MICROSTRUCTURAL, PHYSIOLOGICAL AND PROCESSING CHARACTERISTICS OF IMPROVED SWEETPOTATO (*Ipomoea batatas* Lam.) VARIETIES

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DECLARATION

I hereby declare that, except for references to other people's work which have been duly acknowledged, this write-up is the result of my own original research and this thesis has not been presented for any degree elsewhere.

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ABSTRACT

Sweetpotato has great potential to significantly impact Ghana's food and nutritional security. It however remains largely under-utilized due to knowledge gaps about important quality traits and the major factors influencing stability. This study was carried out to characterize selected sweetpotato varieties for important quality attributes and their stability under natural controlled factors. Six improved high-yielding and disease-resistant varieties were studied for fresh roots tissue microstructure, storage stability and wound healing response. Influence of harvest maturity on flour pasting properties and selected nutrient components was also investigated using Rapid Viscosity Analysis (RVA) and Near Infra-red Reflectance Spectroscopy (NIRS) respectively. Starch granule morphology by light microscopy and starch pasting properties using RVA were also determined. The varieties were analyzed for fried crispy chips quality and stability at different stages of crop maturity using Instrumental Texture analysis and Sensory evaluation. Differences were observed in storage parenchyma tissue cell shapes, relative sizes and arrangement for the varieties studied. Storage stability of fresh roots varied significantly by variety and type of primary packaging ($p<0.001$ and $p<0.05$, respectively) over a 41- day storage period. *Faara* was the most stable variety in storage, with minimum average weight loss (7.80%) while *Apomuden* was the most susceptible to dehydration, with the highest average weight loss (28.02%). Size of sweetpotato roots also had an influence on storage characteristics, with larger-sized roots (330 - 602g) showing better resistance to weight loss than smaller roots (140 - 250g) during a 64-day storage period. Physiological response to wounding assessed through microscopy was found to vary among varieties, and the efficiency of tissue repair in wounded roots had a direct bearing on shelf-life of healthy undamaged roots. Key nutrient components of flour were influenced by harvest maturity and fresh roots storage. At harvest time protein contents ranged from 3.0 to 7.25% and starch contents ranged from 53.93 to 79.40%. Total soluble sugars ranged from 3.92 to 25.02% at harvest and 11.29 to 44.44% after storage. For protein, zinc and iron contents, samples harvested at earlier maturity had higher values. In all the varieties, there were losses in starch content during storage ranging from 1.95 - 23-73% of the total starch. *Faara* and *Hi-starch* had the lowest reduction or degradation of starch during storage, with *Hi-starch* showing the best stability across all maturity stages. Sugars increased concomitantly with the loss of starch during storage. Flour Peak viscosity and Stability ratio were significantly influenced by both maturity and storage ($p<0.001$), with storage resulting in a lowering of Peak viscosities in all the varieties. Stability ratio reduced at advanced maturity and also with storage, indicating better stability when processed at earlier maturity right after harvest. Among the RVA indices, flour Peak viscosity was the most affected by activity of amylase enzymes. Normal enzyme action accounted for decreases of 13.33% - 45.05% in Peak viscosity when compared with enzyme-inhibited flour pasting profiles. Starch granule shapes were heterogeneous and approximate size distributions varied from 2-15µm to 8-40µm, with *Apomuden* having the smallest granule sizes. Starch Peak Viscosity ranged from 4077 - 5260 centipoise, Pasting temperature 77.95 - 82.45ºC, Setback ratio 1.25 - 1.61 and Stability ratio 0.52 - 0.73. Starches with larger granules had relatively higher Peak viscosities, lower Stability and Setback ratios. The effects of both variety and harvest maturity on starch pasting properties were significant ($p<0.001$). Instrumental hardness of fried crispy chips was influenced significantly by harvest maturity ($p<0.05$) and increased with increasing harvest age. Low sweetness and low flavour intensities were associated with higher Overall Acceptability. Chips from varieties with relatively larger starch granule sizes had higher Acceptability scores. These results are relevant in helping to achieve optimal quality and consistency for sweetpotato fresh produce markets as well as processed products for industry. Various recommendations are also made for breeding programmes and other stakeholders.

CONTRIBUTION TO KNOWLEDGE

The following key findings have been established from this study:

a. Wound healing response across different portions of sweetpotato root (proximal, middle and distal) was linked with actual storage stability or shelf-life of healthy undamaged fresh roots (*this is the first report demonstrating variation in wound healing response from different locations of sweetpotato storage root*).
b. Larger sized sweetpotato roots (>300g) exhibited better storage or shelf-life, assessed as better resistance to weight loss or dehydration during storage.
c. Changes in fresh roots composition and amylase enzyme activity were not only variety specific but also significantly influenced by harvest maturity and storage.
d. Varieties with large starch granule sizes, high RVA Peak viscosity and low Setback ratio produced very acceptable fried crispy chips relative to those with smaller starch granule sizes, low RVA Peak viscosity and high setback.

Publications from the work:

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DEDICATION

To the cause of Christ, and to His soon return.

To my cherished husband, Abraham Adu-Kwarteng
and to my lovely children Joel, Stephen and Michelle

whose love and inspiration have made it all possible

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CHAPTER ONE

1.0 GENERAL INTRODUCTION

Sweetpotato is one of the world's most versatile yet under-exploited food crops; it currently ranks as the fifth most important food crop in developing countries after rice, wheat, maize, and cassava (Scott and Maldonado, 1998). It is an efficient producer of utilizable energy per hectare per unit time, producing more edible energy per hectare per day than wheat, rice or cassava (CGIAR, 2005); it is speculated to produce more biomass and nutrients per hectare than any other food crop in the world (Prakash, 1994). Sweetpotato is moderately drought tolerant, does well on poor soils with little or no fertilizer and also has relatively few natural enemies, so pesticides are rarely used in its production (Baafi *et al*., 2011). It is also known to do well in a broad range of geographical locations (Kays, 2005b); it is an early-maturing crop and can be harvested within 3 to 6 months, unlike other starchy root crops which can occupy the land for up to a year or more. In Ghana available data show average yields of approximately 8 Mt/ha and achievable yields of 18 Mt/ha (MOFA, 2010), indicating great potential. Sweetpotato has a long history as a lifesaver in times of natural disaster and its unique and versatile nature has earned it the title of 'saviour' crop during times of famine. For example, the Japanese survived on sweetpotato when typhoons demolished their rice fields and it also kept millions from starvation in famine-plagued China in the early 1960s; in Uganda, where a virus ravaged cassava crops in the 1990s, rural communities depended on the sweetpotato to keep hunger at bay (CIP, 2006). Due to its unique features, it was selected in the U.S.A. as a candidate crop for feeding astronauts on long-term space missions (Wilson *et al*., 1998; Bovell-Benjamin, 2007).

Sweetpotato is rich in simple and complex carbohydrates, dietary fibre, and also provides nutritionally significant quantities of ascorbic acid, riboflavin, pyridoxine, iron, calcium and protein. In addition, the orange-fleshed varieties are rich in ß-carotene, a nutrient which may be effective in preventing certain types of cancer (Prakash, 1994) and has also been sustainably employed in public health campaigns for the alleviation of vitamin A deficiency (van Jaarsveld *et al*., 2005). Among the food crops, sweetpotato has the highest recorded net protein utilization (based on percentage of food nitrogen retained in the body) (Prakash, 1994). In North America sweetpotato is used extensively as a baby food (BCC Research, 2012). The nutritional superiority of this crop also includes the presence of nutraceuticals (for example, bioactive phenolic compounds and anthocyanins in the purple fleshed varieties) and a glycaemic index much lower than that of the Irish potato (Kays, 1992; 2005a). Despite the name "sweet", sweetpotato may be a

beneficial food for diabetics as various studies have revealed that it helps to stabilize blood sugar levels and to lower insulin resistance (Hung, 2004; Zakir, 2005; Allen *et al*., 2012). According to Islam and others, regular consumption of sweetpotato is helpful for preventing a number of disease conditions due to its unique combination of inherent beneficial active compounds (Islam *et al*., 2003a; Islam, 2006). Other studies (Patil *et al*., 2007; WHFoods, 2011) also indicate that sweetpotato has healing and immune-boosting properties as an antioxidant food. In this regard, it has been developed in some countries for new uses as a bioactive functional health food (Shih *et al*., 2009). Sweetpotato has also been successfully used in a number of African countries to combat widespread Vitamin A deficiency that results in blindness and even death for 250,000-500,000 African children a year; about two-thirds of children developing xerophthalmia (the blindnessinducing disease resulting from lack of vitamin A) die within a year of losing their sight (CGIAR,
2005; van Jaarsveld *et al*., 2005). Strategies to control vitamin A deficiency include dietary diversification, food fortification and supplementation with imported vitamin A capsules. Promoting the production and consumption of orange-fleshed sweetpotato varieties rich in betacarotene (pro-vitamin A) offers a more sustainable, cost-effective approach in vitamin A deficiency alleviation.

Sweetpotato is a very versatile crop and in Asia nearly half of what is produced goes into industrial applications, while the rest is used for human consumption either as fresh or processed products. Although in many developing countries such as Ghana it is generally regarded as a subsistence crop, in other parts of the world the options for utilization are very diverse. Its uses include food and industrial products such as starch, sweeteners, noodles, citric acid, soft drinks, desserts, flour, industrial alcohol, ethanol fuel and livestock feed (Jangchud *et al.*, 2003; Truong and Avula, 2010;

Baafi *et al*., 2011). The green leaves and young, tender vines of the plant are also edible and very nutritious for both humans and livestock.

1.1 Justification of Research

Although this nutritious and high-energy crop grows well in all the various agro-ecologies of Ghana, it is currently not well integrated into the average Ghanaian diet and its level of utilization in the country is very low as compared to the other root and tuber crops generally consumed (AduKwarteng *et al*., 2002). On the local scene, the use of the crop is evident only in a few communities and processing is currently limited to boiling, roasting or frying in isolated households and by roadside food vendors. It is clear that the immense industrial potential of sweetpotato is yet to be explored in Ghana. Sweetpotato has been described as one of the most misunderstood of the major food crops (Scott and Maldonado, 1998). Generally, in Ghana, this crop has not received much research attention over the years compared to the other starchy staples, in spite of its superior nutritional quality and industrial potential. Knowledge about sweetpotato as food or industrial raw material to the average Ghanaian is limited, although some research has shown that as a staple food commodity it is versatile enough to be used in various food preparations in place of rice, cassava, yam, plantain and other well-integrated staples (Baafi *et al*., 2011; Zuraida, 2003; Meludu *et al*., 2003; Ellis *et al*., 2001).

Crops Research Institute, under the Council for Scientific and Industrial Research (CSIR), Ghana, in a bid to promote sweetpotato utilization in the country has over the years released several highyielding, high-nutrient varieties which have the potential of boosting nutritional sufficiency and also for small-scale industrial applications, if adopted. Per capita consumption of sweetpotato over the years has however, not increased. The low level of cultivation in Ghana over the years may be attributed to various factors including:

1. High perishability of the crop, leading to high postharvest losses
2. Inadequate clarity on inherent characteristics of available varieties
3. Limited information about diversified processing options (for both domestic and industrial applications)
4. Inadequate sustained markets: This may be due to a combination of all the abovementioned factors

The diversity in sweetpotato is so broad that many different types can be made available for special product development depending on the characteristics needed. Often, it is difficult to determine, even through trial and error, what the best characteristics are for particular products and what accounts for inconsistencies in product characteristics in using any particular variety. There is inadequate understanding of factors affecting storage behaviour and enzyme activities and this has led to inconsistent results from various studies. Since crop quality depends on inherent properties that have direct or indirect effects on the final food products, more information must be acquired about important quality indices of the varieties that thrive under local conditions in Ghana in order to exploit the full potentials of this crop.

1.2 Objectives

This study was carried out to characterize selected sweetpotato varieties for important quality attributes and to assess their stability under natural controllable factors. The specific objectives were to determine:

1. Tissue microstructure, wound-healing response and storage characteristics of sweetpotato fresh roots
2. Effects of crop maturity and postharvest storage on key nutrients and pasting properties of sweetpotato
3. Morphological and quality characteristics of native starch from six (6) varieties of sweetpotato
4. Sweetpotato product quality: Influence of raw material characteristics (the case of fried crispy chips)

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 BACKGROUND AND SIGNIFICANCE OF SWEETPOTATO

2.1.1 Botany, origin and domestication

Sweetpotato (*Ipomoea batatas* Lam.), in spite of its name, is not related to potato (*Solanum tuberosum* Lam.). Potatoes belong to the *Solanaceae* family which also includes tomatoes, red peppers, and eggplant, while sweetpotatoes belong to the morning-glory family (*Convolvulaceae*) (Plate 2.1). Unlike the potato which is a tuber or thickened stem, the sweetpotato is a storage root. The name 'sweetpotato' is currently written as one word, not two separate words (CIP, 1995).

Plate 2.1 Sweetpotato vine showing purple flowers characteristic of 'morning glory' family

Sweetpotato is a very important crop in developing countries, where it has the potential to play key roles in food security; it also ranks seventh among the world's food crops. The crop was domesticated more than five thousand years ago in the Americas and it spread through Asia and Africa during the 17th and 18th centuries due to its hardy nature, broad adaptability, and rapid vegetative propagation; it is currently grown in more than 100 countries (CIP, 2002; Food and Agriculture Organization, 2002).

2.1.2 Production and diversity in utilization

Sweetpotato is grown in tropical and subtropical regions under widely variable agro-ecological or geographic conditions, due to its adaptability to different environments. Most of it is however, produced on marginal soils in low-input subsistence farming systems (Gruneberg *et al.*, 2005). It is widely distributed globally, with an annual planting area of approximately nine million hectares worldwide. Over 133 million tonnes are produced annually and Asia (the world's largest producing region) produces 125 million tonnes. Almost half of Asia's production is used for animal feed while the rest is used for human consumption (CIP, 2002). Latin America, the original home of sweetpotato, has an annual production of 1.9 million tonnes, while North America produces about 600,000 tonnes a year. Portugal is the only European country that produces substantial quantities, with annual production levels of 23,000 tonnes. In sub-Saharan Africa sweetpotato is the third most important root crop, after cassava and yam (Scott and Ewell, 1992) and it is grown on about 2.1 million hectares of land with an estimated production of between seven to 9.9 million tonnes (Kapinga *et al*., 2001). Yields in Africa however, are quite low (about one-third of Asian yields) and this indicates a huge potential for future growth. In Ghana, there is currently no available information on national production levels of sweetpotato, although yield data show an average of 8.1 metric tonnes per hectare. This estimated yield is only 45.2% of achievable yields in Ghana (MOFA, 2010). Sweetpotato has a very broad genetic base; it has a high polyploidy level (hexaploid), and large chromosome number (2n=6X=90) (Lin *et al*., 2007; Wilson *et al*., 1989; Collins, 1995). It is known to have tremendous diversity (Austin, 1988) not only in terms of nutritional characteristics but also in such visible traits as peel and inner flesh colour, which have direct relevance to food quality. Different varieties exist in colours ranging from white or cream to yellow/orange and even to deep purple (Plate 2.2).

Plate 2.2 **Genetic diversity of sweetpotato: varietal differences in shape, skin colour and inner flesh colour**

Due to its wide diversity in colour, taste, flavour, nutritional composition, functional properties and processing attributes, it is extremely adaptable for processing into a wide range of domestic and industrial products (Woolfe, 1992; Nabubuya *et al*., 2012)

A sweetpotato gene bank at the International Potato Center contains over 5,000 different cultivated accessions of sweetpotato from 57 countries (Zhang *et al*., 1999). In Ghana, various improved varieties with different characteristics in terms of yield, nutritional composition and processing qualities have been released to farmers. The versatile nature of the crop in terms of food and industrial products is illustrated in Table 2.1. and Plate 2.3. In spite of its huge potential to contribute to food security and help reduce malnutrition and poverty, this versatile crop, a wealthy resource, has remained untapped in many parts of the developing world (Woolfe, 1992).

Table 2.1 Potential food and industrial applications of sweetpotato in Ghana

Product type	**Description**	**Local name**
Staples	- Breakfast mix (shelf-stable, quick-cooking)	*Koko*
	- Boiled and served with beans stew	*Ampesi*
	- French fries with salad	
	- Mashed with pepper and onions, served with groundnuts, salted fish	*Eto, Oto*
	- Casserole or hash with palm oil, fish and vegetables	*Mpotompoto*
	- Mixed with corn meal and cooked into thick mass, shaped into balls, served with various accompaniments	*TZ, banku*
	- Pounded, served with soup (high starch, low sugar varieties)	*Fufu*
	- Toasted fermented granules	

	(shelf-stable)	*Gari*
Snacks, desserts	- Beverage	
	- Deep-fried chunks	*Koliko*
	- Yoghurt filler	
	- Crispy chips	*Chips*
Industrial	- Starch	
	- Glucose/fructose/maltose syrup	
	- Flour	
	- Livestock feed	

Baafi *et al.*, (2011)

Plate 2.3 Some sweetpotato products: Salad cream, juice/beverage and crispy chips *(Photographs: personal)*

2.1.3 Sweetpotato trade and industry

A small fraction (about 1%) of global sweetpotato production enters world trade. The USA is the largest exporter of sweetpotato, accounting for 35% of world trade. Other exporters are China (12%) and Israel (9%). The major importing countries are Canada, the United Kingdom, France and the Netherlands (Katan and De Roos, 2004). Most of the world's harvested sweetpotato crop is used for table consumption with a small percentage going into industrial uses and animal feed. The crop plays considerably different roles in human diets in different parts of the world, being either a supplemental or luxury food (as in North America and parts of Europe) or a staple crop in Papua New Guinea, parts of the Philippines, Tonga and Solomon Islands (Sosinski *et al.*, 2001). In some parts of Asia, the use of sweetpotato ranges from supplementary food of little status (for instance, in Thailand) to a very important supplementary food in the Ryukyu Islands of Japan (Collins, 1987). In Japan, sweetpotato features highly in the production of novel plant products and/or nutraceuticals (Oke and Workneh, 2013). Sweetpotato with its impressive array of nutrients, has an exciting potential for contributing to the nourishment of the global population. In spite of this, global trends in production and consumption have so far not supported the position and potential of this highly nutritious vegetable. In the United States, the annual per capita consumption of sweetpotato was found to have declined in the past few decades from 12 to 2kg while consumption of potato increased to over 60kg (USDA, 2002). Research efforts have demonstrated that sweet potatoes can be processed into a variety of products such as beverages, soups, baby foods, ice cream, baked products, restructured fries, breakfast cereals and various snack and dessert items (Collins and Walter 1992; Dansby and Bovell-Benjamin 2003; Truong 1992; Walter *et al.*, 2001; Woolfe 1992; Truong and Avula 2010).

2.2 MAJOR NUTRIENTS OF SWEETPOTATO

Carbohydrates form the major constituents of the dry matter in sweetpotato storage roots and are made up of starch, sugar, cellulose, pectin and hemicelluloses (Collins and Walter, 1985; Picha, 1987). Sweetpotato has high energy-density and can produce more edible energy per hectare per day than wheat, rice or cassava. In addition to this, compared to most other starchy food crops it is nutritionally superior. It is an excellent source of vitamin A (in the form of beta-carotene) and a good source of vitamin C, vitamin B6, manganese, copper, potassium, iron, dietary fibre and other nutraceuticals or bio-active components; it also has a low glycaemic index (Kays, 2005b; WHFoods, 2011). Proximate composition as well as the mineral and vitamin profile of sweetpotato compares very favourably with various fruits and vegetables, and some varieties are known to contain higher levels of minerals and proteins than many other vegetables (Woolfe, 1992). Fresh sweetpotato storage roots contain 60 - 82% moisture; this corresponds to 16 - 40% dry matter and is characteristic of most starchy root and tuber crops (Collins and Walter, 1985). High dry matter content in bulky food crops is desirable for staple uses as well as animal feed and industrial applications. This is because less moisture content has an influence on organoleptic properties, storability, processing yield and efficiency and also reduces transportation costs, with less load to carry compared to high moisture types. The chemical composition of sweetpotato varies widely between varieties.

2.2.1 Sweetpotato starch

Starch is the main component of the carbohydrates in sweetpotato. Different varieties are known to exhibit a wide range of different starch characteristics due to the tremendous genetic diversity of the crop. Attempts have been made to establish links between sweetpotato starch properties and cooking or processing qualities (Walter *et al*., 2000; Chen *et al*., 2003) and various workers have also studied variations that occur due to genetic and environmental factors (Brabet *et al*., 1998; Collado *et al*., 1999; Noda *et al*., 2001; Ishiguro *et al*., 2003; Yempew *et al*., 2001; Subramonthy, 2002). Variability in sweetpotato starch properties may be viewed as an opportunity for the selection of an optimal combination of variety, growing conditions and extraction process for obtaining the desired starch quality for specific industrial uses. Although tailor-made modified starches for different applications can be obtained through chemical and physical treatments, when it comes to food applications there are limitations on chemically-treated starches. The growing demand for natural foods and the shift away from additives and artificial ingredients has resulted in increased search for functional properties from starches in their native, unmodified form (Garcia, 1993).

2.2.1.1 Starch granule size

Starch granules from different sources exhibit a broad range of size distributions in nature. In general, starches from the Irish potato have the broadest granule size distributions (5 - 100µ) of all types of native starches; sweetpotato starch has a granule size distribution range of 4 to 40µ (Satin, 1988). Physicochemical properties and structures of different size granule fractions of starches from various crops have been characterized (Kainuma *et al.,* 1978; Ghiasi *et al.,* 1982; Soulaka and Morrison, 1985; Jane *et al.*, 1992; Vasanthan and Bhatty, 1995; Wilhelm *et al.,* 1998; Takeda *et al.*, 1999; Fortuna *et al.*, 2000). There is increasing interest in starches manufactured from novel materials for use in special products. Starches having small granules and narrow granule size distributions can be used in many applications and a wide range of starches with small-sized granules exists in nature (for example, starches from rice, barley, millet and taro). However, one main challenge faced in the industry is in the application of commercial purification methods after extraction. There is the need for improved methods for refining small granule starches to enhance the potential for new applications and new markets for such starches (Hoover, 2001). Small-size granule fraction starches have been reported in the applications of fat substitutes, starch-filled degradable plastic films, face (dusting) powders, stabilizers in baking powder, and laundrystiffening agents (Jane 1992; Jane *et al.,* 1992). In potato and sweetpotato, small-size granule fractions of starch exhibited higher freeze-thaw stability (resistance to syneresis) than larger size granule fractions; and in starch noodle-making and noodle quality, granule size dimension was found to play a very important role, and sweet potato starches performed better with decreasing granule size. Gelatinization temperature was however reported to be more affected by the origin of the starch than by granule size or homogeneity in granule size distribution (Zhenghong Chen, 2003) .

2.2.1.2 Sweetpotato starch digestibility

Non-cereal starches generally tend to have a relatively low susceptibility to enzymatic degradation (Fuwa *et al*., 1977). Cassava starch is one of the most digestible raw root starches (Rickard *et al*., 1991) whereas starch from Irish potato is very resistant (Madamba *et al*., 1975). Sweetpotato starch is more susceptible than potato starch but less susceptible than cassava starch to degradation by alpha-amylase and glucoamylase (Delpeuch and Favier, 1980). The digestibility of sweetpotato starch was found to be in between that of potato starch (low digestibility) and maize starch (high digestibility), (T. Zhang and Oates, 1999). The importance of starch digestibility is associated with its nutritional significance: lower digestibility is due to the presence of 'resistant starch', which is reported to improve gut health and impart various health benefits to consumers. Resistant starch is that portion of starch that is not broken down by human enzymes in the small intestine; it therefore enters the bowel where it is slowly fermented by colonic flora to release several health-promoting metabolites such as acetic, propionic and butyric acids ((Liu, 2005). Resistant starches have been shown to have very good impacts on human health and these impacts include: decreasing dietary caloric values for body fat deposition (important for the prevention of obesity), lowering glycemic response (important for diabetics), reducing blood cholesterol levels to prevent and control cardiovascular diseases, and decreasing the risk of colon cancer through enhancing short chain fatty acid production, especially butyrate (Liu, 2005). Reports on the influence of granule size on susceptibility of starch to acid and enzyme hydrolysis are often conflicting. For instance, workers (Farmakis *et al*., 2000) studying barley starch, reported that large-size granule fractions were more susceptible to chemical and enzymatic hydrolysis, while others (Kulp, 1973; Vasanthan and Bhatty, 1995) had earlier reported that small granules of barley and wheat starch were hydrolysed faster with acid or enzyme than the large granule fractions. Resistant starch levels in the range of 14.2 - 17.2% of the total starch were found in Sri Lankan sweetpotato cultivars and lower digestibility (more resistant starch) was associated with larger granule size (Senanayake *et al*., 2013). Sweetpotato starch digestibility is reported to have a negative correlation with amylose content (Nabubuya *et al*., 2012).

2.2.1.3 Retrogradation of starch

Retrogradation is an important characteristic in starch utilization. Sweetpotato starch was reported to retrograde more slowly than cereal starches; it was also found to have retrogradation rate similar to or slower than Irish potato and cassava (Rasper, 1969; Takeda *et al*., 1986; Ishiguro *et al*., 2003). Del Rosario and Pontiveros (1983) observed that bread made with sweetpotato flour did not become stale as fast as other types of bread. This has the potential of being exploited to the advantage of bread consumers in non-wheat consuming areas, and also for the production of gluten-free baked products, or in the formulation of composite flours. Varietal differences in retrogradation among sweetpotato starches arise due to differences in amylose content and proportion of short unit-chains of amylopectin. Influence of cultivation practices and environmental conditions also play significant role (Ishiguro *et al*., 2000; Ishiguro *et al*., 2003).

2.2.2 Soluble sugars

The sugar composition of sweetpotato is an important fundamental component of its eating quality (Lewthwaite *et al*., 1997) and for certain ethnic groups, for example in many parts of Africa, preferred types are the ones that are non-sweet or only slightly sweet, and high in dry matter content. In categorizing the types of sweetpotato with different eating qualities, Villareal (1981) described them as staple, supplemental staple and luxury types. Further characterization (Collins, 1987) suggested that sugar levels for staple and supplementary staple sweetpotato varieties should be up to 2 and 5% respectively on fresh weight basis, with associated dry matter content of over 35%. Luxury or dessert types are those with higher sugar content and less dry matter. Low sugar types generally predominate in the tropics, and high starch content is a desired attribute of such staple types. In the United States, the preference is for high sugar dessert types, and high-sugar has been the focus of some breeding efforts (La Bonte *et al*., 2000; Mcharo and La Bonte, 2007). Sweet taste in sweetpotato is due to a combination of endogenous sugars (sucrose, glucose and fructose) present in the raw tissue, with sucrose being the most abundant. Maltose is not detected in raw roots, but is formed during cooking through hydrolysis of starch by the activity of alpha- and betaamylases. Maltose is usually the most abundant sugar in cooked sweetpotatoes (Walter *et al*., 1975; Picha, 1985); the extent of starch conversion into maltose and dextrins is cultivar dependent (Babu, 1994). It is well established that different sugars at the same concentrations evoke different levels of perceived sweetness. Biester *et al*. (1925) reported that fructose was about 5 times as sweet as maltose, sucrose was 3 times sweeter than maltose, whereas glucose was twice as sweet as maltose; Shallenberger (1993) also found fructose to be 2.8 times sweeter than maltose. In addition, not all sugars are equal in flavour quality. In a study conducted in the United States on cooked sweetpotato, the taste of maltose was preferred over the other sugars presented to sensory panellists. When sensory panellists compared individual sugars at the same level of sweetness in sweetpotato puree, they consistently ranked the sugars in order of preference as: maltose > sucrose > fructose (Koehler and Kays, 1991). This demonstrates that the type of sugar has an effect on flavour in addition to sweetness. In a study involving 272 clones of sweetpotato from 34 countries that collectively accounted for 93% of the world's production in the year 2000, the relative sweetness of baked roots expressed as sucrose equivalents was determined and the results indicated that essentially all of the sweetpotato clones tested from around the world were classified as equal to or greater than moderate in sucrose equivalents (Kays *et al.,* 2005). This means that there is enough genetic diversity within the genepool such that there is great potential for tailoring the flavour of new cultivars, by significantly increasing or decreasing sugar content to meet specific consumer preferences and/or product uses (Walter and Hoover, 1984). In general, the sugar content of sweetpotato increases during curing (Edmond, 1971; Picha, 1987). During storage (after curing), sugar concentrations vary with storage conditions and length of storage, depending on the cultivar. Refractive index (RI) of juice expressed from raw sweetpotato has been explored as a possible inexpensive indicator of postharvest changes in sugar content (William M Walter, 1992). Sweetpotato sugars have been the subject of much interest and several reports in this area have been documented (Picha, 1985; Truong *et al*., 1986; Picha, 1987; Walter, 1992; Lewthwaite *et al*., 1997). In the search for controllable factors affecting variability of sugar content in sweetpotato genotypes, various pieces of information have emerged. For example high N fertilizer was found to increase free sugar content, and free sugar correlated positively with N, Ca and Mg content (Inukai *et al*., 2002). Adu-Kwarteng *et al*. (2014) also found that maturity of the crop was a significant factor influencing free sugar content during the postharvest phase.

2.2.3 Protein

In general, sweetpotato storage roots have low protein content, but among the food crops it is reported to have the highest recorded net protein utilization (based on percentage of food nitrogen retained in the body) (Prakash, 1994). There is considerable genetic variability for crude protein in sweetpotato germplasm; a range of 1.27 - 10.07% (dry weight basis) was reported among 300 lines grown in Taiwan under similar cultural management in a single season, with the majority containing 4 - 5% protein (Li, 1982). Various environmental factors such as growing season, cumulative rainfall, location and application of nitrogen fertilizer have been reported to affect protein content (Purcell *et al*., 1982; Bouwkamp *et al*.,1985; Bradbury *et al*., 1985; Lin, 1989).

Different crops have their own unique storage proteins; e.g. soybeans contain glycinins, potatoes have patatins, sweetpotatoes have sporamins, yams contain dioscorins, while maize has zeins. Cassava is an exception among starchy root crops, having no storage proteins at all, while taro (cocoyam family) differs slightly by having two major types of storage proteins (Shewry, 2003). Sweetpotato's storage proteins, sporamins, have been shown to have unique and potent antioxidant capacities. In one study, these proteins had about one-third the antioxidant activity of Glutathione – one of the body's most important internally produced antioxidants (Hou *et al*., 2001).

