exploited. Most of the yams which produce edible fleshy tubers do not contain appreciable amount of diosgenin, they are therefore not normally grown for pharmaceutical purpose (Onwueme, 1978).

The alkaloids present in yams include dioscorine in *D. hispida*, and dihydrodioscorine in *D. dumetorum*. Both substances are nerves poisons and the species that contain them are therefore used are as sources of poison for hunting, fishing and pharmaceutical purposes. Alkaloids are soluble in water, so the tubers containing high amounts of the alkaloids can be detoxified by prolonged soaking in water (Onwueme, 1978).

2.9 Sensory evaluation of food products

Sensory evaluation is "a scientific discipline used to evoke, measure, analyse and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch and hearing" (IFT, 1975). In the food industry, sensory evaluation is applied in the following areas: new product development, product matching, product improvement, process change, cost reduction and/or selection of a new source of supply, quality control, storage stability, product grading and rating, consumer acceptance and/or opinions, consumer preference, panelist selection and training. Sensory evaluation is also used for the correlation of sensory properties with chemical and physical measurements (IFT, 1981).

Analytical and affective tests are two major classifications of sensory tests. Affective tests are used to evaluate preference and/or acceptance of products. A large number of respondents is required for evaluation. These panelists are untrained, but are selected at large to represent target or potential target populations (IFT, 1981).

Analytical tests are used for laboratory evaluation of products in terms of differences or similarities and for the identification and quantification of sensory characteristics. Discriminative and descriptive tests are the major types of analytical tests. Both tests require the use of trained and/or experienced panelists. Potential panelists are screened for selected personal traits, interests, and ability to discriminate differences and generate reproducible results (IFT, 1981).

Studies have shown that the sensory preference of yam products are not the same and also differ from country to country. According to a survey conducted in Benin, Akissoe *et al.* (2001 and 2006) reported that *amala*, which is a traditional thick paste consumed in West Africa, should be soft but firm, non-sticky and elastic, while in Nigeria, Akingbala *et al.* (1995) reported that softness and stickiness are the two most important factors that affect the quality of *amala*.

Pounded yam which is a glutinous dough made by pounding boiled yam also has different attributes. Its strecthability, cohesiveness (moldability), hardness (soft but firm, not very soft or very hard), smoothness and stickiness are the important attributes used in determining its desired quality (Otegbayo *et al.*, 2007).

Colour, wetness, taste, hardness and mealiness were attributes generated for boiled yam evaluation by Baah (2009) using standard analytical tests such as descriptive test. Descriptive analysis involves the identification, description and quantification of the sensory attributes of a product by a trained panel. A trained panel of about 5 to 15 is used (Baah, 2009). It was based on her work that sensory attributes of boiled yam were selected for this study.

2.10 Conclusion on literature review

Varietal differences affect the choice of yam by consumers. It is therefore necessary to study the effect of varietal differences on the properties of yam. The organoleptic, physicochemical and functional properties of yam may affect the consumer preference and its behaviour in food products, hence its use both domestically and industrially. Knowledge on these properties would provide information on their end use quality, thereby leading to increased utilization of these yam varieties.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Market survey

3.1.1 Survey area

The study was conducted in July, 2011, in Asante Mampong, a yam growing community located in the Ashanti region of Ghana.

3.1.2 Survey method

Semi-structured questionnaires were designed to interview fifty respondents who were mainly female farmers and marketers of yam. The questionnaires were designed to inquire information about the varieties of yam that are being cultivated in the community and why they are cultivated and reasons for their preference of certain yam varieties. Respondents were also interviewed on their perception of quality of yam, as well as their perception of factors that influence the choice of yam by consumers (App. 3).

3.2 Source of materials

Four varieties of white yam namely *Pona*, *Labreko*, *Asobayere* and *Muchumudu* were selected for this study based on preliminary survey results on yam consumption in Asante Mampong. These varieties were planted in December, 2010 and harvested in July, 2011. Twenty fresh yam tubers of each variety were obtained from two farmers at a market in Asante Mampong 24 hours after harvest, from which tubers were randomly selected for analysis. Three tubers of each variety were randomly selected for flour preparation, another set of three were selected for starch extraction and a final batch of two tubers were randomly selected for sensory evaluation. The two tubers were washed, peeled and divided into four longitudinal sections resulting in a total of eight portions. Two opposite portions from each tuber were selected and cut into cubes and cooked for sensory evaluation according to the method of Baah *et al.* (2009a).

3.3 Sampling for sensory, physicochemical and functional analysis

3.3.1 Flour preparation

The yam tubers were washed, peeled, sliced into cubes and dried in hot air oven at a temperature of 60°C for 72 hours. The dried yam chips were then milled using a hammer mill with a 250 µm sieve to obtain yam flour. The flour was packaged in low density polyethylene zip-lock bags and stored in a freezer for analysis of physicochemical and functional properties.

3.3.2 Starch extraction

Starch was extracted from freshly harvested yam tubers by the wet extraction method described by Ellis *et al.* (2003).

The tubers were first sorted out and then peeled with knife. The peeled tuber was washed with tap water to remove all dirt and cut into chunks of about 2-3 gram sizes. One kilogram of the chunks were weighed and blended with 500 ml of distilled water using the Waring Blender (Model 51BL30 (7010), Torrington, Connecticut, USA) to obtain a slurry.

The slurry was then pressed through clean cheese cloth. The solids retained by the cloth were mixed thoroughly with 1500 ml of distilled water and the resulting slurry pressed through clean cheese cloth. This process was repeated again. Starch in filtrate was allowed to sediment for 3 hours after which the supernatant was decanted and discarded. The starch was re-suspended in 500 ml of distilled water and the sedimentation and decanting steps repeated without pressing through cheese cloth. The starch was dried using solar dryers for 48 hours. The dried starch was ground into powder using a Waring Blender (Model 51BL30 (7010), Torrington, Connecticut, USA) and then stored in low density polyethylene zip-lock bags prior to use.

3.3.3 Boiled yam preparation

An amount of 400 g of peeled yam tuber per variety from the two tubers selected (section 3.2) was cut into uniform pieces. Two hundred and fifty millilitres of water was added to the sliced tubers and cooked for a period of 10 min. By the use of a fork, yam was judged as cooked when the core became soft. Cooked slices were drained, wrapped in a cling film and stored in food ice chest to keep warm, until all the varieties were ready for sensory evaluation.

3.3.4 Sensory evaluation

Ten trained assessors from the Department of Food Science and Technology were selected based on previous involvement in sensory evaluation tests for a descriptive sensory test on the yam varieties. In a group dialogue with assessors, sensory attributes for boiled yam and similar products were generated. Assessors were trained to understand the attributes generated and also to use these attributes to describe other similar food products common to assessors. At evaluation session, each of the panellists received simultaneously samples of boiled yam and conducted independent assessments in separate sensory booths. Taste, wetness, mealiness and softness were the sensory attributes considered. The levels of perception were assessed using a 7-point scale. Points were awarded in the order as shown in Table 3.1.

Table 3.1: A 7-point scale showing levels of perception

Points	Wetness	Softness	Mealiness	Taste
7	Wet	Soft	Mealy	Sweet
5	Slightly wet	Slightly soft	Slightly mealy	Slightly sweet
3	Slightly dry	Slightly hard	Soggy	Bland
I	dry	hard	Waxy	Bitter

3.4 Laboratory analysis

3.4.1 Analysis on fresh yam tuber

3.4.1.1 Determination of Moisture

The moisture content was determined using the Official Methods of Analysis (AOAC, 1990). About 5 g of chopped fresh yam tuber was weighed and transferred into previously dried and weighed glass dishes. The dishes with yam samples were placed in a thermostatically controlled oven and heated at 105^{o}C for 5 hours to a constant weight. The dishes were removed and cooled in a desiccator and re-weighed. The dishes were dried again for 30 minutes, cooled down and weighed. This procedure was repeated until constant weight was reached. The moisture content was then determined by difference and expressed as a percentage.

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

3.4.2 Analysis on yam flour/starch

3.4.2.1 Determination of starch yield

Starch yield was determined as the percentage starch recovered after extraction from a weighed kilogram of sample.

3.4.2.2 Determination of pH

Five grams of yam flour/starch was weighed and mixed with 50 ml of distilled water to obtain slurry. The pH was then determined using a Fisher Science Education pH (Model S90526, Singapore) meter by inserting the pH probe into the slurry.

3.4.2.3 Determination of moisture

The same methodology of moisture determination used for the fresh yam tuber was used for the yam starch.

3.4.2.4 Determination of ash

The ash content was determined using the Official Methods of Analysis (AOAC, 1990). Two grams of yam flour/starch was transferred into a porcelain crucible which had previously been ignited, cooled and weighed. The crucible and its contents were then placed in a muffle furnace preheated to 600^{o}C for 2 hours. The crucible was removed and cooled in a desiccator. The crucible and its contents were weighed. The total ash content was calculated and expressed as a percentage.

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

3.4.2.5 Determination of crude fat

The crude fat content was determined using the Official Methods of Analysis (AOAC, 1990). A previously dried (air oven at 100^{o}C) and cooled 250 ml round bottom flask was accurately weighed. Two grams of the dried yam flour was transferred to a 22x80 mm filter paper (thimble). Glass wool was placed into the thimble to prevent loss of flour. One fifty millilitres of petroleum ether were added to the round bottom flask and the apparatus was assembled. The Quickfit condenser was connected to the Soxhlet extractor and refluxed for 16 hours using a heating mantle. The flask was then removed and evaporated on a steam bath. The flask and its content were then heated in an oven for 30 minutes at 105^{o}C. The flask and its contents were cooled to room temperature in a desiccator and weighed. The fat content was expressed as percentage by weight. This was calculated as follows:

$$\% \text{ Crude fat} = \frac{\text{Weight of extracted matter}}{\text{Weight of sample}} \times 100$$

3.4.2.6 Determination of crude fibre

The crude fat content was determined using the Official Methods of Analysis (AOAC, 1990). The defatted flour used for the crude fat determination was transferred into a 750 ml Erlenmeyer flask and approximately 0.5 g of asbestos was added. Two hundred millilitres of boiling 1.25% H_2SO_4 was added and the flask was immediately set on a hot plate and condenser connected to the Erlenmeyer flask (cold finger type). The flask and its content were heated for 30 minutes. The flask was then removed and the contents immediately filtered through linen cloth in funnel and washed with a large volume of boiling water until washings were no longer acidic. This was done using a pH meter.

