Influence of growth locations on physicochemical properties of starch and flour from amadumbe (*Colocasia esculenta*) genotypes

By

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Declaration

I, declare that the dissertation herewith submitted to the Department of Biotechnology and Food Technology, Durban University of Technology for the award of Master's Degree in Food Science and Technology is my work and has not been previously submitted for a degree at any other University or any Higher Education Institution.

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Dedication

This research work is dedicated to God Almighty, alpha, and omega of my faith, the creator of my life, the heavens and earth, the one that has been with me throughout my life. All glory be to your name only.

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Abbreviations

ADF- Acid detergent fibre

ANOVA- Analysis of Variance

BV-Breakdown viscosity

Ca- Calcium

CHO- Carbohydrate

Cu- Copper

DSC- Differential scanning calorimetry

FAO- Food and Agriculture Organisation

Fe- Iron

FTIR- Fourier transform infrared spectroscopy

FV- Final viscosity

G- Genotype

hr- hour

K- Potassium

KOH- Potassium hydroxide

Mg- Magnesium

Min- Minutes

Mn- Manganese

NAOH- Sodium hydroxide

NDF- Neutral detergent fibre

N.d- Not detected

P- Phosphorus

PT- Pasting temperature

PV- Peak viscosity

R- Roodeplaat

RVA-Rapid Visco Analyser

SEM- Scanning electron microscopy

SV- Setback viscosity

Tc- Conclusion gelatinisation temperature

Tm- Melting temperature

To- Onset gelatinisation temperature

Tp- Peak gelatinisation temperature

TV- Trough viscosity

USDA- United States Department of Agriculture

U- Umbumbulu

µm- Micrometre

µl- Microlitre

XRD- X-Ray Diffraction

Zn- Zinc

Papers submitted for Publication

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Conference attended

1. Mawoyo B, Patrick O. Adebola, Abe S. Gerrano, Amonsou E.O*. Influence of growth locations on physicochemical properties of starch and flour from newly bred amadumbe genotypes grown in South Africa. 2016 DUT/ARC/UFS Consortium seminar, Bloemfontein, from 6th -7th March 2017.

Abstract

Amadumbe commonly, known as taro is a traditionally underutilised tuber crop in Southern Africa. Nutritionally, amadumbe corms contain appreciable levels of carbohydrate mainly in the form of starch which is resistant to digestion. It also contains mucilage, a soluble fibre, which is good for the human digestive health. Thus, amadumbe starch and mucilage can be used as functional ingredients in food formulations. The aim of this research was to investigate the effects of genotypes and growth location on the physicochemical properties of amadumbe flour and starch.

Eighteen (18) amadumbe genotypes grown in Roodeplaat, Gauteng and Umbumbulu, Kwazulu-Natal, South Africa, were studied. Roodeplaat received a lower annual average rainfall (514 mm) and high environmental temperature (24^{o}C) compared to Umbumbulu (828 mm, 19^{o}C) during the cropping season. Specifically, the influence of growth location and genotypes on the chemical composition (proximate composition and mineral contents) as well as the functional properties of amadumbe flours were investigated. Furthermore, starch was extracted and its physicochemical and functional properties were also studied.

The carbohydrate contents (73-81%) of amadumbe flours were substantially high and varied with growth location. Mucilage contents (6-9%) were very low across genotypes in both locations. Water absorption and oil absorption capacities positively correlated to carbohydrates and mucilage in the flour irrespective of growth locations. Swelling power and solubility index was influenced by the amylose content of the flour. Genotype and growth location significantly affected the pasting properties of amadumbe flour. The pasting temperature was very high (approx. 90^{o}C) across genotypes in both locations, while peak viscosity differed significantly (54-242 RVU) for genotypes grown in different environments.

The amylose contents (0-14.4%) of amadumbe starches were low and varied significantly with growth location and among genotypes. Three genotypes, G2, G20, and G21 grown in Roodeplaat lacked amylose. Amadumbe starches showed reflective peaks at 2θ=15^{o} and doublet at 17^{o}, 18^{o} and 24^{o} typical of A-type starches. Amadumbe genotypes had small sized (1-5 µm) and polygonal starch granules. Functional properties including water absorption, swelling power, gelatinisation temperature and peak viscosity significantly positively correlated with amylose content. These findings further suggest that water availability could have a major effect on starch synthesis as the two locations received a different amount of

rainfall during the growing season. Findings from this study are important for future improvement programmes and selection of appropriate genotypes for industrial production or food application of amadumbe flour and starch.

CHAPTER ONE

1.0 Introduction

Amadumbe (*Colocasia esculenta*), also known as taro is a tuber crop grown for its edible corms (Aboubakar et al., 2008). They are largely produced in Africa, reaching to nearly 60% of the total world taro production (Mweta et al., 2010). In South Africa, amadumbe is grown in remote areas of Limpopo, Mpumalanga, North West, Gauteng and KwaZulu-Natal provinces (Mabhaudhi et al., 2013). In comparison with other tuber crops such as cassava and potatoes, amadumbe remains an underutilised crop that is mainly grown for subsistence (Ugwu, 2009). Traditionally, amadumbe corms are prepared by boiling, roasting, frying, baking, or can be pounded into paste and consumed with soup (Lewu et al., 2010). Nutritionally, amadumbe corms contain appreciable amounts of carbohydrates (approx.70-96%) (Aboubakar et al., 2008; Naidoo et al., 2015). The bulk of the carbohydrates is starch which varies between 70 and 78% (Aboubakar et al., 2008; Moorthy, 2002). Furthermore, amadumbe also contains mucilage (approx. 7-10%) (Hong & Nip, 1990; Huang et al., 2010), a soluble fibre which is good for the human digestive health (Guevara-Arauza et al., 2012). Hence, amadumbe flour, starch and mucilage are potential components which can be incorporated as functional ingredients in food formulations (Liu et al., 2006).

However, many factors including growing conditions, genotypic differences or processing can influence the properties of these components of amadumbe. According to FAO (1998), intensive research on the characteristic properties of flour and starch from underutilised traditional crops such as amadumbe is of great importance. Due to their high moisture content (approx. 70%), amadumbe tubers are highly perishable. Hence, they must be processed into stable products such as flour (Falade and Okafor, 2015). The use of flour in the food industry as a food ingredient is primarily governed by their functional and physicochemical properties. Flour composition may be influenced by growth location or genotypic differences, which may impact on its functionality and application. For instance, Tattiyakul et al. (2006) studied the composition and functional properties of taro varieties grown at four different locations in Thailand. Different growth locations showed different flour protein contents (0.9-1.7 g 100 g^{-1} flour) indicating an environmental influence on the composition of taro flours. In addition, the swelling power (11.3-15.9 g/g) and solubility index (0.08-0.13 g/g) of the flours also varied with growth location (Tattiyakul et al. 2006). Besides growth location, genotypic differences

may also influence flour functionality such as pasting properties. Falade and Okafor (2015) found significant differences in the peak viscosities (97.3-201.2 RVU) of taro genotypes grown in the same location.

Furthermore, starch application in the industry primarily and equally depends on the knowledge of its functional properties such as water absorption, pasting and gelatinisation (Moorthy, 2002). These starch properties are affected by many factors such as botanical origin, genotypic differences, growing conditions and composition (especially amylose contents). For example, higher amylose content in starch is known to restrict swelling during pasting which results in low peak viscosity (Tester & Morrison, 1990). The physicochemical properties of starch can also be significantly influenced by factors which include, soil temperature, or average rainfall (Noda et al., 2001; Tester & Karkalas, 2001). For instance, Noda et al. (2001) studied the physicochemical properties of starches from sweet potato grown at four different soil temperatures (15, 21, 27 and 33^{o}C). The amylose contents (13-17%) of the starches were observed to increase with increasing soil temperature. Also, the sweet potato starches similarly showed a soil temperature dependent increase in peak gelatinisation temperature from 57 to 80^{o}C (Noda et al., 2001). Water stress levels can also influence starch composition and functionality (Zhong-Min et al., 2008). Starches from water-stressed wheat grains showed significantly lower amylose content (approx. 28%) than starches from unstressed environments (approx. 31%). According to these authors, water stress conditions might have reduced the activity of granule-bound starch synthase responsible for the synthesis of amylose. (Zhong-Min et al., 2008).

Amadumbe grown in Southern Africa has received less research attention in terms of utilisation and value addition. Previous studies on amadumbe focused on DNA fingerprinting of wild and cultivated amadumbe Mabhaudhi and Modi (2013) and water-use and drought resistance of locally grown varieties (Mabhaudhi et al., 2013). These studies revealed significant genetic variations among amadumbe landraces grown under different environmental conditions**.** According to Mabhaudhi et al. (2013), different irrigation treatments were found to have an effect on the harvested amadumbe corm mass. The corm mass was reported to decrease with decreasing water availability. Furthermore, Naidoo et al. (2015) studied the physicochemical properties of wild and cultivated amadumbe starches. Amadumbe starches were found to be polygonal and small (approx. 3 µm), similar to previously reported data for taro starches (Aboubakar et al., 2008; Jane et al., 1992). The effort to promote the utilisation of amadumbe

in South Africa has focused on breeding of locally grown varieties largely on the agro-morphological and molecular markers. The integration of breeding for yield and yield-related traits, as well as physicochemical properties, is important for food and nutritional security. Although breeding data was encouraging and largely positive, breeding can influence the inherent properties of flour and starch which may influence functionality. Hence, in this study, composition, morphology, structural and physicochemical properties of flour and starch extracted from amadumbe genotypes grown in different locations were investigated.

CHAPTER TWO

2.0 Literature review

2.1 Background

Root and tuber crops are plants rich in carbohydrates mainly in the form of starch (Aprianita, 2010). According to Villordon et al. (2014), root and tuber crops are the second major source of carbohydrates globally after cereal crops which provide half of the calories consumed by humans. Tubers are the cheapest sources of dietary energy in most developing countries. For food stability to increase especially in rural areas, local traditional sources of carbohydrates must be explored. Some tuber and root crops have superior propagation properties compared to major carbohydrate sources such as rice and can withstand conditions that are unfavourable to these common carbohydrate sources. For rural people when seasonal conditions do not favour the growth of usual carbohydrate sources, tuber crops such as amadumbe can play a role as an alternative source of carbohydrates (Lebot, 2009).