2.2.4 Dietary fibre

Root crops generally contain some non-starch polysaccharides, including celluloses, pectins and hemicelluloses, as well as other associated structural proteins and lignins, which are collectively referred to as dietary fibre. Sweetpotato is a significant source of dietary fibre as its pectin content can be as high as 5% of the fresh weight or 20% of the dry matter at harvest (Collins and Walter, 1985). Various epidemiological and physiological studies have confirmed that dietary fibre performs important functions in the human diet, providing protection against cardiovascular disease, colon cancer, diabetes, etc. (Woolfe, 1992). Dietary fibre removes toxic substances found in food such as artificial food colour, aluminium, mutagens and cholesterol by adsorbing them from the body; it also improves the flora of intestinal bacteria. Dietary fibre has been used as a functional food for protection from colon cancer and heart disease in Western countries and to relieve constipation in Japan; it has also been actively used to decrease calories and improve food quality. A study (Lund, 1984) compared the cholesterol-binding capacities of 28 fibre samples from various common tropical fruits and vegetables and found that sweetpotato fibre was the most effective cholesterol binder. Sweetpotato root is reported to have a well-balanced content of soluble and insoluble fibre in a ratio of about 1:1 (excluding lignin), unlike wheat bran, which is mainly insoluble fibre. This means that sweetpotato dietary fibre contains an abundance of soluble components (pectin or hemicellulose), suggesting that physiological functions may be higher in sweetpotato fibres than in other crops (Yoshimoto *et al*., 2005). Salvador (2000) demonstrated that among the root crops, sweetpotato cell wall material had the highest amount of pectin; it has been suggested that pectin with high methoxyl content is important in reducing serum cholesterol. The methoxyl content of sweetpotato pectin was high at 9.7% of a cold-water extract, the highest being for onion at 11% and wheat bran having only 0.1% in a study with a series of fruits and vegetables. Other results demonstrated that pectin from sweet potato starch residue is mainly low methoxyl pectin with potential for food applications (Nurdjanah, 2008). These reports demonstrate that sweetpotato dietary fibre is an excellent candidate for lowering cholesterol levels. Sweetpotato fibre was found to be by far the most effective binder of cholesterol (30%) compared to cassava fraction (3%), citrus pectin (8%) and <20% for 28 fibre samples from a variety of commonly consumed tropical fruits and vegetables (Lund, 1984).

2.2.5 Vitamins and minerals

Sweetpotato provides nutritionally significant quantities of ascorbic acid (vitamin C), iron, potassium and calcium (Prakash, 1994). It is also a good source of pyridoxine, pantothenic acid, folic acid, and a moderate source of thiamine, riboflavin and niacin (Kays, 1992). The yellow- and orange-fleshed sweetpotatoes are an excellent source of provitamin A (in the form of betacarotene). It contains per 100g of the fresh roots, 21-36 mg of calcium, 38-56 mg of phosphorus, 0.7-2.0 mg of iron, 10-36 mg of sodium, 210-304 mg of potassium, 35-5280 mg of beta-carotene and 24 g of magnesium (Duke, 1983; Woolfe, 1992). Other minerals also present in trace quantities are zinc, iodine, copper and manganese. Zuraida (2003) compared the content of vitamins and minerals per

Table 2.2 Comparison of vitamins and minerals in sweetpotato and rice

Component	Sweetpotato (mg/100 g)	Rice (mg/100 g)
Beta-carotene	0–>20	0.00
Thiamin	0.09	0.02
Riboflavin	0.06	0.01
Niacin	0.60	0.40
K	243.00	28.00
P	47.00	28.00
Fe	0.70	0.20
Ca	32.00	10.00

100 g of cooked sweetpotato and cooked rice, and found sweetpotato to contain higher levels of important nutrients compared to rice (Table 2.2).

Source: (Zuraida, 2003)

2.3 HEALTH BENEFITS FROM SWEETPOTATO CONSUMPTION

Sweetpotato is reported to contain various biologically active compounds (Islam *et al*., 2003b; Truong *et al*., 2007). A snapshot of beneficial effects of some of these components is shown in Table 2.3.

Table 2.3 Health beneficial functions of some bioactive sweetpotato components

Health Beneficial Function	Component(s)
Antioxidative activity	Polyphenol, vitamins, anthocyanin
Reduction of liver injury	Anthocyanin, beta-carotene
Antimutagenicity	Polyphenol, vitamins, anthocyanin
Anticarcinogenesis	Dietary fibre, polysaccharide

Anti-inflammation	Dietary fibre
Promotion of bowel movement	Dietary fibre, jalapin
Anti-diabetic effect	Acidic glycoprotein
Ultraviolet protection	Polyphenols, vitamins

Source: (Islam *et al*., 2003b)

anthocyanin contents of sweetpotato flours were significantly positively correlated with the DPPH radical scavenging effects of the flours (Huang *et al*., 2006). These workers found that steam treatment actually increased the DPPH radical scavenging effects of sweetpotato. The mucilage from sweetpotato has also been demonstrated to have antioxidant activities against both hydroxyl and peroxyl radicals (Huang *et al*., 2006). Several other investigators have reported the antioxidant activity and suppression of melanogenesis of melanoma B16 in mice by sweetpotato extracts, as well as the reducing effects of sweetpotato juice against carbon tetrachloride-induced liver injury (Hayase and Kato 1984; Shimozona *et al*., 1996; Suda *et al*., 1997).

2.3.2 Low glycaemic index and anti-diabetic properties

The glycaemic index (GI) of steamed, baked or microwaved sweetpotato was found to range from 63-66, as compared to 65-101 for potatoes cooked by the same methods (Soh and Brand-Miller, 1999). This was confirmed by other workers (Allen *et al*., 2012), who obtained GI values of 63 ± 3.6, 64 ± 4.3 and 66 ± 5.7 for steamed, baked and microwaved sweetpotato respectively. Allen *et al*. (2012) further demonstrated the low glycaemic index of raw sweetpotato, especially the skin, and showed that a commercial extract of the cortex of the variety, tended to lower the glycaemic index of english potato to a level that was not different from the raw sweetpotato peel. An extract of the sweetpotato variety *Caiapo* has been demonstrated to have beneficial effects on plasma glucose and cholesterol levels of patients with type 2 diabetes, according to the results of a randomized, double-blind, placebo-controlled trial (Hung, 2004). The study confirmed the beneficial effects of *Caiapo* on fasting and postprandial plasma glucose levels, as well as on cholesterol, in patients with type 2 diabetes. Anti-hyperglycaemic (antidiabetic) effect of sweet potato anthocyanins (from purple-fleshed varieties) included in rat diet has also been reported (Konczak *et al.,* 2004).

2.4 ISSUES IN POSTHARVEST HANDLING OF SWEETPOTATO

2.4.1 Production and harvesting practices

Sweetpotato does not show any clear signs of developmental maturity, unlike in other root crops; there is no senescence and the storage roots continue to grow indefinitely. Under favourable conditions the storage roots will keep on enlarging until they get to a stage where the interior becomes anaerobic and begins to rot (Kays, 1998). Unlike crops such as maize in which developmental stages are well defined and can be easily identified (for example on the basis of number of days after pollination), the parameter for defining developmental stages of sweetpotato roots has not been established. In sweetpotato storage root, tuberisation or secondary thickening is a complex developmental process characterized by the cessation of root elongation, genesis of primary and secondary vascular cambium, anomalous and interstitial cambia, increase in radial growth by increased rate of cell division, cell proliferation and cell expansion. This is concomitant with the massive deposition of starch and storage proteins such as sporamin which eventually result in enlargement of storage roots (Ravi *et al.,* 2009). Due to this unique feature, the crop is harvested when majority of roots have reached the size desired by the producer, which is often around four or five months but can be up to six or more months after planting. This makes harvesting time very subjective, mainly at the discretion of the farmer. Harvesting time or maturity stage is known to have an impact on the composition and eating quality of various crops, and this includes sweetpotato.

2.4.2 Shelf-life of fresh produce

Under natural tropical conditions (without cooling facilities), sweetpotato fresh roots are marketable for only about 2-3 weeks, although under controlled conditions storage for up to a year is achievable (Rees *et al.*, 2003). Sweetpotato has numerous varieties, and the effect of variety on storage duration has been observed to be a very important factor. Several workers have reported on significant differences in the shelf-life of sweetpotato varieties under tropical conditions. Data (1985) observed that after 10 days of storage some varieties sprouted, shrivelled or decayed while others did not; after 90 days in storage, however, sprouting and shrivelling became severe in all the varieties studied. This is due to the fact that varieties differ in respiration rate, dormancy and susceptibility to invasion by pathogens and insect pests. Sweetpotato has numerous varieties, and the effect of variety on storage duration has been observed to be a very important factor; several workers have reported on significant differences in the shelf-life of sweetpotato varieties under tropical conditions (Acedo Jr *et al.,* 1996; Gautam 1996; Oirschot *et al.,* 2006). The effectiveness of any storage method developed to extend sweetpotato shelf-life under natural tropical conditions will depend to some extent on the variety being stored; it is therefore important for breeding programs to select for storability as a desirable trait in the development of new sweetpotato varieties (Diamante and Data, 1986). Sweetpotato storage roots continue to maintain metabolic activity after harvest and because they are detached from the supply of photosynthates from the leaves, they rely on their own internal food reserves for such activity. This leads to changes in both the physical appearance and chemical composition of the fresh roots in storage; the extent of these changes depends on the cultivar and the storage method applied (for example, conditions of temperature and relative humidity). According to Zhang *et al*. (2002), sweetpotato roots stored for 180 days after harvest showed a decrease in starch content and increase in alpha-amylase activity, while glucose and sucrose concentrations increased early in storage then reduced later on. These changes also have an influence on cooking and sensory properties. Zhang *et al*. (2002) observed that flour pasting viscosity generally reduced with storage. In general, when the shelf-life of sweetpotato fresh storage roots are successfully prolonged over a long period (for example up to one year) there may be a decline in sensory qualities such as changes in texture and flavour.

2.4.3 Appropriate storage technologies

Storage of sweetpotato is very necessary to extend its availability beyond the main harvesting season. Due to its perishability and seasonal nature which leads to fluctuations in supply under tropical conditions, many storage methods have been developed and tested but there still remains a huge potential for improvement. Adequate storage is a major and basic need if the crop is to be successfully industrialized, since year-round raw material supply is essential for any commercial venture.

2.4.3.1 Low temperature storage

In tropical climates, temperature management is critical in the efficacy of any storage system designed for perishable produce. For sweetpotato the optimal environment for long-term storage of fresh roots is low temperature ranging from 13 to15°C and high relative humidity around 8595% (Kushman, 1975; Picha, 1987; Walter and Schadel, 1982). At higher temperatures and lower relative humidities, there is excessive loss of weight through a combination of respiration and transpiration activities (Picha, 1986); storage at temperatures higher than 19°C results in considerable sprouting after several months, with an associated loss in root quality and marketability (Kays, 1998). At low temperatures, the activities of various pests e.g. weevils (*Cylas* sp.) and microbial pathogens are effectively suppressed, although storage of roots below 12°C also tends to result in chilling injury; the effective control of temperature within the optimal range throughout storage is therefore required.

2.4.3.2 Controlled atmosphere storage

Sweetpotato can be stored under Controlled Atmosphere (CA) conditions that reduce the rate of respiratory losses and increase total sugars (Chang and Kays, 1981). However, further research on oxygen and carbon dioxide concentrations and ratios, timing, and varietal requirements are needed. Uncured roots have been shown to decay rapidly when stored in low oxygen, although after curing, 2 and 4% oxygen concentrations did not appear to be harmful to roots during CA storage (Delate and Brecht, 1989). The beneficial effects of CA storage for sweetpotato fresh produce has not yet been shown to outweigh the additional expense involved, especially in less developed economies. Achieving and maintaining such controlled environments however, can be expensive, as it requires high-level infrastructure and access to utilities such as electricity and water supply.

2.4.3.3 Indigenous storage methods

In low-income areas, especially in parts of Africa, traditional storage methods such as pit and clamp storage are practiced although these are associated with high rates of postharvest losses. Room storage and gradual or piecemeal harvesting are other strategies applied by farmers in trying to extend their supply of fresh roots to the market. These strategies are however, also challenged by rodent attack, dehydration and severe infestation by weevils. In Nigeria, it was found that leaving tubers unharvested to circumvent storage problems actually led to 12 - 90% losses due to weevil

infestation (Tewe *et al.,* 2003). In the Central Region of Ghana, it was reported by OseiGyamera (2000) that 30% of sweetpotato farmers did not store their produce (left unharvested),
15% stored in sacks and boxes, 10% stored in pits and 45% stored on platforms in rooms. Under these conditions, an average of 50% of the harvested roots stored well for less than two weeks, 25% for two to four weeks, 15% for four to six weeks and 10% for six weeks. However, it is reported that when appropriate technologies are applied, sweetpotatoes can be successfully kept in long-term storage for several months up to even a year (Picha 1987; Lewthwaite *et al.,* 1997; Hu *et al*., 2011). In Ghana, other studies have focused on various improved storage strategies for sweetpotato including the use of evaporative cooling barns and modified traditional structures, with varying levels of success (Tortoe *et al*., 2008; Teye, 2010; Abano *et al*., 2011).

2.4.4 Pre-storage treatments

2.4.4.1 Curing

Curing is an old practice normally carried out right after harvest for most root and tuber crops prior to actual storage. For sweetpotato, it is done by placing fresh roots in a warm environment (30 °C ± 2) with high relative humidity (approximately 90%) for about four to seven days (Walter and Schadel, 1982). In advanced countries, this is achieved using specialized facilities known as curing rooms, with well-regulated controls that maintain the stable environmental conditions required for efficient curing. The purpose of curing is to rapidly heal any damage, for example cuts and bruises sustained during harvest, thereby minimizing decay and water loss. Freshly harvested sweetpotatoes have a thin skin that is very susceptible to breakage, and skin toughness usually improves with curing and subsequent storage (Villavicencio *et al*., 2007; Boyette *et al*., 1997). In parts of Sub-Saharan Africa and other low income economies, fresh roots after harvest are often gathered in heaps and covered with vines on the field, prior to packing and transportation from the field. This is often regarded as 'accidental curing', although under those circumstances the prevailing humidities may not be adequately high enough for optimal wound healing and skin toughening. The reality is that in the developing world, standard curing is not consciously practiced in a consistent way since it requires considerable mechanization and infrastructure. Such facilities are easily accessible in advanced economies where standard curing practices for sweetpotato and other root crops are well-established (Walter and Schadel, 1982; Kays 1998; Edmunds *et al*., 2008).

2.4.4.2 Heat treatment

Heat treatments have been used widely as non-chemical means to stabilize postharvest quality and reduce pathogen levels and disease development of various horticultural products. For sweetpotato hot water treatment was found to significantly inhibit sprouting and decay in fresh roots during long-term storage (Hu *et al*., 2011). Weevil infestation during storage was also controlled when sweetpotato was immersed in hot water at 52^{o}C, prior to storage (Tewe *et al*., 2003).

2.4.4.3 Surface coatings

Coating the surface of horticultural products with natural polymers is a treatment used on a number of commodities including citrus fruits, apples and on a lower scale cassava and sweet potato (Hoa *et al*., 2002; Sunmola and Bukoye 2011). For example, waxing is a simple technique that slows down the rate of moisture loss, maintains turgor and plumpness and modifies the internal atmosphere of the commodity (Shewfelt, 1986). Waxing of cassava for instance can extend its storage life from a few days up to about 30 days, preventing discoloration in the vascular tissue. This technique has been applied to sweetpotato as a pre-storage treatment, solely and in combination with other coatings, for example 3% w/v calcium chloride dip (Sunmola and Bukoye, 2011). Application of wood ash as a pre-storage treatment to inhibit microbial pathogen and insect proliferation has also been reported (Tewe *et al*., 2003; Hall and Devereau 2000; Teye *et al*., 2011).

2.5 UNDERSTANDING SWEETPOTATO PRODUCT QUALITY

Sweetpotato is often expected or assumed to have processing characteristics similar to or exactly like other starchy root and tuber crops. Limitations in the adoption and utilization of sweetpotato in many parts of Africa and especially in Ghana, could be partly attributed to hitches encountered whenever this assumption is brought to bear in the handling and processing of this unique commodity. To enhance expansion in domestic and commercial utilization of the crop, it is important to appreciate the presence and activity of various intrinsic features that bring about significant changes during postharvest storage and also during cooking or processing.

2.5.1 Unique enzyme activities

Key among the enzymes in sweetpotato are alpha-amylase, beta-amylase, starch phosphorylase, sucrose synthase and polyphenol oxidase. Among these, the ones that have direct bearing on cooking and eating qualities are the amylases and polyphenol oxidase. Endogenous amylases play an important role in the processing of sweetpotato, causing changes in taste and texture during cooking. Beta-amylase occurs mainly in the seeds of higher plants and in sweetpotato. Sweetpotato is a very rich source of the enzyme, which accounts for about 5% of total soluble proteins in the storage root. This is quite substantial compared to other root crops, which usually contain only trace amounts of the enzyme (Nakamura *et al.*, 1991). Beta-amylase action during cooking, produces maltose (Kiribuchi and Kubota, 1976). During cooking, when sweetpotatoes are heated to starch gelatinization temperature (60 - 78^{o}C), α- amylase rapidly degrades the starch to lower molecular weight dextrins which are concurrently hydrolyzed into maltose by β-amylase (Truong and Avula, 2010). The formation of maltose by enzyme action results in an increase in sugar content and sweetness of the final product, as well as changes in texture due to reduction in starch content. In the quest for sweetpotato varieties with very stable cooking characteristics in terms of initial and final sugar content, Plant Breeders came up with a 'Beta-amylase null' variety with no beta-amylase activity at all (Kumagai *et al*., 1990). Levels of both alpha- and beta-amylase are known to undergo various changes during storage of the fresh roots (Morrison *et al*., 1993). Morrison *et al*. (1993) proposed that sweetpotato germplasm could be separated into four general classes based on enzyme-related changes during cooking, and initial sugar content:

Class 1: Low starch hydrolysis /low initial sugar concentration

Class 2: High starch hydrolysis /low initial sugar concentration

Class 3: Low starch hydrolysis /high initial sugar concentration

Class 4: High starch hydrolysis /high initial sugar concentration

At one extreme end, Class 1 types have low inherent sugar contents and also produce very little maltose upon cooking, resulting in a product that is bland and has a substantially reduced flavour impact. These are staple-types and often do not undergo much starch hydrolysis due to inhibition of β-amylase synthesis or a non-enzyme mediated mechanism. Class 4 types are at the other extreme, with high alpha- and beta-amylase enzyme activities leading to high levels of sweetness (Morrison *et al*., 1993) after cooking/processing.

The browning potential of various fruits and vegetables has been shown to be directly related to the ascorbic acid level, polyphenol content, the polyphenol oxidase (PPO) activity or a combination of these factors (Golan *et al*., 1977; Walter and Purcell, 1980). Disruption of sweetpotato cells in the presence of oxygen causes differing degrees of brown discoloration to occur, depending on the variety. When browning occurs in processed sweetpotato, it is a serious quality defect. Other reports show that many fruits such as papaya and mango, which are high in carotenoids, are characterized by a low browning potential (Arya *et al.*, 1983; Sharon-Raber and Kahn, 1983). The introduction and promotion of yellow- and orange-fleshed sweetpotato varieties with different levels of beta-carotene may contribute towards solving issues of browning during processing.

2.5.2 Characteristic flavour

Flavour is a primary criterion in food selection, and flavour preference for sweetpotato is known to vary with ethnic background and geographical location (Kays and Horvat, 1983). While used as a staple in many countries, sweetpotato is generally not the first choice over other crops such as rice or yam, even though it is more nutritious than most staple crops. This has been attributed, among other things, to the distinct flavour of sweetpotato which tends to be quite dominant in many varieties, and may limit the frequency and quantity of consumption (Kays, 2005a). Sweetness is the central feature that significantly modulates the overall flavour of sweetpotato not only through its direct impact on taste but also through the role of monosaccharides as precursors in the synthesis of several key aroma compounds. There is substantial variation in flavour and taste within the sweetpotato genepool, due to the endogenous sugars (sucrose, glucose, and fructose) present in raw roots as well as the formation of maltose and various aroma compounds during cooking (Morrison *et al.,* 1993; Wang and Kays, 2000; Wang and Kays, 2003). A 'non-sweet' breeding line GA90-16 was developed at the University of Georgia with major distinguishing traits being reduced aroma, exceptionally low endogenous sugar content, low maltose formation during cooking and firm texture in the cooked product. GA90-16 may have excellent potential in breeding programmes for developing commercial cultivars with low flavour impact for use as a staple food, tailoring the flavour for specific consumer preferences and product uses and thereby increasing utilization of the crop worldwide (Kays *et al*., 2001; Kays *et al*., 2005).

2.6 OPPORTUNITIES FOR FURTHER RESEARCH IN CROP QUALITY AND UTILIZATION

The International Potato Center (CIP) conducted a survey in developing countries to elicit perspectives on the most important constraints facing poor and small-scale sweetpotato growers in their countries.

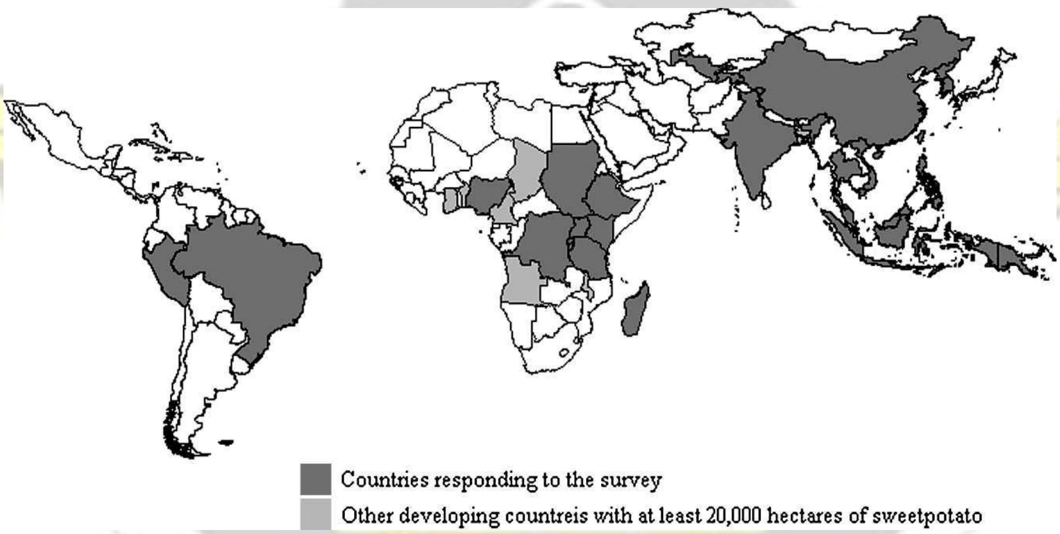


Figure 2.1 Survey of priority needs of sweetpotato farmers in developing countries
Source: Fuglie (2007)

The identified needs or priority areas that scored highest in most of the major sweetpotato producing areas, specifically in developing countries, were:

1. Control of viral diseases and improvement in planting material quality and access
2. Development of improved varieties with early maturity, high and stable yields

3. Development of medium and micro-industries for sweetpotato processing
4. Reforms in national agricultural and food policies, which should lead to improvements in storage facilities and infrastructure

The third and fourth priority areas are of direct relevance to the food industry, and the survey data indicated that compared with earlier surveys there now seemed to be a greater need for postharvest utilization research, especially in sub-Saharan Africa (Fuglie, 2007). In the tropical world, challenges in root crop production and utilization mainly have to do with storage losses and limited processing technologies.

CHAPTER THREE

3.0 TISSUE MICROSTRUCTURE, WOUND-HEALING RESPONSE AND STORAGE CHARACTERISTICS OF SWEETPOTATO FRESH ROOTS

3.1 INTRODUCTION

Sweetpotato is a fast-growing, high-yielding and very nutritious crop which also adapts well to climatic irregularities; it has great potential to impact positively on national development. Most of the world's harvested sweetpotato crop is used for table consumption with a small percentage going into industrial uses and animal feed (Lin *et al.*, 2007; Oke and Workneh, 2013). The crop plays considerably different roles in human diets in different parts of the world. It has a large potential to be used in developing economies as a cost-effective nutritional intervention for public health, if only the levels of production and utilization can be increased and sustained.

One major drawback in sweetpotato's value chain is its high perishability under ambient tropical conditions. Such perishability poses a challenge to utilization in tropical areas that lack the required infrastructure for extending shelf-life, due to high prevailing temperatures. A study on several cultivars in East Africa reported that in tropical developing countries, under marketing conditions sweetpotato have a shelf-life of only one to two weeks (Rees *et al.*, 2003; Oirschot *et al.*, 2003). A study in Nigeria also reported that many farmers discarded their harvested roots after about two (2) weeks due to high perishability (Tewe *et al.*, 2003). During harvesting and handling, various levels of damage may occur, thereby further compromising the shelf-life characteristics.
Sweetpotato has a delicate or thin skin and is very susceptible to cuts and loss of skin, thereby exposing underlying tissue. This can lead to an increased rate of moisture loss, weight loss, shrivelling of the root surface, increased susceptibility to pathogen attack, and unattractive appearance (Villavicencio *et al.*, 2007). In Ghana, storage for several weeks has been achieved under some improved conditions and modified traditional systems depending on the agroecology (Tortoe *et al.*, 2008; Tortoe *et al.*, 2010; Teye, 2010; Abano *et al.*, 2011). However, this has come with various associated costs and sustainability issues. After harvest, curing the fresh roots for

some days is known to heal wounds and generally improve the toughness of the skin, leading to better chances of good storage quality. Curing requires a stable temperature (approx. 30^{o}C) and high relative humidity (>90%) for a number of days up to a week; the duration may vary depending on the variety (Walter and Schadel, 1982; Picha, 1986). Curing before storage and marketing is therefore a well-established and standardized practice in areas such as the United States of America. Low-temperature storage (normal refrigeration) is unsuitable for sweetpotato as it leads to chilling injury (Padda and Picha, 2008). High-end facilities with controlled atmosphere and negative horizontal ventilation technologies for curing and subsequent storage have therefore, been developed in advanced economies and commercial sweetpotato varieties are stored for up to a year (Boyette *et al.,* 1997). In many developing economies, however, there are no well-established systems for efficient long-term storage. In the absence of such facilities, seasonal gluts and shortages accompanied by large losses have hindered the growth and industrialization of the sweetpotato sector. Adequate storage of fresh roots is a major and basic need if the crop is to be successfully industrialized, since year-round raw material supply is essential for any commercial venture. Various simple strategies have been explored for the effective curing of yams (*Dioscorea* spp.) in Ghana without the use of automated facilities (CSIR, 2014) and these strategies can be applied to sweetpotato. Due to the broad genetic diversity of the crop, however, varietal differences in the efficiency of curing on wound healing response must be factored into specific recommendations for production and utilization (Aked, 2001). Diversity of the crop offers opportunities to capitalize on various important traits. There is the need to understand the physiological basis for differences in storage stability, as well as the storage characteristics of different varieties available in Ghana. Characterization of improved varieties to understand important physiological traits, and the generation of basic information that can be applied to improve shelf-life and reduce losses would go a long way to sustain the promotion and industrialization of this remarkable crop.

Another factor that may have impact on product quality and utilization is the diversity in fresh roots tissue microstructure. In other parts of the world, for example the United States, varieties that are predominantly produced and marketed have been studied in detail (Schädel and Walter, 1981; Villavicencio *et al.*, 2007) and information on cellular-level features of those varieties can be accessed by industry and other stakeholders. In the Irish potato industry for instance, microstructural characteristics such as parenchyma cell size, cell wall composition and thickness have been reported to have a considerable effect on the final texture of cooked potatoes (Bordoloi *et al*,, 2012). Advanced microscopic techniques (confocal scanning laser microscopy and electron microscopy) have been used by various researchers to study the microstructural characteristics of potato (Reeve 1970; Bordoloi *et al.*, 2012). Such information on sweetpotato varieties is however, not much documented in Ghana. As a step forward in harnessing the great potential of this unique crop for food security and national development, there is the need to study local varieties for more information on such traits, help develop systems to reduce perishability of the fresh roots and also improve upon product quality through targeted varietal selection.

The aim of this study was to characterize high-yielding and disease-resistant Ghanaian varieties of sweetpotato for physical and physiological attributes of the fresh roots in terms of tissue microstructure, storage stability and wound healing response as a means of obtaining key information for relevant stakeholders such as breeding programmes, commercial producers and marketers.

3.2 MATERIALS AND METHODS

Six (6) improved high-yielding and disease-resistant varieties of sweetpotato were obtained from CSIR-Crops Research Institute, Fumesua, Ghana. The selection captured varieties with a broad spectrum of dry matter content, skin colour and flesh colour, which are basic traits for diversity usually applied in selection breeding or crop improvement. Local names and colour description are given in Table 3.1.

Table 3.1. Names and description of sweetpotato varieties used in the study

NAME	SKIN COLOUR	FLESH COLOUR
Apomuden	Reddish brown	Orange
Bohye	Light brown	Light orange
Faara	Purple	Off-white
Hi-starch	Pinkish brown	Yellow
Ligri	Cream	Cream
Okumkom	Light purple	White

Skin colour and inner flesh colour are shown in Plate 3.1.

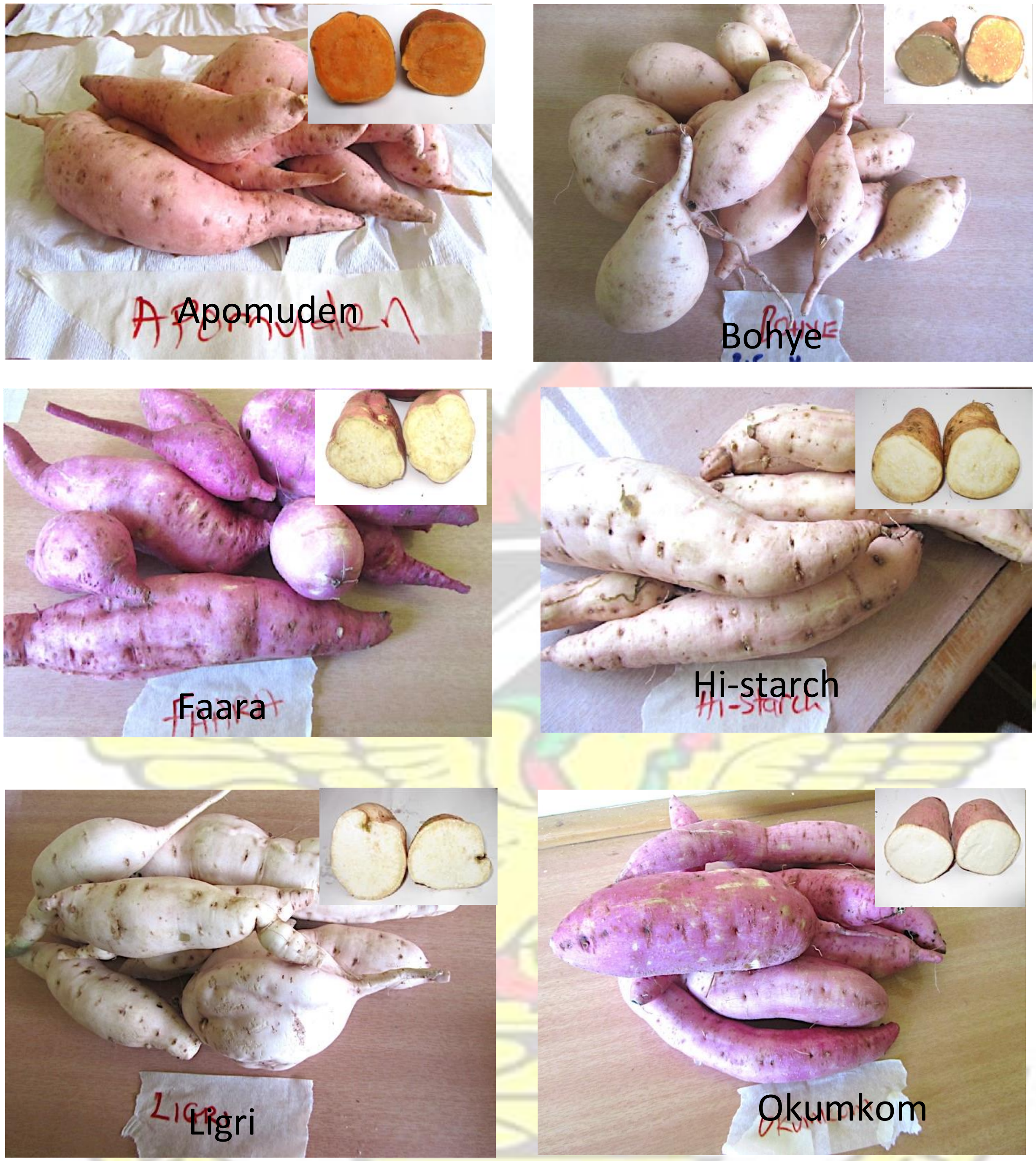


Plate 3.1 Fresh roots samples of six (6) improved high-yielding and diseaseresistant varieties of sweetpotato used for the study

The varieties were cultivated under identical management practices at Fumesua Station of CSIR-Crops Research Institute and harvested at four and five months.