The filtrate and asbestos were washed back into a flask with 200 ml boiling 1.25% NaOH solution. Flask was then connected to the condenser and boiled for exactly 30 minutes. At the end of 30 minutes, the contents of the flask were filtered through linen cloth in a funnel and washed with large volumes of boiling water.

The residue was transferred into a Gooch crucible with water from a wash bottle and was then washed with 15 ml alcohol. The crucible and its contents were dried for 1 hour at 100^{o}C, cooled in a desiccator and weighed. The crucible with its content was then ignited in a muffle furnace preheated to 600^{o}C for 30 minutes, cooled in a desiccator and reweighed.

$$\text{\% Crude fibre} = \frac{\text{Weight of dried sample - Weight of ash}}{\text{Weight of sample}} \times 100$$

3.4.2.7 Determination of protein

Kjehdahl method was used to determine crude protein content. This method involves stages of digestion, distillation and titration.

Two grams of yam flour was transferred into a digestion flask. Half of selenium based catalyst tablet and a few anti-bumping agents (broken porcelain crucibles) were also added to the flask. Twenty five millilitres of concentrated sulphuric acid (H_2SO_4) was added and the flask shaken to ensure that the yam flour was thoroughly wet. The flask was then placed on a digestion burner and heated slowly until boiling ceased and the resulting solution became clear. The flask and its content were cooled to room temperature. The digested flour solution was transferred into a 100 ml volumetric flask and distilled water was added to the mark.

Distilled water was boiled in a steam generator of the distillation apparatus to flush out the apparatus before use, with the connections arranged to circulate through the condenser, for at least 10 minutes. Twenty five millilitres of 2% boric acid was pipetted into a 250 ml conical flask and 2 drops of mixed indicator added. Liquid from the steam trap was drained. The conical flask and its contents were placed under the condenser in such a position that the tip of the condenser was completely immersed in solution formed in the conical flask. Ten millilitres of the digested solution sample was measured. The stopcock of the funnel on the steam jacket was opened and the 10 ml of the digested solution poured. Excess of 40% NaOH was added to the decomposition flask and the funnel stopcock closed. The stopcock on the steam trap outlet was shut to force steam through the decomposition chamber in order to drive the liberated ammonia into the collection flask. The distillate was titrated with 0.1 N HCl solution. The acid was added until the solution was colourless. Additional acid caused the solution to become pink. The same procedure was followed for the blank.

3.4.2.8 Determination of total carbohydrate

Total carbohydrate was calculated by the difference between 100 and the sum of moisture, ash, crude fat, crude protein and crude fibre (Kirk and Sawyer, 1981).

3.4.2.9 Determination of total titratable acidity

Eighteen grams of flour was weighed and made into slurry using 200 ml distilled water in a flask. The flask was loosely stoppered and placed in a water bath at 40^{o}C for an hour and shaken occasionally. The slurry was then filtered using Whatman's No. 1 filter paper. 100 ml of the filtrate was titrated against 0.2 M NaOH using phenolphthalein as indicator. The total titratable acidity was calculated as percent lactic acid (Oduro *et al*., 2001).

3.4.2.10 Determination of amylose

The amylose content of the yam flour/starch was determined based on the iodine colorimetric method of Juliano (1971). About 0.1 g of the flour/starch sample was solubilised with 1 ml of 95% ethanol and 9 ml of 1 N NaOH, and heated in a boiling water bath for 10 min. Nine millilitres of distilled water was added to 1 ml of the extract to make a total volume of 10 ml. 0.5 ml of the diluted extract was pipetted into a beaker, 0.1 ml I N acetic acid and 0.2 ml iodine solution (0.2 g I_2+2.0 g KI in 100 ml of distilled water) was added to develop a dark blue colour. The coloured solution was made up to 10 ml with distilled water and allowed to stand for 20 min to fully develop colour. The solution was vortexed and its absorbance was read on a spectrophotometer (Helios Gamma UVG 121108, Thermo Electron Corporation, England) at 620 nm**.** Absorbance of standard corn amylose with known amylose concentration was used to estimate the amylose content in the sample as follows

$$\% \text{ Amylose} = \frac{\% \text{ Amylose of standard} \times \text{Absorbance of sample}}{\text{Absorbance of standard}}$$

3.4.2.11 Determination of water binding capacity

Water binding capacity of yam flour/starch was determined according to the method of Medcalf and Gilles (1965).

An aqueous suspension of yam flour/starch was made by dissolving 2.0 grams (dry weight) of flour in 40 ml of distilled water. The suspension was agitated for 1 hour on a Griffin flask shaker and centrifuged at 2200 rpm for 10 minutes. The free water (supernatant) was decanted from the wet flour, drained for 10 minutes and the wet flour/starch was then weighed. The water binding capacity was calculated by difference as follows

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

3.4.2.12 Determination of solubility and swelling power

Solubility and Swelling power determinations were carried out based on a modification of the method of Leach *et al.* (1959).

One gram of yam flour/starch was dissolved with distilled water to a total volume of 40 ml using a weighed 50 ml graduated centrifuge tube. The suspension was stirred just sufficiently and uniformly avoiding excessive speed since it might cause fragmentation of the starch granules. The slurry in the tube was heated at 85^{o}C in a thermostatically regulated temperature water bath for 30 minutes with constant gentle stirring. The tube was then removed, wiped dry on the outside and cooled to room temperature. It was then centrifuged at 2200 rpm for 15 minutes. The supernatant was decanted into a preweighed moisture can. The solubility was determined by evaporating the supernatant in a thermostatically controlled drying oven at 105^{o}C and weighing the residue. The sedimented paste was weighed and swelling power was calculated as the weight of sedimented paste per gram of flour used.

$$\text{Swelling power} = \frac{\text{Weight of sediment}}{\text{Sample weight - Weight of soluble}}$$

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

3.4.2.13 Determination of pasting properties

A smooth slurry was made from the prepared flour/starch (40g) in 420 ml distilled water (8.8% slurry) for viscoelastic properties using Brabender Viscoamylograph (Viskograph-E, Brabender Instrument Inc. Duisburg, Germany) equipped with a 1000 cmg sensitivity cartridge. The smooth paste was heated at a rate of 1.5°C min^{-1} to 95°C and maintained at 95°C for 15 min. Viscosity profile indices were recorded for pasting temperature, peak temperature, peak viscosity, viscosity at 50°C, viscosity after 15 min hold at 50°C (50°C Hold or Cold Paste Viscosity)viscosity at 95°C, viscosity after 15 min hold at 95°C (95°C Hold or Hot Paste Viscosity), breakdown and setback as described by Shuey and Tipples (1980) and Walker *et al.* (1988).

3.4.2.14 Determination of minerals

Mineral analysis was done using the method of Benton and Vernon (1990).

The flour sample was weighed into a porcelain crucible. An empty crucible was included as a blank. The crucibles were placed in a muffle furnace and heated to 600^{o}C over a period of 2 hours and cooled in a desiccator. The ashed samples were transferred into 50 ml centrifuge tube and the crucibles were rinsed with 5 ml distilled water and 5 ml (3 times) of *aqua regia* (1200 ml of distilled water was poured into a 2 L volumetric flask. 400 ml concentrated hydrochloric acid and 133 ml of 70% nitric acid were carefully added and the volume was made to 2 L.) to a total volume of 20 ml. The tubes were stoppered and vortexed to mix the contents thoroughly and centrifuged at 3000 rpm for 10 min. The supernatant was decanted into micro-vials.

The flame atomic absorption spectrophotometer was used in the determination of calcium (Ca), phosphorus (P), iron (Fe), sodium (Na) and potassium (K) contents.

3.4.2.15 Determination of starch granule size and shape

The size and shape of starch granules were obtained from extracted yam starch samples. A small amount of starch powder was scooped with a spatula onto a clean micro-slide (75 x 25 mm). A drop of distilled water was added and distributed thinly on the slide and covered with a glass cover slip. Starch granules were observed under a light microscope (LEICA CME, Leica Microsystems) and sizes were determined by measuring the granule diameter with an ocular micrometer fixed to the lens of the microscope. The actual sizes of the granules were calculated by multiplying their mean diameters by a factor of 2.47 μm (i. e. the factor for objective magnification that was used) which was calculated earlier using the parallax obtained between a stage micrometer (Graticules Ltd, Tonbridge, England) and the calibrations of the eye piece. A minimum of 10 granules were selected randomly and measured for each variety. Observation was done under x 400 magnification. A digital camera was used in obtaining images of the starch granules under the microscope.

3.5 Statistical analysis

Data obtained was subjected to one way Analysis of Variance (ANOVA) and significant differences were reported at 95% confidence level using Tukey's test.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Organoleptic Properties of *Dioscorea rotundata*

4.1.1 Market Survey

Thirty eight percent (38%) of the respondents were males and 62% were females. Twenty four (24), 19 and 7 of the respondents had cultivated yam between 1 to 10 years, 11 to 20 years and over 20 years respectively.