Amadumbe, commonly known as taro or (*Colocasia esculenta*) is an important tuber crop normally grown for its fresh corms and nutritious leaves (Deo et al., 2009). The amadumbe plant is an annual herbaceous plant, which can grow up to approximately 1-2 m above the ground when planted in nutrient-rich soils where enough rainfall is available (Prajapati et al., 2011). The plant is comprised of a central corm which grows under the soil, while leaves develop from the apical bud at the top of the corm. Amadumbe leaves are peltate, with a fibrous root system that lies mainly above the soil. The corm is its central nutrient storage organ and has similar characteristics with other food storage organs like potatoes. Amadumbe crops are mainly cultivated in heavy or clay soils which are slightly acidic with a pH range of 5.5-6.5 (Weightman, 1989). Though sometimes grown as a mono-crop, amadumbe is also widely grown in multiple cropping systems with crops such as beans or maize. Shading may improve establishment, but productivity is higher when exposed to direct sunlight in later stages of growth.

Amadumbe is polymorphic comprising of two botanical varieties namely *colocasia esculenta var. esculenta* or dashen and *colocasia esculenta var. antiquorum* or eddo. Dashen has large central corm with several smaller side cormels while eddo is comprised of a small central corm and well-developed side corms (Fig. 1) (Mergedus et al., 2015).

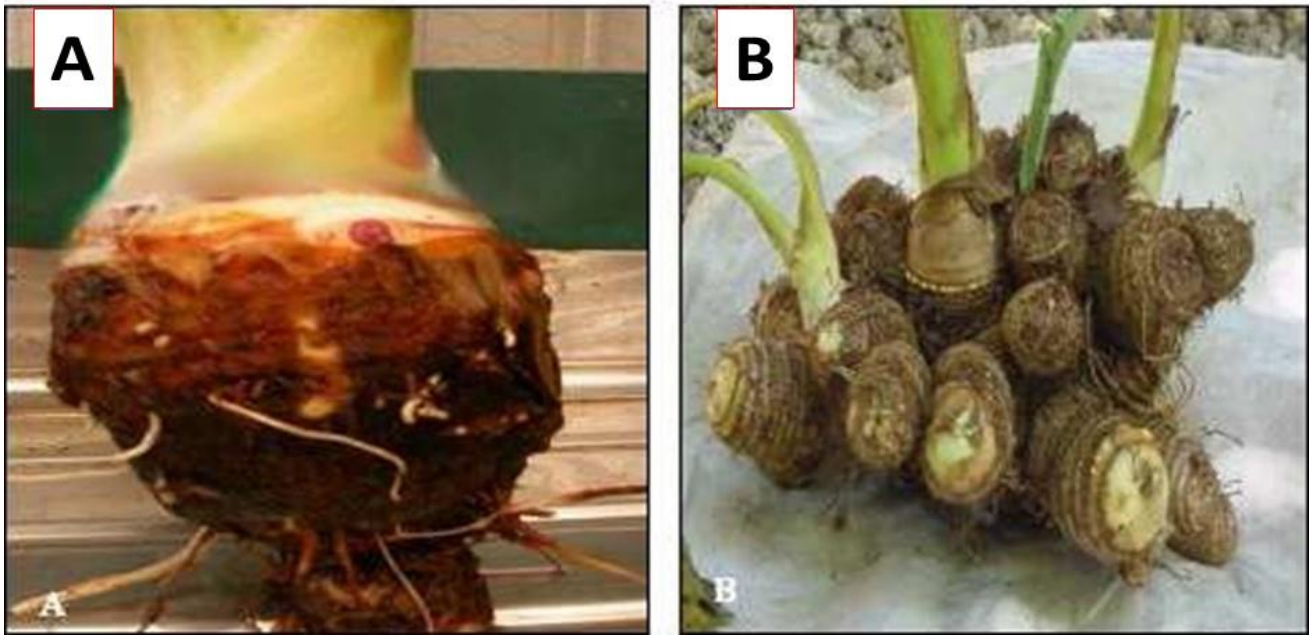

Figure 1*:* (**A**) *Colocassia esculenta var. esculenta (*dasheen) has a large central corm and (**B**) *Colocassia esculenta var. antiquorum (*eddo*)* has a small central corm with multiple fairly large cormels

Source: (Onwueme, 1999)

Figure 2: Amadumbe plants growing in the fields

Source: (Onwueme, 1999)

2.2 Origin and the distribution of amadumbe

The origin of amadumbe is traced back to Asia, North Eastern India and the Mediterranean region (Hanson & Imamuddin, 1983; Ivancic, 1992). Settlers moving from one region to another gradually spread the cultivation and consumption of amadumbe worldwide. As such, amadumbe crop cultivation has spread to more than 65 countries worldwide (USDA, 2001). Amadumbe is ranked as the fourteenth most consumed vegetable worldwide. Statistically, approximately 60% of world taro production comes from Africa while Asia and the Pacific countries account for the remaining 40% (FAO, 2003; Mweta et al., 2010). Based on their varieties and different cultural beliefs, amadumbe leaves, flowers and stems are used in the sauces, purees, stews, and soups (Ejoh et al., 1996; Ferreres et al., 2012). Apart from its nutritional value, amadumbe leaves are also used as medicine to treat wounds in some communities.

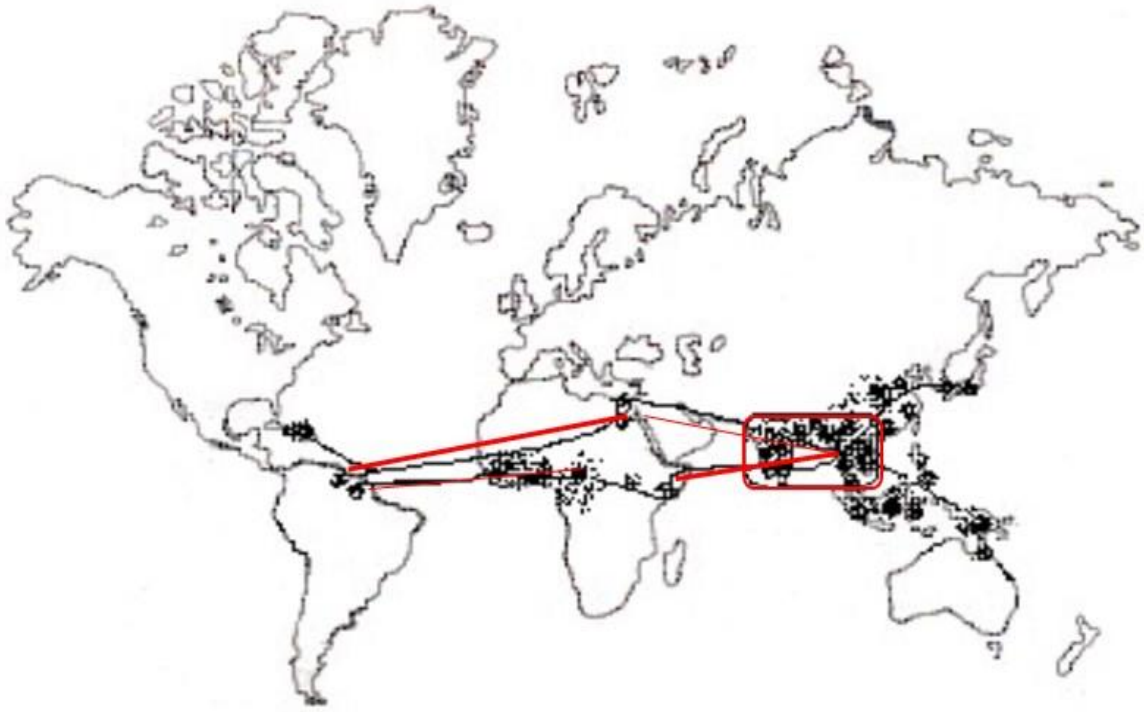

Figure 3: Origin and distribution of Amadumbe

Source: (Wickramasinghe et al., 2009)

Key: Dots represents cluster movement of settlers from one region to another

2.3 Utilisation and Economic importance of amadumbe corms

Amadumbe (*colocasia esculenta*) remains one of the most underutilised root tubers in Africa since limited information is available about their potential use. Their production is very low when compared to tuber crops such as cassava, potatoes or sweet potatoes (Ugwu, 2009). In some ethnic groups, such as people from Asia and the Pacific region, or some parts of West Africa, amadumbe has earned great socio-economic importance. They regard amadumbe corms as a prestigious crop and the choice crop for royalty, gift giving, traditional feasting and fulfillment of other social obligations such as in marriage ceremonies (Onwueme, 1999). Nevertheless, amadumbe has been stigmatised as food for the poor, thus commercial farmers have not shown interest in the crop. In Southern Africa, amadumbe is grown by small-scale farmers for subsistence in countries such as Zimbabwe, Malawi, Swaziland and other remote parts of KwaZulu-Natal, Mpumalanga, Limpopo and the Eastern Cape provinces of South Africa (Shange, 2004). Traditionally, amadumbe corms are normally boiled, fried or pounded into paste and consumed with soup (Lewu et al., 2010). In some communities, the leaves of amadumbe plant are eaten as a relish, as well as making vegetable salads (Lewu et al., 2010; McEwan et al., 2014). Furthermore, complementary food and noodles which are cost effective and highly nutritious has been produced from amadumbe and cowpea composites (Ikpeme-Emmanuel et al., 2009; Maga et al., 1993). However, food products produced from amadumbe has been reported to have acridity factors, which leads to itchiness, sharp irritation and burning sensation in the throat or mouth when eating (Akpan & Umoh, 2004). These acridity factors can be reduced by soaking and fermentation during processing (FAO, 1990). Long cooking periods and removal of the thick skin layer is an excellent way of removing acridity (Crabtree & Baldry, 1982; Kaushal et al., 2015). Other methods used to reduce acridity are baking or extraction with ethanol. These also help in enhancing the texture, cooking quality, palatability and digestibility of the products (Kaushal et al., 2015).