3.2.1 Microstructure of parenchyma tissue (cell shapes and relative sizes)

Healthy, undamaged roots of six sweetpotato varieties were selected after harvest and thin sections (approx. 20 – 30 microns) of storage parenchyma tissue were taken from the middle portion with a sharp surgical blade using free-hand sectioning. According to Belehu (2003), the internal tissues of sweetpotato storage roots have homogeneity along their axis from end to end.

i. *Anatomy of starch-filled parenchyma cells*: cross-sections were stained with two drops of Iodine solution and two drops of Fast Green solution.
ii. *Assessment of relative cell wall thickness*: longitudinal sections from the innermost tissue were washed by dipping in distilled water and gently swirling with a soft brush for 30 seconds (to remove much of the starch from the cells), and stained with two drops of 1 % aqueous Safranin.

Sections were observed using a light microscope (Novex, Holland) at x100 magnification; photomicrographs were captured using a digital camera (Canon SX210 IS) attached to the eye piece of the microscope.

3.2.2 Storage characteristics of fresh roots (resistance to weight loss)

i. Varietal differences and influence of immediate storage environment

Healthy looking roots from six (6) varieties (*Apomuden, Faara, Hi-starch, Okumkom, Ligri* and *Bohye*) were selected after harvest, washed and allowed to air-dry for 24 hours. Approximately 3 kg of each variety was placed in two different types of packaging:

1. plastic bowls (45cm in diameter, 18cm deep), uncovered
2. woven polypropylene bags (locally referred to as fertilizer sacks), securely tied

Samples were then kept in a storage barn which was made of bamboo with a thatched roof, and situated under shade. Each treatment was set up in duplicate, and placement within the barn was randomised. Temperature and relative humidity throughout the storage period were recorded by data loggers (Model: Easylog USB, Lascar Electronics Co. Ltd., UK). Weights were recorded after 41 days in storage, using a top-loading digital scale. Weight loss (%) at each time of assessment was calculated as:

$$\text{Weight loss (\%)} = \frac{\text{Original weight} - \text{Current weight}}{\text{Original weight}} \times 100$$

ii. Influence of root size

To investigate the influence of root size on storage performance, four (4) varieties were selected based on observed differences in storage stability from the first storage experiment (*Faara*: very good stability; *Apomuden*: poor stability; *Hi-starch* and *Okumkom*: intermediate stability). They were harvested and separated into two (2) broad size categories: small-size (140 - 250g average root weight) and large-size (330 - 602g average root weight). For each sample, approximately 3kg of roots was placed in a polypropylene sack, securely tied and placed in the bamboo storage barn. Weights were recorded at 15, 35, 46, 57 and 64 days in storage. Weight loss (%) at each time of assessment was calculated as previously stated.

3.2.3 Wound healing response

Experiment 1 (Varietal wound healing characteristics): Freshly harvested sweetpotato storage roots of the six varieties were subjected to uniform wounds on the epidermis (or skin) using a potato peeler to peel off strips of skin about 2cm wide and 1 - 1.5mm deep. The artificiallywounded samples were then kept in an environment that favours natural wound healing, i.e. a curing environment (temperature range of 25-35ºC and relative humidity 90-95% (Edmunds *et al.*, 2008). This environment was created by keeping the wounded roots securely tied in woven polypropylene sacks and placed in the laboratory to achieve fairly stable range of temperature and humidity day and night. Formation of protective lignified cell layers and new skin cells (or wound periderm) at the site of the wounds as a natural physiological response was assessed six days after wounding. Wound healing in sweetpotato is reported to be completed within four to seven days after wounding (Walter *et al.*, 1989).

Experiment 2 (Differences in healing response due to wound location): Four (4) varieties were used based on observed differences in their storage stability (*Faara*: very good stability; *Apomuden*: poor stability; *Hi-starch* and *Okumkom*: intermediate stability). Uniform wounds were made in the epidermis at three regions of the storage roots (proximal or vine end, mid-region and distal or tail end) using a potato peeler to peel off a strip of skin about 2cm wide and 1 - 1.5mm deep. Samples were then kept at 25-35ºC and 90-95% relative humidity. Formation of protective lignified cell layers and new skin cells (or wound periderm) at all wound locations was assessed daily using light microscopy, and micrographs were captured four (4) days after wounding (this was the earliest time at which well-differentiated cell layers were observable).

Microscopy: Cross-sections of tissue from previously-wounded roots were obtained with a sharp surgical blade using free-hand sectioning and stained on glass slides using Phloroglucinol-HCl (which reacts with lignin to form a red colour); the progress of wound healing was observed using a light microscope (Novex, Holland) fitted with a digital camera (Canon SX210 IS).

Preparation of Phloroglucinol-HCl solution: Two grams of phloroglucinol powder was weighed into a conical flask and dissolved in 80ml of 20% ethanol. Using a fume hood, 20ml of concentrated HCl was carefully added, swirling constantly and gently to mix well. It was then allowed to cool, transferred into an amber bottle and stored in a dark place away from direct light.

Solution was discarded after one to two weeks, or when it showed signs of discolouration.

3.3 RESULTS AND DISCUSSION

Tissue microstructure

Differences were observed in storage parenchyma tissue cell shapes and arrangement for the sweetpotato varieties studied (Plate 3.2).

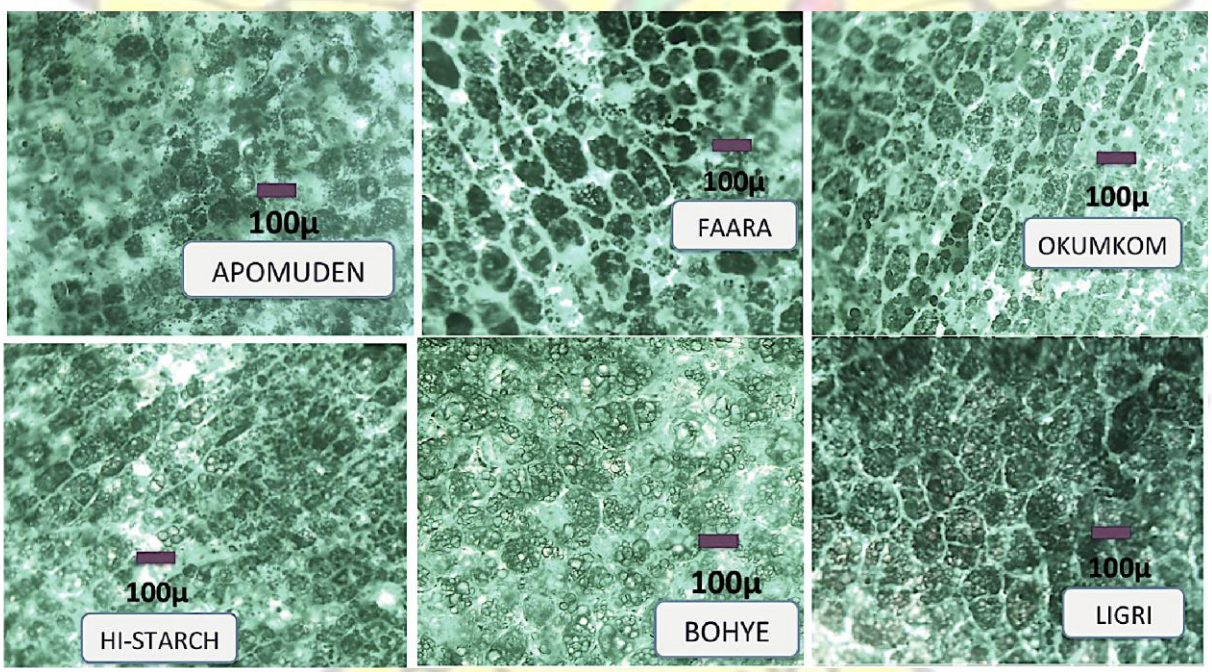


Plate 3.2 Cross-sectional micrographs of sweetpotato fresh root inner parenchyma tissue stained with Fast Green and Iodine, showing shapes and sizes of starch-filled cells and the nature of intercellular spaces (Purple bar = 100µ) Development of storage roots as edible plant parts is a function of the increase in number of

parenchyma cells through cell division and proliferation, and massive filling of these cells with starch (Ravi *et al.*, 2009). Amyloplasts (starch bundles) in *Apomuden* were small in size and were also found to be relatively sparsely populated. The largest amyloplasts were observed in *Bohye* and *Ligri*, and were most densely populated in *Hi-starch* and *Ligri*. Amyloplasts in *Hi-starch* had elongated cylindrical shapes while in the other varieties amyloplasts were in various forms of rounded polyhedral/polygonal shapes. Large amyloplasts to some extent have been linked with large actual cell sizes as well as larger average size of starch granules (Bordoloi *et al.*, 2012). In Irish potato, closely-packed parenchyma cell arrangements were found to be associated with higher hardness values; other textural parameters (fracturability and cohesiveness) of different varieties were observed to be related to their microstructural features although the influence of dry matter and starch contents was also observed (Singh *et al.*, 2005).

In a longitudinal plane, parenchyma cell shapes and arrangements appeared to be quite similar for the six varieties studied and showed mostly rounded polygonal shapes. *Bohye* however seemed to have very thin cell walls while *Hi-starch* had relatively thick cell walls, with others showing intermediate thickness (Plate 3.3).

Plant cell walls constitute the key structural components of many plant-based foods and also play a central role in determining important quality characteristics, especially texture (Waldron *et al.*, 1997; Waldron, Parker and Smith 2003).

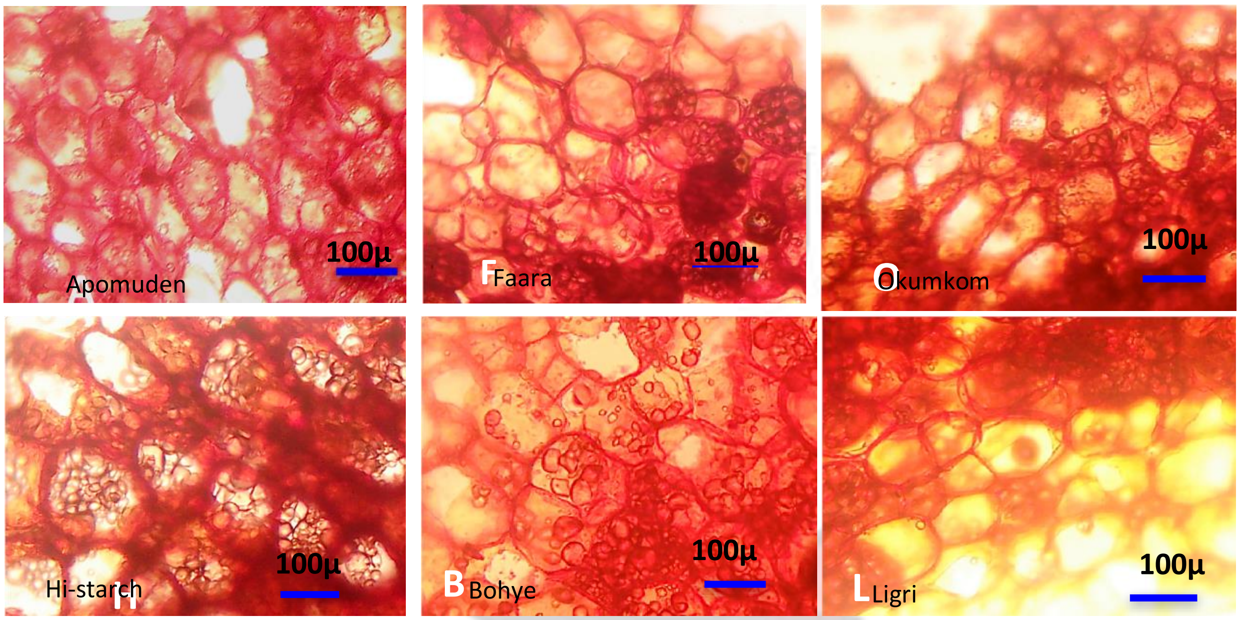


Plate 3.3 Micrographs of longitudinal sections of fresh parenchyma tissue showing cell shapes and relative thickness of cell walls. (Blue bar = 100 microns)

Texture is a complex trait and in plant-based foods, it is determined by the interaction of various factors including cell wall chemistry, cell size and shape, cell packing and cell turgor. Intercellular adhesion of plant cells depends on pectin which is the major constituent of the middle lamella. An earlier study demonstrated that among the root crops, sweetpotato cell wall material had the highest amount of pectin (Salvador, 2000). More studies are required in linking microstructure to the product quality of specific sweetpotato varieties.

Storage characteristics of sweetpotato fresh produce

Varietal differences and type of packaging used were found to have significant influence ($p<0.01$ and $p<0.05$ respectively) on the rate of weight loss during storage (Table 3.2).

Table 3.2 Influence of varietal differences and packaging material (micro-environment) on fresh roots weight loss after 41 days' storage of six sweetpotato varieties in a barn

	Total weight loss (%) after 41 days		
Variety	Bowl	Sack	Average
Apomuden	31.03	25.00	28.02
Bohye	11.02	9.33	10.18
Hi-starch	9.47	8.57	9.02
Faara	8.94	6.67	7.80
Ligri	9.29	8.94	9.12
Okumkom	10.98	7.37	9.18
Average	13.46	10.98	--
Source of variation	*P-value*		
Varieties	0.0002		
Packaging	0.0331		

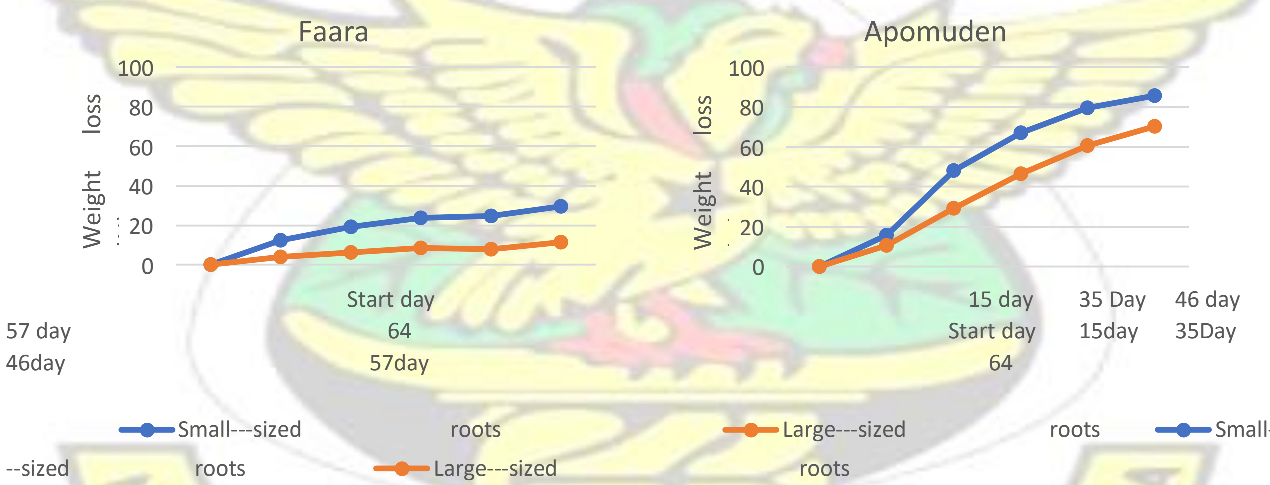
The total combined weight loss for sweetpotato roots kept in sacks was 10.98% while that for those kept in uncovered plastic bowls was 13.46% of original sample weight (Table 3.2). There was therefore better weight retention or resistance to weight loss in the samples that were kept in sacks. However, in both setups the varietal trends were similar, with *Apomuden* being the most susceptible to weight loss through massive dehydration (average weight loss: 28.02%) and *Faara* being the most resistant to such dehydration (average weight loss: 7.80%), retaining more of its original weight than the other varieties after 41 days in storage. The highest weight loss occurred in *Apomuden* kept in uncovered bowl (31.03%) and the lowest was in *Faara* kept in sack (6.67%). Weight loss was calculated as change in weight as a percentage of the original weight of the sample. Influence of both variety and packaging material on total weight loss were significant at p<0.001 and p<0.05 respectively (Table 3.2). Higher relative humidity was achieved with the use of the sacks (Table 3.3), thereby leading to better protection against dehydration that usually accounts for weight loss; ventilation was apparently adequate in preventing build-up of gases and excessive heat.

Table 3.3 Conditions of Temperature (^{o}C) and Relative Humidity (%) recorded in storage environments during sweetpotato storage trial

Environment	Average Temperature (^{o}C)	Average Relative Humidity (%)
Barn ambient	25.65	83.89
Uncovered bowls	25.65	83.89
Inside sacks	25.87	93.73

Water loss through transpiration in sweetpotato and other perishable crops is known to be higher in environments of low relative humidity, and can sometimes be excessive, depending on the variety (Picha 1986; El-ramady *et al.,* 2015). Temperatures lower than $20^{o}C$, in combination with the relative humidity conditions attained would have provided close-to-ideal storage conditions for the sweetpotato varieties. Ideal storage temperature for sweetpotato fresh roots is between $1315^{o}C$, with relative humidity above 90%; under such conditions, using the right infrastructure to maintain a controlled atmosphere, it can be successfully stored for up to one year without sprouting or spoilage (Edmunds *et al*., 2008). Under low-income tropical conditions, achieving temperatures lower than the ambient using zero-energy technologies such as evaporative cooling (Libertya *et al.*, 2013; Basediya *et al.*, 2013) is feasible, but often this is only sustainable with short-term storage of perishable produce (for example high-moisture vegetables) for a few days or a couple of weeks, due to the daily dependence on water and labour availability. Solar cooling has also been studied as another option (Kumar *et al.*, 2015). Under tropical ambient conditions, humidity control (or achieving the desired relative humidity in an environment) is much easier and less complicated than temperature control, as evidenced by the average humidity achieved in the sacks (Table 3.3). This is a plus in sweetpotato storage without the use of electricity; this and other controllable factors when identified can significantly influence storage stability of sweetpotato and contribute to the improvement of shelf life.

Results from storage of sweetpotato roots in two different size categories for a 64-day period showed that small-sized roots lost weight at a faster rate than larger roots (Figure 3.1).



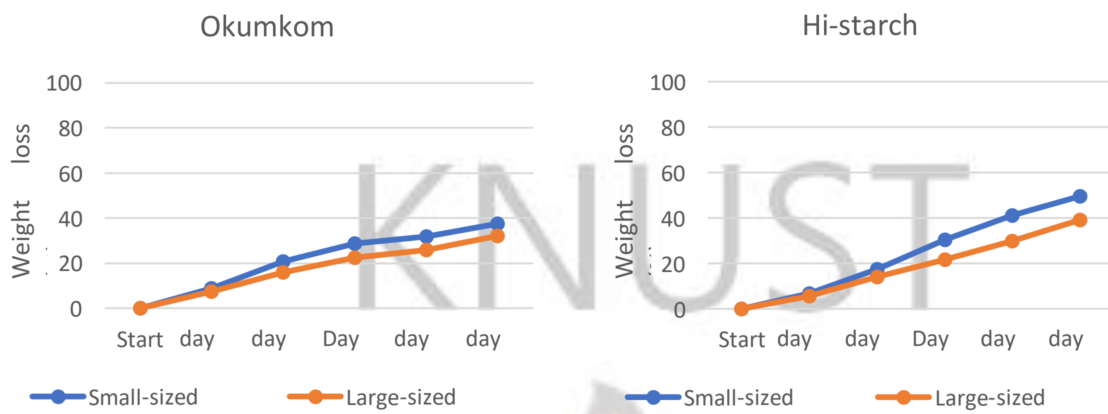


Figure 3.1 Comparative rates of weight loss between small-sized (140 - 250g) and largesized (330 - 602g) sweetpotato root categories

The variety *Faara*, identified in the previous experiment as the most resistant to weight loss, had a total weight loss of 11.49% in large-sized roots at the end of 64 days storage compared to 29.52% in smaller roots (Figure 3.2), indicating a difference of 18.04% in weight loss due to difference in root size.

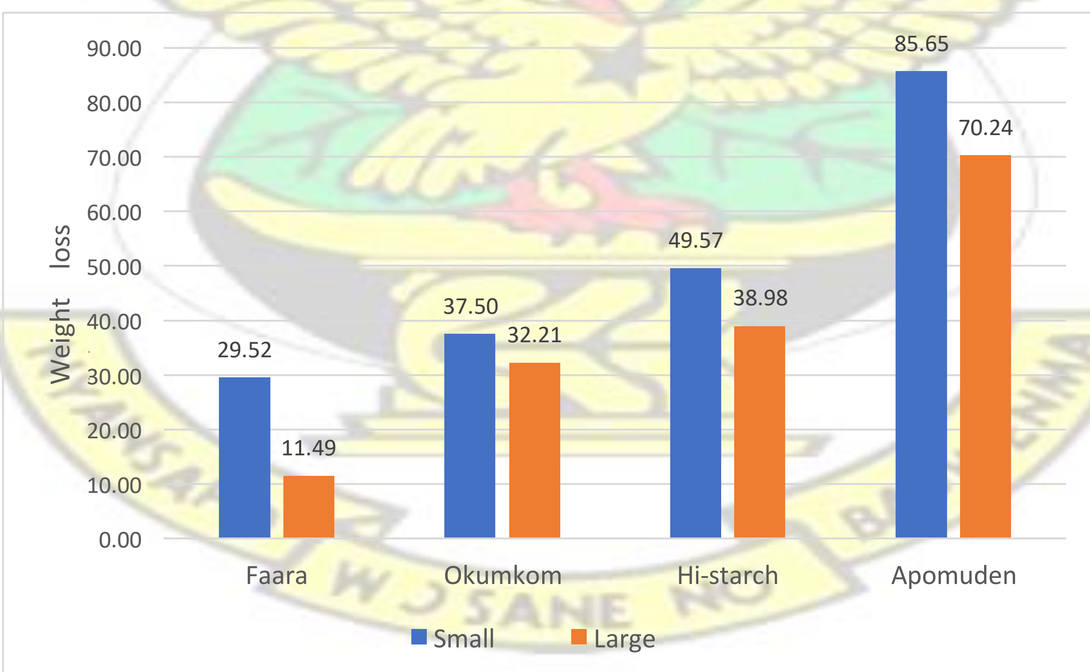


Figure 3.2 Influence of root size on total weight loss (%) in four sweetpotato varieties after a 64-day storage period. Average root weights per category: Small size: 140 - 250g Large size: 330 - 602g

Apomuden, identified as the most susceptible to weight loss in the first experiment, also benefited from size categorization, with larger roots showing less weight loss (70.24%) compared to smaller roots (85.65%) after 64 days in storage (Figure 3.2). This observation could be explained by the fact that in larger-sized roots, diameters are bigger and therefore internal moisture has a longer distance to travel before reaching the surface for evaporation to occur. Hence larger roots had an advantage over smaller roots in terms of resistance to weight loss through dehydration.

These results highlight the relevance of postharvest grading and sorting in the sweetpotato industry. In the USA for instance, after grading, sweetpotato roots 5-9cm in diameter are selected as Number 1 grade for fresh market while smaller roots (2.5-5cm in diameter) are usually sent to processors for canning (Collins, 1995). From the results, improvement in shelf-life of sweetpotato under local conditions can be achieved without electricity through the choice of varieties with inherent traits for good storage stability, selection of larger-sized roots for storage and the maintenance of high relative humidity and lowest possible ambient temperature.

Wound healing response

Variations were observed in wound healing characteristics of the varieties studied. The healed tissue ('new skin') in sweetpotato is made up of an internal band of lignified cells (L) seen as redstained cells after reacting with Phloroglucinol-HCl, and wound periderm (WP) which is an external layer of cork cells (Plate 3.4). Lignins, also known as phenolic polymers, occur in some plant cell walls and generally confer compressive strength, water impermeability and resistance to microbial degradation (Villavicencio *et al.*, 2007). *Apomuden* was found to have very visible lignification or formation of lignified cells, but scanty formation of wound periderm even up to six (6) days after wounding (Plate 3.4). This may explain the high susceptibility of *Apomuden* to moisture loss (measured as weight loss) in the storage studies (Table 3.2) despite its low dry matter content and high sugar content. It was previously reported that low dry matter and high sugar content correlated positively with high ‘lignification score’ and were direct factors that imparted good wound healing response in sweetpotato varieties (Oirschot *et al.*, 2006). This did not apply in the case of *Apomuden*, and the presence or intensity of lignification at the site of a wound may therefore not always be adequate as an indicator of potential storage and shelf-life characteristics.

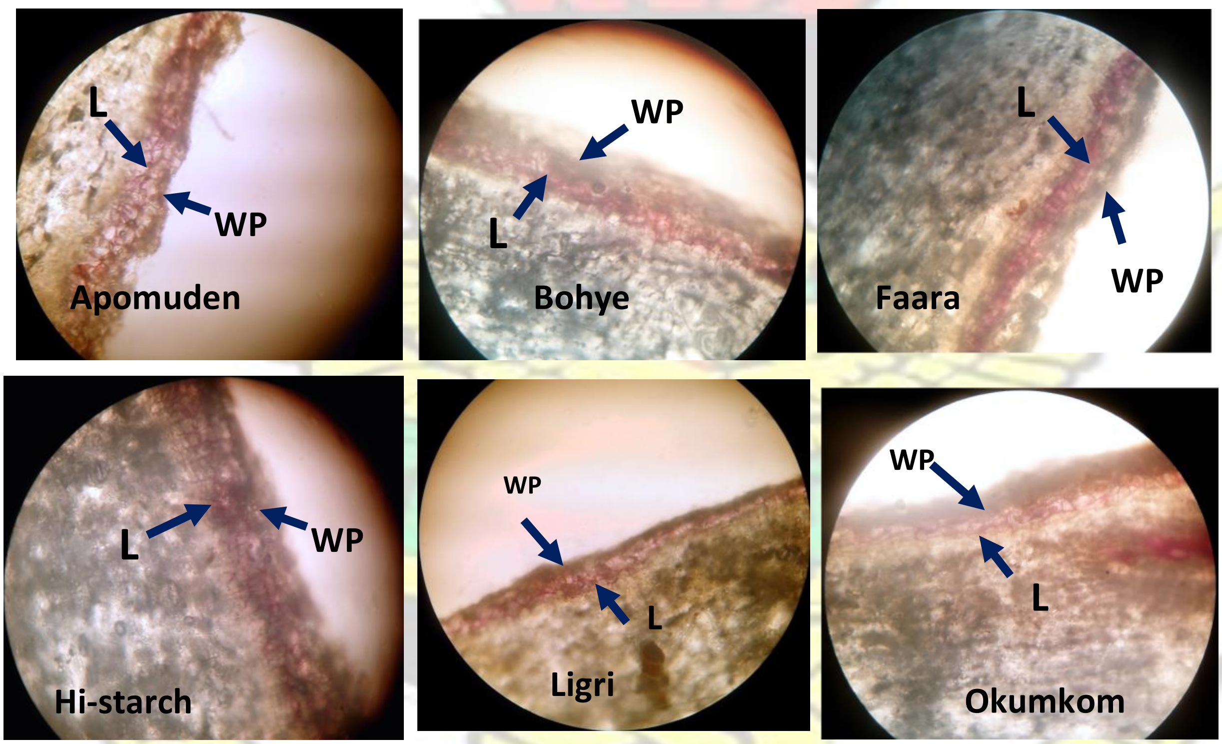


Plate 3.4 Phloroglucinol-HCl stained cross-sections of sweetpotato tissue from six varieties, six (6) days after wounding, showing healed tissue: inner layer of lignified cells (L) and external layer of new wound periderm (WP)

Instead, the speed of wound periderm formation may be more informative and appears to have more association with subsequent storage stability. The lignified layer of cells provides emergency protection from pathogen invasion and excessive moisture loss within some hours after the tissue is wounded, while the thickness of the new wound periderm imparts long-term protection to the underlying tissue. Wound periderm is made up of cork cells (Walter and Schadel, 1982) and is essentially water-proof and impermeable to microbes.

Variations were also observed in the rates of healing based on location of the wound on the storage root, i.e. proximal (vine end), mid-region or distal (tail end) (Plate 3.5).