Different types of yams are cultivated in the area which include *Pona*, *Labreko, Asobayere*, *Afasie (water yam), Nkaseibayere*, *Leele*, *Dente*, *Efun, Nkrukutoa, Krukrupa, Akaba, Mantches*, *Dokoba, Ntipoa, Apoka, Tiinto, Bayere Serwaa, Nkokooko* and *Muchumudu.* All the respondents were into the cultivation of *Pona* because of its high preference by consumers, 82% cultivated *Labreko*, 86% cultivated *Asobayere* and 34% cultivated *Muchumudu*.

Factors that influenced the choice of yam cultivation were consumer preference (100%), high profit (100%), early maturity (10%) and high yield (90%). All respondents (100%) were of the view that taste was the predominant factor that influences consumer preference.

In order of preference by respondents based on taste (Fig. 4.1), *Labreko* was the most preferred (64%), followed by *Pona* (30%), *Asobayere* (6%) and *Muchumudu* (0%). Preference based on mealiness also had *Labreko* recording the highest value of 40%, whiles *Asobayere* had the lowest value of 2%. All the respondents ranked *Muchumudu* as the softest among the four yam varieties. The preference for *Labreko* in this area however contradicted with literature. Otegbayo *et al.* (2001) reported that *Pona* yams are rated superior to other varieties of *Dioscorea rotundata* in terms of eating quality attributes (taste, mealiness and texture). However, this was not the case in the yam farming community of Asante Mampong. *Muchumudu* was ranked the least preferred by all the respondents because they claimed that it has very high water content when harvested, giving it a somewhat bland taste and only becomes tasty when stored for about 4 to 6 months. *Asobayere* was the least preferred in terms of mealiness because respondents claimed it has low moisture content and thus possesses a hard texture even after cooking.

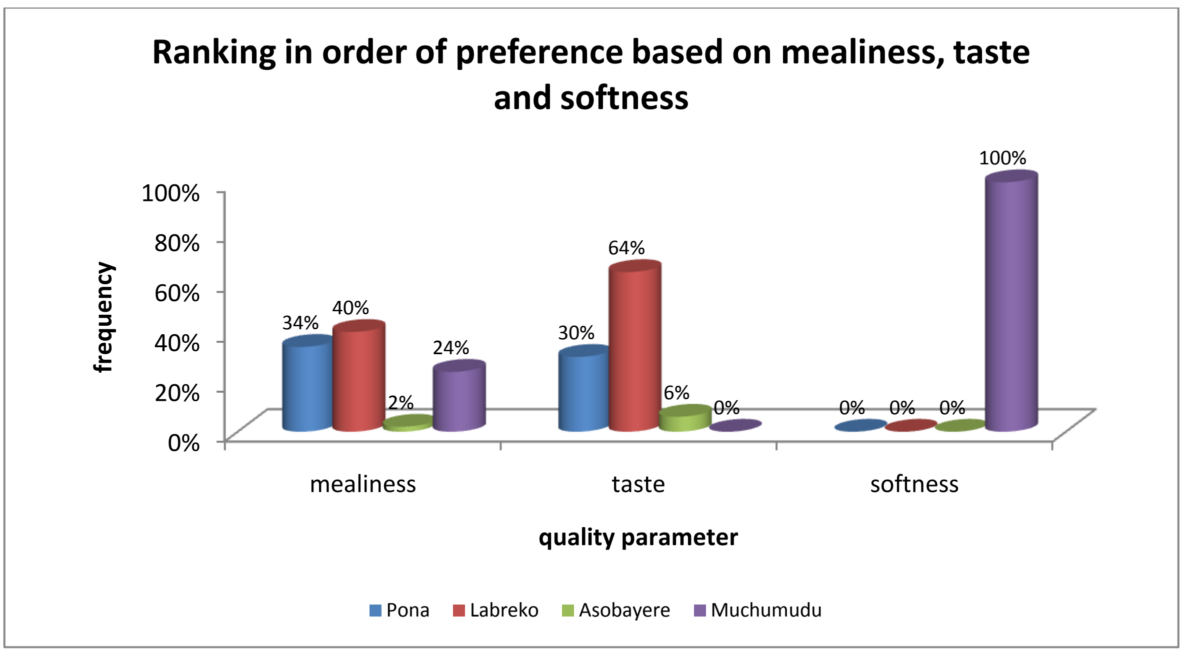

Figure 4.1 Ranking in order of preference (mealiness, taste and softness) of *Dioscorea rotundata* varieties by respondents.

Twenty four of the respondents store yams after harvest. Of these respondents, 25% store yams up to a period of 3 months, whiles 75% store between 3 to 6 months. None of them store yams above six months. Eighty eight percent (88%) of the respondents said yams undergo rotting and quality deterioration during storage, especially when yams are bruised before storage. Other problems encountered during storage are rodent or pest attack (68%) and weight loss (18%).

4.1.2 Sensory properties of boiled yam

Table 4.1 shows the results obtained from the descriptive sensory analysis conducted on the mealiness, taste, wetness and softness of boiled yam prepared from the four varieties of *Dioscorea rotundata.*

Table 4.1 Sensory quality attributes of boiled yam from four yam varieties.

Variety	Mealiness	Taste	Softness	Wetness
Asobayere	2.8	4.4	1.6	2.0
Labreko	5.6	5.2	4.6	4.2
Pona	5.4	4.8	5.0	4.2
Muchumudu	5.6	3.8	5.6	5.0

The higher the score, the higher the attribute.

For mealiness, *Muchumudu* and *Labreko* were not different with a score of 5.6. This was closely followed by *Pona* (5.4), with *Asobayere* being the least mealy (2.4). *Labreko* scored the highest in terms of taste amongst the yam varieties with a score of 5.2, followed by *Pona* (4.8), *Asobayere* (4.4) and *Muchumudu* (3.8). *Muchumudu* had the highest score of 5.0 for wetness and *Asobayere* the lowest (2.0). *Labreko* and *Pona* had the same score of 4.2 for wetness. A similar trend was observed in softness of the boiled yam varieties. *Muchumudu* and *Asobayere* had the highest (5.6) and lowest (1.6) scores respectively. *Labreko* and *Pona* scored 4.6 and 5.0 respectively for softness of boiled yam. Results obtained for wetness and softness may be as a result of the high and low moisture contents of *Muchumudu* and *Asobayere* respectively. The high means of softness and wetness for *Muchumudu* confirms the assertion of the respondents during the market survey that it has high moisture content. Preferred boiled yam content should be very mealy and tasty with average moisture in terms of softness and hardness. Thus, *Labreko* can be said to be the most preferred variety which is reflective of the market survey conducted earlier in the study.

4.2 Physicochemical properties of *Dioscorea rotundata* flours and starches

Physicochemical properties are characteristics of chemical systems determined by application of physical properties. Physical properties are characteristics of substances that do not involve a chemical change (IFIS, 2005).

4.2.1 Proximate composition of Dioscorea rotundata flours and starches

The proximate compositions of *Dioscorea rotundata* flours and starches from the four varieties are presented in Tables 4.2 and 4.3 respectively. Fresh yam tubers of *Asobayere*, *Labreko, Pona* and *Muchumudu* had moisture contents 58.91, 61.12, 64.52 and 74.43% respectively. There were significant differences ($p<0.05$) in the moisture contents of the yam varieties. The average mean of 64.75% in this study was consistent with a value of 64.40% reported for *D. rotundata* by Baah (2009). The moisture content of *Muchumudu* was the highest, indicating that samples are likely to be prone to microbial attack, hence a higher spoilage rate during storage (Baah, 2009). The higher the moisture content, the higher the rate of spoilage. *Asobayere* had the least moisture content of 58.91% which is reflective of better keeping quality during storage.

Asobayere had the highest moisture content of 7.82% for the starches. *Labreko, Pona* and *Muchumudu* had 7.41, 7.22 and 7.50% respectively. Moisture contents of yam starches varied significantly at $p<0.05$. Good quality starch should have moisture content in the range of 10-13.5% to ensure better shelf life (Ellis *et al.*, 2003). However, the moisture levels were below this range. This may be as a result of a longer drying period of the starches after extraction. Hence, drying periods can be monitored and regulated to ensure that moisture content of these starches fall within the acceptable range.

Dry matter is an important parameter of food quality in root and tuber crops which has an influence on the textural perception of foods (Izutsu and Wani, 1985). A significant difference ($p<0.05$) was also observed in dry matter content of the fresh yam tubers as shown in Table 4.2. Dry matter contents of fresh yam tubers were 41.09, 38.88, 35.47 and 25.57% for *Asobayere*, *Labreko, Pona* and *Muchumudu* respectively. These results were similar to a dry matter content of 39.33% for *Pona* as was reported by Otegbayo *et al.* (2001). Differences in dry matter contents may be as a result of different locations the yam varieties were cultivated. *Pona* had the highest dry matter content of 92.78% for the yam starches, whiles *Asobayere* had the lowest value of 90.18%. *Labreko* (92.59%) and *Muchumudu* (92.50%) were not significantly different at $p<0.05$ in their starch dry matter contents. Otegbayo *et al.* (2001) observed that high dry matter content, starch and amylose ratios may be responsible for good cooking quality of boiled yam. The high dry matter and amylose contents of *Pona* and *Labreko* may be a reason for their preference in both market survey and sensory analysis test conducted.

Table 4.2 Proximate composition of *Dioscorea rotundata* flour

Parameters (%)	*Asobayere*	*Labreko*	*Pona*	*Muchumudu*
Moisture (fresh tuber)	58.91±0.07^{a}	61.12±0.03^{b}	64.52±0.06^{c}	74.43±0.06^{d}
Dry matter (fresh tuber)	41.09±0.07^{a}	38.88±0.03^{b}	35.48±0.06^{c}	25.57±0.06^{d}
Ash	1.85±0.03^{a}	2.41±0.05^{b}	2.23±0.05^{c}	3.46±0.04^{d}
Crude protein	3.94±0.02^{a}	5.25±0.02^{b}	4.82±0.02^{c}	5.01±0.01^{d}
Crude fat	0.52±0.03^{a,b}	0.75±0.02^{d}	0.55±0.04^{b,c}	0.53±0.01^{a,c}
Crude fibre	0.54±0.03^{a}	0.46±0.01^{b}	0.75±0.04^{c}	0.71±0.02^{c}
Carbohydrate	34.24±0.22^{a}	29.00±0.07^{b}	26.12±0.04^{c}	14.78±0.09^{d}

Means followed by the same superscripts in a row denote values that are not significantly different at $p<0.05$. Values are means ± standard deviation.