2.4 Nutritional composition of amadumbe corms

Roots and tubers are native tropical crops that belong to Araceae family (Emiri, 2015). Commonly known root crops are potato and cassava which are widely grown and researched especially in developed countries of the world. Traditional crops such as amadumbe grown in developing countries like South Africa are underutilised and under-researched. Recently, there

has been a tremendous effort to explore them as possible food security crops. Roots and tubers contain a vast amount of carbohydrates, while protein, fats and ash are present in relatively lesser amounts (Table 1 & 2). Amadumbe contains appreciable levels of carbohydrates (70-96%) (Aboubakar et al., 2008; Odebunmi et al., 2007) which compares well to other well-established tubers such as cassava and potatoes (Diarra, 2016; Mweta, 2009) (Table 1). In many parts of the world, these root and tuber crops are mainly consumed since they are a good source of calorie, fibre, B-complex vitamins and b-carotene, e.g. sweet potato (yellow cultivars) or giant swamp taro (Huang & Tanudjaja, 1992). However, growing conditions, soil type used for cultivation, fertiliser application, sunlight, genotypic difference or rainfall patterns causes variations in the proximate composition or mineral composition of amadumbe. In recent studies, amadumbe has been reported to contain high amounts of resistant starch, and mucilage (soluble fibre) (Naidoo et al., 2015). These components (starch and mucilage) can be suitable as functional ingredients in food formulations for those suffering from lifestyle diseases such as type II diabetes or obese. However, tuber crops, such as amadumbe are utilised in small quantities since little information is available about their potential use. Thus, focusing on amadumbe major components such as starch may create an opportunity to improve its popularity and utilisation as a starch source for the industry.

Table 1: Proximate compositions of selected tubers (g/100 g) (dry basis)

Parameters	Cocoyam	Cassava	Sweet potato	Irish potato
Carbohydrates	75.5	87.87	83.37	63.13
Crude protein	6.93	2.84	3.13	4.74
Ash	2.10	0.85	0.97	1.45
Crude fat	1.13	0.18	0.79	0.71
Crude fibre	1.28	1.38	0.90	0.77

Source: (Odebunmi et al., 2007)

Table 2: Mineral composition of selected tubes

Parameters	Cocoyam	Cassava	Sweet potato	Irish potato
Manganese	1.40	0.34	0.08	0.57
Fe	1.23	18.80	0	3.60
Zn	0.11	0	0.05	0.14
Ca	0.39	1.11	0.06	0.09
Mg	9.74	12.84	6.33	8.16

Source: (Odebunmi et al., 2007)

2.5 Health benefits of amadumbe corms and leaves

Amadumbe (*Colocasia esculenta)* corms and leaves are rich in trypsin inhibitors (de Oliveira et al., 1977). These are bioactive compounds not strictly required in the diet, but when present in sufficient amounts promote good health and prevent diseases of different origins (Padula et al., 2013; Rouphael et al., 2012). Numerous studies have related the consumption of phenolic compounds to lower risk of cardiovascular diseases and development of cancers. Furthermore, bioactive compounds reportedly showed anti-inflammatory, antioxidant, anti-allergic, hepatoprotective and antiviral activities (Abad-García et al., 2009; Padula et al., 2013; Vinson et al., 1998). The presence of antioxidant activity in amadumbe is due to different phenolic compounds such as (+)-catechin, (-)-epicatechin, (-)-epigallocatechin, garlic acid, chlorogenic acid and possible traces of flavanols and proanthocyanins (Agbor-Egbe & Rickard, 1990). Processing methods such as heating, freezing and drying can affect the activity of antioxidants, free & bound flavonoids and phenolics. It has been found that the antioxidant properties of taro extracts depend on the amount of phenolic content and the antioxidant capacity (Hung & Duy, 2012).

Scientists and the food industry are developing an interest in plants which possess natural phenolic compounds. Recent trends have shown that consumers are becoming more health-conscious therefore vegetables are becoming important due to the special effects they will add to functional foods (Nguimbou et al., 2014). Phenolic compounds have redox properties which make these compounds to be hydrogen donors, singlet oxygen quenchers, reducing agents and potentially metal chelators (Rice-evans et al., 1995). Plant extracts that possess high phenolic compounds have high antioxidant activity and there can be a link between the antioxidant activity in mucilage and phenolics.

2.6 Mucilage and its composition in amadumbe

Tubers and root crops contain viscous polysaccharide polymers called mucilage. Mucilage is a natural plant product sometimes referred to as gums. It is closely related to pectin but their differences are exhibited in their physical properties. One of the differences is that pectins gelatinize in water; gums swell and disperse while mucilage results in the formation of aqueous dispersions which are slippery. Mucilage is a component of plant cell walls which are formed in different parts of plants by mucilage-secreting hairs, canals, and sacs (Hirst & Jones, 1955; Prajapati et al., 2013). Mucilage present in plants assists as water storage, energy reserves and as membrane thickeners (Hirst & Jones, 1955). Plants that have mucilage are resistant to harsh environmental conditions and may tolerate toxic materials (Ebrahimzadeh et al., 2000).

2.7 Physicochemical and functional properties of starches

Flour and starch obtained from cereals, root and tuber crops play a pivotal role in the human diet as the main source of carbohydrates. The use of starch and flour in the industry is determined by their physicochemical properties. Therefore, knowledge of flour and starch properties is important. According to Aprianita et al. (2009), properties of flour are mainly governed by the properties of its respective starch as the main component. The physicochemical and functional properties include morphological studies, FTIR, viscosity, gelatinisation, retrogradation, pasting, and swelling power and these are the very properties used to market flour and starch.

2.8 Starch synthesis and its general background

Starch is a natural carbohydrate-based polymer which is produced by the process of photosynthesis in plants. It is widely present in plant sources such as cereals, roots and tubers such as potatoes or amadumbe (Frost et al., 2009; Lu et al., 2005; Mweta, 2009). In plants, starch is manufactured in amyloplast and chloroplast where it functions as temporal energy and a carbon store (Fig 4), (Lawton, 2004; Robyt, 2008; Sivak & Preiss, 1998).

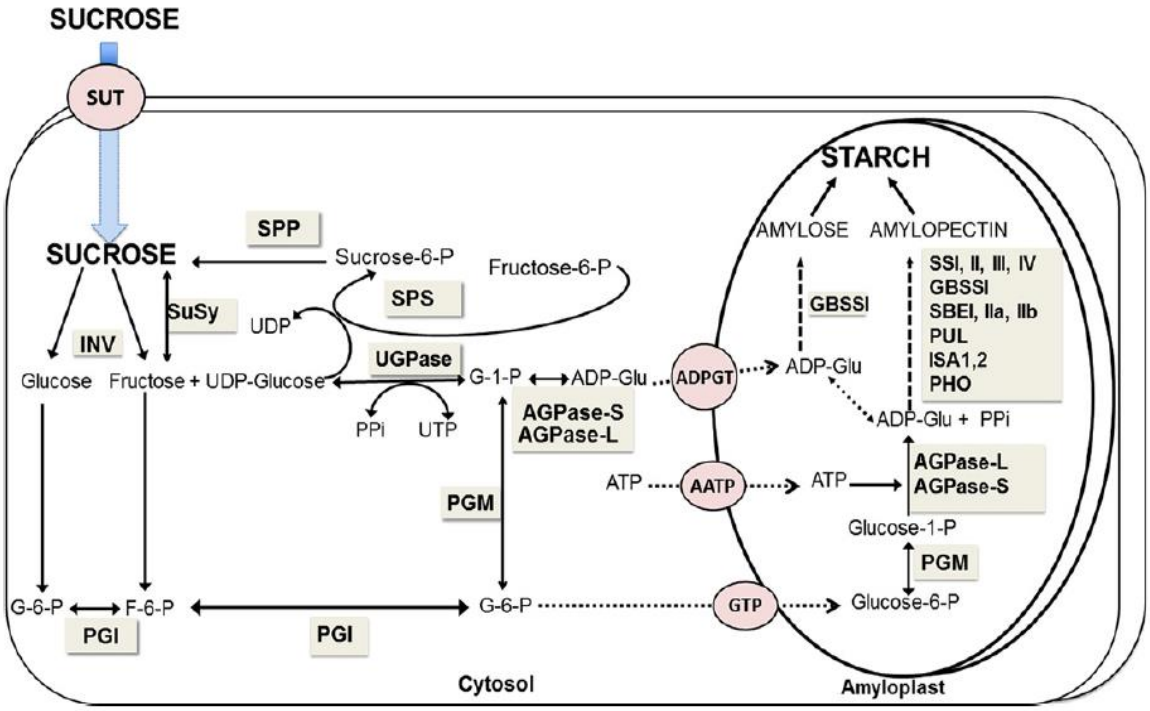

Figure 4: A simplified model of Starch biosynthesis pathway

Source: (Thitisaksakul et al., 2012)

Starch is a vital raw material, used for various applications in both food and non-food industries. Apart from its nutritional value, its use and importance can be traced back to ancient times. For instance, in Rome and Egypt around 4000BC, starch from wheat was used to whiten cloth and in the body, papyrus to increase the ability to hold ink respectively (Robyt, 2008). Since then, industrial starch applications have drastically increased. Starch is now used to control texture in various foods, improving paper strength in pulp and paper industries (Ellis et al., 1998; Jobling, 2004; Lawton, 2004). Because of rapid and escalating industrial demand for starches, there is a great need for intensive research on new and alternative sources of starch. Underutilised traditional crops like amadumbe, have received less attention in this regard. Extensive research on the major components of amadumbe such as starch is needed to unlock the potential in these tuber starches (Hoover, 2001).