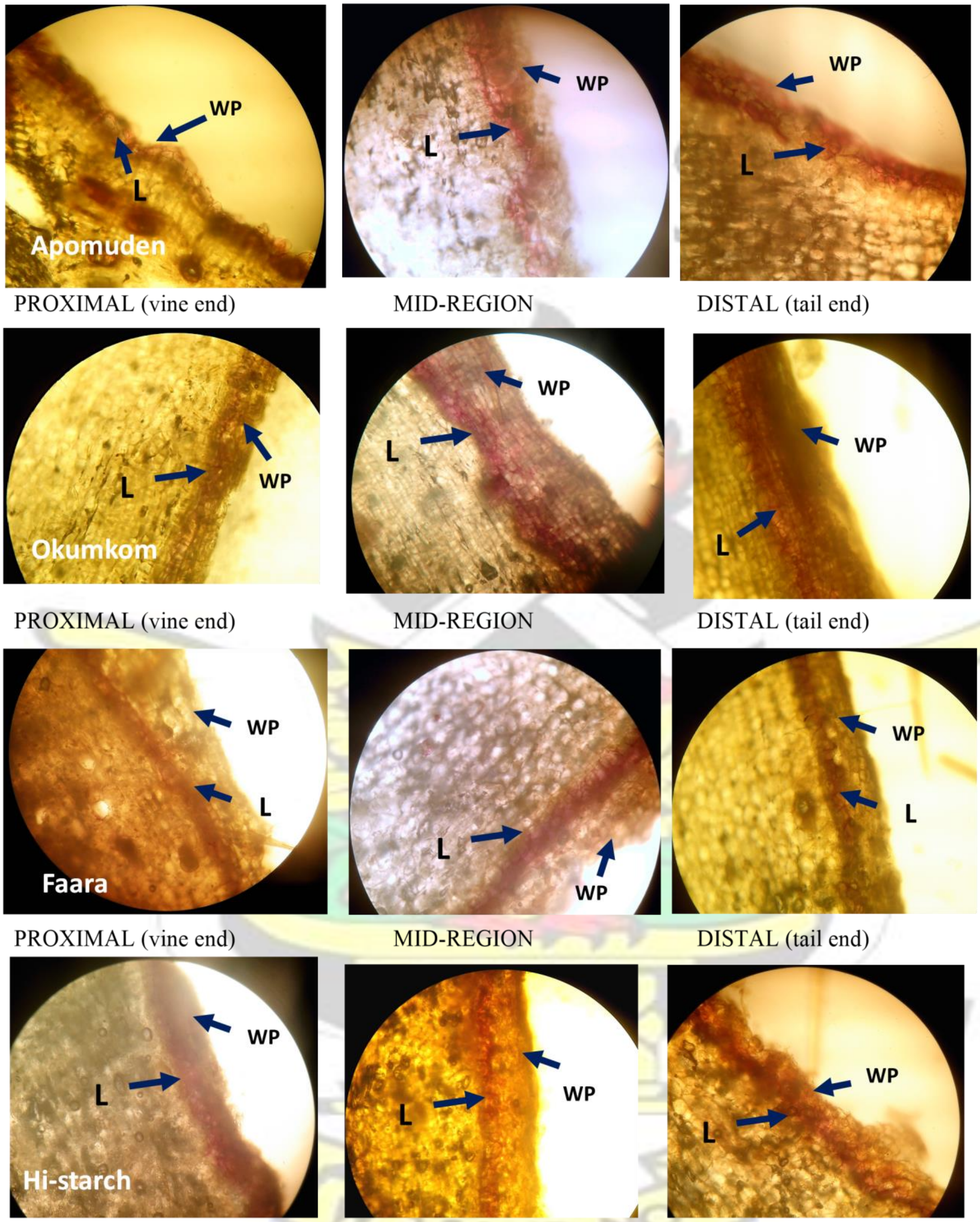


Plate 3.5 **Phloriglucinol-HCl stained cross-sections of sweetpotato tissue 4 days after wounding, showing healed tissue, i.e. inner layer of lignified cells (L) and external layer of new wound periderm (WP) at the proximal, middle and distal sections**

Previous reports on wound healing response in sweetpotato have hitherto focused on wounds at the mid-region or simply not discriminated between different portions of the root. This may have contributed to conflicting reports on evidence of the role of wound healing in storability and shelflife of sweetpotato. Walter *et al*. (1989) were of the view that the relationship was indirect and that factors other than wound healing strongly influenced storage stability, while Van Oirschot (2000) suggested that wound healing ability was a major factor for the shelf-life of sweetpotato cultivars when subjected to sub-optimal curing conditions. Sections from the mid-region of the roots were found to be quite well-protected by 4 days after wounding (with the exception of *Apomuden*), with several layers of wound periderm cells formed over a clear band of lignified cells. *Apomuden* however had relatively scanty layer of wound periderm cells, indicating higher susceptibility to moisture loss through the site of the wound. The results also showed very scanty layer of new periderm cells over the lignin layer at the proximal area (i.e. point of attachment to the vine or mother plant) in three of the varieties with the exception of *Faara* (Plate 3.5). This reveals the potential for dehydration through moisture loss at that region of the root.

In addition to scanty formation of new periderm cells at the proximal ends, both *Apomuden* and *Okumkom* also had inadequate lignin formation at the site of the wound (lignin was observed as a reddish band of cells). This presented an additional issue of potential susceptibility to pathogen invasion. At the distal or tail end, each variety (except *Apomuden*) had very good formation of new skin consisting of a well-defined band of wound periderm cells over a band of lignified cells. At that portion of the root, *Apomuden* had limited formation of wound periderm, and the lignin layer was also not a continuous band but rather had gaps in it (Plate 3.5). In *Apomuden* and *Okumkom* the proximal end did not appear to have adequate layer of lignified cells thus presenting an issue of potential susceptibility to pathogen invasion. For *Okumkom* and *Faara,* at the distal or tail end, both had adequate formation of new periderm consisting of a thick band of wound periderm over a band of lignified cells (Plate 3.5); although *Apomuden* and *Hi-starch* each had a clear band of lignified cells, there was limited presence of wound periderm layer at that portion of the root (Plate 3.5). Excessive moisture loss through the distal end of *Apomuden* and *Hi-starch* is therefore likely to occur over a period of days after any wound or damage; the risk of microbial pathogen invasion through this end is also high. The low storage performance of *Apomuden* (Table 3.2) may be linked with its slow physiological response to surface injuries observed through cellular level observation, indicating vulnerability and deficiency in wound periderm formation at all areas of the root. Such vulnerable varieties when identified, may require a longer curing period than the four to seven days generally recommended as various levels of injuries are known to occur during harvesting and handling of bulky root and tuber crops. Location of the wound on the root appears to have an impact on the rate of wound healing as clearly demonstrated by the results of this study, and may have played a role in the apparent mixed conclusions of various studies. The use of lignification index as the major or only measure of wound healing efficiency (Oirschot *et al*., 2006; Tumuhimbise *et al*., 2010) may be one of the probable factors for the conflicting opinions about the role of wound healing characteristics in actual storability of sweetpotato. Formation of a lignified layer during the healing process is not an end in itself, but actually seems to be a vital prerequisite for the formation of wound periderm (new skin or cork cells at the wounded site).

Formation of the wound periderm is therefore, the ultimate aim of the wound healing process. According to Walter and Schadel (1982), lignification ceases when new cork cells (wound periderm) begin to form. Thus, from the varieties studied, *Faara* and *Okumkom* showed rapid wound response evidenced by the formation of relatively abundant cell layers of wound periderm in all or most portions of the roots just four days after wounding (Plate 4.5), while *Apomuden* and *Hi-starch* showed a slower response, with relatively scanty wound periderm cells in spite of clearly visible lignification. The variety *Faara* showed outstanding wound healing response at all areas of the root and this may help to explain why it was also the best storing variety, showing maximum resistance to weight loss. Varieties identified to have rapid wound healing response at all parts of the root could be included in crossing blocks of breeding programmes, to tap into this remarkable physiological trait.

3.4 CONCLUSIONS

Diversity was observed in storage parenchyma tissue cell shapes, relative sizes and arrangement for the varieties studied. Resistance to weight loss during storage of fresh roots was influenced by variety, type of primary packaging and the sizes of roots being stored. *Faara* was the most stable variety in storage while *Apomuden* was the most susceptible to weight loss. Selecting bigger root sizes (>300g) and maintaining high relative humidity (90 – 95%) in the immediate environment resulted in better resistance to weight loss during storage. Physiological response to wound healing varied among varieties, and the efficiency of wound healing in wounded roots had a direct bearing on storage stability or shelf-life of healthy undamaged roots. For example *Faara* the best-storing variety (when healthy, undamaged roots were stored) also showed outstanding wound healing response in artificially-damaged roots. Variations were observed in healing response based on location of the wound (proximal end, mid-region and distal end) on the fresh roots. This is the first report on sweetpotato wound healing response from different locations of sweetpotato storage root. Additionally, formation of new wound periderm was found to be more relevant in assessing the efficiency of wound healing response than using only the formation of lignified cell layers.

CHAPTER FOUR

4.0 EFFECTS OF CROP MATURITY AND STORAGE ON KEY NUTRIENT COMPONENTS AND PASTING PROPERTIES OF IMPROVED SWEETPOTATO VARIETIES

4.1 INTRODUCTION

Sweetpotato is a versatile and nutritious root crop cultivated in more than 100 countries. It is gaining increased significance globally not only as food for domestic consumption but also as a raw material in commercial processing. The crop is very productive and has the potential to play key roles in food and nutritional security. In Ghana, sweetpotato is currently receiving some emphasis in terms of utilization research and value addition. It is also being promoted as a food and industrial crop, and several improved varieties with diverse characteristics have been developed and released. The crop is genetically diverse and nutritionally superior to most starchy staples, yet has experienced persistent low utilization for decades (Kays 2005a; Shih *et al.,* 2009). Sweetpotato has been described as one of the most misunderstood of the major food crops (Scott and Maldonado, 1998). Due to its wide genetic diversity coupled with inherent postharvest changes that occur (Zhang *et al.*, 2002), it is often difficult to determine the most suitable characteristics for particular products and what accounts for inconsistencies in product characteristics when using any particular variety. Although changes occurring during fresh root storage may be inevitable, a better understanding of factors influencing these postharvest changes is necessary if marketing and utilization are to be enhanced in a sustainable manner. In many tropical regions, due to the warm climate there are no well-established systems for efficient long-term storage of sweetpotato fresh roots; this is in contrast to some developed economies where storage for several months up to even a year is possible through the use of sophisticated facilities. A study on several cultivars in East Africa (Rees *et al.*, 2003) reported that in tropical developing countries under marketing conditions sweetpotatoes have a shelf-life of only one to two weeks. In Ghana, storage for a month or more under improved conditions has been achieved (Teye, 2010). There is insufficient understanding of the factors that influence various important quality attributes of sweetpotato during storage, and how to control or manipulate these quality characteristics. Unlike most other crops, sweetpotato storage roots do not have any clear maturity stage. Rather the roots grow indefinitely, and under favourable conditions will continue to enlarge until the interior of the root becomes anaerobic or rots. Due to this characteristic, the crop is harvested when majority of the storage roots have reached the desired size (Kays, 1998). This method of determining when to harvest is quite subjective and remains at the discretion of the farmer. In the quest to find means of understanding how to achieve and maintain optimal quality characteristics in sweetpotato, various workers have investigated the influence of cultivation conditions on sweetpotato starch properties (Noda *et al*., 2001; Yempew *et al*., 2001; Genkina *et al*., 2003; Ishiguro *et al*., 2003). Harvest time, being easy to manipulate in the crop's production cycle, may offer some amount of control if it is found to significantly impact on storage root composition and processing quality. The aim of this study was to identify the influence of maturity on pasting properties and selected nutrients, and their impact on stability during storage under tropical ambient conditions.

4.2 MATERIALS AND METHODS

Six (6) improved high-yielding and disease-resistant varieties of sweetpotato obtained from CSIRCrops Research Institute, Ghana were cultivated at Fumesua in the Ashanti Region under identical management practices and harvested at 3.5, 4 and 5 months after planting. At each harvest time, a 3kg batch of representative root sizes (small, medium, large) was sampled for each variety and half of the weight of each sample was processed immediately into flour while the other half was stored at room temperature (26^{o}C ± 3) for 3 weeks before being processed into flour.

4.2.1 Preparation of flour samples

At each harvest time, a portion of fresh roots was processed immediately into flour while another portion was saved and stored at room temperature (26°C ± 3) for 3 weeks before being processed into flour.

4.2.1.1 Flour Preparation Method for Rapid Viscosity Analyser studies

Roots were washed and scrubbed without peeling. The clean roots were then air-dried and shredded using a hand grater, dried in an air oven at 60°C for 72 h, and milled (using a Cyclotec 1093 sample mill; Rose Scientific, Ontario, Canada) to pass through a 60–80 mesh screen. These flour samples were kept in airtight plastic bags at room temperature.

4.2.1.2 Flour Preparation Method for Near Infra-red Reflectance Spectroscopy

Roots from each sample batch were washed, scrubbed and air-dried for 24 hours. Each root from the sample was quartered, and the quarters pooled to form one sample. From this, fifty (50) gram portions were weighed in triplicate, placed in special sample bags and kept in a deep freezer (20°C) to freeze. The frozen samples were then freeze-dried for 72 hours (YK-118-50 Vacuum Freeze-dryer, True Ten Industrial Co. Ltd., Taiwan), milled with a Cyclotec 1093 sample mill (Rose Scientific, Ontario, Canada) to pass through a 60–80 mesh screen and kept in airtight plastic bags at room temperature.

4.2.2 Dry matter and nutrients analyses

Dry matter contents were determined in triplicate using the method of Bainbridge and others

(Bainbridge *et al.*, 1996). Near Infra-red Reflectance Spectroscopy (NIRS, Model XDS Near infrared; XM-1100 series, Sweden) was used to analyse nutrient components in freeze-dried sweetpotato flour samples. The equipment was composed of a monochromameter and rapid content analyser. Each sample was spread into a special NIRS cuvette and scanned using pre-set calibrations developed by the International Potato Center (CIP) for protein, starch, sucrose, glucose, fructose, iron and zinc. Tests were run in triplicate.

4.2.3 Flour pasting properties

Pasting properties were determined by the Rapid Viscosity Analyser (RVA model 4500, Perten Instruments-Australia) using 14% flour slurries (dry weight basis). Parameters measured were:

- Peak time (time taken to reach Peak viscosity)
- Pasting temperature (temperature at which starch gelatinisation begins)
- Peak viscosity (PV) - the highest viscosity during heating
- Hot paste viscosity (H) - the viscosity after holding at 95^0C
- Cold paste viscosity (C) - the viscosity after cooling down and holding at 50^0C

From the above parameters, the following indices were derived:

- Stability ratio - H / PV
- Setback ratio - C / PV

Pasting properties of flour were run in both in distilled water and in 0.05mM $AgNO_3$, a potent amylase inhibitor (Dixon and Webb, 1964). An estimated Index of amylase activity was calculated as (PV2-PV1)/PV1, where PV1 was Peak viscosity in amylase-active samples (obtained using distilled water) and PV2 was that in amylase-deactivated samples (obtained using $AgNO_3$)

(Collado and Corke, 1999). For flour pasting, samples from only two maturity stages (4 and 5 months) were used, and tests were run in duplicate.

Statistical Analysis

All RVA tests were run in duplicate and NIRS analyses were done in triplicate. Statistical analysis was performed using GenStat Release 12.1 (2009). Data were analyzed by general linear model (GLM). Differences at $p < 0.05$, $p < 0.01$, and $p < 0.001$ were considered to be significant. Means were separated by LSD and correlation analyses were performed on various parameters.

4.3 RESULTS AND DISCUSSION

COMPOSITION OF KEY NUTRIENTS

Dry matter content

Wide differences in dry matter contents of freshly harvested roots were observed among the sweetpotato varieties indicating diversity. *Hi-starch* and *Faara* had the highest dry matter contents with average of 37.5% and 33.5% respectively, while *Apomuden* with 19.56% had the lowest; across maturity stages *Faara*'s dry matter content was the most stable, while *Ligri* had the widest variation (Figure 4.1). Overall, dry matter was highest at four months and lowest at 3.5 months; the widest range in dry matter contents was observed at five months (Table 4.1). Dry weight in sweetpotato correlates well with starch content (Li and Liao, 1983); as dry matter content increases, there is said to be a corresponding decrease in acceptability as a table food in some parts of the world (Lin *et al.*,1995). However, high dry matter content is generally desirable in Ghanaian sweetpotato-based products (Ellis *et al*., 2001; Adu-Kwarteng *et al*., 2003; CSIR-CRI, 2012), and when above 35.0% it is also desirable as a raw material in the starch processing industry (Mok *et al*., 1997).

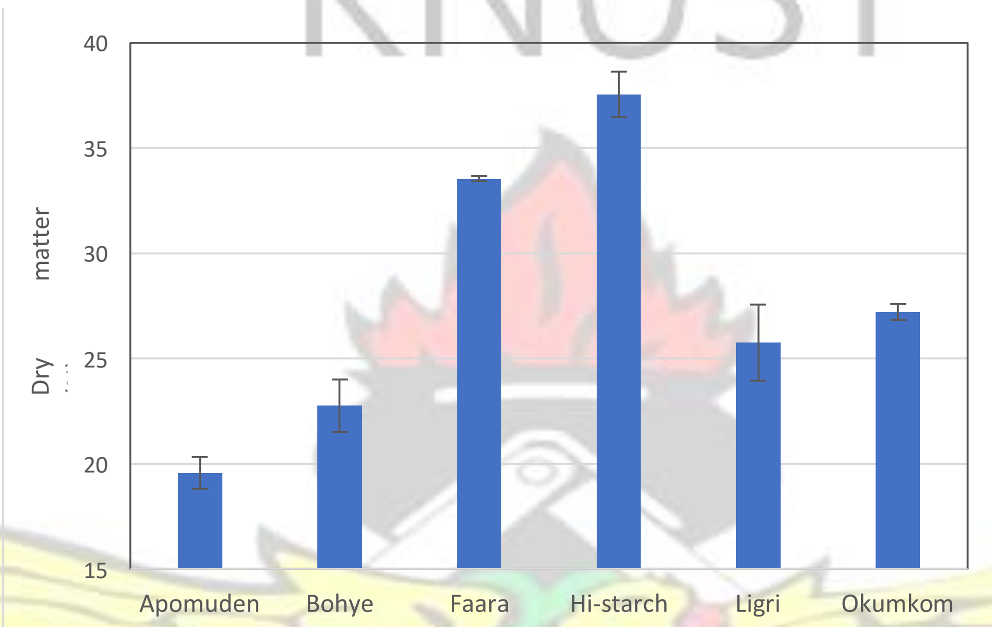


Figure 4.1 Average dry matter contents of sweetpotato varieties at the time of harvest, across three (3) levels of harvest maturity (Error bars show standard deviations for maturity)

Table 4.1 Mean dry matter contents of six (6) sweetpotato varieties at different stages of harvest maturity

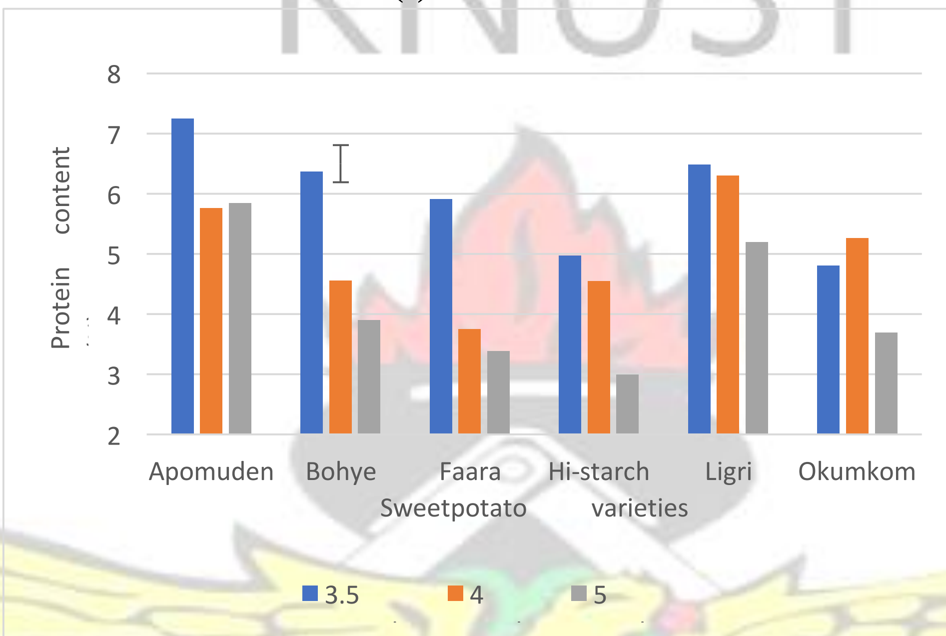
Dry Matter (%) (At harvest)	3.5 months	4 months	5 months
Mean	26.56 (± 6.57)	28.43 (± 6.68)	28.17 (± 7.46)
Range	20.26 – 35.25	20.58 – 37.86	17.83 – 39.49

Numbers in parenthesis are standard deviations

Protein content

Protein contents ranged from 3.0 to 7.25%; *Apomuden* and *Ligri* had the highest protein contents at the time of harvest (Figure 4.2).

(a) At harvest



(b) After storage

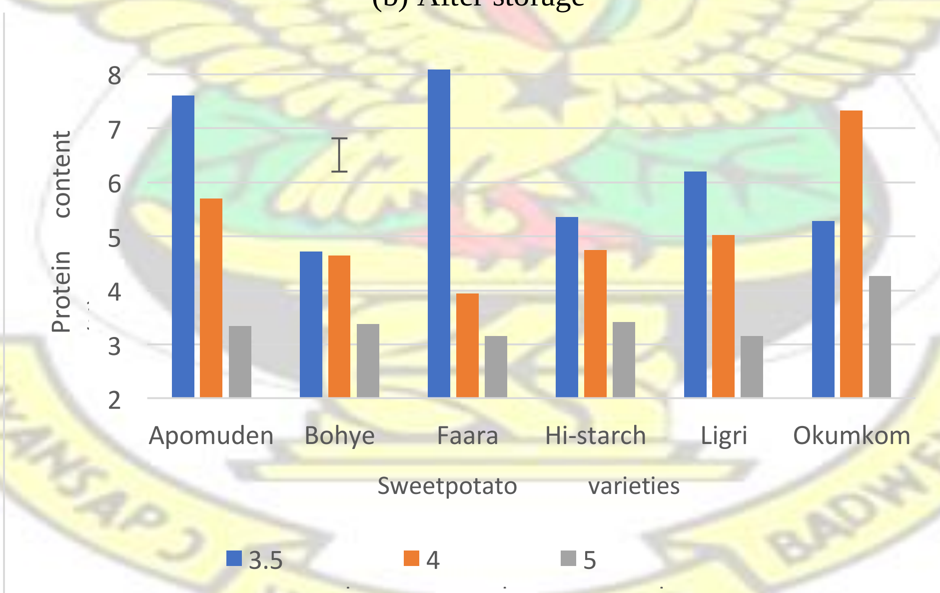


Figure 4.2 Protein contents (% dwb) of sweetpotato varieties (a) at harvest time and (b) after storage. (Error bar shows LSD (0.614) for effect of variety x maturity x storage interaction; LSD for the effects of maturity and storage were 0.174 and 0.164 respectively at p<0.001)

These values are much higher than that obtained by Senanayake *et al*. (2013) (1.2–3.3%, dry matter basis), for five varieties in Sri Lanka. Protein is reported to range from 1.3 to >10% (dry matter basis) in sweetpotato; however, there is evidence of considerable variability of protein content and composition between varieties and also even within the same variety due to the influence of genetic factors, production practices and environmental conditions (Collins and Walter, 1985). The influence of maturity was found to be significant at p<0.001 (Table 4.2).

Table 4.2 Mean squares from combined analysis of variance for key nutrient components of six sweetpotato varieties at three maturity stages and two storage times

SOURCE OF VARIATION	STARCH (%)	PROTEIN (%)	TOTAL SOLUBLE SUGARS (%)	Fe (%)	Zn (%)
Variety	1237.89***	6.12***	804.2***	1.87***	0.704***
Residual	3.65	0.13	8.1	0.01	0.004
Storage	1237.23***	0.26 ns	1120.8***	0.17***	0.0054 ns
Variety x Storage	22.65***	3.72***	39.1*	0.08***	0.054***
Residual	2.13	0.18	10.7	0.01	0.004
Maturity	13.54**	46.91***	105.7***	0.05 ns	0.509***
Variety x Maturity	26.74***	3.28***	31.4**	0.10***	0.040***
Storage x Maturity	4.68 ns	2.67***	40.7*	0.68***	0.018*
Variety x Storage x Maturity	14.26***	1.39***	27.5**	0.09***	0.059***
Residual	2.28	0.13	9.1	0.012	0.005

***Significant at p<0.001
**Significant at p<0.01
*Significant at p<0.05

Protein content was generally higher at 3.5 months and reduced with increasing maturity. The influence of storage was however not significant. For child feeding programs or other purposes where protein content needs to be maximized, sweetpotato of lesser maturity may be recommended. Although non-protein Nitrogen (NPN) forms part of sweetpotato's total Nitrogen content, the nutritional quality of sweetpotato protein is reported to be high. Some studies (Walter and Catignani, 1981; Walter *et al.*, 1983) reported that the protein efficiency ratio (PER) of isolates and concentrates was nearly equal to that of casein, and depended on the severity of the heat treatment used in the manufacture of the sweetpotato flour. One Japanese variety was found to have no limiting amino acid – indicating a complete protein (Collins and Walter, 1985). Decreases in protein content during storage (shown as negative values, Table 4.3) were observed at various points in all varieties with the exception of *Hi-starch*; overall, the decreases were more pronounced at 5 months.

Table 4.3 Percentage change in protein content after storage of sweetpotato varieties harvested at different levels of maturity

	3.5 months	4 months	5 months
Apomuden	4.69	-1.22	-42.91
Bohye	-23.55	1.75	-13.59
Faara	34.86	5.07	-7.08
Hi-starch	7.04	4.18	13.67
Ligri	-4.32	16.35	-39.42
Okumkom	11.43	-4.56	15.14

These decreases could be due to various metabolic processes that take place in living tissues of the fresh roots. Interestingly, increases in protein content after storage were found to occur for each variety in at least one maturity stage or more (Table 4.3). This phenomenon could be due to what has been described as '*de novo* synthesis' of proteins, for example enzymes such as sucrose synthase, starch phosphorylase and amylases. Hagenimana *et al*. (1994), reported that this occurs in sweetpotato especially when stored roots break dormancy in response to various signals, in preparation to begin sprouting. Further studies may be necessary to fully account for this phenomenon.

Starch content

At harvest time starch contents ranged from 53.93 to 79.40% and after storage reduced to 41.13 – 75.16% (dry basis) (Table 4.4).

Table 4.4 Starch contents (% dwb) of sweetpotato varieties at different maturity stages, at harvest and after storage

AT HARVEST	3.5 mths	4 mths	5 mths
Apomuden	58.58	56.14	53.93
Bohye	67.59	68.95	68.49
Faara	73.37	73.58	71.48
Hi-starch	78.81	78.41	79.4
Ligri	64.25	71.81	71.06
Okumkom	68.7	65.81	66.02
AFTER STORAGE	3.5 mths	4 mths	5 mths
Apomuden	47.89	46.6	41.13
Bohye	59.13	59.23	63.22
Faara	63.51	69.55	70.08
Hi-starch	71.93	71.49	75.16
Ligri	61.69	64.81	63.07

Okumkom	59.61	62.98	61.12

Starch content has significant impact on the eating quality of sweetpotato varieties; a recent study reported 33% - 64% starch content for Sri Lankan varieties (Senanayake *et al.*, 2013). The influence of maturity on starch content was found to be significant at $p<0.01$ while that of storage was significant at $p<0.001$; varietal differences were also significant ($p<0.001$) (Table 4.2). In all the varieties, there were losses of starch content during storage, ranging from 1.95 - 23-73% of the total starch (Table 4.4). *Apomuden* (with the lowest original starch content) had the highest reduction in starch content with storage; *Faara* and *Hi-starch* (with the highest original starch contents) had the lowest reduction or degradation of starch during storage, with *Hi-starch* showing the best stability in starch content across maturity stages (Figure 4.3).

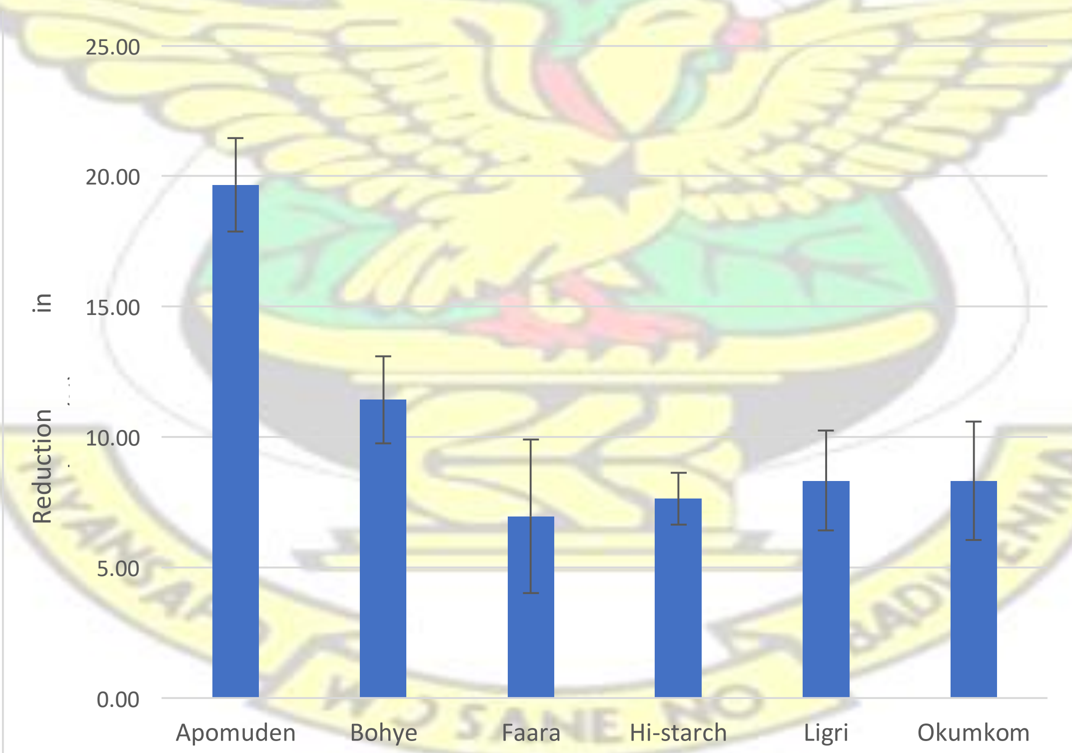


Figure 4.3 Average reduction in starch content (% of original starch) with storage of sweetpotato varieties (Error bars are standard deviations for three (3) levels of maturity)

The extent of reduction or degradation of starch during storage correlated negatively (r = -0.61) with initial starch content across all maturity stages (Table 4.5), indicating higher stability or higher resistance to starch degradation in varieties containing more starch. This association between original starch content and the stability of starch during storage was found to be greater at advanced maturity, the highest correlation being observed at 5 months (r = -0.83) (Table 4.5).

Table 4.5 Correlation of starch degradation during storage of six (6) sweetpotato varieties with original starch contents at 3.5, 4 and 5 months maturity

	Correlation Coefficient (r)
Maturity	**Starch content**
3.5 months	-0.32
4 months	-0.55
5 months	-0.83
Across all maturity stages	-0.61

Soluble sugar contents

Total soluble sugars (TSS) ranged from 3.92 to 44.44%. The lowest was in *Hi-starch* at 3.5 months at harvest and the highest was in *Apomuden* at 5 months after storage (Figure 4.4). The influence of maturity and storage were both significant at p<0.001 (Table 4.2). Sugar in sweetpotato is a key component of its flavour and eating quality (Kays, 2005a). In Ghana, many communities have indicated the desire for non-sweet or low-sugar sweetpotatoes for adoption as a staple in their diets, as sweet taste is generally associated with luxury food, dessert or snack and not with staple foods (Oduro, 2013; Baafi, 2014). Information on changes in sugar content that occur during storage should therefore, be a vital component in the promotion of sweetpotato, especially in the case of high beta-carotene varieties which are employed in combating endemic vitamin A deficiency in deprived communities. The lowest sugar contents were observed at early maturity, especially at 3.5 months when processed after harvest without storage; the influence of storage on the build-up of sugars was highest in samples harvested at five months (Figure 4.4). The variety *Bohye* exhibited a unique feature, being a moderate beta-carotene variety (light orange-fleshed colour, second only to *Apomuden*) and yet having relatively low sugar contents at all maturity stages. Betacarotene is reported to be genetically linked with high sugar content (Mcharo and La Bonte, 2007); however at five months after storage, other varieties *(Ligri* and *Okumkom*) with no beta-carotene (cream or white-flesh) had higher sugar levels than *Bohye* (Figure 4.4). In certain applications where high sugar content is of interest, this information is also valuable in selection and management of the raw material. The influence of maturity and storage history during screening of sweetpotato genotypes in breeding programmes may be one of the keys to unlocking more unique features of this diverse crop. The highest contents for each type of sugar (sucrose, glucose and fructose) were observed at five months after storage (Figure 4.4). Since higher levels of sucrose are often known to compensate for a lower monosaccharide content, and likewise higher levels of monosaccharides (fructose and glucose) also usually compensate for a lower sucrose content, it has been debated whether varieties combining high levels of both sucrose and monosaccharides exist (La Bonte *et al.*, 2000). *Apomuden* when harvested at five months and stored under the study conditions, exhibited a combination close to this rare type of relatively high fructose and glucose content.