Ash content is a measure of the mineral status of a sample. Ash level may also be regarded as a measure of the quality or grade of the flour and often a useful criterion in identifying the authenticity of food (Aurand *et al.*, 1987). A significant difference ($p<0.05$) was observed in the ash contents of the four varieties of yam flours and starches. *Muchumudu* and *Pona* had the highest (3.41%) and lowest (2.23%) ash contents respectively. With the exception of *Muchumudu* (3.41%), ash values were consistent with values of 2.29-2.76% reported by Otegbayo *et al.* (2001). The ash content of yam starches ranged from 0.24 (*Pona*) to 0.86% (*Asobayere*). Varietal differences may account for the variation in ash contents. Variation may also arise from the type of soil from which it was harvested, the moisture content and the maturity of the crop (Osagie, 1992). The results also indicate that *Muchumudu* could be an important source of mineral elements (Table 4.2).

Table 4.3 Proximate composition of *Dioscorea rotundata* starches

Parameters (%)	*Asobayere*	*Labreko*	*Pona*	*Muchumudu*
Moisture	7.82±0.05[a]	7.41±0.06[b]	7.22±0.04[c]	7.50±0.03[b]
Dry matter	92.18±0.05[a]	92.59±0.06[b]	92.78±0.04[c]	92.50±0.03[b]
Ash	0.55±0.01[a]	0.86±0.04[b]	0.24±0.02[c]	0.47±0.02[d]
Crude protein	1.31±0.01 [a]	1.32±0.01 [a]	1.32±0.01 [a]	1.31±0.01 [a]
Crude fat	0.04±0.01 [a]	0.05±0.00 [a]	0.05±0.01 [a]	0.05±0.01 [a]
Crude fibre	0.15±0.01[a,b]	0.10±0.01[b]	0.13±0.01[c]	0.14±0.01[ac]
Carbohydrate	90.13±0.08[a]	90.26±0.08[b]	91.06±0.05[c]	90.53±0.04[d]

Means followed by the same superscripts in a row denote values that are not significantly different at $p<0.05$. Values are means ± standard deviation.

Crude protein content of the flours ranged from 3.94 (*Asobayere*) to 5.25% (*Labreko*) with a mean value of 4.76%. The mean value was slightly higher than 4.30% reported by Otegbayo *et al.* (2001). There were also significant varietal differences ($p<0.05$) in protein content. However, there were no significant differences in the protein contents of yam starches (Table 4.3).

Labreko had the highest crude fat content (0.75%) and was significantly different ($p<0.05$) from *Asobayere* (0.52%), *Pona* (0.55%) and *Muchumudu* (0.53%). Otegbayo *et al.* (2001) also reported 0.32 and 0.39% fat contents for *D. rotundata* flour which were lower than the values obtained in this study. Varietal differences may account for the differences in fat contents. Fat is known to impact desirable mouth feel and texture of food products (DANISCO, 2011). The slightly high fat content of *Labreko* may be a contributing factor to the preference of *Labreko* to the other varieties as observed in the market survey and sensory analysis test (Table 4.1 and Figure 4.1). Crude fat content in yam starches were relatively lower with no significant difference at $p<0.05$ (Table 4.3). Fibre has an important function in providing roughage or bulk that aids in digestion, softens stools and lowers plasma cholesterol level in the body (Norman and Joseph, 1995). The crude fibre content of the yam flours were 0.54, 0.46, 0.75 and 0.71% for *Asobayere*, *Labreko*, *Pona* and *Muchumudu* respectively. The result indicates that *Pona* and *Muchumudu* varieties were not significantly different from each other and had the highest fibre contents which were quite similar to the value of 0.70% for *D. rotundata as* reported by Alinnor and Akaledzi (2010). For the yam starches, *Asobayere* had the highest (0.15%) whiles *Labreko* had the lowest (0.10%). Significant differences existed between *Labreko* and *Pona* at $p<0.05$.

Carbohydrate plays a vital role in the supply of energy to cells such as brain, muscles and blood (Alinnor and Akalezi, 2010). Carbohydrates contribute to fat metabolism and spare proteins as an energy source and act as mild natural laxative for human beings and generally add to the bulk of the diet (Gordon, 2000; Gaman and Sherrington, 1996). The percentage carbohydrates also varied significantly at $p<0.05$ ranging from 14.78 to 34.24% for the flours. *Asobayere* had the highest carbohydrate content of 34.24% followed by *Labreko* (29.0%), *Pona* (26.12%) and *Muchumudu* (14.78%). Significant differences ($p<0.05$) also existed in the carbohydrates contents of yam starches ranging from 90.13% (*Asobayere*) to 91.06% (*Pona*). This supports literature on yam being cultivated for its carbohydrate content. The results indicate that *D. rotundata* varieties could be good sources of carbohydrates to its consumers. It may also be useful in nutritional applications and especially in diet formulations that require improvements in ash or carbohydrate contents.

4.2.2 Mineral analysis of Dioscorea rotundata flours

Table 4.4 shows the mineral contents of the yam flours. Calcium is a very essential element necessary in building and maintaining bones and teeth. It also plays a role in blood clotting, nerve conduction and muscle contraction (FAO/WHO, 2002). Calcium content varied significantly ranging from 63.00 to 91.60 mg/100g. *Muchumudu* had the highest calcium content of 91.60 mg/100 g. The World Health Organization (WHO) recommended daily allowance (RDA) for adolescents and adults is about 800-1200 mg (WHO, 2009). The estimated per capita consumption/year of yam is 42.3 kg (MOFA, 2006). In order to meet the RDA, consumers may have to eat about 1.0 to 1.5 kg of yam which is quite higher than the normal per capita consumption daily.

Phosphorus is also important in the production and maintenance of bones and teeth. It also strengthens cell wall and used to help regulate the acid/base balance in the body (FAO, 1987). *Muchumudu* also had the highest phosphorus content of 114.50 mg/100g followed by *Asobayere* (72.20 mg/100g), *Pona* (66.75 mg/100g) and *Labreko* (47.20 mg/100g). Significant differences ($p<0.05$) existed among varieties. A phosphorus content of 110.27 mg/100g for *Pona* and 104.79 mg/100g for other *D. rotundata* varieties were reported by Otegbayo *et al.* (2001). These values were slightly lower than value obtained for *Muchumudu*, but higher than values obtained for *Asobayere, Labreko* and *Pona.* The type of soil on which yams were grown may account for the variations in levels of phosphorus. Kim *et al.* (1996) reported that phosphorus is associated with amylopectin to which it is bound in the form of phosphate esters. From Tables 4.5 and 4.6, it was observed that *Muchumudu* and *Asobayere* had high amylopectin levels. This may explain why *Muchumudu* and *Asobayere* had high phosphorus contents. About 800 mg of phosphorus is recommended daily (Alinnor and Akalezi, 2010). Individuals may have to consume about 1330 g of yam to meet the RDA.

The production of haemoglobin which carries oxygen in blood and muscles require the use of iron. Iron acts as a transport medium for electrons within cells, and as an integrated part of important enzyme systems in various tissues (FAO/WHO, 2002). Results obtained for iron content also showed significant difference ($p<0.05$). *Pona* had the highest content of 4.45 mg/100g and *Labreko* had the lowest content of 2.50 mg/100g. Recommended daily allowance for adults and children is about 10 mg (WHO, 2002) which is higher than amounts found in the white yams. Consumption of about 300 g of white yam may be required to meet the RDA for iron. A value of 8.05 mg/100g recorded by Baah (2009) in *Dioscorea rotundata* was higher than values obtained in this study. Differences in both studies may be attributed to variation in soil types.

Table 4.4 Mineral composition of *Dioscorea rotundata* flours

Parameters (mg/100g)	*Asobayere*	*Labreko*	*Pona*	*Muchumudu*
Calcium	83.50 ± 0.14^{a}	63.00 ± 0.00^{b}	73.90 ± 0.00^{c}	91.60 ± 0.14^{d}
Phosphorus	72.20 ± 0.00^{a}	47.20 ± 0.14^{b}	66.75 ± 0.21^{c}	114.50 ± 0.00^{d}
Iron	3.30 ± 0.14^{a}	2.50 ± 0.14^{b}	4.45 ± 0.07^{c}	2.80 ± 0.00^{b}
Sodium	$0.16 \pm 0.01^{a,b}$	0.24 ± 0.01^{d}	$0.16 \pm 0.00^{b,c}$	$0.18 \pm 0.01^{a,c}$
Potassium	1.21 ± 0.01^{a}	1.88 ± 0.01^{b}	1.21 ± 0.00^{a}	1.30 ± 0.00^{c}

Means followed by the same superscripts in a row denote values that are not significantly different at $p<0.05$. Values are means ± standard deviation.

Sodium and potassium play similar roles in regulating blood volume and pressure. They also aid in nerve transmission and muscle contraction (FAO, 1987). The recommended daily intake of sodium is 500 mg for adults and 400 mg for children (WHO, 1973). The WHO recommended daily intake of potassium is 2000 mg for adult and 1600 mg for children. *Asobayere*, *Labreko*, *Pona* and *Muchumudu* had 0.16, 0.24, 0.16 and 0.18 mg/100g respectively for sodium content. About 16900 g of yam is required to achieve the RDA. *Labreko* varied significantly from all the other varieties. *Asobayere*, *Labreko, Pona* and *Muchumudu* obtained 1.21, 1.88, 1.21, 1.30 mg/100g respectively for potassium content. Consumers may have to eat 142900 g of yam to meet the RDA for potassium.