In manufacturing industries, application of starch in various products is governed by its functional properties such as gelatinisation, pasting or swelling power. These properties differ by the botanical origin of crops with ecological and agronomic influences (Chen et al., 2003; Sefa-Dedeh & Sackey, 2002; Yuan et al., 2007). The composition and molecular structures of starch amylose: amylopectin ratio and phosphorous content can also vary due to genotypic

differences, growth environments or botanical origin. Investigating how these parameters influence the physicochemical and functional properties of neglected tuber starches like amadumbe is vital.

Amylose and amylopectin constitute the starch molecule. Previous studies have reported that normal starch contains 20-30% amylose, the difference being made up by amylopectin. Waxy and high amylose starches contain at most 15% and more than 40% amylose respectively (Tester et al., 2004; Van Hung et al., 2006). Amylose contents for cassava (14- 24%); sweet potato (20-25%) and cocoyam starches (3-43%) varied depending on the botanical source and variety (Moorthy, 2002; Tian et al., 1991). Similar observations were found by Shujun et al. (2006), who also reported different amylose contents for four different varieties of Chinese yam (*Dioscorea opposita* Thunb) grown in the same environment.

The conformation of amylose and amylopectin within starch granules has been found to differ with plant species. The enzyme activity involved in the starch biosynthesis may be responsible for the variation in amylose content between the different starches (Kossmann & Lloyd, 2000). The difference between starch granules among plant species accounted for is not merely by the ratio of constituent molecules, but also by their location and interaction. Starch is a morphologically complex polymer substance with the crystalline composition of around 15-45% starch molecules. The crystalline region is dominated exclusively with amylopectin component, whereas the amorphous region is mainly composed of amylose (Hoover, 2001).

Previous studies have reported that starch functionality is influenced by its amylose content. For instance, as the amylose content of starch increases, lower swelling power and solubility has been reported on cocoyam and wheat starches (Lu et al., 2005; Sasaki & Matsuki, 1998). Moreover, Collado et al. (1999) also observed that high levels of amylose in sweet potatoes were associated with low peak viscosity and hot peak viscosity for approximately 11% of starches. Similarly, an increase of the onset and peak gelatinisation temperature was observed with a decrease in amylose content in starch (Fredriksson et al., 1998). In contrast to this Waduge et al. (2006), found out that high amylose barley starches showed a different response towards annealing due to variations in amylose/amylopectin ratio and possibly starch arrangement within the amorphous and crystalline regions of native starches.

Apart from amylose and amylopectin, starch granules contain minor non-carbohydrate components such as minerals (approx. 1%), lipids ranging from 0-1%, and a negligible amount

of proteins. The most common minerals found in starch are Ca, Mg, Phosphorous, K, and Na. Although these minerals are in relatively small quantities (<0.4%) and of little significance, phosphorous is an exceptional mineral. Phosphorous exists in three different forms and these are phosphate monoesters, phospholipids and inorganic phosphates (Tester et al., 2004). In root and tuber starches phosphorous exists in the form of monophosphate esters, covalently bonded to starch whereas phospholipids are mainly concentrated in cereal starches. According to Jane et al. (1996), phosphorus content influence the functional properties of starch such as viscosity consistency or paste stability. Higher levels of phosphate in potato starches resulted in a higher swelling power of potato starches (Karim et al., 2007). Moreover, Swinkels (1985), also reported that phospholipids form helical complexes with starches reducing their water binding capacity, resulting in improvement of opaqueness and clarity of starches. However, the phosphorous content in starch differs with the botanical source, environmental growth conditions or agronomic practices. For instance, variations in phosphorus content (0.03-0.09%) have been reported for sweet potato and cocoyam starches (Jane & Chen, 1992; Moorthy, 2002).

Besides amylose, amylopectin, and non-carbohydrate components, starch absorbs moisture when in equilibrium with its environment. Previous studies have reported that starch contains (10-15% w/w) water of hydration. However, moisture content of 6-16% has been previously reported by Moorthy (2002), and the differences in moisture have been attributed different drying mechanisms. Regardless of this variation, to improve the shelf life and to prevent starch from microbial damage and avoid deterioration in quality, low levels of moisture content are required (Moorthy, 2002).

2.9 Starch Composition

The major starch fractions are amylose and amylopectin. Amylose and amylopectin contain polymers of ɑ-D-glucose units and these differ in degree of polymerization and branch frequency. According to Aprianita (2010), amylose comprises 23-31% of starch by dry weight while amylopectin accounts for approx. 69-73%.

2.9.1 Structure of amylose

Amylose exists as a linear chain of approximately 1500 units of ɑ-D-glucopyranosyl residues, joined by ɑ-1,4 glycosidic links (Fig. 5). Some molecular fractions do have a few branches of ɑ-1, 6 linkages although these branches do not have any influence on the hydrodynamic behaviour of amylose (Sivak & Preiss, 1998; Wang et al., 1998). Amylose has an estimated molecular mass of approximately 10^5-10^6 Da. About 200-700 glucose residues with an approximate weight of 32 400-113 400 Da per chain molecule has been reported. However, depending on the botanical source, environmental growth factors, the size and structure of amylose has been observed to differ considerably as previously discussed (Hoover, 2001). Amylose content in starch can be determined using several methods, which includes blue value, potentiometric, and amperometric titration. These methods rely on the formation of an amylose-iodine complex that gives a blue colour characterised by a maximum absorption wavelength of 620 nm. This iodine reaction is the most commonly used method in determining amylose content due to its specificity, sensitivity and easy to use. Amylose content estimated using methods based on iodine complex formation is considered as apparent amylose content (Liu, 2005).

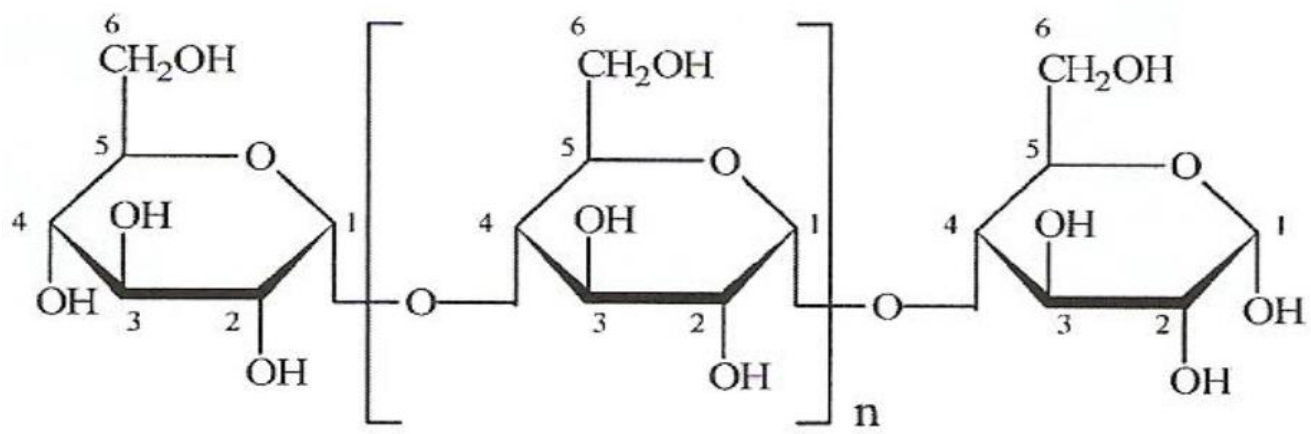

Figure 5: Diagram showing a chemical structure of amylose

Source: (Herrero-Martínez et al., 2004)

2.9.2 Structure of amylopectin

Amylopectin is a highly branched polysaccharide consisting of (ɑ-1,4) and non-random (ɑ-1, 6) glycosidic linkages (Fig. 6). It constitutes 70-80% of starch and is a heavy molecule with a molecular mass ranging from 10^6-10^8 Da (Jobling, 2004; Robyt, 2008). When compared to amylose, amylopectin chains are relatively short and usually about 18-25 units long with a

broad distribution profile. The presence of branching points allows the short linear chains to pack closely as parallel left-handed double helices, giving rise to a crystalline nature of a starch granule.

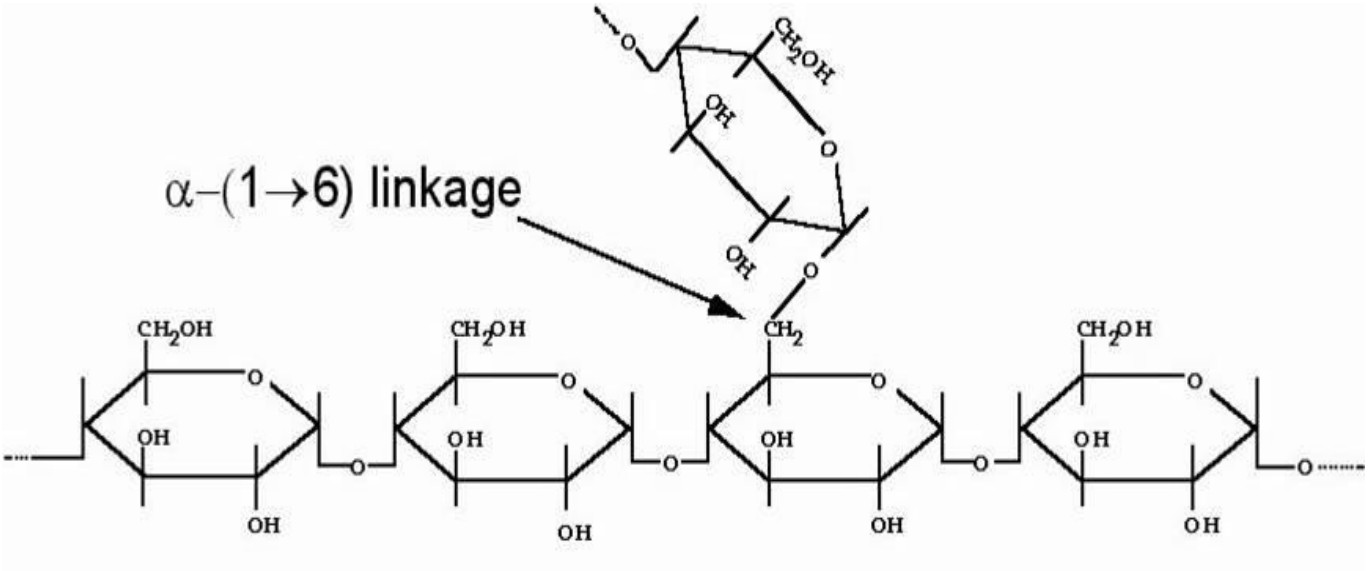

Figure 6: Diagram showing chemical structure of Amylopectin structure
Source: (Herrero-Martínez et al., 2004)

With reference to their chain length and branching points, amylopectin is categorised into A, B and C chains. The A chain is the shortest and carries no branch chains while B chains are the longest whose reducing ends attach to other B or C chains, which do not carry any other chain. The B chains have their reducing ends attached to other B or C chains while they also carry another A or B chains. The C chain is the only chain of the molecule carrying a reducing end (Fig. 7). Furthermore, B chains have a different chain length that is subdivided into B1-B3 groups with B3 groups containing the longest chain. Similar to amylose, depending on the starch type, molecular size or shape, structure differs with the botanical origin, environmental growth conditions and genotypes as previously explained (Ellis et al., 1998; Hoover, 2001; Jobling, 2004; Tester et al., 2004).