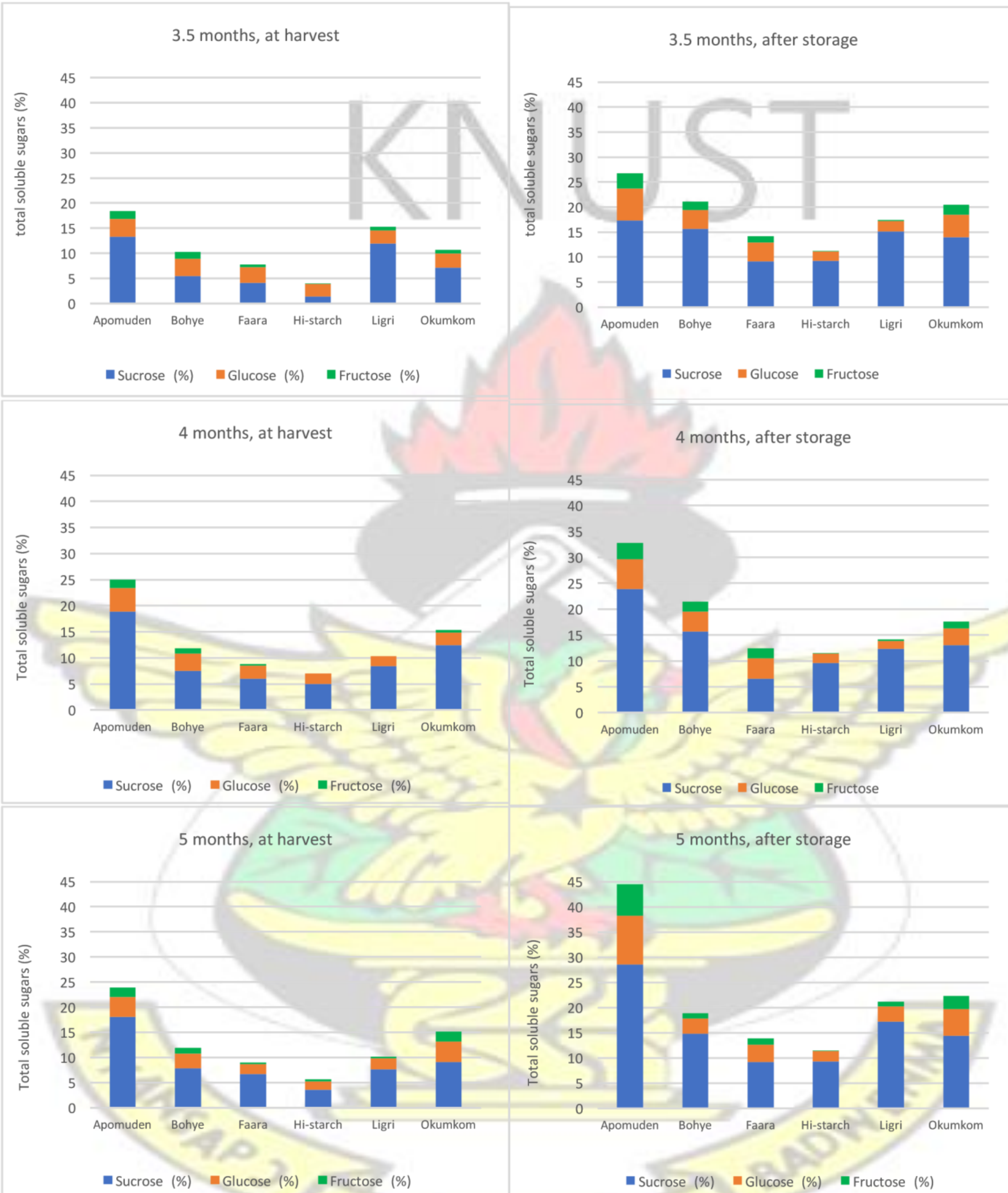
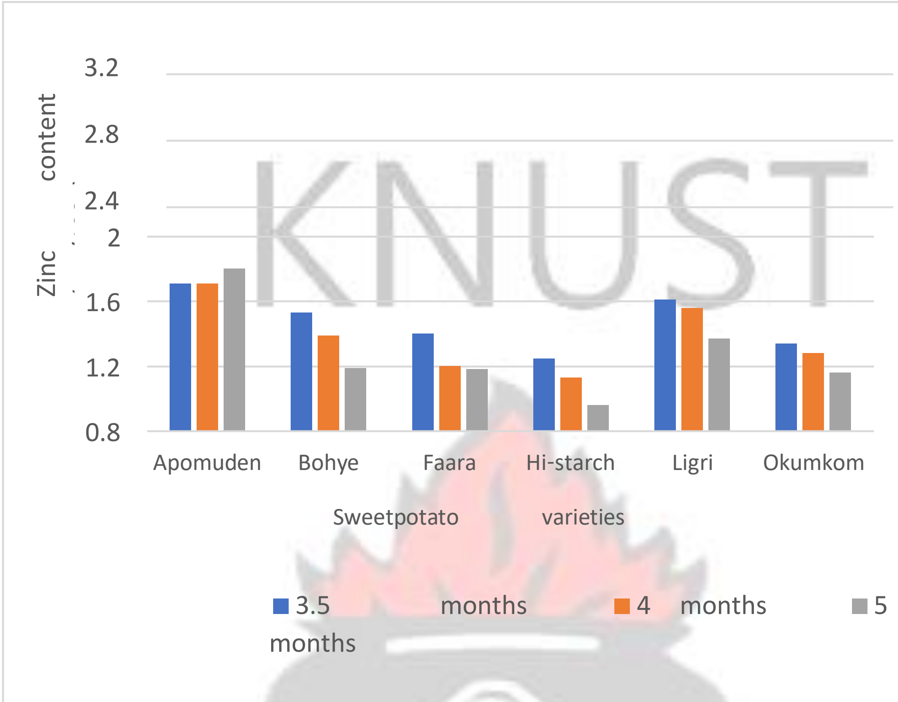


Figure 4.4 Total soluble sugars (% dwb) in sweetpotato varieties at 3.5, 4 and 5 months maturity, before and after storage

Significant changes in sugar content during storage have been well-documented (Lewthwaite *et al.*, 1997) although often the changes were reported to be quite random without well-defined trends, even within the same variety (Deobald *et al*., 1970). This highlights the importance of maturity when studying any particular variety for important traits. Results from other studies also highlight the varietal diversity of sweetpotato (La Bonte *et al*., 2000; Nath *et al*., 2005; Wang *et al*., 2006; Adu-Kwarteng *et al*., 2014;). The role of other external factors, for example time of planting, also cannot be overlooked. A wider spectrum of varieties as well as the possible influence of planting season on carbohydrate accumulation need to be studied further.

Minerals (Zinc, Iron)

Zinc contents ranged from 0.96 to 1.80 mg/100g. Some literature values for sweetpotato zinc content are 0.42 – 1.13mg/100g (Singleton, 2008) and 0.23 – 0.27 mg/100 g (Sanoussi *et al*., 2016) on dry weight basis. Iron contents ranged from 1.53 – 3.00mg/100g, dry weight basis; other workers studying different varieties reported iron levels of 1.25 – 2.38mg/100g (Singleton, 2008), 0.73 – 1.26mg/100g (Laurie *et al*., 2012) and 0.53 – 0.73 mg/100 g (Sanoussi *et al*., 2016) on dry weight basis. Results from this study indicate higher contents of both iron and zinc as compared to values reported for other varieties in different climates. The influence of maturity on zinc content was significant ($p<0.001$) (Table 4.2), with early maturity having the highest zinc levels except in *Apomuden* (Figure 4.5). For iron content, the influence of maturity was not significant at $p<0.05$; however, the highest iron levels were observed at 3.5 months, with the exception of *Apomuden* (Figure 4.5).



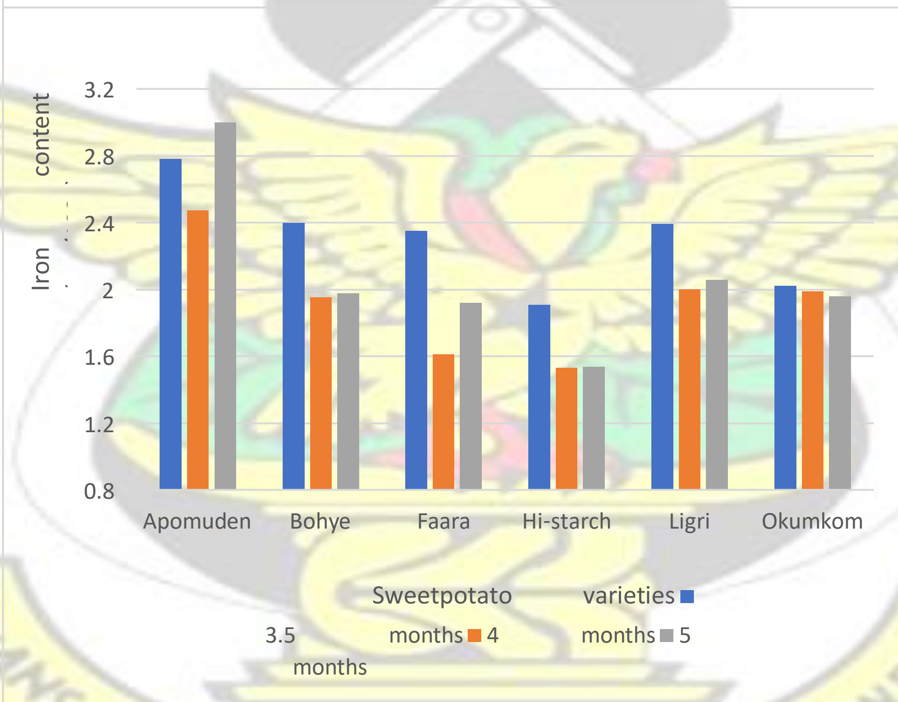


Figure 4.5 Zinc and iron contents (mg/100g dwb) of six sweetpotato varieties harvested at different levels of maturity. (LSD for the effect of maturity: zinc = 0.032, iron = 0.044; $p<0.001$)

This observation coupled with the significant influence of maturity on zinc content brings to issue a suggestion by a previous study that in the evaluation of genotypes by breeding programmes, sweetpotato storage root can be harvested at any time for measurement of micronutrients, and that such selection could be made at early maturity to speed up the process (Singleton, 2008). In the current drive towards biofortification of food crops, more investigation is required in this regard by breeding programmes, since results of this study suggest that beyond 3.5 months there were substantial reductions in zinc and iron contents for five out of the six varieties studied. Genotype selections must therefore factor in micronutrient stability across maturity stages. Varieties rich in carotenoids (visible as orange-fleshed colour) are reported to be good sources of some important minerals (Zuraida, 2003). This was confirmed in our study as *Apomuden*, the highest beta-carotene variety (deep orange-flesh), had the highest values of both iron and zinc at all harvest stages (Figure 4.5). Sweetpotato is known to contain significant amounts of essential minerals including manganese, copper, iron, zinc and especially high levels of potassium (Woolfe, 1992; WHFoods, 2011). In low-income areas, most infants are given cereal-based complementary foods prepared at home; these foods tend to be high in phytate which limits the bioavailability of certain minerals including iron, calcium and zinc which are crucial to the development of infants. In a study on infant complementary foods, sweetpotato-based formulations were reported to have much lower phytate/mineral ratios for calcium, iron and zinc compared to maize-based formulations, suggesting that absorption of these minerals could be better from the sweetpotato-based infant food (Amagloh *et al*., 2012). The recommended daily human requirement for iron and zinc are 8 – 15mg and 3 – 12mg respectively. The six Ghanaian sweetpotato varieties studied in this current work can be recommended for regular consumption to provide important portions of this requirement. Beta-carotene in foods is also known to be a possible enhancer of iron absorption, and this could be an advantage in the advocacy for orange-fleshed sweetpotato as a public health tool in alleviating micronutrient deficiencies.

FLOUR PASTING PROPERTIES

Peak viscosity

Peak viscosity (PV) for the six sweetpotato varieties ranged very widely from 117 to 4,061 centipoise across harvest times (Table 4.6).

Table 4.6 Range of RVA pasting indices of six (6) sweetpotato varieties across all sampling times

RVA parameter	Minimum	Overall Mean	Maximum
Peak viscosity	117	1654	4061
Peak time	3.933	4.921	7
Stability ratio	0.324	0.739	0.99
Setback ratio	1.192	1.619	1.9
Pasting Temperature	79.05	82.21	84.8

The varieties *Apomuden* and *Faara* had the lowest Peak viscosities among the six varieties (Figure 4.6). This was unusual since *Faara* had very high starch and low sugar content relative to *Apomuden* and therefore would ordinarily be expected to have higher pasting viscosity than *Apomuden* which had the lowest starch and highest sugar content at all stages. Soluble sugars are known to influence gelatinization of sweetpotato starch (Kohayama *et al.*, 1991). This unique feature of *Faara* is a deviation from the norm, and indicates diversity in the expression of cooking qualities. It also buttresses the need for characterization of individual varieties; predicting or concluding that high starch content will translate into high cooking viscosity may not be valid for all varieties. High fibre content, especially of pectins and other soluble fibre materials is known to influence the texture of cooked sweetpotato (Collins and Walter 1985; Waldron *et al*., 1997). This needs to be studied in our Ghanaian varieties. *Hi-starch* and *Ligri* had the highest Peak viscosities among the six varieties studied.

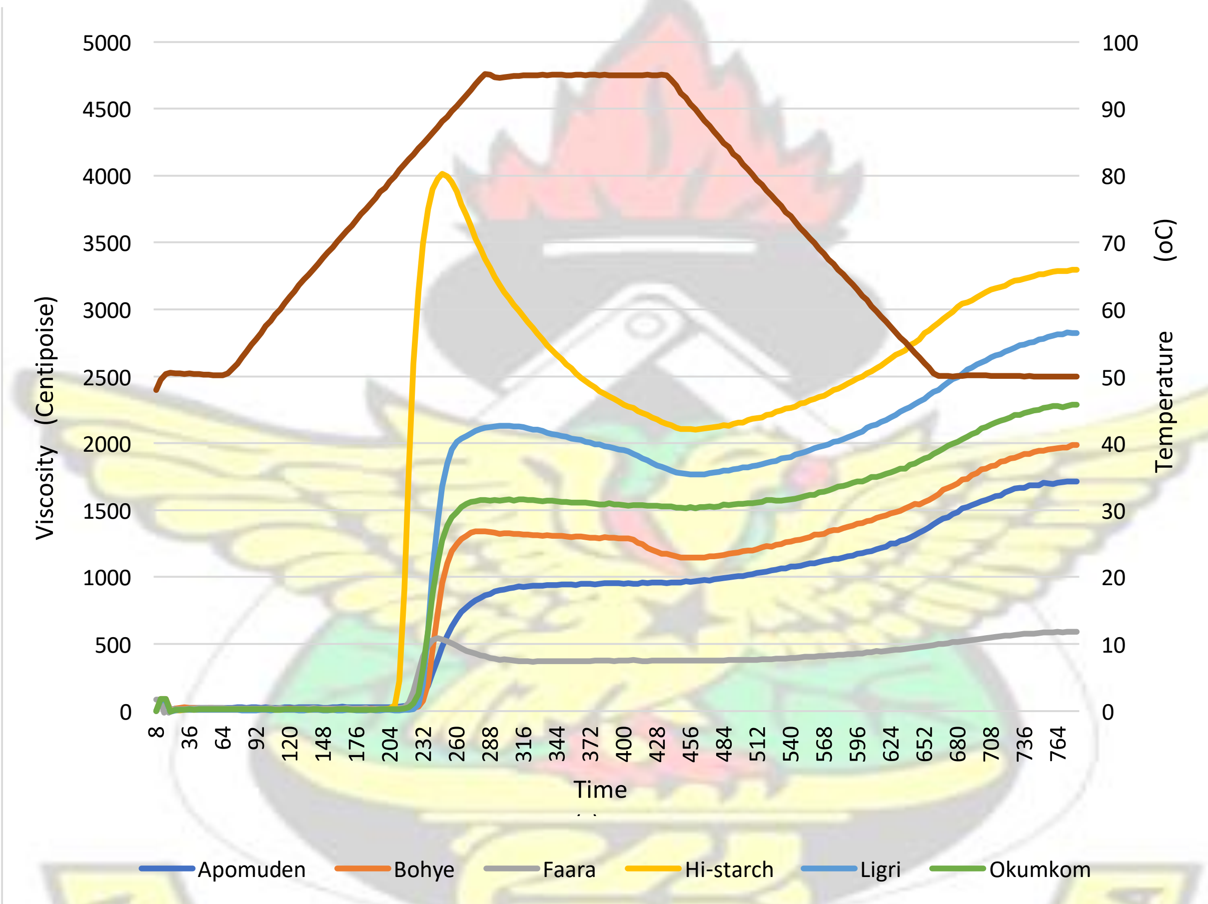


Figure 4.6 Combined pasting profiles of flours from six (6) sweetpotato varieties at 4 months maturity, processed right after harvest

Peak viscosity was significantly influenced by both maturity and storage ($p<0.001$) (Table 4.7).

Table 4.7 Mean squares from combined analysis of variance for RVA pasting properties of flour from six sweetpotato varieties at two maturity stages and two storage times

Source Of Variation	Amylase Activity Index	Pasting Temp.	Peak Viscosity	Peak Time	Setback Ratio	Stability Ratio
REP Stratum	0.019	0.008	261.400	0.114	0.000	0.000
Variety	8.690***	17.81***	918138***	6.470***	0.150***	0.220***
Residual	0.0127	0.239	582.900	0.015	0.001	0.000
Storage	12.460***	0.013 ns	376999***	0.554*	0.009*	0.040***
Variety x Storage	4.440***	1.316 ns	550676***	0.487*	0.06***	0.110***
Residual	0.001	0.330	1044.300	0.069	0.001	0.000
Maturity	5.860***	1.50**	237579***	0.032 ns	0.018 ns	0.030***
Variety x Maturity	1.329***	0.736*	951161***	0.592**	0.028**	0.030***
Storage x Maturity	10.930***	0.725*	148015***	1.270**	0.090***	0.000 ns
Variety x Storage x Maturity	1.895***	0.083 ns	320600***	0.229*	0.037**	0.050***
Residual	0.007	0.145	153.300	0.061	0.004	0.000

***Significant at $p<0.001$
**Significant at $p<0.01$
*Significant at $p<0.05$

Mean PV at five months maturity was higher than at four months, and the influence of storage on reduction of PV was more pronounced at five months (Figure 4.7).

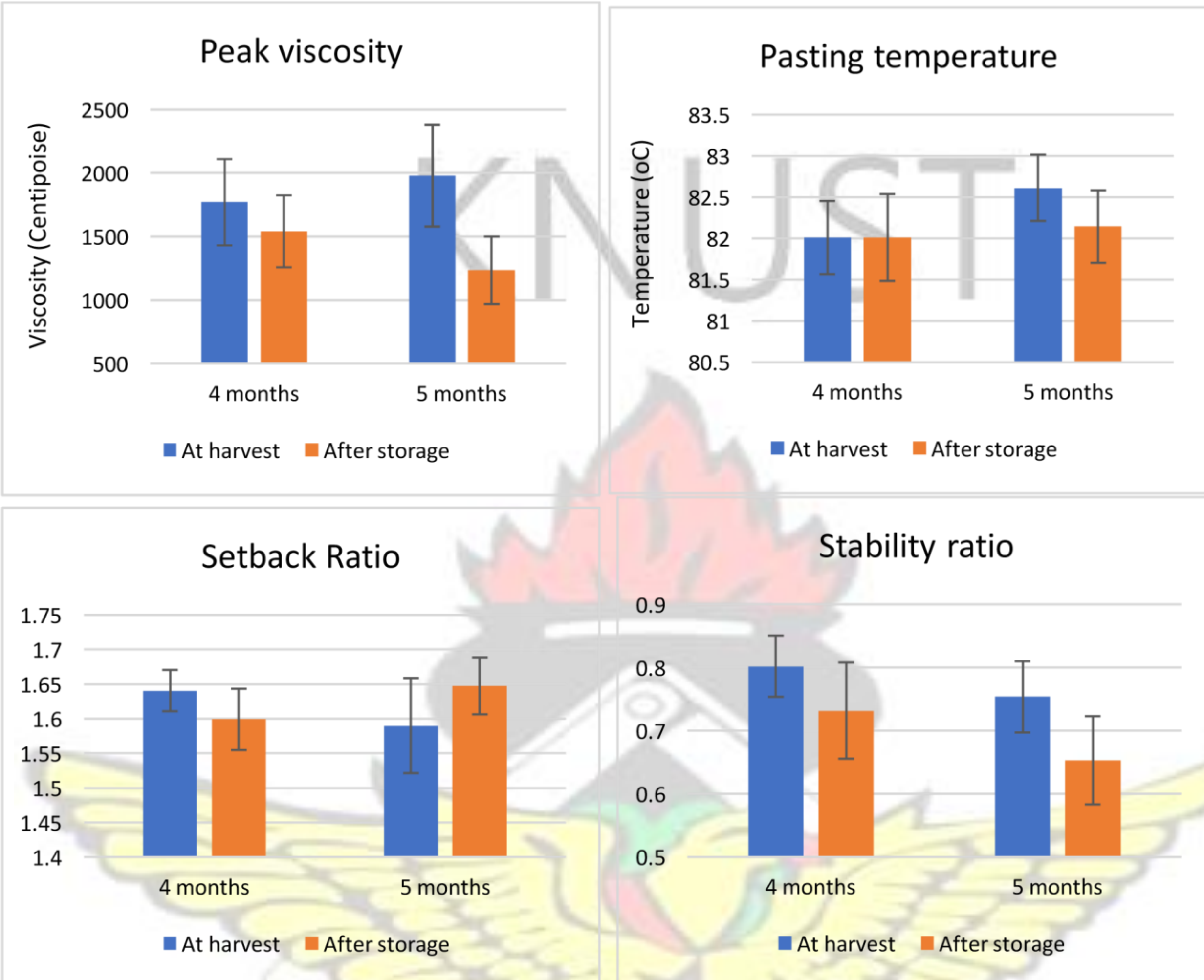


Figure 4.7 Mean RVA pasting indices of flour from six sweetpotato varieties at 4 and 5 months maturity, before and after storage (Error bars are standard deviations for the 6 varieties)

Stability ratio

Stability ratio ranged from 0.32 to 0.99 (Table 4.6); it reduced at higher maturity and also with storage (Figure 4.7). The influence of maturity and storage were each significant at $p<0.001$ (Table 4.7). Higher stability during heat processing is an important factor for many processes in the food industry.

Setback ratio

Setback ratio ranged from 1.19 to 1.90 (Table 4.6). Setback occurs due to retrogradation, which is the progressive re-association or recrystallization of starch molecules upon ageing or cooling which results in gel formation (Eliasson and Gudmundsson, 1996). The influence of maturity on Setback ratio was not significant ($p<0.05$) but interaction between maturity and storage was highly significant at $p<0.001$ (Table 4.7). Setback ratio reduced with storage at four months maturity but increased substantially in samples harvested at five months. This has interesting implications for utilization especially in pastry-type products where high retrogradation leads to pre-mature staling or loss of freshness. For such purposes, sweetpotato harvested at 5 months maturity may have to be processed immediately into flour to retain a low level of setback, since pre-processing storage would lead to undesirable increases. However, when harvested at 4 months, short-term storage prior to processing into flour would favour reduction in retrogradation tendency.

Pasting temperature

Pasting temperature is directly related to ease of cooking. It was found to be influenced significantly by maturity ($p<0.01$) in the sweetpotato varieties studied. The effect of storage was not significant ($p<0.05$) but maturity had a significant effect ($p<0.01$) (Table 4.7). Pasting temperature was higher at five months than at 4 months, indicating that cooking of samples harvested at four months maturity would be more energy-efficient than at 5 months.

Influence of amylase enzyme activity on pasting properties

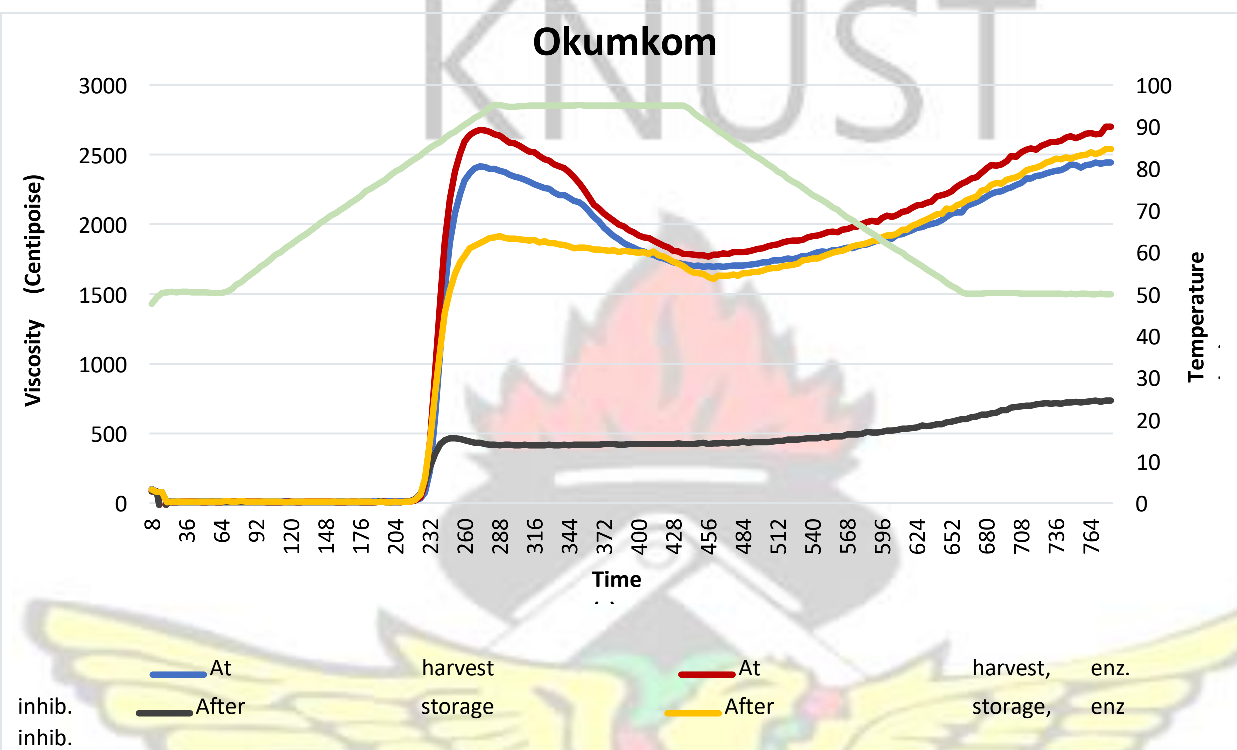
Among the RVA indices, Peak viscosity was the most affected by the activity of amylase enzymes. Amylase activity Index, a calculated estimate based on the Peak viscosities of normal and enzyme inhibited flours was found to be significantly ($p<0.001$) influenced by variety, maturity, storage and all their interactions (Table 4.7). Normal enzyme action accounted for decreases of 13.33 - 45.05% in Peak viscosity when compared with enzyme-inhibited flour pasting profiles (Table 4.8). This was to be expected, as the main action of both alpha- and beta-amylase is starch hydrolysis. The result is a breakdown of starch into dextrins and sugars and this translates into direct loss of viscosity. Walter *et al*. (1975) reported that texturally perceived moistness of baked sweetpotato was not directly related to dry matter or starch content but rather influenced by endogenous amylase hydrolysis of starch. A subsequent study on sensory textures of cooked sweetpotatoes (Walter *et al*., 2000) described a broad spectrum including moist, intermediate and dry types in terms of mouthfeel. These are all linked with the influence of amylase enzyme activity during cooking. Stability ratio or resistance of the cooked paste to viscosity breakdown was also found to be substantially influenced by amylase activity (Table 4.8). In the cooked paste of normal enzymeactive flour, stability was reduced by up to 16.28% when compared to cooked paste without any enzyme activity. The major influences of enzyme activity were observed after storage, especially at five months maturity (Table 4.8).

In the pasting profiles, evidence of enzyme activity was observed as a gap or difference in viscosity (especially Peak viscosity) between normal profile (normal enzyme-active flour slurry) and enzyme-inhibited profile ($AgNO_3$ - treated flour slurry) of any sample. *Okumkom* at 5 months had appreciable enzyme action evidenced by a wide gap or difference between viscosity profiles (especially after storage), while *Ligri* showed negligible enzyme activity both before and after storage, with enzyme-active and enzyme-inhibited profiles having very little gap or no difference, due to negligible starch hydrolysis during the pasting cycle (Figure 4.8).

Table 4.8 Extent of amylase action on RVA pasting properties of sweetpotato flour from six varieties

RVA Parameter	Maturity (months)	Amylase-inhibited profile	Normal profile	Difference due to enzyme action (%)
	AT HARVEST			
Peak Viscosity (centipoise)	4	2648.09	1770.58	-33.14
	5	2285.75	1981.08	-13.33
Peak Time (minutes)	4	4.897	4.883	-0.29
	5	5.326	5.260	-1.24
Stability Ratio	4	0.900	0.801	-11
	5	0.746	0.754	1.07
Setback Ratio	4	1.612	1.640	1.74
	5	1.580	1.589	0.57
Pasting	4	82.059	82.012	-0.06
Temperature (°C)	5	82.758	82.612	-0.18
	AFTER STORAGE			
Peak Viscosity (centpoise)	4	2112.50	1539.60	-27.12
	5	2248.80	1235.70	-45.05
Peak Time (minutes)	4	5.093	5.119	0.51
	5	4.906	4.359	-11.15
Stability Ratio	4	0.803	0.731	-8.97
	5	0.780	0.653	-16.28
Setback Ratio	4	1.647	1.599	-2.91
	5	1.632	1.647	0.92
Pasting	4	82.02	82.01	-0.01
Temperature (°C)	5	81.91	82.15	0.29

The effects of sweetpotato amylase enzyme action during heat processing, apart from the impacts on viscosity and texture of the finished product, also include a build-up of newly-formed sugar in the form of maltose. This directly results in taste and flavour modifications which may or may not be desirable depending on the target product and target consumer. Staple-types are suggested to lack starch hydrolysis due to inhibition of β-amylase synthesis or a non-enzyme mediated mechanism (Morrison, *et al*., 1993).