The high calcium and phosphorus contents of *Muchumudu* may be a reason for its high ash content of 3.46% (Table 4.2). *Muchumudu* may thus be a good source of calcium and phosphorus for its consumers.

All the minerals analysed in this study were below the RDA values. Therefore yams can be combined with other foods during consumption in order to meet the RDA values for these minerals.

4.2.3 Chemical properties of Dioscorea rotundata flours and starches

The chemical characteristics of *Dioscorea rotundata* flours and starches are presented in Tables 4.5 and 4.6 respectively. pH is an essential measurement of eating quality since it contributes to taste (Oduro *et al.,* 2001). The pH of the extracted yam starches varied significantly ($p<0.05$) from 5.57 (*Asobayere*) to 6.25 (*Labreko*), whiles that of the flours also varied significantly from 7.36 (*Muchumudu*) to 7.76 (*Labreko*). pH of extracted yam starches were slightly above acceptable range of 4.7-5.3 (Onwueme, 1982). The values for titratable acidity were low (0.18-0.23%). The lower pH values of *Pona* and *Muchumudu* may explain why they had the same and highest values of 0.23% for titratable acidity. *Asobayere* showed a slightly higher titratable acidity than *Labreko.* Titratable acidity had a direct correlation with pH. The lower the pH, the higher the titratable acidity. Low values of acidity are an indication of little or no fermentation.

Table 4.5 Chemical characteristics of *Dioscorea rotundata* flours

Parameters	*Asobayere*	*Labreko*	*Pona*	*Muchumudu*
pH	7.67±0.01[a]	7.76±0.01[b]	7.54±0.01[c]	7.36±0.01[d]
TTA	0.19±0.02[a]	0.18±0.00[a]	0.23±0.02[b]	0.23±0.02[b]
Amylose (%)	15.34±0.51[a]	24.54±0.51[b]	23.46±0.50[c]	20.84±0.51[d]
Amylopectin (%)	84.66±0.51[a]	65.47±0.51[b]	76.54±0.50[c]	79.76±0.51[d]

TTA – Total titratable acidity. Means followed by the same superscripts in a row denote values that are not significantly different at $p<0.05$. Values are means ± standard deviation.

Table 4.6 Chemical characteristics of *Dioscorea rotundata* starches

Parameters	*Asobayere*	*Labreko*	*Pona*	*Muchumudu*
Starch yield (%)	20.89±0.10[a]	14.23±0.04[b]	15.63±0.06[c]	12.61±0.12[d]
pH	5.57±0.01[a]	6.25±0.01[b]	5.74±0.01[c]	6.11±0.01[d]
Amylose (%)	27.48±0.47[a]	31.55±0.47[b]	30.36±0.47[b]	28.57±0.47[a]
Amylopectin (%)	72.52±0.47[a]	68.45±0.47[b]	69.64±0.47[b]	71.43±0.47[a]

Means followed by the same superscripts in a row denote values that are not significantly different at $p<0.05$. Values are means ± standard deviation.

Starch extracted from the yams showed significant differences in yield at $p<0.05$. *Asobayere* had the highest yield of 20.89% and *Muchumudu* the lowest (12.61%). It was observed that the starch yields had an inverse relationship with moisture content (Tables 4.2 and 4.6). The higher the starch yield, the lower the moisture content. A study carried out by Chien-Chun *et al*. (2006) revealed that starch content of yam tubers increased as growth progressed. Starch yield is therefore likely to increase over a period of time when water is lost to the environment by yam tubers, thereby impacting on its end use.

Amylose-amylopectin ratio is one of the parameters reported to contribute to good textural attributes of root and tuber crops (Otegbayo *et al.*, 2001). Significant differences ($p<0.05$) existed between amylose contents of both starches and flours. Flours processed from *Asobayere, Labreko, Pona* and *Muchumudu* had 15.34, 24.54, 23.46 and 20.84% amylose contents respectively. Amylose contents of the extracted starches were 27.48, 31.55, 30.36 and 28.57% for *Asobayere, Labreko, Pona* and *Muchumudu* respectively. Amylopectin content ranged from 65.46 to 84.66% and 68.45 to 72.52% for flours and starches respectively. The results indicate that *Labreko* had the highest amylose content and *Asobayere* had the lowest. The higher values observed for amylose contents in starches may be attributed to the level of purity of the starch due to the absence or lower levels of other components such as fat, fibre and proteins that might be present in the flours. Otegbayo *et al.* (2001) observed that boiled yam with superior eating qualities is characterized by high amylose, dry matter and starch contents. The high amount of amylose in *Labreko* may be a reason for the high mealiness and thus its preference in the market survey (Fig. 4.1) and sensory evaluation conducted (Table 4.1). High amylose flours and starches such as *Labreko* and *Pona* may be exploited to improve the organoleptic properties of certain starch-based products such as breakfast cereals and parboiled products. This is because retrogradation reduces stickiness and causes hardening. Retrogradation is faster with amylose due to the short chain lengths (Baah, 2009).

4.3 Functional properties of *Dioscorea rotundata* flours and starches

Functional properties are characteristics of a substance that affect its behaviour and that of products to which it is added (IFIS, 2005).

4.3.1 Swelling power, solubility and water binding capacities of Dioscorea rotundata flours and starches

For the yam flours, *Pona* had the highest value (12.26%) of swelling power, followed by *Labreko* (11.12%), *Muchumudu* (10.92%) and *Asobayere* (10.16%). There was significant difference ($p<0.05$) in swelling power. A value of 11.0% swelling power was reported for *D. rotundata* by Baah *et al*. (2009b). The swelling power of the yam starches showed significant difference between *Pona* and *Labreko* at $p<0.05$. *Pona* had the highest value of 12.48% and *Asobayere* had the lowest value of 10.57% swelling power. The results show that *Pona* starch may have the lowest associative forces and *Asobayere* may have the highest associative forces. This may explain its hard and waxy texture as revealed from market survey and sensory evaluation.

Solubility indices of yam flours varied significantly ($p<0.05$). The results in Table 4.5 show that flours from *Asobayere, Labreko, Pona* and *Muchumudu* had 9.40, 9.21, 8.89 and 9.39% respectively for solubility indices. There was no significant difference between *Asobayere* and *Muchumudu.* For yam starches, *Asobayere*, *Labreko, Pona* and *Muchumudu* had 8.90, 8.52, 8.73 and 9.32% respectively for solubility indices. There were no significant differences at $p<0.05$ among the different varieties. Riley *et al.* (2006) reported that solubility increased with decreasing amylose content in *Dioscorea alata* cultivars. This observation is similar with results obtained for *Asobayere* and *Muchumudu*, however, not similar to the findings of Soni *et al*, (1993) who associated high solubility with high amylose content. The difference could be attributed to varietal differences, ecological effect, tuber maturity, and differences in granule sizes and their arrangement within their cells (Baah, 2009).

Table 4.7 Some functional properties of *Dioscorea rotundata* flours an starches

Parameters (%)	Flour				Starch			
	Aso	*Lab*	*Pona*	*Much*	*Aso*	*Lab*	*Pona*	*Much*
Swelling Power	10.16 $\pm0.01^{a}$	11.12 $\pm0.04^{b}$	12.26 $\pm0.02^{c}$	10.92 $\pm0.02^{d}$	10.57 $\pm0.04^{a}$	10.74 $\pm0.01^{b}$	12.48 $\pm0.02^{c}$	12.14 $\pm0.07^{a}$
Solubility	9.40 $\pm0.03^{a}$	9.21 $\pm0.08^{b}$	8.89 $\pm0.03^{c}$	9.39 $\pm0.01^{a}$	8.90 $\pm0.09^{a,b,c}$	8.52 $\pm0.02^{a,d}$	8.73 $\pm0.01^{c,d}$	9.32 $\pm0.05^{b}$
WBC	215.20 $\pm0.14^{a}$	218.30 $\pm0.19^{b}$	216.87 $\pm0.07^{c}$	232.45 $\pm0.23^{d}$	176.47 $\pm0.52^{a}$	178.47 $\pm0.47^{b}$	175.25 $\pm0.26^{a}$	182.69 $\pm0.25^{c}$

Aso – Asobayere; Lab- Labreko; Much- Muchumudu; WBC – Water binding capacity. Means followed by the same superscripts in a row denote values that are not significantly different at $p<0.05$. Values are means ± standard deviation.

The water binding capacities of the yam flours varied significantly ($p<0.05$) with *Asobayere*, *Labreko*, *Pona*, and *Muchumudu* recording 215.20, 218.30, 216.87 and 232.45% respectively. High water binding capacities are desirable as they increase the unit yield of products. It stabilizes starches against effects such as syneresis, which sometimes occurs during retorting and freezing (Ellis *et al.,* 2003; Oduro *et al.,* 2001; Baker *et al.,* 1994). Water binding capacity is also an important functional characteristic in the development of ready-to-eat foods since high water absorption capacity may assure product cohesiveness (Kulkarni *et al*., 1996). The results indicate that

Muchumudu had the highest water binding capacity and thus, may be better for use in products that require high unit yield. Significant differences existed between *Labreko* (178.47%) and *Muchumudu* (182.69%) starches. Values of *Asobayere* (176.47%) and *Pona* (175.25%) showed no significant difference at $p<0.05$.

4.3.2 Pasting properties of Dioscorea rotundata flours and starches

The pasting characteristics of flours and starches processed from four yam varieties are presented in Tables 4.9 and 4.10. The pasting temperatures of yam flours and starches in this study varied significantly at $p<0.05$. The pasting temperatures of the 4 different flours ranged from 73.4 to 79.3°C with *Labreko* having the lowest and *Muchumudu* the highest. For the starches, pasting temperatures ranged from 75.1 to 77.3°C with *Asobayere* having the lowest and *Muchumudu* the highest. Flour processed from *Labreko* had the lowest pasting time (17.15 min) and pasting temperature (73.4°C), and therefore would be most appropriate for the production of foods that require shorter processing time. There were no significant differences at $p<0.05$ in the peak temperatures of yam flours between *Asobayere* (94.7°C) and *Labreko* (94.7°C), and *Pona* (94.6°C) and *Muchumudu* (94.6°C).