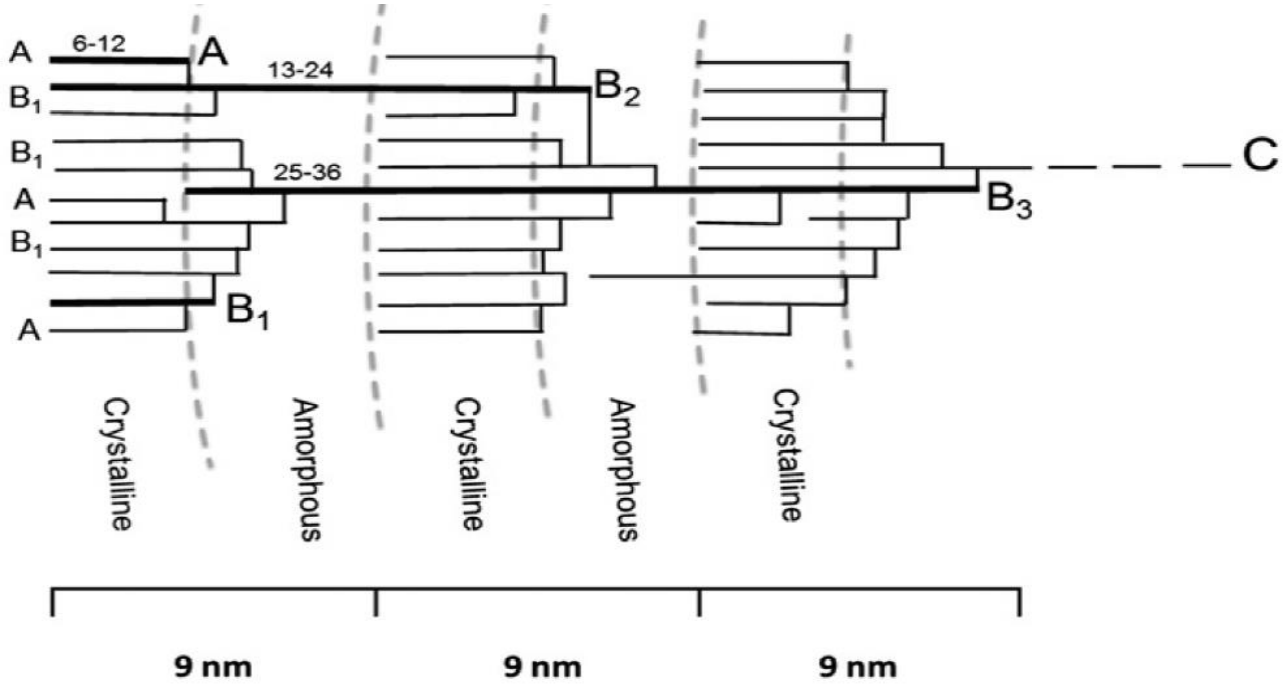

Figure 7: Glucan chain distribution and arrangement in amylopectin
Source: (Tester et al., 2004).

The multiplicity in branching is a mutual feature found between amylopectin and glycogen. Normal arrangement of the chains is defined in terms of A, B, and C chains (Zhang et al., 2008). The outside chains (A) is glycosidically bonded to the reducing group through C6 of a glucose residue to chain B, which is found inside, and these chains are described as chains bearing other chains as branches. Chain C, which is single per molecule carries other chains as branches and comprising the only reducing terminal residue.

Different methods are used to analyse the structure of the amylopectin. Methods such as methylation, periodate oxidation, and partial acid hydrolysis are normally used. Methylation and periodate oxidation techniques are used to analyse the linkage type and frequency of branching of amylopectin molecules. Characterization of polysaccharides is done using partial hydrolysis with acids or enzymes. Previously reported data proved that the α-D-glucopyranose residues are connected mainly by (1α4) linkages with 4-5% of (1α6) linkages (Guilbot & Mercier, 1985; Morrison & Karkalas, 1990). Meanwhile, branching enzymes such as isoamylase and pullulanase are used to determine the ratio of A: B chain in amylopectin (Hizukuri, 1986).

However, previous studies on the molecular structures of starch have proved that the molecular mass of amylose molecules and chain length distribution differs with botanical origin and variety. Amylose molecules with higher molecular mass were found on cassava and sweet potato starches compared to those of yam starches (Peroni et al., 2006).

2.9.3 Minor components associated with starch

Minor components such as proteins, phosphate, lipids, moisture, and ash can be present within starch granules. Depending on their location, these components are classified into three categories. These are (i) particulate material, mainly composed of cell-wall fragments of non-starch materials, (ii) surface components removable by extraction procedures and (iii) internal components (Buléon et al., 1998). Even if they are present in small quantities, these small components play important roles in physicochemical properties of starch.

2.9.4 Lipids

Lipids in the starch can have an influence on starch properties. According to Swinkels (1985), surface lipids affected the diffusion of water into starch granules. Thus, changing starch properties by reducing water binding capacity, swelling and solubilisation of starches. Also, the lipid layer may also prevent amylose from contributing to the thickening power of gelatinized starch by forming a complex with amylose in the starch paste. Moreover, the surface lipid may create an opaque or cloudy starch paste and film due to the presence of insoluble starch-lipid complexes (Craig et al., 1989; Swinkels, 1985). In some instances, the starch-lipid or starch-surfactant complex can improve the textural properties of some foods (Moorthy, 2002).

2.9.5 Starch morphology

Starch exists in the form of a granule, which may vary in size or shape (Blanshard, 1987; Hoover, 2001). Root and tuber starches have voluminous and oval shaped granules with an eccentric hilum (Hoover, 2001). Starch granules of cereals are polygonal or round shaped, while leguminous starch granules have a central elongated or starred hilum (Blanshard, 1987). The size of starch granules is expressed as a range or as an average length of the longest axis.

Starch granules of root starches are bigger when compared to those of cereal starches (Table. 3) (Swinkels, 1985).

Table 3: Characteristics of some starch granules

Starch	Type	Size (µm)	Shape
Cassava	root	4-35	Oval, truncated
Sweet potato	root	5-25	polygonal
Wheat	cereal	2-35	Round, lenticular
Corn	cereal	2-30	Round, polygonal
Arrowroot	root	5-70	Oval, truncated
Cocoyam	root	1-10	Round, polygonal

Source: (Swinkels, 1985)

Functional properties of various starches are influenced by some unique properties of starch which include granule size and size distribution (Moorthy, 2002). Smaller sized starch granules exhibit higher water absorption and a higher solubility index, which makes them desirable in various industries (Tian et al., 1991). For instance, rice starches, which have smaller sized starch granules, are used in the manufacture of skin cosmetics in pharmaceutical industries. Other properties such as pasting of starch are also influenced by starch particle size. According to Zaidul et al. (2007), smaller sized potato starch showed lower peak viscosity temperature. However, as the starch granule size increased, these authors observed higher peak viscosity, breakdown and setback temperature. Various analytical techniques such as microscopic analysis, light, and scanning electron microscopy are used to examine the characteristics of starch granules. Scanning electron microscopy is used to view the three-dimensional shapes and sizes of starch granules (Thomas & William, 1977).

The shape and size of starch granules differ with the botanical source, environmental growth conditions or with variety. Mishra and Rai (2006) studied the morphology of commercial native corn, potato, and cassava starches using light and scanning electron microscopy, and variations were reported. The granule size of potato starch ranged from 14-53 µm, whereas for cassava and corn starches ranged from 4-14 µm and 7-25 µm respectively (Mishra & Rai, 2006). In addition, the shape of potato starch granule was observed to be oval/flattened whereas those of corn were polyhedral. The shape of cassava starch granules is round, with an approximate granule size of 4-43 µm (Moorthy, 2002; Noda et al., 1995; Tian et al., 1991). In contrast, taro

starch granules were very small (1-10 µm) when compared to starches investigated in the plant kingdom. These unique characteristics give taro starch a potential to be useful in various food and non-food applications (Aboubakar et al., 2008; Griffin, 1979). When the taro starch granules were observed under the scanning electron microscope, smooth polygonal ad irregular granules were observed (Naidoo et al., 2015). Furthermore, different size ranges of starch granules between wild and cultivated amadumbe grown in South Africa were reported (Naidoo et al., 2015). The size of starch granules of cultivated amadumbe was found to be twice that of the wild-type (1.8 µm) (Naidoo et al., 2015). In agreement to this, Moorthy et al. (1993) reported differences in average granule sizes for ten varieties of *Colocasia esculenta* ranging from approx. (3-5 µm). Moreover, Chen et al. (2003) investigated the granule size and particle size distribution of three varieties of Chinese sweet potato (XuShi18, SuShu2, and SuShu8). XuShi18 variety reportedly showed higher starch granule size (approx. 12 µm) when compared to SuShu8 (8 µm). This clearly shows that morphological differences of starches can be influenced by the varietal origin of starch (Chen et al., 2003). Different growing seasons can also influence the size of the starch granule between different crop varieties or same varieties. Two cultivars of cocoyam (*Xanthosoma sagittifolium*) (KCX01 and KCX02) planted in different seasons (summer, spring, and winter) showed differences in their starch granule size (4-6 µm) (Lu et al., 2005). Large starch granules were observed on cultivars planted in the summer season compared to the same cultivars when grown in other seasons, which exhibited smaller sized starch granules. The size of starch granules was in the order summer >spring>winter (Lu et al., 2005). These differences in granule size may be attributed to the availability of soil water. Similar observations were reported by Zhong-Min et al. (2008), who found out that a soil water deficit resulted in the increase of small starch granules and a decrease in larger starch granules for a variety of wheat grown in rain-fed and irrigated conditions respectively. Possibly, differences in rainfall patterns between different growing seasons can play a significant role in varying starch granule size.