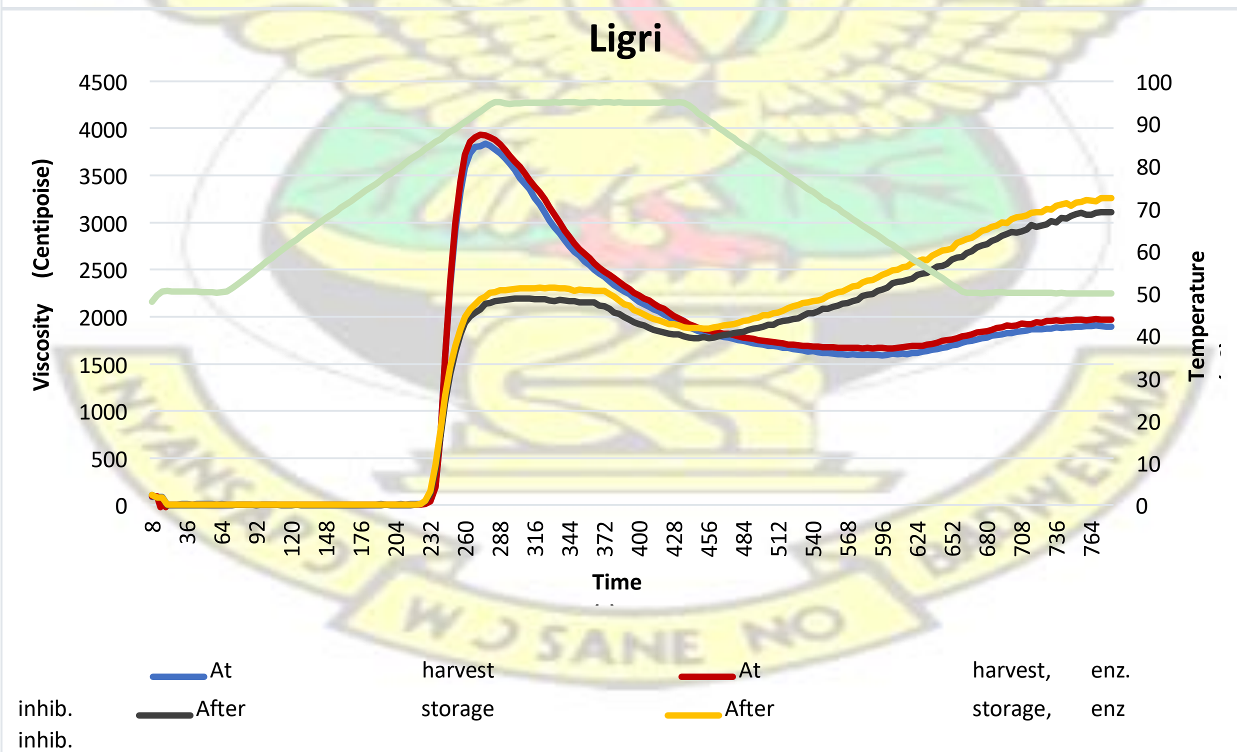


Figure 4.8 Influence of enzyme activity on pasting profiles of two sweetpotato varieties at five months maturity (*Okumkom* showing higher amylase activity after storage than at harvest, and *Ligri* showing negligible enzyme activity both before and after storage)

The variety *Ligri* at five months were found to have the lowest estimated Index of amylase enzyme activity (Figure 4.9).

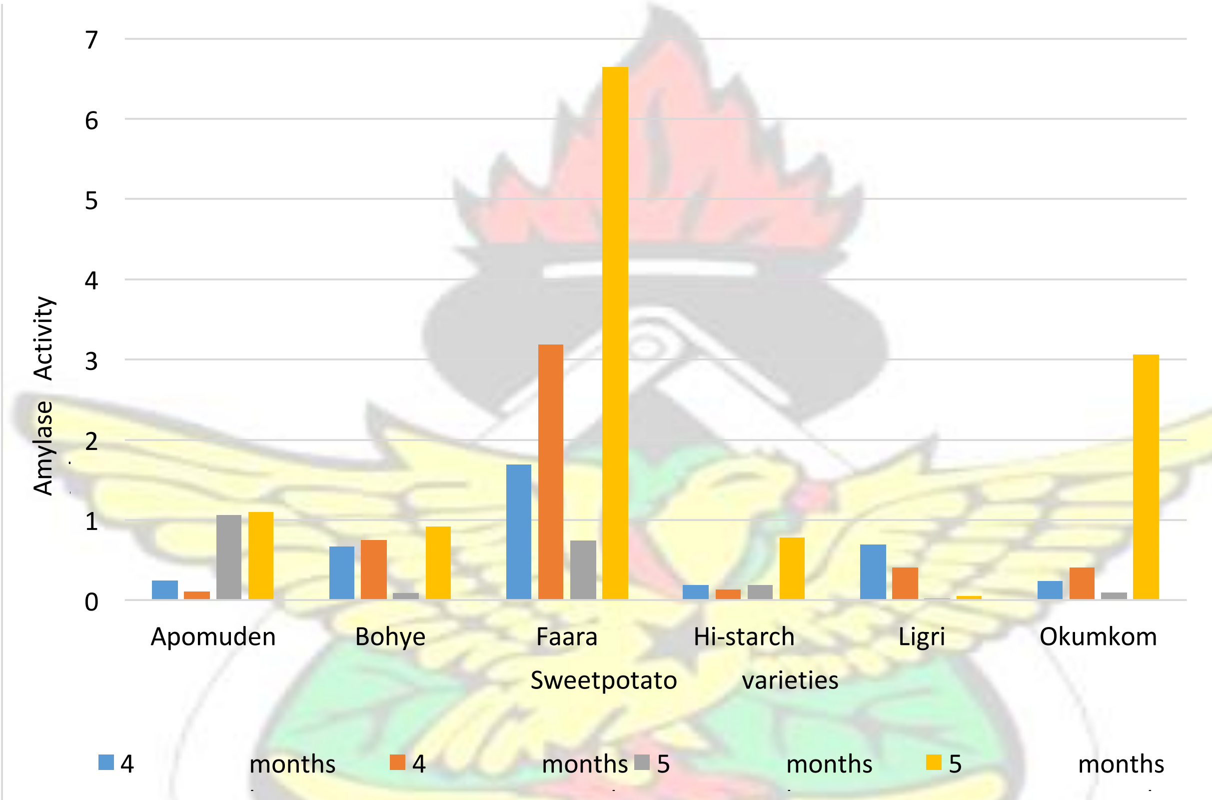


Figure 4.9 Index of amylase activity (before and after storage) in sweetpotato varieties harvested at four and five months maturity. (Least significant difference (LSD) for effect of storage was 0.0214 at $p < 0.01$).

Where necessary, deactivating the enzymes in sweetpotato raw material may be required to achieve or maintain the desired processing characteristics. This can be done through appropriate means, for example by rapid heating to temperatures above 80-85^{o}C at the onset of processing, or adjustment of pH beyond the optimal activity range through addition of acidic or alkaline components to the food material. Selection of a low-amylase activity variety could also be useful for such purposes, especially in local dishes such as ‘fufu’, where minimal or zero starch hydrolysis is desirable for maximum viscosity and minimum sugar expression (Adu-Kwarteng *et al*., 2003). The variety *Ligri* when harvested at five months may present interesting opportunities in this regard (Figure 4.9). On the other hand, where high amylase enzyme activity is desirable, selection of the right variety (for example *Faara*), harvesting at advanced maturity and subjecting to shortterm ambient storage prior to processing could help enhance the full expression of amylase activity in the sweetpotato material. Sweetpotato flours with high amylase activity have been successfully used in place of exogenous enzymes in applications such as sorghum brewing (Etim and EtokAkpan, 1992) and also in achieving target sensory qualities such as texture, consistency and flavour in other products (Walter and Hoover, 1984). Curing conditions, or exposure to warm humid environment for a few days prior to normal storage is known to enhance various metabolic processes leading to changes in sugar content and enzyme activities (Shen and Sterling, 1981; Walter *et al*., 1976; Zhang *et al*., 2002). Dziedzoave *et al*. (2010), studying a selection of Ghanaian varieties, found *Faara* and *Okumkom* to have high beta-amylase activities among the varieties they studied, and it was also highest at five months. This study confirms their finding, but also additionally highlights the importance of factoring in the influence of postharvest storage on the full expression of enzyme activity in sweetpotato. At five months, these varieties had moderate or low estimated amylase activity index at the time of harvest, but after three weeks’ storage were found to have the highest among all the varieties studied (Figure 4.9).

4.4 CONCLUSIONS

The varieties studied were diverse in terms of composition and processing quality, and these were all significantly influenced by maturity and storage. For protein, zinc and iron contents, samples harvested at early maturity (3.5 months) tended to have higher values. Lower starch varieties were found to be more susceptible to starch breakdown during storage. Starch losses during storage ranged from 1.96 - 23-73% of the total starch and correlated negatively (r = -0.61) with initial starch content. This indicated higher stability or higher resistance to starch degradation in the varieties that originally contained more starch. The negative correlation (r = -0.83) between original starch content and loss of starch during storage was found to be greater at advanced maturity. This means that if a high-starch variety is targeted for the starch industry it would be better to harvest at five months to prevent starch losses during storage. Cooking or processing qualities, portrayed by RVA pasting characteristics, were found to be impacted significantly by the activity of endogenous starch-hydrolyzing enzymes. The action of endogenous amylolytic enzymes were significantly different even for a given variety, depending on harvest maturity and storage history. *Ligri* at five months had negligible amylase acitivity both before and after storage, while *Faara* harvested at five months and stored had remarkably high enzyme activity. Due to varietal differences in the extent of influence of maturity and storage, variety-specific studies are worthwhile if any commercial venture is to select a particular variety for a target application.

CHAPTER FIVE

5.0 MORPHOLOGICAL AND QUALITY CHARACTERISTICS OF NATIVE STARCH FROM SIX (6) IMPROVED VARIETIES OF SWEETPOTATO

5.1 INTRODUCTION

Sweetpotato is one of the most important starch-producing crops in the world (Katayama et al., 2006). The crop is known to differ in its starch characteristics and various attempts have been made to establish links between starch properties and cooking, processing and eating qualities (Walter *et al*., 2000; Chen, 2003). Characterization of sweetpotato starches in various parts of the world is well documented (Garcia, 1993; Collado, 1997; Ishiguro *et al*., 2000; Mweta, 2009; Tsakama *et al*., 2010; Zhu *et al*., 2011; Abegunde *et al*., 2012; Senanayake *et al*., 2013; Zhu and Wang, 2014). Efforts have also been made to identify various factors that influence the quality, for example, growth temperature (Ishiguro *et al.*, 2003; Toyama *et al.*, 2003). Ghanaian varieties have, however, not been studied much in this regard.

Sweetpotato has a wide range of diversity in physical and compositional characteristics. Being a short duration crop (about four months) with high potential yields of improved varieties currently available, if cropped continuously throughout the year, sweetpotato could compete favourably with other popular starch sources such as cassava which requires about eight months to one year to mature. Sweetpotato has a very high dry matter productivity rate (Scott *et al.*, 2000) and the starch content of some varieties can be as high as 80% of the dry matter (Zhu and Wang, 2014). Despite the view in some circles that the crop lacks potential in commercial starch exploitation due to relative advantages of other alternative starch sources (Wheatley and Loechl, 2008), sweetpotato starch has performed creditably well in some Asian economies. For example, it has been used for the manufacture of starch noodles in China, Korea and Japan for many years (Zhenghong Chen, 2003). Starch is an important industrial commodity and has numerous applications in both food and non-food sectors. Globally, 60 million tonnes of starch is produced each year from various starchy crops and the major sources are wheat, maize, potato, rice, cassava and sweetpotato. Approximately 60% of worldwide starch production is used for food applications and 40% for non-food applications (Copeland, 2009). Some food applications of starch include canning, frozen foods, sugar syrups, snack foods, bakery products, soups and sauces, salad dressings, cooked meat binder, flavours and beverage clouds, fat replacers, confectionery, dairy and imitation dairy products and microwavable products. Non-food applications include adhesives, explosives, paper industry (tissues, cardboard, baby diapers), textiles, feeds, fertilizer, seed coatings, building materials, cement, oil drilling, cosmetic and pharmaceutical industries (Satin, 1988; Copeland, 2009).

Native starch from different sources may have unique characteristics that could be of interest in various specific applications. Although modified starches are used extensively as food ingredients (Abbas *et al.*, 2010) due to desirable features such as better uniformity and functionality, there are often the associated issues of extra costs involved in starch modification processes, legal restrictions on some chemical modification methods and consumer demands for more natural ingredients. Modified food starch is classified as a food additive and so limits of its use and labelling are clearly defined in the US Code of Federal Regulations (21 CFR 172.892) (Sajilata and Singhal, 2005). There is therefore, a constant search for specialty starches in the native or natural form to fit into niche applications. In Ghana, sweetpotato has been gaining more attention over the years in terms of utilization, research and value addition. It is being promoted as a food security crop as well as an industrial raw material (Baafi *et al*., 2011). It is therefore important to study not only starch content with regards to processing and eating quality, but also to determine the native starch characteristics of improved and high-yielding varieties available in the country. The objective of this study was to characterize starches from six improved sweetpotato varieties and assess the influence of harvest maturity, as an initial step towards better exploitation of the crop locally.

5.2 MATERIALS AND METHODS

Six (6) high-yielding and disease resistant improved varieties of sweetpotato planted in the same location under identical management practices were harvested at three, four and five months maturity at CSIR-Crops Research Institute. At each harvest time starches were extracted within 48 hours.

5.2.1 Starch extraction

Fresh roots were washed, peeled, macerated and filtered through cheesecloth using tap water. Filtering was repeated and the starch milk was left to settle. The supernatant was discarded and the settled starch re-suspended in water twice (tap water was used in order to simulate local starch extraction practices). Starch sediment was air-dried for 72 hours to approximately 12% moisture level, packed and sealed in polyethylene bags, and stored at room temperature ($26 \pm 3^{o}C$) till analysis.

5.2.2 Starch granule morphology

A small amount (7 – 10mg) of starch sample was taken using the tip of a spatula and placed on a glass slide. The sample was mixed with 1–2 drops of 0.2% Iodine solution, spread out and observed under a light microscope (Novex, Holland) fitted with a calibrated eyepiece to calculate the size range of the granules. Micrographs were taken with a digital camera (Canon SX210 IS) at magnification of x400. Starch from sweetpotato samples harvested at optimal maturity (four months) were used for the microscopy.

5.2.3 Starch pasting properties

Starch pasting properties were determined by the Rapid Viscosity Analyzer (RVA model 4500, Perten Instruments-Australia) using 11.2% starch slurries (dry weight basis). Parameters measured were:

- Peak time (time taken to reach Peak viscosity)
- Pasting temperature (temperature at which starch gelatinisation begins)
- Peak viscosity (PV) - the highest viscosity during heating
- Hot paste viscosity (H) - the viscosity after holding at 95^0C
- Cold paste viscosity (C) - the viscosity after cooling down and holding at 50^0C

From the above parameters, the following indices were derived:

- Stability ratio - H / PV
- Setback ratio - C / PV

Starch from sweetpotato samples harvested at three, four and five months were used in the RVA studies.

Statistical Analysis

RVA tests were run in duplicate. Statistical analysis was performed using GenStat Release 12.1 (2009). Data were analyzed by general linear model (GLM). Differences at $p < 0.05$, $p < 0.01$, and $p < 0.001$ were considered to be significant. Pair-wise comparison of means was done by Duncan's multiple comparison procedure.

5.3 RESULTS AND DISCUSSION

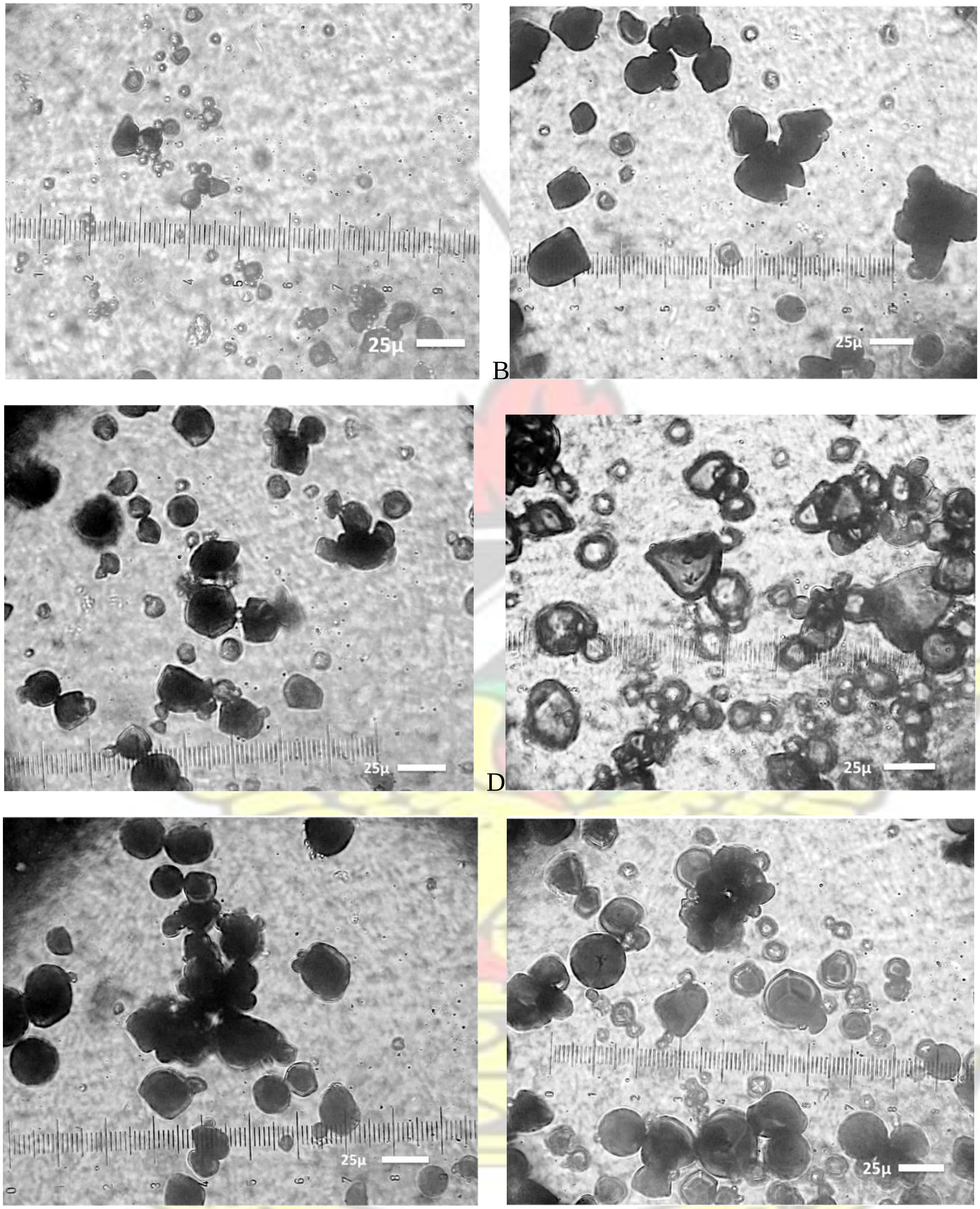
Granule morphology

Granule shapes observed were heterogeneous, mainly spherical, polygonal and truncated oval or 'half egg' shapes. Size distribution ranges were also varied, with *Apomuden* having the smallest (2 – 15µ) and *Hi-starch* the largest (8 – 40µ) range (Plate 5.1; Table 5.1). Sweetpotato starch is generally known to have a granule size distribution range of about 4 – 40µ. Starch granules from different sources exhibit a broad range of size distributions in nature, and granule size and shape are said to be among the most important morphologically distinguishing factors of starches from different origins. For example the Irish potato is reported to have a very broad granule size distribution reaching up to over 70µ while cow cockle *(Saponaria vaccaria* L.) starch granule size is smaller than 2µ (Satin, 1988). In one study on Malawian sweetpotato, the widest starch granule distribution was found to be 9 - 36µ (Tsakama *et al*., 2010) and in another study, five Sri Lankan sweetpotato varieties were reported to have polygonal or round shaped starch granules with average granule size of 16.8 – 23.5µ; a low level of *in vitro* starch digestibility was observed in varieties containing larger granules, indicating the presence of resistant starch (Senanayake *et al*., 2013). This might be linked with the higher amount of surface area available for enzyme action in smaller-sized granules. *Apomuden* could be recommended for the production of baby foods due to

A

C

E
F



B

D

Plate 5.1 **Photomicrographs of native starch granules extracted from six sweetpotato varieties. A: Apomuden, B: Bohye, C: Faara, D: Hi-starch, E: Okumkom, F: Ligri (white bar in each micrograph is 25 microns)**

Table 5.1 Starch granule morphologies of six sweetpotato varieties

VARIETY	Granule size distribution range (microns)	Granule shapes **(predominant)**
Apomuden	2 - 15	Truncated oval, spherical
Bohye	6 - 34	Truncated oval, spherical
Faara	4 - 22	Polygonal, spherical
Hi-starch	8 - 40	Spherical, truncated oval
Okumkom	6 - 26	Spherical, polygonal
Ligri	5 - 30	Spherical, polygonal, truncated oval

its high nutrient content and very small starch granule size (Table 5.1), as it may have the potential for higher starch digestibility than varieties with larger granule sizes. However, digestibility was not determined and should be investigated further. Different size granule fractions of starches from various crops have been characterized (Appolonia and Gilles, 1971; Kulp, 1973; Goering and DeHaas, 1974; Kainuma *et al.*, 1978; Ghiasi *et al.*, 1982; Soulaka and Morrison, 1985; Jane *et al.*, 1992; Vasanthan and Bhatty, 1995; Wilhelm *et al.*, 1998; Takeda *et al.*, 1999; Fortuna *et al.*, 2000; Tang *et al.*, 2001a, 2001b). It is reported that starches with small granules and narrow granule size distributions are very useful in many different applications, for example as fat substitutes, starchfilled degradable plastic films and stabilizers in baking powder. The small granule size of rice starch (2 – 13μ) makes it suitable for application in skin cosmetics and laundry-stiffening agents (Jane, 1992; Jane *et al.*, 1992). In this study *Apomuden*, *Faara* and *Okumkom* were found to have smaller size distribution ranges compared to the other three varieties studied (Table 5.1).

Starch pasting characteristics

Typically, the pasting profile of sweetpotato starch is described as type A and is known to show a high peak viscosity followed by a high degree of shear-thinning (Collado *et al.*, 1999). This type of profile was observed in the six sweetpotato varieties studied; however, sharper peaks were observed in those with larger granule size ranges (*Bohye*, *Hi-starch* and *Ligri*) while varieties with smaller-sized granules had less sharp, slightly broader peaks indicating some degree of resistance to shear thinning (Figure 5.1). The influence of both variety and harvest maturity on all RVA pasting properties were significant (p<0.01, p<0.001) (Table 5.2).

Table 5.2 Mean Square values from Analysis of variance of the influence of variety and harvest maturity on starch RVA pasting properties

Source of variation	**d.f.**	**Pasting Temp**	**Peak Time**	**Peak Viscosity**	**Stability Ratio**	**Setback Ratio**
VARIETY	5	7.971***	0.227***	7809***	0.025***	0.061***
MATURITY	2	0.908**	0.013***	3149***	0.009***	0.002***
VARIETY.MATURITY	10	0.501**	0.036***	8022***	0.002***	0.007***
Residual	15	0.109	0.001	5272	0.00006	0.0001

***Significant at p<0.001
**Significant at p<0.01
*Significant at p<0.05

Peak viscosities ranged from 4077 to 5260 centipoise and were highest in varieties that had larger granule sizes while the lowest were observed in *Apomuden*, *Faara* and *Okumkom*, the smallersized granule varieties (Table 5.3). There is less molecular bonding in larger granules and this leads to faster swelling; larger granules therefore, tend to give higher viscosities than smaller

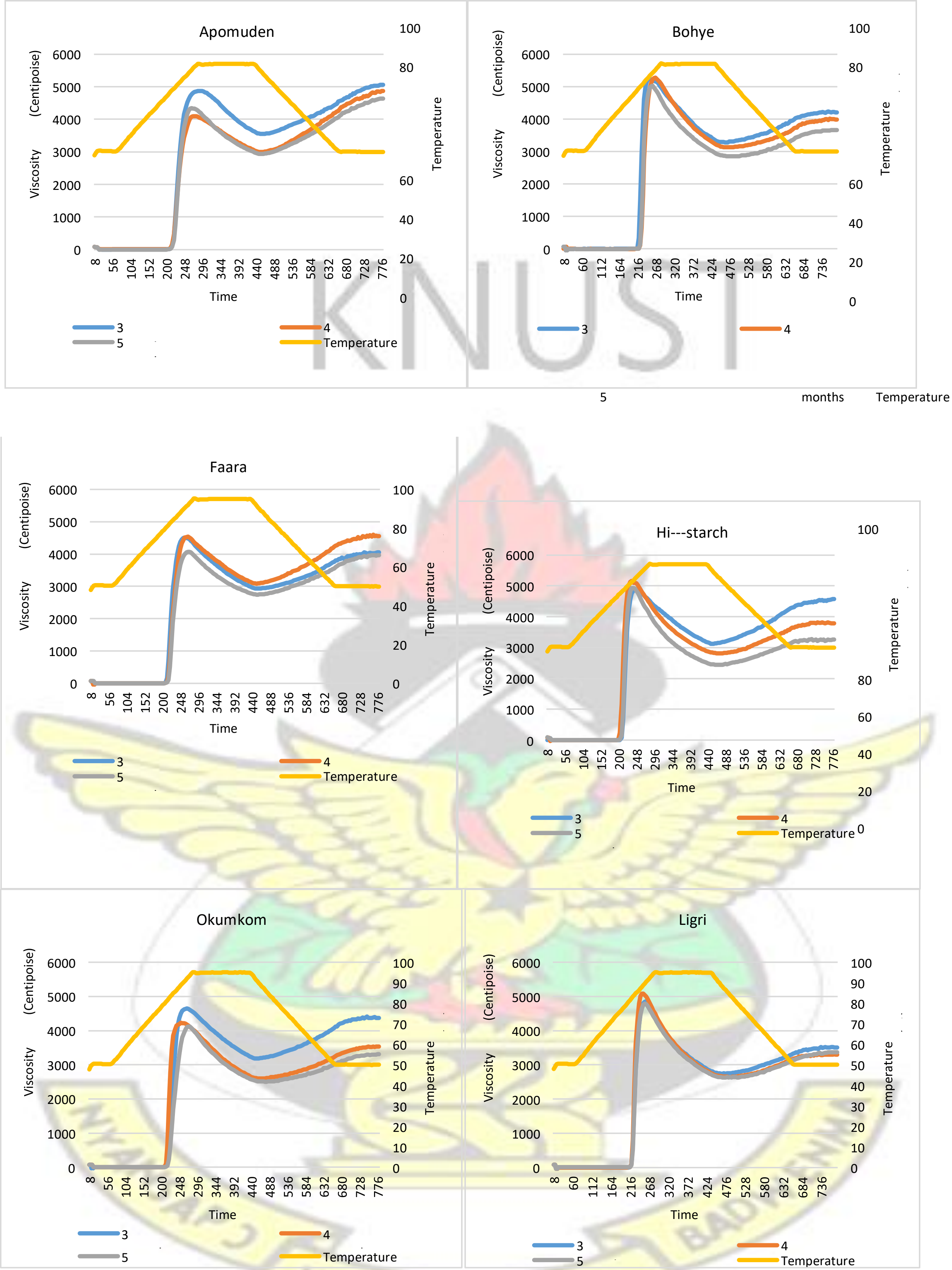


Figure 5.1 Pasting profiles of starches from six sweetpotato varieties at 3, 4 and 5 months harvest maturity

granule fractions, and the physical size of the granule also makes it more sensitive to shear (Chen *et al.*, 2003; Thao and Noomhorm, 2011). Stability ratio indicates the extent of a cooked starch's resistance to viscosity breakdown in the presence of shear stress, and is calculated as the ratio of the lowest (trough) viscosity to the highest (peak) viscosity attained during the heating phase of the pasting cycle. Stability ratio ranged from 0.52 to 0.73; starches with high peak viscosity (*Bohye*, *Hi-starch* and *Ligri*) were found to have low stability ratio, meaning they were more susceptible to breakdown (Table 5.3). A similar trend where sweetpotato starches with high peak viscosities were found to break down easily, leading to weak gels was reported by Tsakama *et al*. (2010). They also reported that starches with longer peak time were more susceptible to shearinduced disintegration; however, the sweetpotato varieties in this study showed a contrary trend, where longer peak times were rather associated with higher stability (Table 5.3). Starches with smaller granules had relatively low peak viscosities and high stability (resistance to breakdown); these starches from *Apomuden*, *Faara* and *Okumkom* may therefore, be suitable as thickening agents for sauces, cream soups, pie fillings and other applications requiring more stability and resistance to various stresses during the heating process. Pasting temperatures ranged from 77.95 – 82.45ºC. Pasting temperature for sweetpotato starches are reported to generally range from 61.5 – 86.3°C (Moorthy 2002) and a study in Vietnam reported values of 80.1 to 82.3°C (Thao and Noomhorm, 2011). Pasting temperature relates to the ease of cooking and has implications for the efficiency of energy usage in processing. Chen *et al.* (2003) found that in three sweetpotato starches, the larger the granule size the higher the gelatinization temperature. In this current study, two of the larger sized granule varieties (*Bohye* and *Ligri*) had the highest pasting temperatures; *Hi-starch* was however unique, having the largest granule size range and yet the lowest pasting temperature among all the varieties (Table 5.3).