The peak temperatures of yam starches showed significant difference at $p<0.05$. *Asobayere*, *Labreko*, *Pona* and *Muchumudu* had 81.7, 90.1, 84.3 and 94.8°C respectively. Generally, the pasting temperatures and peak temperatures of the yam flours were higher than observed for the yam starches. This may be attributed to other components such as fibre, fats and sugars present in the flour, hampering the movement of water into the starch granules, hence delaying gelatinization (Oduro *et al.,* 2001).

Table 4.8 Pasting properties of *Dioscorea rotundata* flours

Parameters	Varieties			
	Asobayere	*Labreko*	*Pona*	*Muchumudu*
Pasting Temp (°C)	77.0[a]	73.4[b]	76.2[c]	79.2[d]
Pasting Time (min)	18.50[a]	17.15[b]	18.10[c]	20.05[d]
Peak Temp (°C)	94.7[a]	94.7[a]	94.6[b]	94.6[b]
Peak Viscosity (BU)	575 [a]	499 [b]	437 [c]	290 [d]
Viscosity at 95°C (BU)	557 [a]	444 [b]	385 [c]	171 [d]
HPV (BU)	460 [a]	480 [b]	431 [c]	288 [d]
Viscosity at 50°C (BU)	578 [a]	596 [b]	481 [c]	338 [d]
CPV (BU)	578 [a]	569 [b]	474 [c]	313 [d]
Paste stability at 95°C	-97 [a]	36 [b]	46 [c]	117 [d]
Paste stability at 50°C	0 [a]	-27 [b]	-7 [c]	-25 [d]
Breakdown (BU)	115 [a]	18 [b]	6 [c]	2 [d]
Setback (BU)	118 [a]	113 [b]	50 [c]	49 [d]

HPV- Hot Paste Viscosity CPV- Cold Paste Viscosity BU- Brabender Unit

Means followed by the same superscripts in a row denote values that are not significantly different at $p<0.05$

Peak viscosity is a measure of the ability of starch to form a paste; it indicates the highest value of viscosity during the heating cycle (Jimoh *et al*., 2009). It is also the ability of starch to swell freely before their physical breakdown (Sanni *et al*., 2004). It has been reported to be closely associated with the degree of starch damage. High starch damage results in high peak viscosity (Sanni *et al*., 2001). Both flours and starches varied significantly at $p<0.05$. Peak viscosity of flours ranged from 290 to 575 BU. *Asobayere* had the highest peak viscosity of 726 BU for the starches; whiles *Pona* had the lowest (614 BU). High peak viscosity is suitable for products requiring high gel strength, thick paste and elasticity such as pounded yam. Thus, *Asobayere* may be most suited for such products.

Table 4.9 Pasting properties of *Dioscorea rotundata* starches

Parameters	Varieties			
	Asobayere	*Labreko*	*Pona*	*Muchumudu*
Pasting Temp (°C)	75.1[a]	75.5[b]	75.7[b]	77.3[c]
Pasting Time (min)	17.40[a]	17.55[b]	18.05[b]	19.10[c]
Peak Temp (°C)	81.7[a]	90.1 [b]	84.3 [c]	94.8[d]
Peak Viscosity (BU)	726 [a]	685 [b]	614 [c]	639 [d]
Viscosity at 95°C (BU)	586 [a]	547 [b]	395 [c]	605 [d]
HPV (BU)	340 [a]	542 [b]	320 [c]	614 [d]
Viscosity at 50°C (BU)	570 [a]	876 [b]	401 [c]	791 [d]
CPV (BU)	596 [a]	758 [b]	385 [c]	817 [d]
Paste stability at 95°C	-246 [a]	-5 [b]	-75 [c]	9 [d]
Paste stability at 50°C	26[a]	-118 [b]	-16 [c]	26[a]
Breakdown (BU)	385 [a]	142 [b]	293 [c]	25 [d]
Setback (BU)	229 [a]	337 [b]	79 [c]	176 [d]

Means followed by the same superscripts in a row denote values that are not significantly different at $p<0.05$

High peak viscosity is an indication of high starch content (Osungbaro, 1990; Adebowale *et al*., 2005; Shimelis *et al.*, 2006). The high starch yield of *Asobayere* (Table 4.6) may explain its high peak viscosity.

Final viscosity is the most commonly used parameter to define the quality of a particular starch-based sample as it indicates the ability of the material to form viscous paste or gel after cooking and cooling, as well as the resistance of the paste to shear force during stirring (Adeyemi and Idowu, 1990; Shimelis *et al*., 2006).

According to Shimelis *et al*. (2006), less stability of starch paste is commonly accompanied with high value of breakdown. There were significant differences at $p<0.05$ in all the viscosities measured. With regards to viscosity at 95°C, *Muchumudu* flour had the lowest viscosity (171 BU) and *Asobayere* flour the highest (557 BU). For yam starch, *Pona* had the lowest viscosity (395 BU) and *Muchumudu* had the highest (605 BU). Paste stability at 95°C for the yam flours ranged from -97 BU for *Asobayere* and 117 BU for *Muchumudu.* Paste stability at 95°C for the yam starches also ranged from -246 BU for *Asobayere* and 9 BU for *Muchumudu.* Paste stability reflects the strength of the flour and starch pastes (Oduro *et al.,* 2001). Oduro *et al.* (2001) reported that flour with low paste stability has very weak cross-linking within the granules. Holding strength measures the ability of starch to remain undisrupted when yam paste is subjected to a long duration of high, constant temperature during the process of steaming (Jimoh *et al.*, 2009). After a 15 min hold at 95°C, viscosities (Hot Paste Viscosity) for yam flours ranged from 288 BU (*Muchumudu*) to 480 BU (*Labreko*), and for yam starches, 320 BU (*Pona*) to 614 BU (*Muchumudu*). There was a general increase in viscosity when paste was cooled to 50°C.

Final viscosity formed at the end of cooling at 50°C is called cold paste viscosity (CPV). Cold paste viscosity is an important property if extruded starch is to be used as an ingredient in foods that require cold thickening capacity like instant creams, sauces or soups (Alves *et al*. 1999). For yam flours, CPV's ranged from 313 BU (*Muchumudu*) to

578 BU (*Asobayere*). Cold paste viscosities of yam starch also ranged from 385 BU (*Pona*) to 817 BU (*Muchumudu*). The increase in CPV of all the starch varieties could be attributed to aggregation of the amylose molecules on cooling (Kaur *et al.*, 2007). Afoakwa and Sefa-Dedeh (2001) reported that the drastic increase in viscosity of yam paste during cooling might have resulted from the high retrogradation property of yam starch during cooling. On the other hand, differences amongst varieties in CPV could be associated with differences in amylose contents. High amylose starches have been found to re-associate more readily than high amylopectin starches. This is because the linear chains can orient parallel to each other, moving close enough together to bond (Shimelis *et al.*, 2006). Collado *et al.* (2001) also reported that starches that have high cold positive viscosities are better for production of noodles. Thus, starches extracted from *Muchumudu* and *Labreko* may be better suited for production of noodles.

Breakdown measures the ability of starch to withstand collapse during cooling or the degree of disintegration of granules or paste stability (Jimoh *et al.*, 2009; Tsakama *et al.*, 2010). At breakdown, swollen granules disrupt further and amylose molecules generally leach into solution (Zaidul *et al*., 2007). Significant differences existed in breakdown viscosities of all yam starch and flour varieties. *Muchumudu* and *Asobayere* had the lowest (2 BU) and highest (118 BU) breakdown viscosities respectively for the flours. A similar trend was observed in the breakdown viscosities of the yam starches. *Muchumudu* had the lowest (25 BU) and *Asobayere* had the highest (385 BU). 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. This is an important factor for most food processing operations and a factor in describing the quality of starch gels (Madsen and Christensen, 1996). From the results, flour and starch from *Muchumudu* have the highest ability to withstand heating and shear stress during cooking.

Setback is the phase of the pasting profile where re-association occurs between starch molecules to a greater or lesser degree (Baah, 2009). Significant differences were observed in both yam flours and starches at $p<0.05$. Setback values of flour ranged from 49 BU for *Muchumudu* to 118 BU for *Asobayere*, and for yam starch, 79 BU for *Pona* to 337 BU for *Labreko*. Kin *et al*. (1995) reported that a high setback value is associated with a cohesive paste while a low value is an indication of a non-cohesive paste. Low setback values are useful for products such as weaning foods, which require low viscosity and paste stability at low temperatures (Oduro *et al.,* 2001), and as such, flour and starch from *Muchumudu* and *Pona* respectively, may be useful for such products. Conversely, flour from *Asobayere* and starch from *Labreko* may be useful for products such as fufu and pounded yam that require high cohesive pastes. According to Baah (2009), lower setback values in flour samples suggest that its flour or starch is relatively more stable when cooked and will have a lower tendency to undergo retrogradation during freeze/thaw cycles. Thus, *Muchumudu* and *Pona* would be more stable when cooked and will have lower retrogradation ability than the other varieties.