2.9.6 Crystallinity of starch

Starch has a distinct crystalline nature, which is due to the well-organised structure of the amylopectin polymer inside the granules. Previous studies have reported that starch molecules can exist as helices which can have a different packing arrangement giving rise to different crystalline patterns (Mweta, 2009). X-ray diffractometry techniques are used to determine the type of starch crystallinity. Crystalline patterns are determined by the position of the diffraction

peaks while relative crystallinity is obtained by integrating the areas under the diffraction peaks (Zobel, 1988). There are three categories of starch crystallinity that are A, B and C type precisely. In A type crystallinity, the double helices are closely packed in a monoclinic unit cell with eight water molecules per unit cell. In B-type crystallinity, the double helices are more openly packed in a hexagonal unit cell with 36 water molecules per unit cells. This disparity in packaging pattern has caused a higher crystallinity in starches having A-type crystallinity compared to starches with B-type. Starches with A-type crystallinity are in cereals while B-type starches are mainly root and tuber crops and starches with high amyloses content. The third type of crystalline pattern classified as C-type crystallinity is a mixture of A and B polymorphic forms. In this group, A-type starches are more intense in the external division of the granule while the B-type are in the internal division of the granule. C-type crystallites are mainly found in legume starches such as smooth pea or bambara starch (Lopez-Rubio et al., 2008; Tester et al., 2004). According to Tian et al. (1991), C-type starch patterns are further divided into Ca, Cb and Cc depending on whether the pattern is closer to A or B. Certain factors such as average chain length of amylopectin and moisture content of starch granules influence the formation of A or B-type crystallites (Imberty et al., 1991). Shorter chains of amylopectin result in forming A-type starch crystallites while B-type crystallites are (created) from longer chains. Circulation of water molecules inside starch granules is vital in the development of crystallites (Paris et al., 1999). Increasing the amount of water in starch granules might alter the ratio of A and B-type crystallites (Paris et al., 1999). Differences in the packaging of amylopectin side chains cause different degrees of crystallinity. Starch with A-type pattern reportedly showed a higher degree of crystallinity than B-type starch (Srichuwong et al., 2005). The difference in the relative crystallinity can have an influence on the functionality of starches. The higher the relative crystallinity, the higher the structural stability and consequently, results in the increase in gelatinisation temperature. This is because water molecules require a much longer period to go through the rigid crystalline areas (Moorthy, 2002; Srichuwong et al., 2005).

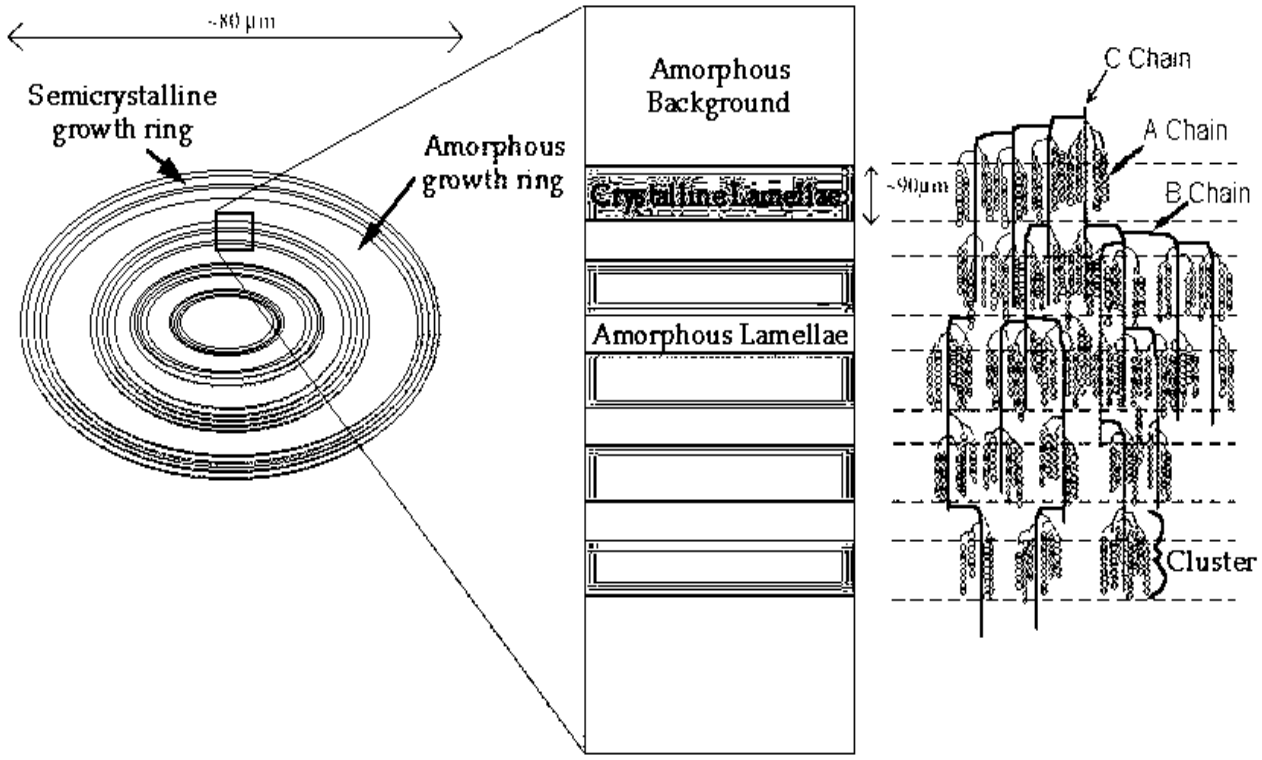

Figure 8: Diagram showing the structure of starch granule with alternating amorphous (A) and the structure of amylopectin branch chains (B)

Source : http://www.cheng.ca.ac.uk

Previous studies have reported different X-ray patterns of B and C-type on sweet potato starch, in contrast to wheat and corn starches which revealed A-type while potato showed a B-type pattern (Zobel, 1988). Native starch granules have absolute relative crystallinity ranging from 15-45%. Previous studies found that A-type starches have higher levels of crystallinity (33-44%) and higher gelatinisation temperatures. Lower levels of relative crystallinity (15-28%) and lower gelatinisation temperature has been reported on B-type starches (Tian et al., 1991). The crystalline pattern of starches varies with the botanical source, varietal difference or amylose: amylopectin ratio (Hoover et al., 1996; McPherson & Jane, 1999; Singh et al., 2006). Cereal grain starches, such as maize, wheat, and rice usually show typical A-patterns while most root and tuber starches exhibit B-patterns. A-type starches show diffraction peaks at 15°, 17°, 18° and 22° 2θ angles while B-type starch has four main reflection intensities at 5.5°, 17°, 22° and 24° 2θ angles (Mweta, 2009). The B-type X-ray pattern of starch is usually characterised by the position and relative peak intensity in the range of 2θ=5-6° while the absence of 2θ=5-6° is a characteristic of A-type starch. The C-type X-ray pattern, which is a combination of A and B polymorphic forms reflects at 5.5°, 17°, 18°, 20° and 23.5°. Sweet

potato starch shows variable X-ray patterns between C and A-type while cocoyam starch exhibits A-type pattern (Hoover, 2001; Moorthy, 2002). Differences in crystalline nature of starches from the same crops are attributed to many factors. These include sample separation, growth conditions and maturity of the plant at the time of harvest (Noda et al., 1995; Sugimoto et al., 1987).

2.10 Functional properties of flour and starch

Functional properties such as viscosity, gelatinisation, retrogradation, pasting, and swelling power are properties used to market flour and starch. According to FAO (1998), functional properties of starch and flour differ considerably with variety, botanical origin or growth environment. Structural properties of starch such as the molecular weight of amylose and amylopectin also affect the functional properties of starches. Shibanuma et al. (1996) observed higher pasting peak viscosity in wheat starches with high molecular weight of amylose and amylopectin. Furthermore, Lu et al. (2005) also found that taro with a high proportion of short chains and long chain fraction of amylopectin displayed high elasticity and gel of great strength during heating. Similarly, Jane et al. (1999) studied the effect of amylopectin branch chain length and amylose content on gelatinisation and pasting properties of starches from different botanical sources. Low gelatinisation temperatures were reported for starches with short average amylopectin branch chain length (Bultosa & Taylor, 2003).

2.10.1 Gelatinisation

Gelatinisation is the vital functional property of starches that determines its application in industry. It involves the disruption of the semi crystalline structure of starch when starch is subjected to heating in the presence of water. During this process, heat disrupts hydrogen bonds between polymer chains weakening the granules. Then, the amorphous region, which contains fewer hydrogen bonds and more susceptible to dissociation starts to imbibe water and increase in size (swelling). Amylose begins to solubilise and leaches out from the granule into the aqueous solution causing the increase of viscosity (Thomas & William, 1977).

Gelatinisation happens when starch is heated continuously in the presence of excess water. According to Blanshard (1987), there are six main stages that happen during the gelatinisation process. The stages include (1) hydration and swelling of the amorphous regions between the

crystallites and (2) a hydration-facilitated melting of the starch crystallites (3) further hydration and swelling of the molten crystallites and interstitial regions (4) double helices undo as hydrogen bonds are ruptured resulting in crystalline regions being converted in amorphous regions (5) granules continue to imbibe water and swell (6) ultimately the granule swells so much that granular form is lost and they tend towards gelation and solubilisation (Fig. 9).