Table 5.3 RVA pasting indices of starch from six sweetpotato varieties across three (3) levels of harvest maturity

RVA Pasting Parameter	Variety	Maturity 3 months	4 months	5 months	Mean
Peak viscosity (Centipoise)	Apomuden	4882	4202	4336	4473.3 [±360.2] c
	Bohye	5260	5233	5027	5173.3 [±127.4] a
	Faara	4540	4442	4077	4353.0 [±243.9] d
	Hi-starch	4902	5146	4866	4971.3 [±152.3] b
	Okumkom	4722	4210	4082	4338.0 [±338.6] d
	Ligri	4867	5062	4845	4924.6 [±119.4] b
Setback ratio	Apomuden	1.43	1.61	1.58	1.54 [±0.098] a
	Bohye	1.29	1.28	1.28	1.28 [±0.004] e
	Faara	1.37	1.49	1.45	1.44 [±0.060] b
	Hi-starch	1.46	1.35	1.34	1.38 [±0.067] c
	Okumkom	1.36	1.37	1.33	1.35 [±0.020] d
	Ligri	1.27	1.25	1.28	1.27 [±0.016] e
Stability ratio	Apomuden	0.73	0.72	0.67	0.71 [±0.029] a
	Bohye	0.62	0.60	0.57	0.60 [±0.028] d
	Faara	0.65	0.69	0.68	0.67 [±0.018] b
	Hi-starch	0.64	0.55	0.50	0.56 [±0.070] e
	Okumkom	0.68	0.61	0.61	0.63 [±0.042] c
	Ligri	0.56	0.52	0.53	0.54 [±0.021] f
Peak time (mins)	Apomuden	4.80	4.60	4.43	4.61 [±0.184] a
	Bohye	4.23	4.47	4.33	4.34 [±0.117] c
	Faara	4.33	4.47	4.46	4.42 [±0.078] b
	Hi-starch	4.10	3.97	4.03	4.03 [±0.067] e
	Okumkom	4.43	4.20	4.53	4.23 [±0.170] d
	Ligri	4.33	4.13	4.23	4.39 [±0.099] b
Pasting temp (°C)	Apomuden	80.33	79.95	80.33	80.20 [±0.217] c
	Bohye	81.13	82.40	82.45	81.99 [±0.751] a
	Faara	79.48	79.95	80.68	80.04 [±0.607] d
	Hi-starch	79.15	77.95	79.13	78.74 [±0.686] d
	Okumkom	80.80	79.90	80.75	81.51 [±0.506] b
	Ligri	81.48	81.55	81.50	80.48 [±0.036] c

Numbers in square brackets represent standard deviation. Means followed by a common letter are not significantly different

Peak time ranged from 3.97 to 4.80 mins, and again was lowest in *Hi-starch* variety; this was however, to be expected since larger granules tend to build viscosity faster than smaller-sized granules. The varieties with smaller granule sizes were found to have the longest peak times, the longest being *Apomuden* which had the smallest granule size range. Peak time is the length of time to reach the highest viscosity during the heating phase. Other workers reported peak times ranging from 4.15 to 4.40 min (Thao and Noomhorm, 2011). Setback ratio ranged from 1.25 to 1.61, and was found to be higher among the smaller granule size starches (*Apomuden, Bohye, Faara*). It is used to predict the retrogradation tendency of starch. Cooked or gelatinized starch molecules tend to re-associate with one another after cooling, forcing water out of the molecule and thereby causing the starch to recrystallize. The tendency of a starch to recrystallize or retrograde determines its suitability in certain products when long-term stability is a requirement. Sweetpotato starch is reported to retrograde more slowly or has less setback than cereal starches (Takeda *et al*., 1986). *Bohye* and *Ligri* starch had the lowest values for setback (Table 5.3), indicating less retrogradation and potentially better long-term cold paste stability. These starches may therefore be suitable for adhesives and also in cold desserts and frozen foods. For other product types, retrogradation is a desirable feature and it may even be promoted to modify structural, mechanical, or organoleptic properties of certain starch-based products, for example, breakfast cereals and parboiled products. This is because retrogradation results in hardening and reduces stickiness. Setback is therefore, considered an important criterion for starch selection for many industrial food applications such as noodles (Chen *et al.*, 2003; Thao and Noomhorm, 2011). Among the smallsized granule starches, *Okumkom* had the least setback ratio or retrogradation tendency (Table 5.3);

The importance of starch granule size and retrogradation tendency in some snack formulations was demonstrated in a study where starches with smaller granules and low degree of retrogradation yielded products with the best puffing quality as well as a smooth mouth feel (Park *et al.*, 2001).

The influence of maturity

Although varietal and environmental differences have received more emphasis in most studies, the influence of maturity on sweetpotato starch properties have also been reported (Noda *et al.*, 1997; Yempew *et al.*, 2001; Ishiguro *et al.*, 2003). This is of relevance due to the fact that sweetpotato has no clear-cut maturity time; harvesting is often done when storage roots have reached sizes desirable for marketing, making it very subjective. In Ghana, the recommended harvest age for improved varieties is four months. Noda *et al*. (1997) observed that sweetpotato starches of the same variety, but grown and harvested at different times had varying properties, and reported that starch extracted from older roots had higher gelatinization temperature and peak viscosity, but lower hot paste stability. This current study confirmed this with the exception of peak viscosity, which was lower at advanced maturity; mean peak viscosity for all the varieties reduced with increasing harvest maturity and was lowest at 5 months (Figure 5.2). However, when varieties were categorized according to starch granule size range, differences in the effects of maturity became obvious; for larger granule varieties a slight increase in peak viscosity was observed between three and four months while for smaller granule varieties, reduction in peak viscosity occurred progressively with advancing maturity (Figure 5.2).

Granule size category may be an important factor to consider when studying trends in the influence of maturity on starch functional properties. RVA pasting properties of the starches were influenced significantly by variety and harvest maturity.

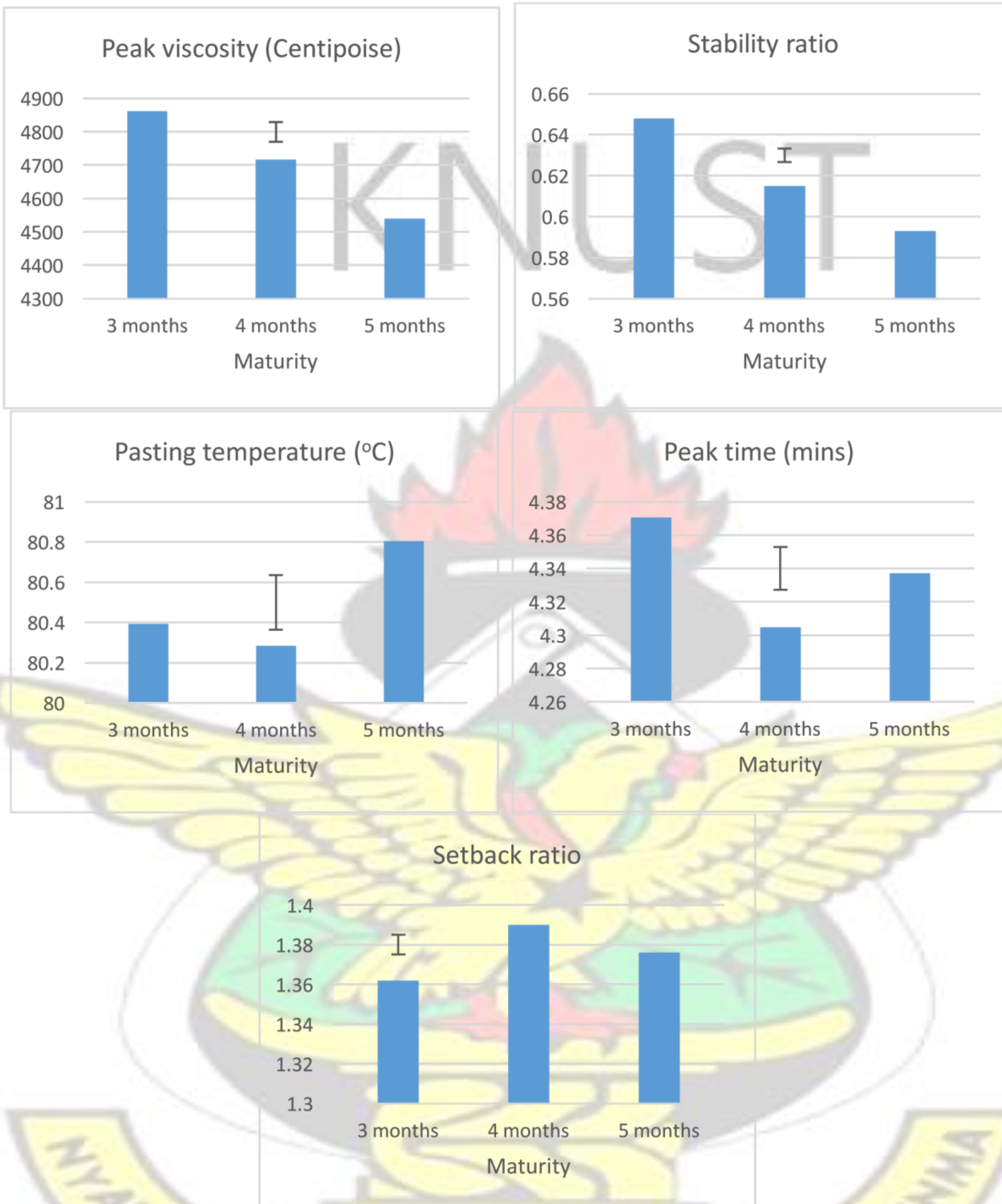


Figure 5.2 Influence of harvest age on RVA pasting properties of starch from six (6) sweetpotato varieties (Error bar in each chart = LSD for effect of maturity; p<0.001)

The influence of maturity on peak viscosity and setback ratio followed different trends based on granule size category. Small starch granule size varieties (≤ 26µ) when harvested at four and five months, had the lowest peak viscosities and highest setback ratio (retrogradation tendency); larger granule size varieties (≤ 40µ) when harvested at four months had the highest peak viscosities and lowest setback ratio (Figure 5.3).

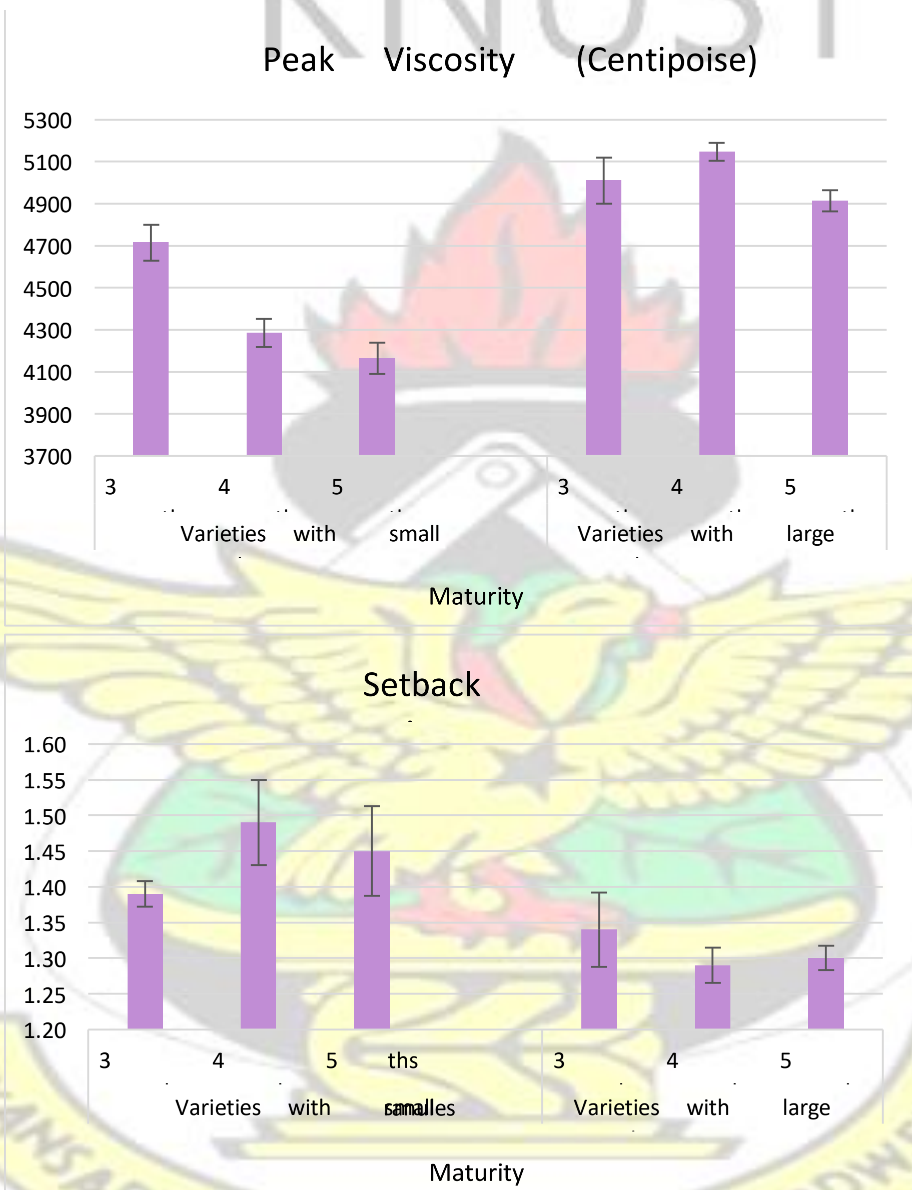


Figure 5.3 Influence of granule size on changes in peak viscosity and setback ratio with increasing maturity. Small granule size category: ≤ 26µm; large granule size category: ≤ 40µm. (Error bars are standard deviations for varieties)

Other workers also reported that granule size had substantial effects on sweetpotato starch pasting properties, although the link between granule size and how pasting properties varied during maturation or crop development was not factored into those studies (Chen *et al.*, 2003; Abegunde *et al.*, 2012). It would be interesting if basic features such as granule size category and harvest maturity could be used as broad indicators of functional properties in sweetpotato starch. This is worth investigating, as it could be a useful and cost-effective tool in selection breeding or in tailoring native starch for certain applications. With the exception of *Faara*, early harvested samples (i.e. three months) had the highest final viscosities (cold paste or gel viscosities), indicating harder texture of gels formed upon cooling; the lowest cold paste viscosities at the end of the pasting profiles (indicating softest gels) were observed at five months for all the varieties (Figure 5.1). *Okumkom* starch at five months may be suitable for incorporation into flours for baked products, due to its low peak viscosity coupled with good stability (resistance to breakdown) and very low cold paste viscosity observed at the end of the pasting cycle (Figure 5.1). The best performance of sweetpotato starch in industry may be achieved by selecting not only the appropriate variety, but also the best recommendations for harvest timing. Selection of sweetpotato starch for utilization must take into account not only varietal uniqueness, but also harvest maturity. These findings are relevant in understanding the overall eating quality of sweetpotato, whether consumed in fresh form or when processed into secondary products. The results also have a bearing on industrial utilization of the starches studied, as food ingredients or in other applications.

5.4 CONCLUSIONS

Starch granule shapes and size ranges showed some amount of diversity among the varieties studied. *Apomuden* starch was observed to be unique, showing a very small size range close to that of rice and uncharacteristic of root and tuber crop starches. *Bohye* and *Ligri* starch had the lowest values for setback, indicating less retrogradation and better long-term cold paste stability; these starches may therefore be suitable for adhesives and also in cold desserts and frozen foods. Starches with smaller granules (*Apomuden*, *Faara* and *Okumkom*) had relatively low peak viscosities and high stability ratio or resistance to breakdown; they may therefore be suitable as thickening agents for sauces, cream soups, pie fillings and other applications requiring more stability and resistance to various stresses during the heating process. *Okumkom* starch at five months may be suitable for incorporation into flours for baked products, due to its low peak viscosity coupled with good stability and very low cold paste viscosity observed at the end of the pasting cycle.

RVA pasting properties of the starches were influenced significantly ($p<0.01$) by variety and harvest maturity; the influence of maturity on peak viscosity and setback ratio followed different trends based on granule size category. Small starch granule size varieties ($\leq$ 26µ) when harvested at 4 and 5 months, had the lowest peak viscosities and highest setback ratio (retrogradation tendency); larger granule size varieties ($\leq$ 40µ) when harvested at 4 months had the highest peak viscosities and lowest setback ratio. Selection of sweetpotato starch for utilization must take into account not only varietal uniqueness but also harvest maturity. The results of this study are relevant in understanding the processing and utilization quality of the varieties studied, and also in identifying potential niche applications for sweetpotato starch in both food and non-food sectors.

CHAPTER SIX

6.0 SWEETPOTATO PRODUCT QUALITY: INFLUENCE OF FRESH ROOTS CHARACTERISTICS (THE CASE OF FRIED CRISPY CHIPS)

6.1 INTRODUCTION

Sweetpotato is a major crop that feeds millions of people in the developing world. It is especially popular among farmers with limited resources, and can produce more edible energy per hectare per day than wheat, rice or cassava (CGIAR, 2005). It is speculated to produce more biomass and nutrients per hectare than any other food crop in the world (Prakash, 1994). Sweetpotato is rich in simple and complex carbohydrates, dietary fibre, and also provides nutritionally significant quantities of ascorbic acid, riboflavin, pyridoxine, iron, calcium and protein. In addition, the orange-fleshed varieties are rich in ß-carotene, a nutrient which may be effective in preventing certain types of cancer (Prakash, 1994) and has also been sustainably employed in public health campaigns for the alleviation of vitamin A deficiency (Van Jaarsveld *et al.*, 2005). Among the food crops, sweetpotato has the highest recorded net protein utilization based on percentage of food nitrogen retained in the body (Prakash, 1994). According to Islam *et al.*, (2003) and Islam (2006), regular consumption of sweetpotato is helpful for preventing a number of disease conditions due to its unique combination of inherent beneficial active components. Patil *et al.*, 2007 and WHFoods (2009) also indicated that sweetpotato has healing and immune-boosting properties as an antioxidant food. In this regard, it has been developed in some countries for new uses as a bioactive functional health food (Shih *et al.*, 2009).

Although this nutritious and high-energy crop produces good yields in all the various agroecologies of Ghana, it is currently not well integrated into the average Ghanaian diet and its level of utilization in the country is very low as compared to the other root and tuber crops generally consumed. On the local scene, the use of the crop is evident only in a few communities and processing is limited to boiling, roasting or frying in isolated households and by roadside food vendors. It is clear that the immense industrial potential of sweetpotato is yet to be explored in

Ghana. To increase utilization, there is the need for more information about existing varieties and their processing characteristics, as well as an understanding of the factors affecting these characteristics in order to achieve consistent product quality.

In the United States of America, the sweetpotato sector is highly developed; however, the common U.S.A sweetpotato varieties that were developed primarily for fresh markets were found to be unsuitable for the manufacture of crispy chips and French fries, despite various modern improvements in processing technologies including vacuum frying and vacuum belt drying (Ravli, 2012; Xu, 2012). Selection of novel specialty sweetpotato cultivars for making chips or fries with more acceptable attributes may help to sustain or enlarge their market shares (Gao *et al.,* 2014). Varietal diversity exists in sweetpotato fresh roots composition, and variations are known to also occur based on agronomic and postharvest handling practices; these could all impact on product quality. Diversifying uses of key varieties would help expand or encourage industrialization of the crop in Ghana; basic food processing methods such as chipping and frying can convert perishable sweetpotato fresh produce into shelf-stable, highly marketable snack foods.

Snack foods are considered the most enjoyable food products consumed all over the world. Early snack products such as cookies, crackers, and biscuits were made from wheat flour. As the new products evolved, other base ingredients such as rice, maize, potato, and tapioca were constantly added to the list of important raw materials (Pichetnawin, 2004). Sweetpotato is potentially a good raw material for many healthy snack and staple food products in Ghana since being a shortduration crop, and year-round production is possible with the application of irrigation. The objective of this study was to characterize selected sweetpotato varieties for their fried crispy chips quality attributes, and to assess the stability or variability of these attributes based on fresh roots characteristics at different levels of maturity and storage.

6.2 MATERIALS AND METHODS

Six (6) improved high-yielding and disease-resistant varieties of sweetpotato obtained from CSIRCrops Research Institute, Ghana were cultivated at Fumesua in the Ashanti Region under identical management practices and harvested at 3.5, 4 and 5 months after planting. At each harvest time, a batch of fresh roots was sampled for each variety and half was processed immediately into fried crispy chips while the other half was stored at room temperature (26ºC ± 3) for three weeks before being processed.

6.2.1 Preparation of crispy chips

Sweetpoato roots were washed and lightly peeled. Two tapering ends (proximal and distal) were cut off to aid in uniformity during slicing. The peeled roots were sliced along the longitudinal plane into thin flat strips of approximately 1.5 – 2.0 mm thickness, using a manual sweetpotato slicer obtained from the International Potato Center. The strips were then fried at 190˚C for approximately 90 seconds (100g of sample in 1500ml oil), until intense bubbling stopped, signifying the adequate removal of moisture. After frying, samples were spread on paper towels to remove excess oil and allowed to cool naturally to room temperature; they were then packaged in plastic bags, sealed and stored at room temperature. All samples were analyzed for both instrumental and sensory attributes within 24 hours after production.

6.2.2 Measurement of Instrumental textural hardness

Hardness of the crispy chips was measured at various sampling times as shown in Table 6.1.

Table 6.1 Fresh roots sampling times for instrumental and sensory analysis of fried crispy chips quality in six (6) sweetpotato varieties*

SAMPLING TIME	INSTRUMENTAL TEXTURE ANALYSIS	SENSORY ANALYSIS
3.5 months, at harvest	--	✓
3.5 months, after storage	✓	--
4 months, at harvest	✓	✓
4 months, after storage	✓	--
5 months, at harvest	✓	✓
5 months, after storage	✓	✓

**Due to delayed access to a functional Texture Analyzer, a set of instrumental data was missed (3.5 months at harvest) and subsequent Instrumental Analyses had to be done in a different city (Accra) instead of the actual location of the whole study (Kumasi). All further sensory analyses therefore had to be staggered to accommodate several trips to Accra in view of logistical practicalities encountered; each batch of samples was analyzed within 24 hours after processing, and every effort was made to keep the whole study feasible.*

The instrument used was Texture Analyzer (Model: TA XT Plus; Exponent Stable Micro systems, UK) with the following accessories: Crisp Fracture Rig (HDP/CFS) using 25kg load cell; Heavy Duty Platform (HDP/90). The probe type was 6.0mm spherical. A compression test mode with test speed of 1.0mm/s and distance of 3.5mm was used and sample type selected was 'Snack, tortilla chip'. Chips with most uniformity in terms of size and shape were selected and removed from packets just prior to testing. Test results were obtained from 15 replications (15 chips per sample) and the mean maximum force value was calculated to represent 'Hardness" and the force value (Peak breaking force) was presented in grammes.

6.2.3 Sensory evaluation

A trained panel was used to perform a quantitative descriptive analysis (QDA) to evaluate the intensities of key sensory attributes of crispy chips from six sweetpotato varieties. The panel consisted of 8 people selected from a Research Institution and a University (4 females and 4 males, of age 22 to 45), having experience with consumption of various types of crispy chips. This information was gathered through brief interviews conducted during selection of suitable panellists. Before the sensory evaluations started, the selected panel engaged in a brainstorming session to generate descriptive terminologies suitable for sweetpotato chips. This was done using commercial chips products (plantain chips and cocoyam chips) and other products of varying flavour, taste and texture (potato chips and corn flakes). In Ghana sweetpotato chips are not commercially available. Table 6.2 shows the descriptive terminologies generated.

Table 6.2 Descriptive terminologies generated for sweetpotato crispy chips by panellists prior to sensory evaluation

Descriptive term	Meaning (by consensus)	Rating
1. Loudness	Intensity of the sound the product makes in the ears at the start of chewing	From 'gentle' to 'loud'
2. Stickiness	How the product clings to the inner teeth during chewing	From 'not sticky' to 'very sticky'
3. Sweetness intensity	How sugary the product tastes in the mouth	From 'no sugary taste' to 'very sugary'
4. Flavour	Aroma quality as perceived by senses of both taste and smell	From 'mild' to 'strong'
5. Overall Acceptability	Personal judgement of the product's overall quality, as an expert consumer	Subjective rating

At each time of actual evaluation, samples were presented with a 3-digit blind coding system, using a different order of presentation for each panellist. Quantitative scoring of perceived intensities was done by placing a pencil mark freely on an unstructured 12-cm-interval scale in the direction of the intensity, as shown in Figure 6.1.

SWEETPOTATO CRISPS SENSORY EVALUATION FORM

NAME:
OCCUPATION: PHONE #:
AGE: GENDER: Male/Female

PRODUCT ATTRIBUTES

Loudness

Gentle — Loud

Stickiness

Not sticky — Very sticky

Sweetness intensity

No sugary taste — Very sugary

Flavour

Low intensity — High intensity

Overall Acceptability

Low — High

Figure 6.1 Score sheet used for sensory evaluation of sweetpotato crispy chips quality attributes

Statistical analysis

Data were subjected to Analysis of Variance (ANOVA) using SPSS 11.5 Windows package. Correlations between various parameters were determined using Pearson's product-moment correlation coefficient tests. A significance level of $P < 0.05$ was used.

6.3 RESULTS AND DISCUSSION

Instrumental texture analysis (Peak breaking force)

The highest Peak force (hardest chip texture) was in *Hi-starch* at five months (518.22 g) and the lowest was in *Apomuden* at four months (51.86 g) (Table 6.3).

Table 6.3 Instrumental Peak breaking force (g) of fried crispy chips prepared from sweetpotato fresh roots at different sampling times

	PEAK BREAKING FORCE (g)					
VARIETY	3.5 months (Stored)	4 month	4 months (Stored)	5 months	5 months (Stored)	Mean (All sampling times)
Hi-starch	361.56	436.99	339.99	518.22	278.42	387.04±82.90
Ligri	433.81	301.03	472.01	480.52	411.54	419.78±72.08
Okumkom	197.74	363.44	338.98	349.67	314	312.77±66.80
Faara	263.67	314.77	341.5	442.43	228.87	318.25±82.07
Apomuden	113.07	51.86	245.81	239.18	152.67	160.52±83.04
Bohye	201.47	261.84	259.32	280.17	341.28	268.82±50.14
Mean (All Varieties)	261.89 ± 117.82	288.32 ± 130.55	332.94 ± 80.64	385.03 ± 112.85	287.80 ± 90.20	

Influence of Variety: ns
Influence of Sampling time: * (p = 0.025)

ns: not significant * : significant at p<0.05

Peak breaking force of chips was influenced significantly (p<0.05) by maturity but not variety; it appeared to increase with increasing harvest age. Influence of storage was inconclusive due to the absence of data for 3.5 months freshly harvested samples (Table 6.1). However, for four months and five months samples, the effects of storage on chips hardness was variety-dependent with Peak force either increasing or decreasing with storage based on the variety. At four months, storage resulted in a net increase in chips hardness (Peak force) while at five months there was a net decrease, as shown in the overall mean values for the six varieties (Table 6.3).

There were trends in the influence of storage on the correlation between compositional attributes and Peak breaking force of the chips (Table 6.4). Higher correlations ($r > 0.80$) between chips hardness (Peak force) and major constituents of the raw material (starch, sugar and dry matter content; data from CHAPTER 4) were observed in freshly harvested samples and the lowest correlations were observed after fresh roots storage. Table 6.4 shows correlation coefficients before and after storage between instrumental texture and fresh roots composition (starch, dry matter and sugar contents).

Table 6.4 The effect of sampling time on correlation (r) between crispy chips Instrumental Peak breaking force (g) and starch, dry matter and total soluble sugar contents (%) of six sweetpotato varieties

SAMPLING STAGE	Correlation (r) with Peak force (g)		
	Starch (%)	Dry matter (%)	Total soluble sugars (%)
3.5 months stored	0.73	0.56	-0.75
4 months at harvest	0.87	0.81	-0.86
4 months stored	0.57	0.47	0.26
5 months at harvest	0.86	0.81	-0.84
5 months stored	0.45	0.17	-0.51
Combined sampling times	0.64	0.48	-0.51

At harvest, for four months and five months maturity stages, fresh roots composition (starch, dry matter and sugar contents) were fairly good predictors of instrumental texture. Peak force in chips made from freshly harvested samples correlated negatively (r = -0.86, -0.84) with sugar content and positively with dry matter (r = 0.81) and starch contents (r = 0.87, 0.86) (Table 6.4). This means that in freshly harvested roots, low sugar, high dry matter and high starch contents were associated with harder texture of fried crispy chips. After storage, however, there were no clear relationships between the components and instrumental texture (Table 6.4). Therefore, in processing fried crispy chips from these sweetpotato varieties, using varietal composition to predict or anticipate the hardness of the chips may be more practicable only when using freshly harvested roots.

Across all sampling times combined, dry matter of varieties was not a good determinant of chips instrumental texture, since samples with similar Peak breaking force yet having very different dry matter contents were observed to occur (Figure 6.2). In the potato industry, chip quality is routinely predicted based on dry matter classifications (Ooko and Kabira, 2011). Gao and others suggested that the upper limit for dry matter in making sweetpotato crispy chips of appropriate texture was a dry matter content of 22.6% (Gao *et al*., 2014). Harvest maturity and short-term storage of fresh roots had an influence on sweetpotato crispy chips texture, regardless of dry matter content. For example, in *Hi-starch* and *Faara* (with high dry matter contents > 30%) chips had moderate Peak breaking force at 3.5 months after storage (361.56 g and 263.67 g respectively), high values at five months harvest (518.22g and 442.43g respectively) and low values (278.42g and 228.87 g) respectively after storage (Table 6.2).

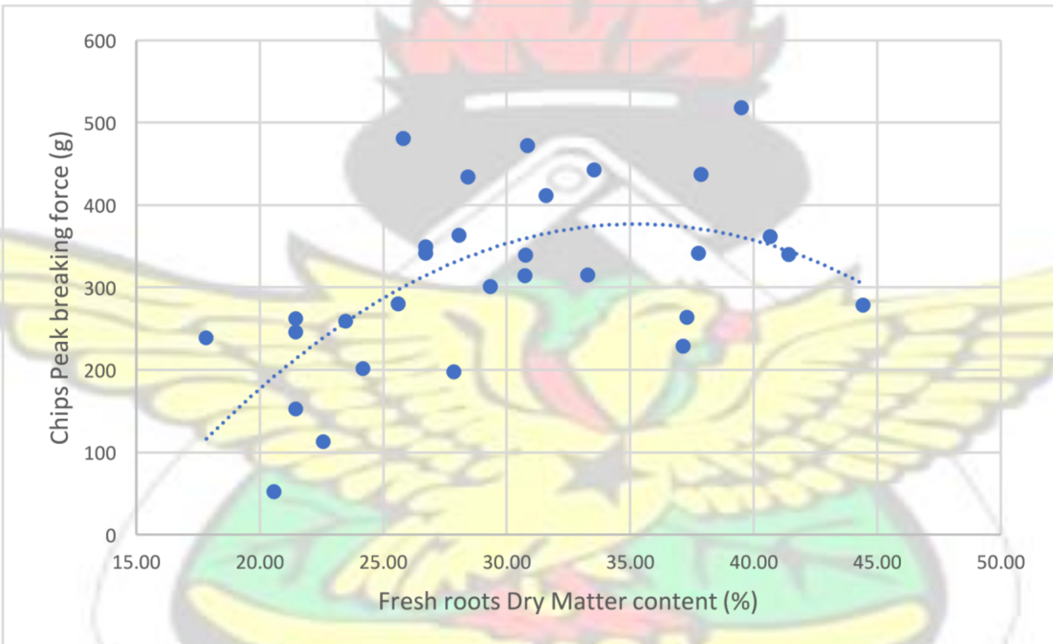
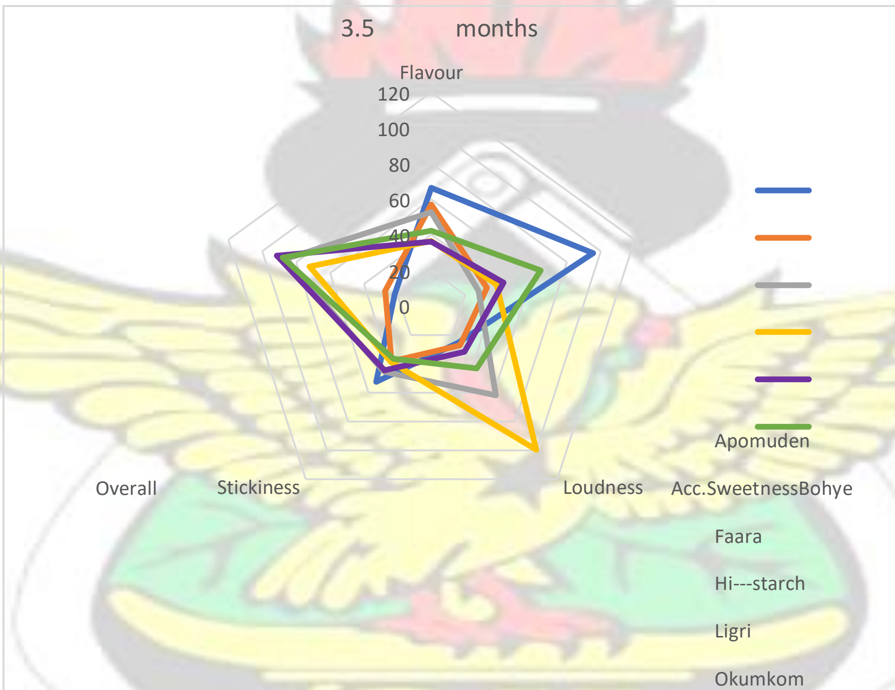


Figure 6.2 Relationship between fresh roots dry matter content (%) and chips instrumental texture (Peak breaking force, g) for six sweetpotato varieties across five sampling times (3.5 months after storage, 4 months at harvest and after storage, 5 months at harvest and after storage)

Chips from some varieties with low dry matter contents (< 25%) also had Peak breaking force between the range of 200g to 300g at some sampling times, similar to other varieties with dry matter contents as high as > 35% (Figure 6.2). This is in agreement with Gao *et al*. (2014), who observed that unlike potato, total dry matter content is not the main determinant of textural qualities of fried sweetpotato chips.