4.4 Granule morphology of *Dioscorea rotundata* starches

The starch granules of *Asobayere, Labreko, Pona* and *Muchumudu* consisted of different shapes. These shapes are presented in Plates 4.2 to 4.5. Generally, most of the varieties exhibited spherical, elliptical to oval shaped granules. However, in *Labreko* a dominant proportion of angular shaped granules were observed. A small proportion of angular shaped granules were also observed in *Pona* and *Muchumudu*. Starch granules were predominantly oval and elliptical in *Asobayere.*

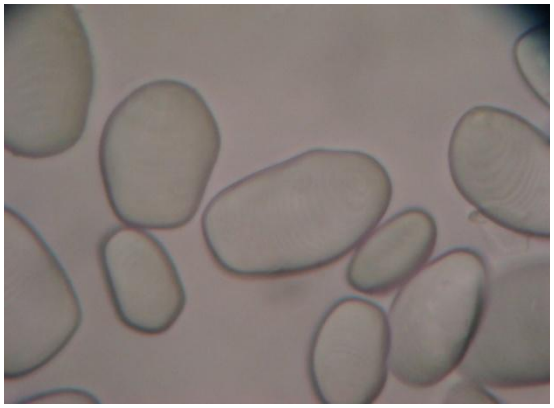

Plate 4.2 Starch granule shape of *Asobayere*

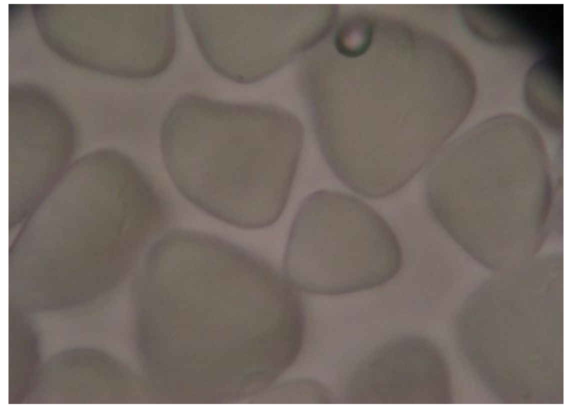

Plate 4.3 Starch granule shape of *Labreko*

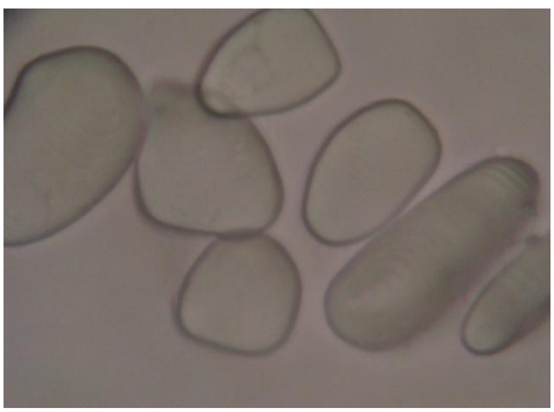

Plate 4.4 Starch granule shape of *Pona*

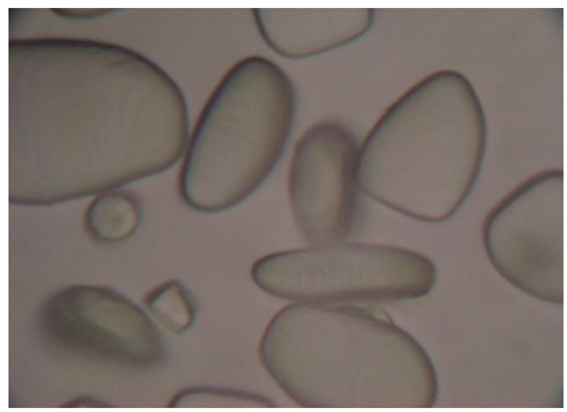

Plate 4.5 Starch granule shape of *Muchumudu*

Granule size and size distribution of the yam starches are presented in Table 4.10. Mean granule size varied from 25.94 for *Muchumudu* to 32.06 µm for *Pona*. Granule sizes ranged from 9.88 to 56.81 µm, 10.10 to 62.36 µm, 9.27 to 66.99 µm and 7.10 to 59.28 µm for *Asobayere, Labreko, Pona* and *Muchumudu* respectively. *Pona* showed the widest granule size distribution (9.27-66.99 µm). Granules sizes in this study were comparable to work done by Malomo and Jayeola (2010) who reported 10 to 56 µm for

D. rotundata. Granule dimensions, size distribution and shape are characteristic of botanical source (Tsakama *et al.*, 2010).

Table 4.10 Mean granule size of extracted starch granules

Variety	RANGE (µm)	MEAN SIZE (µm)
Asobayere	9.88 – 56.81	31.48
Labreko	10.10 – 61.36	36.64
Pona	9.27 – 66.99	39.92
Muchumudu	7.10 – 59.28	30.77

The granule size and shape affect the functional characteristics of starches and may influence their industrial uses (Baah, 2009). Starch granule size contributes to the rate at which starch gelatinizes, its gelatinization temperature, swelling power and viscosity (Tsakama *et al.*, 2010; Singh *et al.*, 2003). Smaller granules have high molecular bonding which leads to lower swelling. Fortuna *et al.* (2000) also reported that large granules increase swelling. *Pona* had the largest granule size, therefore low molecular bonding and thus higher swelling. This confirms the high swelling power of *Pona* as shown in Tables 4.7.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the market survey, taste, mealiness and softness were the attributes used in determining the desired quality of yam by consumers.

It has been shown from this study that another local *D. rotundata* variety, *Labreko* has a superior eating quality, higher protein and carbohydrate contents than *Pona*. Based on the results of this study, Muchumudu may also be used for mashed products such as yam pottage because of its softness and could be an additional source of calcium and phosphorus for growing children. Calcium and phosphorus are essential elements necessary for the building and maintenance of strong bones and teeth. *Asobayere* may also be a very good export commodity because of its potential keeping quality.

Muchumudu may also be used industrially for products that require high unit yield as well as products such as weaning foods that require low viscosity and paste stability at low temperatures. *Labreko* and *Asobayere* may also be used in food preparations that require shorter processing time. *Asobayere* may also be exploited for starch production because of its high starch yield. The extracted starch may be used in the industries or for food products that require thick paste, high gel strength and elasticity.

Labreko, Asobayere and *Muchumudu* can be promoted based on these unique characteristics to increase the range of options for consumers on the local and export markets.

5.2 Recommendations

From the study, *Labreko* had lower moisture content than *Pona* which is reflective of a better keeping quality. Further studies can be carried out to ascertain the shelf life of *Labreko* in order to increase its credibility for export.

Results from the market survey also revealed that *Muchumudu* gains a high consumer preference after 4 to 6 months of storage, at which point most of its water content would have reduced considerably, thereby concentrating the sugars and giving it a sweet taste. Further studies can also be carried out on the storage of *Muchumudu* and its preference evaluated monthly through sensory analysis.

Further studies can be carried out to screen other underutilized *D. rotundata* varieties for good sensory, physicochemical and functional properties that can bring out their full potential for diverse uses.

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APPENDIX

APPENDIX 1. Formulae for the calculation of protein and pasting properties

Appendix 1.1 Calculation of % Crude protein

$$\%\ \text{Total nitrogen} = \frac{100 \times (\text{VA} - \text{VB})\ \times \text{NA}\ \times 0.01401\ \times 100}{\text{W}\ \times 10}$$

Where:

VA = volume in ml of standard acid used in titration

VB = volume in ml of standard acid used in blank

NA = normality of acid

W = weight in grams of the sample

A nitrogen conversion factor of 6.25 was used to determine percent crude protein in the sample.

Appendix 1.2 Calculation of % Paste stability at 95°C

% Paste stability at 95°C = Viscosity at 95°C - Viscosity after 15 min hold at 95°C

Appendix 1.3 Calculation of % Paste stability at 5O°C

% Paste stability at 50°C = Viscosity at 50°C - Viscosity after 15 min hold at 50°C

APPENDIX 2. Questionnaire for Sensory Analysis

SENSORY EVALUATION OF YAM

Name………………………………………………………………....Number………………...

Sex..……………….

Date.………………..

You have been provided with four coded samples, could you please indicate by ticking which of these attributes best describe boiled yam. Please take water after evaluating each sample.

ATTRIBUTE	Degree	675	459	145	366
Wetness	Wet				
	Slightly wet				
	Slightly dry				
	Dry				
Texture	Soft				
	Slightly soft				
	Slightly hard				
	Hard				
Mealiness	Mealy				
	Slightly mealy				
	Soggy				
	Waxy				
Taste	Sweet				
	Slightly sweet				
	Bland				
	Bitter				

Any other comments

……………………………………………………………………………………………

APPENDIX 3. Questionnaire for Market Survey

Questionnaire: YAM CULTIVATION IN ASANTE MAMPONG

1. Sex
    a. Male   b. Female
2. How many years have you cultivated yam?
    a. 1-10yrs   b. 11-20yrs   c. over 20 yrs
3. How many varieties of yam do you know?

4. Which of these varieties do you prefer most? Rank in order of preference.
    a. Pona   b. Labreko   c. Asobayere   d. Muchumudoo
5. Which of these varieties of yam do you cultivate;
    a. Pona   b. Labreko   c. Asobayere   d. Muchumudoo
6. Do you have different types of these varieties mentioned above?
    Pona
    Labreko
    Asobayere
    Muchumudoo
7. Why the choice of .... ?
    a. Consumer preference
    b. Yield
    c. Early maturity
    d. Draught resistant
    e. Storability
    f. High profit
    g. Others...
8. Why do you not prefer ....?
    a. Poor consumer preference
    b. Low yield
    c. Late maturity
    d. Low draught resistant

e. Low storage period
f. Low profit
g. Others...

9. How long does .... take to reach maturity?

   ………………………………………………………………………………………

10. At what time of the year is planting done?

    …………………………..

11. What factor influences consumer choice of ....?
    a. Size b. quality c. taste d. price

12. Is yam cultivation a profitable venture? If yes, would you recommend others to go into yam cultivation?
    a. YES b. NO

13. What problems do you encounter during yam cultivation?

14. Do you store harvested yam?
    a. YES b. NO

15. If yes, how do you store?
    a. Barn b. Pit c. Both d. other

16. How long do you store?
    a. Up to 3 months
    b. 3-6 months
    c. 6-9 months
    d. Other

       ....