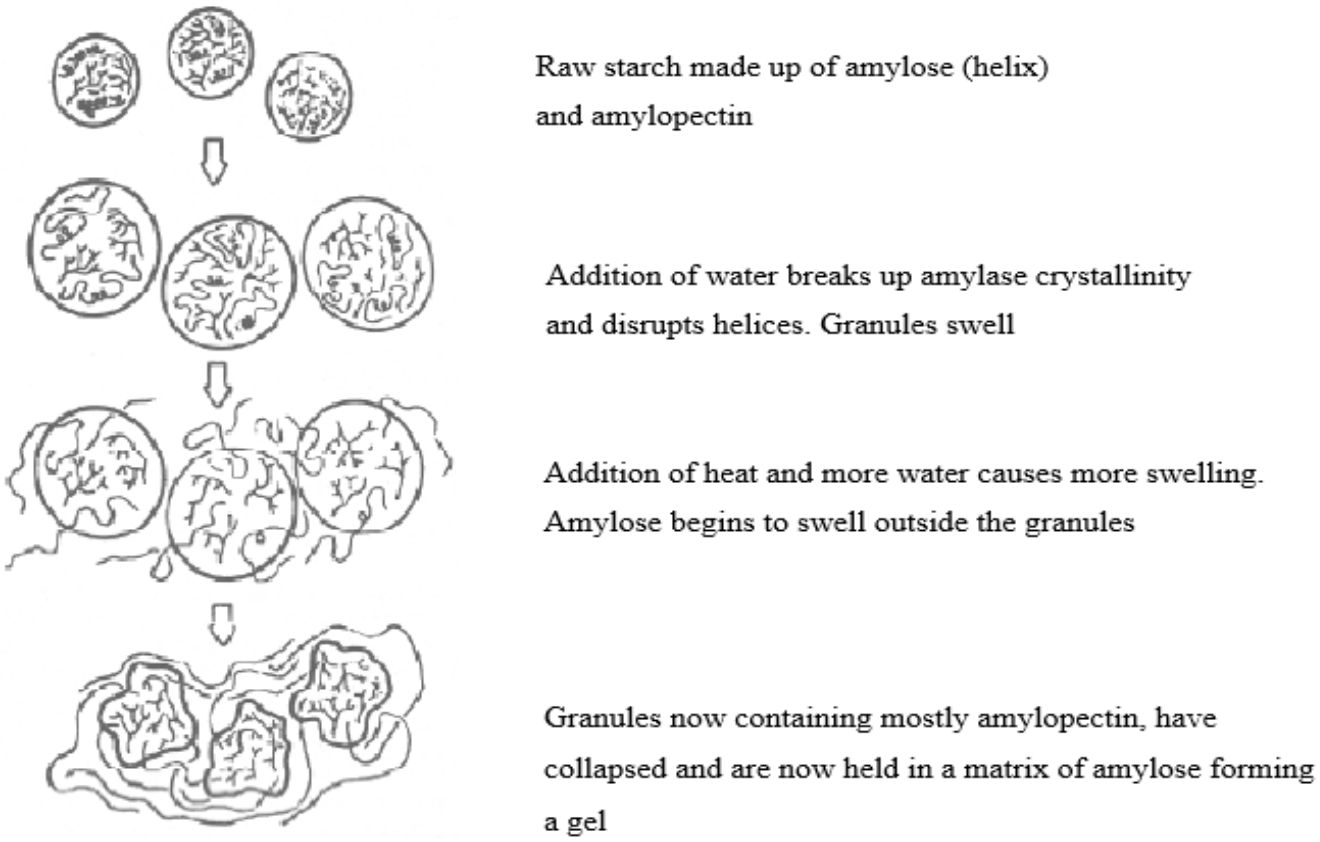

Figure 9: A model illustrating swelling of starch granule during a heating process in the presence of water
Source: (BeMiller & Whistler, 2009)

During the process of gelatinisation, short chains of amylose come out of the starch granules resulting in a formation of viscous paste (Tester & Karkalas, 1996). The temperature at which starch begins to undergo these changes is called gelatinisation temperature. Gelatinisation is an endothermic reaction. Hence, it requires energy and this differs between different starch granules (Ellis et al., 1998). When the starch paste is cooling, gelation and retrogradation takes place. Gelation happens when the amylose component of the starch paste sets and forms a gel, whereas retrogradation is when starch reverts or retrogrades to a crystalline structure. The gel

which is formed due to the reduced energy results in the subsequent formation of intermittent hydrogen cross bonds among amylose and re-association of amylose molecules at random intervals (Mweta et al., 2010). The strength of the internal structure of the starch granule is known to control the swelling process during gelatinisation process. The stronger the internal molecular structure, the higher the temperature required for gelatinisation (Hari et al., 1989). Differential scanning calorimeter is used to study the gelatinisation properties of starch granules. Factors such as amylose content, botanical origin and the structure of amylopectin influence starch properties like onset gelatinisation temperature (T_o), peak gelatinisation temperature (T_p), conclusion gelatinisation temperature (T_c) and the enthalpy of gelatinisation. Low amylose content results in high gelatinisation temperature (Kaptso et al., 2016; Naidoo et al., 2015). Higher gelatinisation temperature (82^{o}C) was reported for starch isolated from black bambara variety with low amylose (25%) content in comparison to the other white bambara variety (77^{o}C) with higher amylose content (28%) (Kaptso et al., 2016). Similarly, Chen et al. (2017) also observed that starch from waxy maize (with low amylose content) exhibited higher gelatinisation temperature than non-waxy maize starch with high amylose content. However, higher amylose starches have been found to show high gelatinisation temperature (Madamba et al., 1975; Seog et al., 1987; Takeda & Hizukuri, 1974). For instance, potato starch with low amylose content exhibited a low gelatinisation temperature (Singh et al., 2003). On the other hand, Noda et al. (1996), reported that the T_o, T_p, and T_c were greatly influenced by amylopectin structure rather than its amylose content. Starches with a higher proportion of long amylopectin chain normally exhibit higher T_o, T_p, and T_c while those with many short amylopectin chains showed low T_o, T_p, and T_c. Nevertheless, other factors such as variety and environmental growth conditions also influence the onset peak gelatinisation temperatures (Table. 4) (Chiang & Chen, 1988). Noda et al. (2001), working with sweet potatoes starch observed an increase of both T_o and T_p as the soil temperature increased from 15-27^{o}C. Similar findings were reported on barley where an increase in onset gelatinisation temperature (T_o) and T_p was observed as the environmental growth temperatures were elevated (Tester et al., 1991). But no information is known on how genotypic differences or growth environments affects gelatinisation properties of starch extracted from amadumbe grown in South Africa.

Table 4: Gelatinisation temperature of different varieties of sweet potato grown in different environments

Variety	T°C (onset)	T°C (peak)	T°C (conclusion)	ΔH (J g^{-1})
TN57	70	78	84.8	12.3
TN66	67	73	81.9	10.0
TN68	75	79	81.4	11.5
Kangoshima 1	68.1	73.5	84.6	15.9
Chiba	65.6	72.8	84.9	15.1

Source: (Tian et al., 1991)

Various analytical techniques are used to study the mechanism of gelatinisation. Microscopic examination of granules that undergo gelatinisation can reveal the integrity and size of swollen granules as well as the degree and duration of swelling (Cooke & Gidley, 1992). To examine the changes in crystallinity and to characterise the change in crystal structure during gelatinisation an X-ray diffraction technique is used (Nara et al., 1978). The FTIR technique is used to detect the absorption of different bond vibrations in starch molecules during gelatinisation (Goodfellow & Wilson, 1990). Factors which include temperature, the moisture content of the starch-water mixture, starch crystallinity, botanical source and environmental growth condition influences the gelatinisation process (Tester et al., 1999). Gelatinisation is important in industrial uses of starch such as in the texture resizing industry as it affects rheology and viscosity properties of the system (Ellis et al., 1998).

2.10.2 Pasting properties

Pasting is a process that occurs after starch gelatinisation. Continued heating of starch in excess water with stirring causes the granules to further swell, which leads to leaching of amylose and the granules to disintegrate, forming a viscous material called paste (BeMiller, 2007). Starch pasting is a two-phase system composed of a disperse phase of swollen granules and a continuous period of amylose leaching. Heating processes cause granules to become swollen which results in leaching of amylose from starch granules causing a rise in viscosity (Fig. 10) (Thomas & Atwell, 1999). The capability of starch to form a paste is important for starch as an ingredient to improve food texture (Katayama et al., 2002).

Pasting properties of starch are essential indicators of how starch performs throughout processing. Rapid Visco Analyser (RVA), Brabender Viscometer and other viscometers are used to measure this process. Primarily, heated up starch suspension results in starch granule swelling. Consequently, as heating is prolonged, there will be an increase in viscosity and this indicates the process of pasting as the amylose leaches. Pasting temperature is defined as the temperature at the commencement of an increase in viscosity. The peak viscosity (PV) is explained as the process whereby viscosity increases with continued heating till the rate of granule collapse is equal to the rate of granule swelling. The process of PV reflects water binding or the swelling level of starch and it usually associates with ultimate product quality because the collapsed and swollen granules recount to the texture of cooked starch. Once PV is reached, a drop-in viscosity known as the breakdown is observed due to the disintegration of starch granules. The breakdown is a measure of the ease of disrupting swollen starch granules and suggests the degree of stability during cooking (Adebowale et al., 2002). Minimum viscosity, also called hot paste viscosity, holding strength or trough, marks the end of the holding stage at the maximum temperature of the RVA. The cooling stage begins which causes a rise in viscosity (setback) which is caused by retrogradation of starch. The setback is an indicator of final product texture and is linked to syneresis or weeping during freeze-thaw cycles. Viscosity normally stabilises at a final viscosity or cold paste viscosity, which is related to the capacity of starch to form viscous paste or gel after cooking and cooling. Other components naturally present in the starchy material or additives interact with starch and influence pasting behaviour.