Sensory attributes

Varietal differences in chips Loudness were significant ($p<0.05$), and *Apomuden* had the lowest Loudness scores at all sampling times (Figure 6.3). Maturity differences in Loudness were however, not significant, although the trend showed an increase in Loudness with increasing



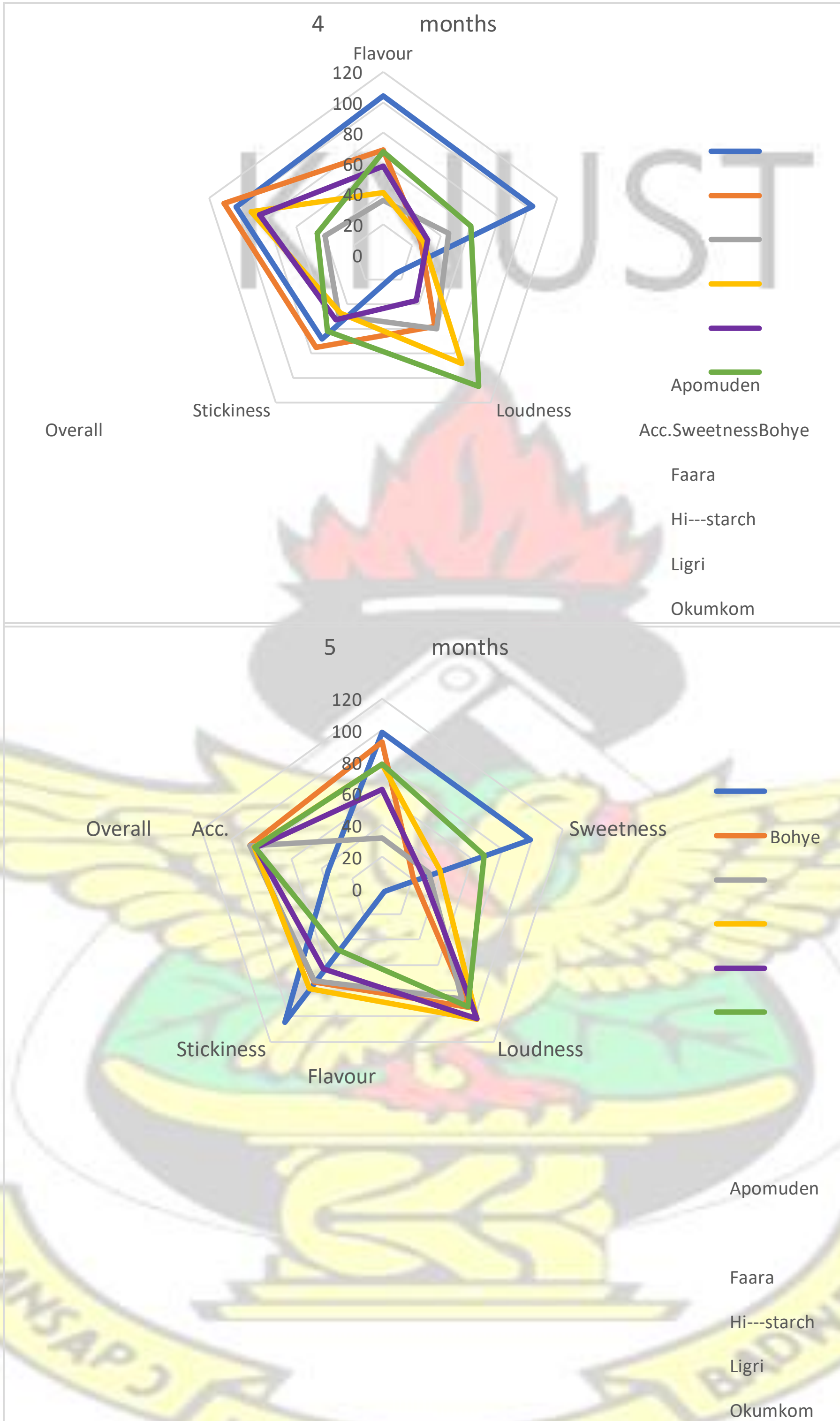


Figure 6.3 Influence of harvest time on sensory attributes of chips from six sweetpotato varieties harvested at 3.5, 4 and 5 months maturity

harvest maturity. Flavour intensity was influenced significantly ($p<0.05$) by both variety and maturity while Stickiness score was significantly influenced ($p<0.01$) only by harvest maturity.

Defining chip quality (finding the main determinants of acceptability)

In potato, the major indicators of suitable varieties as raw material for processing include high dry matter content and texture of product (Ooko and Kabira, 2011). Similarly, Gao *et al*. (2014), studying attributes of sweetpotato fresh roots that were most critical to quality of the fried crispy chips, based their evaluation of chips quality on Instrumental texture only, and concluded that lower Peak breaking force (chips with less hardness) was equivalent to more favourable quality. Their assessment of chips quality did not involve sensory analysis. Results from this current study, however, showed weak correlation (i.e. no strong association) between textural hardness and Acceptability scores, both for the instrumental (Peak breaking force, r = 0.25) and sensory (Loudness, r = 0.40) assessments (Figure 6.4).

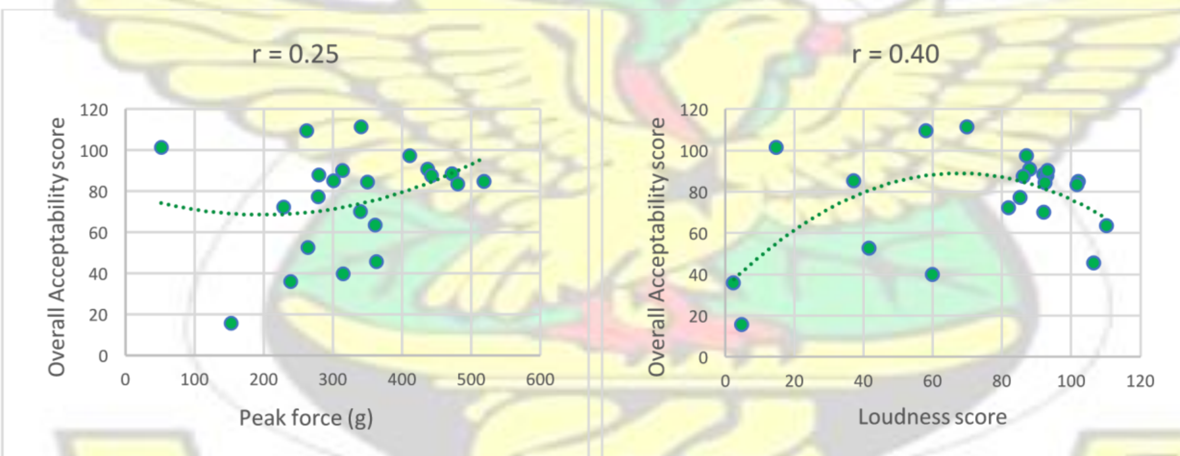


Figure 6.4 Relationship between textural hardness of fried chips (Peak breaking force and Sensory Loudness score) and Overall Acceptability

This means that sweetpotato varieties with similar chips hardness attributes were observed to have different Overall Acceptability, based on the influence of other sensory parameters such as Stickiness (mouthfeel), Sweetness and Flavour intensity. Selection of sweetpotato varieties for crispy chips may therefore require some more insight into factors other than texture and texturerelated primary constituents (dry matter and carbohydrate contents). Correlations of Overall Acceptability scores with other sensory attributes and fresh roots composition varied with harvest maturity (Table 6.5). At 3.5 months the key attribute linked with chips Overall Acceptability was Flavour intensity (r = -0.81); at 4 months there were no clear links between Sensory attributes and Acceptability. At 5 months however, Flavour, Sweetness, Loudness and Stickiness were major attributes influencing acceptability (r = -0.86, -0.87, 0.97 and -0.79 respectively). Correlation between Stickiness and Overall Acceptability was weaker at early maturity; apart from four months, all other sampling times showed a negative association between Stickiness and acceptability (Table 6.5).

Table 6.5 Coefficients of correlation (r) between Acceptability and other quality attributes of six (6) sweetpotato varieties

ATTRIBUTE	Correlation (r) with Acceptability			
	MATURITY			
	3.5 months	4 months	5 months	5 months (after storage)
Peak force	-	-0.41	0.60	0.88
Loudness	0.42	-0.50	0.97	0.83
Stickiness	-0.34	0.49	-0.79	-0.94
Flavour	-0.81	0.48	-0.51	-0.69
Sweetness	-0.43	-0.02	-0.86	-0.60
Starch (%)	0.48	-0.21	0.84	0.67
Dry matter (%)	0.55	-0.44	0.68	0.31
Total soluble sugars (%)	-0.37	0.24	-0.87	-0.74

Sweetness, Stickiness and flavour perception generally had negative correlations with acceptability in all samples except those harvested at four months; this indicates that low sweetness, less stickiness during chewing, and low flavour perception in the fried crispy chips were associated with higher Overall Acceptability. Notably at four months, there were negative correlations between hardness attributes (instrumental Peak breaking force and sensory Loudness score) and Overall Acceptability, while Stickiness score showed a weak positive correlation. This was the direct converse or opposite of what was observed at other sampling times (Table 6.5). Chips prepared from four months harvested samples appeared to have unique trends in the association between Overall Acceptability and other quality attributes; this could be due to individual varietal changes at that stage of maturity.

Apomuden had the most variable Overall Acceptability scores while *Ligri* and *Hi-starch* had relatively stable acceptability scores among all the varieties, with very little variation across all sampling times (Figure 6.5); this stability characteristic is a very desirable trait in any raw material targeted for industry. *Bohye* had the highest mean Overall Acceptability scores recorded in the study (109.5 and 111.4), occurring in samples at four months fresh harvest and five months after storage respectively. *Apomuden* had the lowest acceptability scores recorded (21.8, 35.8 and 15.6), occurring at 3.5 months, five months and five months after storage respectively; however, at four months *Apomuden* had a very high acceptability score of 101.4. The next highest acceptability score was in Ligri (97.4) at five months after storage (Figure 6.5). *Apomuden* and *Bohye*, being orange-fleshed varieties, are relatively rich in carotenoids and may therefore, be good candidates for the crispy fried chip product due to the positive effect of deep frying on beta-carotene retention and bioavailability (Bengtsson *et al*., 2008), coupled with the high Overall Acceptability ratings observed at certain sampling times (Figure 6.5). *Bohye*, formerly identified as breeding line 199062.1 (CSIR-CRI, 2012), was reported to have an exceptionally high level of alpha-carotene; this compound is known to be several times more anti-carcinogenic than beta-carotene (Ofori *et* *al.*, 2009). A snack product with such high nutritional advantage and biological activity could have high demand in both domestic and export health food markets.

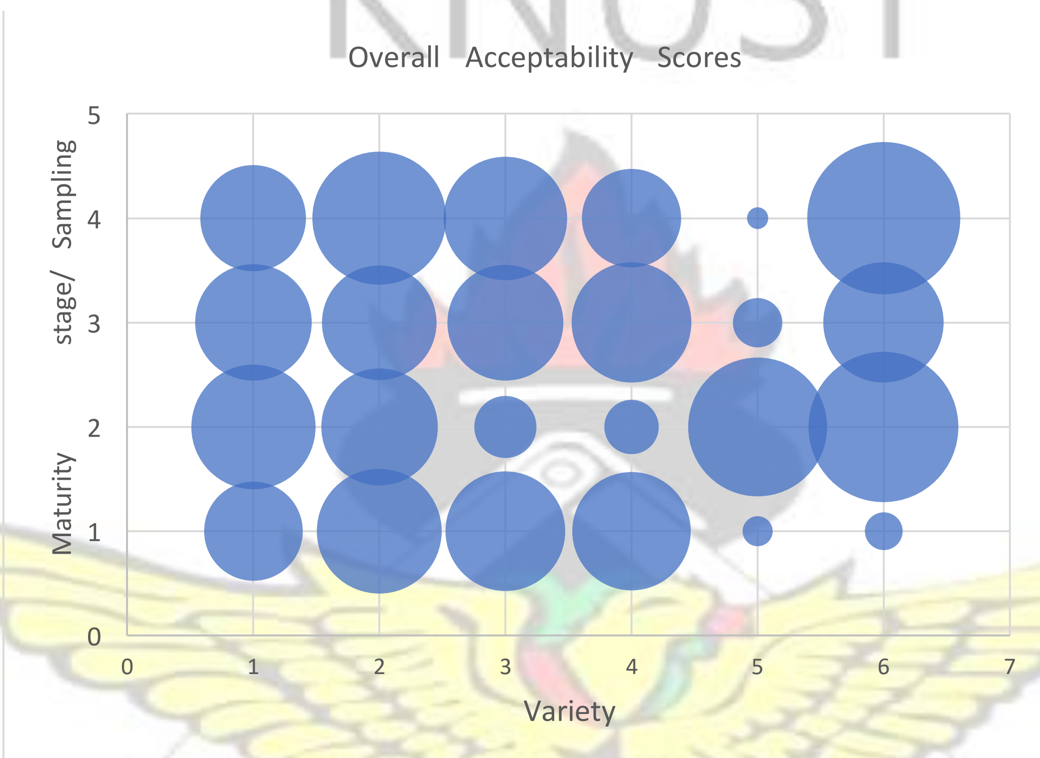


Figure 6.5 Mean Acceptability scores of fried crispy chips from six sweetpotato varieties (1=Hi-starch; 2=Ligri; 3=Okumkom; 4=Faara; 5=Apomuden; 6=Bohye) at different maturity stages/sampling levels (1=3.5 months; 2=4 months; 3=5 months; 4=5 months after storage). The size of the bubble represents the magnitude of Overall Acceptability score.

Although the influence of variety and maturity on various quality attributes were significant, differences in Acceptability scores between varieties and at various sampling times were not statistically significant. More studies are required to understand the basis for wide fluctuations in Overall Acceptability in some of the varieties at certain sampling times (Figure 6.6).

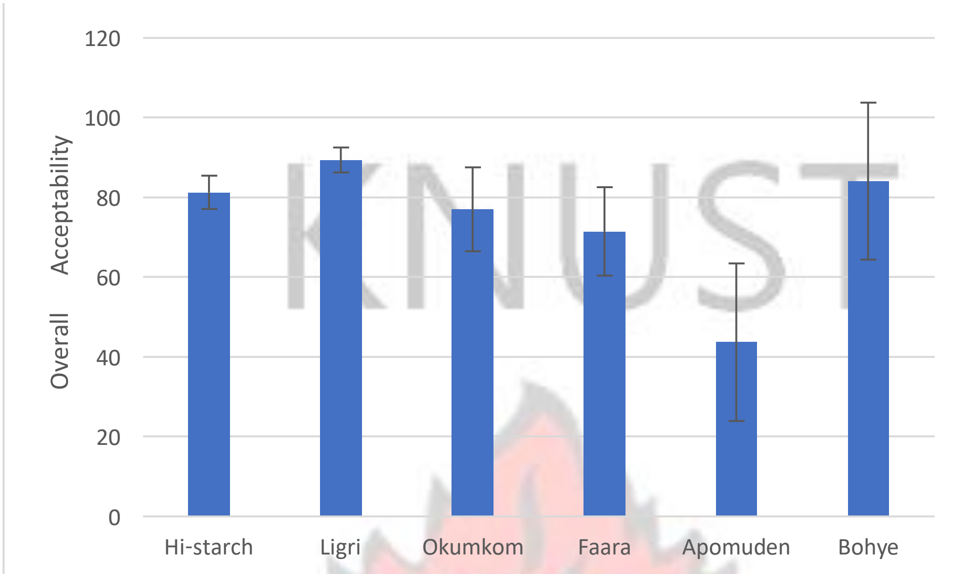


Figure 6.6 Mean scores for Overall Acceptability in chips from six (6) sweetpotato varieties across all sampling times

It is interesting to note, however, that varieties with larger starch granules within their size distribution range (*Hi-starch*, *Bohye* and *Ligri*) (data from CHAPTER 5) were found to have the highest Acceptability scores while those with smaller starch granules within their distribution range (*Apomuden*, *Faara* and *Okumkom*) had the lowest Acceptability scores. RVA pasting characteristics of the starch (Peak Viscosity and Setback ratio) were also found to have a bearing on the acceptability of chips from different varieties.

Large granule size varieties had higher starch RVA Peak viscosities and lower Setback ratios, which were all linked with higher chips Acceptability scores, regardless of total starch content of the variety (Table 6.6).

Table 6.6 Links between varietal starch properties and mean Overall Acceptability of chips across all sampling stages

VARIETY	Starch granule size range (microns)	Starch content (%, dmb) (Mean)	Peak Viscosity (centipoise) (Mean)	Setback ratio (Mean)	Overall Acceptability Score (Mean)
Bohye	6 - 34	68.38	5173.3	1.28	84.03
Ligri	5 - 30	69.04	4924.6	1.27	89.32
Hi-starch	8 - 40	78.87	4971.3	1.38	81.19
Okumkom	6 - 26	66.84	4338.0	1.35	76.92
Faara	4 - 22	72.81	4353.0	1.44	71.4
Apomuden	2 - 15	56.21	4473.3	1.54	43.66

Most previous studies linking sweetpotato composition and starch properties with texture and eating quality focused on steamed or boiled samples in which texture (mealiness, waxiness, moist or dry mouthfeel, smooth and fibrous) is the most dominant factor for acceptability (Walter *et al*., 2000; Oirschot *et al.*, 2003). More recently, however, attention is being devoted to shelf-stable industrializable products, of which crispy chip product types predominate (Ali *et al*., 2012; Ravli 2012; Xu 2012; Tumuhimbise *et al*., 2013; Esan *et al*., 2015). In Ghana, a close parallel to this type of snack product is plantain chips which is very popular in many regional capitals. Its peak breaking force was found to be much higher (813.58g) than chips from all the six sweetpotato varieties studied. The plantain chips sampled was also sliced along the longitudinal plane. Raw material quality stability is key in the success of any enterprise or industry, and more information is required to facilitate quality assurance in a raw material such as sweetpotato fresh roots, which in less-developed economies is produced and stored under ambient tropical conditions rather than stabilized or controlled environments, and therefore, may be more susceptible to fluctuations in quality.

Evaluating the accuracy of the taste panel

Loudness score, a sensorial assessment of chips hardness, was found to correlate significantly with Instrumental Peak breaking force which was an objective assessment of textural hardness ($r = 0.74$, $p<0.05$). This indicated the accuracy and objectiveness of the sensory panel (Table 6.7). Sweetness score also correlated positively with Total soluble sugar content ($r = 0.79$). Stickiness was found to correlate negatively with starch content ($r = -0.60$) and positively ($r = 0.68$) with sugar content (Table 6.7). Higher sugar contents were also associated with less hardness of chips (lower Loudness scores and Peak breaking force).

Table 6.7 Correlation coefficients (r) for the association between objective measurements and sensory scores of fried chips attributes for six (6) sweetpotato varieties harvested at maturity stages of 3.5, 4 and 5 months

Product quality attribute	Correlation coefficient (r)				
	Loudness Score	Stickiness Score	Sweetness Score	Flavour Score	Peak breaking force (g)
Peak breaking force (g)	**0.74**	-	**-0.60**	-0.59	1.00
Starch content (%)	**0.65**	-0.60	**-0.78**	**-0.66**	**0.65**
Dry matter content (%)	**0.67**	-0.21	-	-	0.48
Total Soluble Sugar content (%)	-0.53	**0.68**	**0.79**	**0.73**	**-0.63**

6.4 CONCLUSIONS

Various quality attributes of fried crispy chips were found to be influenced by variety and also by harvest maturity; Hardness (both instrumental and sensory) increased with increasing maturity. In freshly harvested roots, harder texture of chips was associated with low sugar, high dry matter and high starch contents but after storage there were no clear relationships between the components and instrumental texture. Therefore, in processing fried crispy chips from these varieties, employing varietal composition to predict or anticipate the hardness of the chips may be more practicable only when using freshly harvested roots. Textural hardness (Instrumental Peak breaking force and Sensory Loudness score) had no strong links with Acceptability scores; higher Overall Acceptability was associated with low Sweetness and low Flavour Intensities, regardless of chips texture. *Bohye* recorded the highest overall acceptability values while *Hi-starch* and *Ligri* had the most stable scores across all sampling stages. More studies are required to understand the basis for sharp contrasts in acceptability ratings within some varieties at certain sampling times, while others had fairly stable Overall Acceptability across all sampling times. However, starch quality was found to have a bearing on chips Acceptability ratings. Varieties with relatively largersized starch granules, high RVA pasting Peak viscosities and low Setback ratio of their starch had higher Overall Acceptability scores. Selection of suitable raw material for production of sweetpotato crispy chips quality may be optimized by factoring in not only varietal uniqueness but also harvest maturity and storage history of the fresh roots.

CHAPTER SEVEN

7.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

7.1 GENERAL CONCLUSIONS

The National Agricultural Research System (NARS) in Ghana has over the years released several high-yielding, high-nutrient sweetpotato varieties which have the potential of boosting food and nutritional security and also for small-scale industrial applications. Sweetpotato is nutritionally superior to most starchy staples, however, the crop has not experienced any appreciable increases in utilization levels over the years. The low level of cultivation and per capita consumption in Ghana may be attributed to various factors including inadequate awareness of improved varieties, little information about factors that affect fresh roots shelf-life and storage quality and inadequate information on the influence of enzyme activities on processing characteristics of a variety. These gaps have led to high perishability and inconsistent cooking quality, inevitably causing the consumer to turn to other foodstuffs as staple food. Due to the diversity that exists in sweetpotato, and since crop quality is linked with inherent properties that have direct or indirect effects on final products, there is a critical need for more information about important quality indices of the varieties that thrive under our local conditions in Ghana, in order to exploit the full potentials of this crop.

Improved high-yielding, disease-resistant varieties of sweetpotato with diverse characteristics of skin and flesh colour were studied across key elements of the crop's value chain (fresh roots, flour, starch and a ready-to-eat product). The findings from the study showed that in harvested roots, physiological response to wound healing has a direct bearing on storage stability or shelf-life of healthy undamaged roots. In Ghana's sweetpotato industry, selection of varieties with the right genetic traits for good storage would be a plus in addressing shelf-life issues. Routine screening for such traits in crop improvement and breeding programmes can be facilitated through the use of microscopy to assess wound healing efficiency. Storage stability or shelf-life characteristics of fresh roots was also found to be influenced by type of primary packaging and the sizes of roots being stored. Maintaining high humidity and selecting healthy roots of larger sizes (>300g) for storage resulted in a better shelf-life, assessed as better resistance to weight loss or dehydration during storage. In advanced economies, excellent handling technologies have been developed for sweetpotato fresh produce from the farm to the final consumer. In Ghana, however, most postharvest systems are under-developed due to constraints in infrastructural access and the sweetpotato postharvest handling system is no exception. The findings show that it is feasible, through the use of simplified and appropriate technologies, to achieve improved storage quality and shelf-life of sweetpotato fresh produce. This will enhance the availability of raw material supply for sustainable industrialization, fresh roots for domestic utilization, school feeding programmes and other initiatives.

Carbohydrates form the bulk of the dry matter content in sweetpotato, present as starch and soluble sugars. Harvest maturity and storage were found to influence these major components as well as some minor components. Low-starch varieties were found to be more susceptible to starch breakdown during storage, indicating higher stability or higher resistance to starch degradation in the varieties that originally contained more starch. The association between original starch content and stability of starch during storage was greater at advanced maturity. Thus from the study, it is preferable to harvest a high-starch variety targeted for a potential starch industry at five months in order to prevent starch losses during storage. Higher contents of protein, zinc and iron were observed at earlier maturity; this is an interesting phenomenon and for the varieties studied, selection for various target applications must take into account not only varietal uniqueness but also harvest maturity. For example, complementary baby foods made from these varieties should be prepared from early-harvested roots (approximately 3.5 months). It is recommended that genotype selection in breeding programmes should factor in micronutrient stability across maturity stages.

In the current drive towards biofortification of food crops, information on changes in sugar contents that occur during storage should be a vital component of any promotion or utilization campaign, for example for orange-fleshed high beta-carotene varieties which are employed in combating endemic vitamin A deficiency in deprived communities. This is due to the role that sweetness perception is known to play in the acceptance or rejection of sweetpotato varieties as a staple food. From the results from this study, the lowest sugar contents were observed at early maturity, especially at 3.5 months when processed right after harvest. *Bohye* was found to exhibit a unique feature, being a moderately high beta-carotene variety (light orange-fleshed colour, second only to *Apomuden*) and yet having relatively low sugar contents at all maturity stages. This is unique because it is generally believed that the occurrence of beta-carotene is genetically linked with high sugar, and there is a long-standing search for low-sugar sweetpotato types with appreciable beta-carotene content. From the results, low Sweetness and low Flavour Intensities of fried chips were associated with higher Overall Acceptability. Sugar content in sweetpotato is a major factor influencing the perception of flavour and there have been speculations that reducing sweetness through breeding will lead to increased utilization of the crop as a staple food globally.

Despite the importance of knowing the sugar contents of sweetpotato fresh roots, it is important to note that sugar content of the cooked product is usually different, owing to the activity of amylolytic enzymes which break down starch to form sugars during the cooking process. Sweetpotato is reported to be one of the world’s best sources of beta-amylase. The results from this work highlight the fact that amylase activity in sweetpotato, a critical trait influencing utilization quality, is not merely genetic or variety-related but a function of variety, harvest maturity and storage history. It has an influence not only on the texture and appearance of sweetpotato food products but also on sweetness and flavour perception, through the hydrolytic breakdown of starch during the cooking process to form malto-dextrins and maltose. In this manner, even for a variety marketed or labelled as 'high dry matter, low sugar', if at the time of processing it happens to have a high activity of alpha- and beta-amylases, could yield a product with less firm textural features and higher level of sweetness than expected. For sweetpotato there is no visual tracking mechanism in nature to detect the key physiological changes that occur after harvest, unlike other crops such as plantain or banana which have clear physical signals (i.e. change in peel colour, softening of inner tissue) serving as indicators of important internal physiological changes. A simple indicator test to assess sweetpotato amylase enzyme activity in unprocessed fresh roots, if developed, would help track which varieties respond more intensely to the immediate environment and which ones are the most stable; this would be a very useful tool in industrial raw material quality control/assurance as well as in selection breeding. *Ligri* showed negligible amylase enzyme activity both before and after storage and therefore, can be recommended for staple food preparations, since loss of texture and increase in sweet taste during cooking would be negligible or non-existent; at five months when *Ligri* was freshly harvested it had high starch, very low retrogradation (RVA Setback ratio), low sugar and the lowest amylase enzyme activity.This variety would therefore be very good for a product such as *fufu* (flour or fresh pounded) in which minimal or zero starch hydrolysis is desirable to maintain maximum viscosity and minimum sugar expression. Storage of the fresh roots, however, resulted in significant changes in composition and therefore, farmers and processors would have to adhere to specific harvesting and storage recommendations. The varieties *Faara* and *Okumkom* with very high amylase activities when harvested at advanced maturity (five months) and stored, could be recommended as useful starchdegrading enzyme sources (in brewing and glucose manufacture, for example).

Faara with high starch content (71.48 - 73.37% dry basis) and fairly small starch granule sizes (4 - 22µ), may have a potential for the textiles industry. It could complement or easily compete with cassava starch due to its early maturity and high yields compared to the long-gestation cassava crop which requires 9 – 12 months to mature. *Hi-starch* with its very high starch content (78.4179.4%) but relatively large granule sizes (8 - 40 %) may be promoted for applications that normally employ potato starch. *Apomuden*'s very small starch granule sizes (2 - 15µ) may impart higher digestibility to its products, and the variety could therefore be recommended for feeding vulnerable groups (babies, the aged and convalescents), more so due to its unique nutrient composition (high beta-carotene visible as orange flesh colour, low starch content, high contents of protein and minerals). Purees from *Apomuden* roots when used as beverage or dairy product fillers may impart creamy or smooth mouthfeel due to its small starch granule sizes.

The results of this study provide a better understanding of the dynamics of sweetpotato as a commodity under our local environmental conditions. This can enhance marketing and utilization, and contribute immensely in tapping into its enormous potentials by way of job creation, food and nutritional security and poverty alleviation.

7.2 RECOMMENDATIONS

The following are areas recommended for further studies:

1. Development of a simple indicator test to assess sweetpotato amylase enzyme activity in fresh roots to facilitate rapid screening in breeding programmes and for industry

2. Due to the apparent diversity in starch granule size, screening of sweetpotato genotypes for this trait should be incorporated into breeding programmes. The usefulness of applying simple indicators such as granule size category and harvest maturity as predictors of sweetpotato starch functional properties should also be investigated. Starch digestibility studies should be carried out for all the varieties studied
3. The role of dietary fibre constituents (particularly pectin) on stickiness and other quality attributes of crispy fried sweetpotato chips, as well as the role of starch granule size distribution on chips quality should be studied. Packaging, shelf-life studies and standard consumer acceptability testing should be conducted on chips from *Bohye*, *Ligri* and *Histarch*.

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