17. What problems do you encounter during storage?
    a. Rotting
    b. Quality deterioration
    c. Rodent/pest attack
    d. Weight loss
    e. Others

APPENDIX 4. ANOVA tables for physicochemical and functional properties of *Dioscorea rotundata* flours

Appendix 4A: ANOVA Table for MOISTURE

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	423.104	3	141.035	47673.71	0.0000
Within groups	0.0236667	8	0.00295833		
Total (Corr.)	423.128	11			

Appendix 4B: ANOVA Table for DRY MATTER

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	423.104	3	141.035	47673.71	0.0000
Within groups	0.0236667	8	0.00295833		
Total (Corr.)	423.128	11			

Appendix 4C: ANOVA Table for ASH

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	4.26167	3	1.42056	811.75	0.0000
Within groups	0.014	8	0.00175		
Total (Corr.)	4.27567	11			

Appendix 4D: ANOVA Table for CRUDE PROTEIN

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	2.92676	3	0.975586	3776.46	0.0000
Within groups	0.00206667	8	0.000258333		
Total (Corr.)	2.92882	11			

Appendix 4E: ANOVA Table for CRUDE FAT

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.106692	3	0.0355639	112.31	0.0000
Within groups	0.00253333	8	0.000316667		
Total (Corr.)	0.109225	11			

Appendix 4F: ANOVA Table for CRUDE FIBRE

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.172625	3	0.0575417	88.53	0.0000
Within groups	0.0052	8	0.00065		
Total (Corr.)	0.177825	11			

Appendix 4G: ANOVA Table for CARBOHYDRATE

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	571.185	3	190.395	28276.47	0.0000
Within groups	0.0538667	8	0.00673333		
Total (Corr.)	571.238	11			

Appendix 4H: ANOVA Table for pH

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.273225	3	0.091075	1092.90	0.0000
Within groups	0.000666667	8	0.0000833333		
Total (Corr.)	0.273892	11			

Appendix 4I: ANOVA Table for SWELLING POWER

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	4.50314	3	1.50105	2554.97	0.0000
Within groups	0.00235	4	0.0005875		
Total (Corr.)	4.50549	7			

Appendix 4J: ANOVA Table for SOLUBILITY

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.505238	3	0.168413	274.96	0.0000
Within groups	0.00245	4	0.0006125		
Total (Corr.)	0.507688	7			

Appendix 4K: ANOVA Table for WATER BINDING CAPACITY

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	377.296	3	125.765	4340.48	0.0000
Within groups	0.1159	4	0.028975		
Total (Corr.)	377.412	7			

Appendix 4L: ANOVA Table for AMYLOSE

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	150.646	3	50.2155	183.47	0.0000
Within groups	2.1896	8	0.2737		
Total (Corr.)	152.836	11			

Appendix 4M: ANOVA Table for AMYLOPECTIN

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	152.027	3	50.6757	176.13	0.0000
Within groups	2.30173	8	0.287717		
Total (Corr.)	154.329	11			

Appendix 4N: ANOVA Table for TITRATABLE ACIDITY

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.006225	3	0.002075	9.22	0.0056
Within groups	0.0018	8	0.000225		
Total (Corr.)	0.008025	11			

Appendix 4O: ANOVA Table for CALCIUM

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	914.04	3	304.68	30468.00	0.0000
Within groups	0.04	4	0.01		
Total (Corr.)	914.08	7			

Appendix 4P: ANOVA Table for IRON

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	4.41375	3	1.47125	130.78	0.0002
Within groups	0.045	4	0.01125		
Total (Corr.)	4.45875	7			

Appendix 4Q: ANOVA Table for PHOSPHORUS

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	4784.1	3	1594.7	2614.26	0.0000
Within groups	2.44	4	0.61		
Total (Corr.)	4786.53	7			

Appendix 4R: ANOVA Table for POTASSIUM

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.6252	3	0.2084	2084.00	0.0000
Within groups	0.0004	4	0.0001		
Total (Corr.)	0.6256	7			

Appendix 4S: ANOVA Table for SODIUM

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0086	3	0.00286667	19.11	0.0078
Within groups	0.0006	4	0.00015		
Total (Corr.)	0.0092	7			

APPENDIX 5. ANOVA tables for physicochemical and functional properties of *Dioscorea rotundata* starches

Appendix 5A: ANOVA Table for MOISTURE

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.568967	3	0.189656	92.51	0.0000
Within groups	0.0164	8	0.00205		
Total (Corr.)	0.585367	11			

Appendix 5B: ANOVA Table for DRY MATTER

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.568967	3	0.189656	92.51	0.0000
Within groups	0.0164	8	0.00205		
Total (Corr.)	0.585367	11			

Appendix 5C: ANOVA Table for CRUDE PROTEIN

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0000916667	3	0.0000305556	0.61	0.6265
Within groups	0.0004	8	0.00005		
Total (Corr.)	0.000491667	11			

Appendix 5D: ANOVA Table for CRUDE FAT

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0000666667	3	0.0000222222	0.89	0.4872
Within groups	0.0002	8	0.000025		
Total (Corr.)	0.000266667	11			

Appendix 5E: ANOVA Table for CRUDE FIBRE

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.004225	3	0.00140833	18.78	0.0006
Within groups	0.0006	8	0.000075		
Total (Corr.)	0.004825	11			

Appendix 5F: ANOVA Table for CARBOHYDRATE

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	1.53607	3	0.512022	131.29	0.0000
Within groups	0.0312	8	0.0039		
Total (Corr.)	1.56727	11			

Appendix 5G: ANOVA Table for STARCH YIELD

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	77.2121	3	25.7374	3420.25	0.0000
Within groups	0.0301	4	0.007525		
Total (Corr.)	77.2422	7			

Appendix 5H: ANOVA Table for pH

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.913767	3	0.304589	2436.71	0.0000
Within groups	0.001	8	0.000125		
Total (Corr.)	0.914767	11			

Appendix 5I: ANOVA Table for AMYLOSE

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	29.6969	3	9.89896	44.71	0.0000
Within groups	1.77133	8	0.221417		
Total (Corr.)	31.4682	11			

Appendix 5J: ANOVA Table for AMYLOPECTIN

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	29.6969	3	9.89896	44.71	0.0000
Within groups	1.77133	8	0.221417		
Total (Corr.)	31.4682	11			

Appendix 5K: ANOVA Table for WATER BINDING CAPACITY

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	63.943	3	21.3143	136.60	0.0002
Within groups	0.62415	4	0.156038		
Total (Corr.)	64.5672	7			

Appendix 5K: ANOVA Table for SWELLING POWER

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	3.52824	3	1.17608	696.94	0.0000
Within groups	0.00675	4	0.0016875		
Total (Corr.)	3.53499	7			

Appendix 5M: ANOVA Table for SOLUBILITY

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.783137	3	0.261046	23.13	0.0055
Within groups	0.04515	4	0.0112875		
Total (Corr.)	0.828287	7			

APPENDIX 6. Plates of *Dioscorea rotundata* varieties

Appendix 6A: Samples of *Labreko*

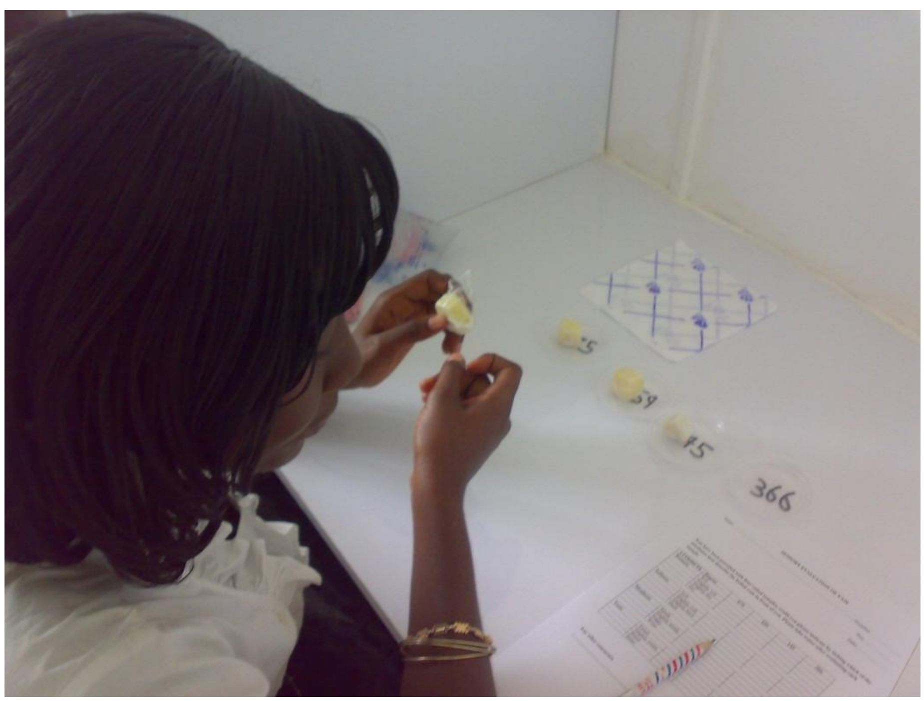
Appendix 6B: Samples of *Pona*

Appendix 6C: Samples of *Asobayere*

Appendix 6D: Samples of *Muchumudu*

APPENDIX 7. Plates of Sensory Evaluation conducted

Appendix 7A: Cross section of panellist analysing sensory attributes of cooked yam



Appendix 7B: A panellist analysing sensory attributes of cooked yam

APPENDIX 8. Plates of Laboratory analysis

Appendix 8A: Griffin flask shaker being used to agitate samples

Appendix 8B: Light microscope being used to view morphology of starch granules