However, several factors such as the botanical origin of starch, the ratio of amylose/ amylopectin, starch granule size or environmental growth temperature significantly influence the pasting properties of starch. For instance, legume starches showed high pasting temperature and high set back temperature, which is attributed to high amylose content (Hoover et al., 2010). Other factors such as the presence of trace amounts of lipid-amylose complexes, amylose-amylose or amylose-amylopectin complexes can influence the pasting properties of starch (Hoover et al., 2010). Furthermore, according to Hizukuri (1969), potatoes reportedly showed an increase in the pasting temperature as the environmental growth temperature increased. Although low peak viscosity was observed in the latter crops, rice starch showed a rise in peak viscosity (Hizukuri, 1969). Similarly, Noda et al. (2001) also observed a temperature-dependent increase in the pasting temperature of sweet potatoes as soil

temperatures increased (15-27^{o}C). However, little information is known about how growth location affects the pasting properties of isolated starch or flour from traditionally underutilised tuber crops such as amadumbe.

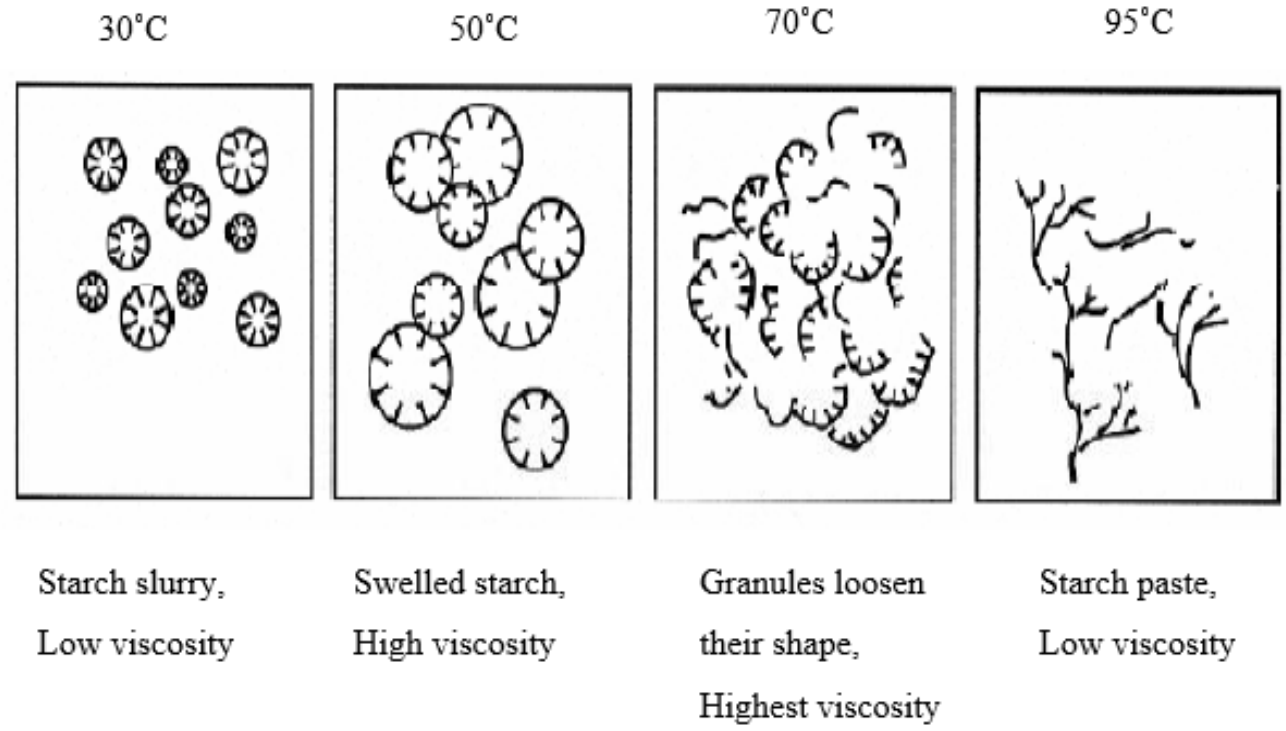

Figure 10: Model to illustrate how pasting of starch granules occur during cooking.

(BeMiller & Whistler, 2009)

2.10.3 Paste clarity and viscosity

Some of the vital characteristics which govern the use of starch in both food and non-food industries include starch paste clarity, stability, and viscosity (Moorthy, 2002). In some cases, where starches are normally used as sole ingredients e.g. as thickeners, gel clarity becomes a desirable characteristic since it directly influences brightness and opacity in foods. Typical starch pastes that are normally used during fruit pie thickening are normally transparent in comparison to those that are normally used in salad dressings, which are opaque. When combining with other colouring agents, starches with clear pastes are mostly preferred (Craig et al., 1989). Moreover, starch paste stability has been reported to be a vital characteristic of starch since it aid in controlling consistency and texture of food products such as sauces and soups (FAO, 1998). Paste clarity of starch also differs with the botanical source of starch or

variety (Achille et al., 2007; Craig et al., 1989; Singh et al., 2003). Higher paste clarity measurement for potato starch (96%T) has been reported compared to corn starch (31%T) or wheat starch (28%T) (Craig et al., 1989). These authors further found that potato starch paste was more transparent (79%T) than cassava (47%T), sweet potato (17%T) and cocoyam (16%T) starch paste (Craig et al., 1989). The higher paste clarity in potato starch than cereal starches can be attributed to the high content of phosphate monoesters as opposed to higher contents of phospholipids in cereal starches. Phospholipids present in starches form complexes with amylose and long chain fractions of amylopectin resulting in limited swelling and hence, the lower light transmittance (Craig et al., 1989; Singh et al., 2003). Amylose reorganisation forms aggregates that reduce light transmittance of starch pastes (Achille et al., 2007). High amylose starches re-associate more readily with amylopectin starches thereby resulting in more opacity (Bultosa et al., 2002).

One of the major functions of starch in the food industry is to impart viscosity to food products. This makes viscosity an important parameter especially in the processing of certain food products like sauces. Viscosity is temperature dependent, where it decreases as heating temperature increases and increases when the starch pastes are cooled. Starches from different sources differ in their viscosity characteristics. Oladebeye et al. (2009) found that sweet potato starch paste exhibited higher viscosity values than red cocoyam starch paste. Differences in the chemical composition of starch accounted for the variations in paste viscosity of different starches. High phosphate monoester content increase pastes viscosity while an increase in phospholipids results in lower paste viscosity (Singh et al., 2003). Viscosity variations also exist between different varieties of crops. Sefa-Dedeh and Sackey (2002) reported varying paste characteristics between varieties of red and white *Xanthosoma sagittifolium* grown in the same environment (soil, temperature) compared to *Colocasia esculenta* grown in another environment. *Colocasia esculenta* starch showed lower hot paste viscosity but higher thermal stability when compared to *Xanthosoma* starches. In support of this, Jane et al. (1992), found out that *Colocasia esculenta* starches from Hawaii Red and Hawaii White varieties showed higher peak viscosities when compared to Bun-long starch which had the lowest peak viscosity. This suggests that varietal/genotypic differences of the starch source can also contributed to the differences in paste viscosity.

2.10.4 Swelling and Solubility

Swelling and solubility occur when starch is heated in the presence of water thereby causing the disruption of the crystalline structure due to the breaking of hydrogen bonds. Evidence of non-covalent bonding between starch molecules is expressed through swelling and solubility which allows comparison for relative bond strength at a specific temperature (Moorthy, 2002). When this happens it exposes the hydroxyl groups of amylose and amylopectin resulting in water molecules being bonded to these hydroxyl groups through hydrogen bonding causing an increase in granule swelling and solubility (Hoover, 2001). Swelling and solubility of starch is temperature dependent where they increase as temperature increases due to the weakening of internal interactive forces that sustains the granular structure (Peroni et al., 2006). Yam and ginger starches reportedly showed lower swelling power when they are compared to cassava and sweet potato starches (Peroni et al., 2006). Amylose/amylopectin ratio, phosphate, lipid content and granular morphology are the major factors that influence swelling and solubility. Low amylose content generally exhibits higher swelling power (Tester & Morrison, 1990). According to Sasaki and Matsuki (1998), wheat starch varieties reportedly showed that amylose content and amylopectin structure accounted for approximately 89% of total variation in their swelling power. Although abundant in long amylopectin chains, a (DP $\geq$ 35) contributed to high swelling power and amylose content was reportedly found to have greater influence than the chain length of amylopectin (Sasaki & Matsuki, 1998). However, the impact of amylose content on swelling power cannot be applied to all starches since the findings reported by these authors were solely on cereal starches (Sasaki & Matsuki, 1998; Tester & Morrison, 1990). Moreover, the reliance of swelling capacity on the amylose content of starches may differ with variety or growing environment. This seems reasonable as previous authors working with starches from different varieties or botanical regions clearly showed that swelling power cannot be interpreted as a function of amylose content alone (Li & Yeh, 2001; Naidoo et al., 2015). According to Ratnayake et al. (2001) working with four different pea varieties with different amylose contents observed similar swelling power on all these varieties. Hence, differences in swelling behaviour of different starches can be attributed to numerous factors not limited to the botanical origin, amylose content, starch granule size, and environmental growth factors.

2.10.5 Retrogradation

Retrogradation involves molecular interactions (hydrogen bonding amylose and amylopectin) of the gelatinised starch after cooling (Hoover, 2001). The re-association of molecules results in the formation of crystalline aggregates and a gelled structure. The degree of retrogradation is determined by calculating the ratio of the enthalpy of retrogradation to that of gelatinisation and usually expressed as a percentage. Different methods such as turbidometry and measurement of syneresis are used to determine starch retrogradation. In turbidometry, a change in light transmittance of stored starch gels is measured with time. The turbidity arises from molecular associations that occur in the initial stages of retrogradation. When the starch gel is stored for a long time either refrigerated or frozen, there is a gradual increase in rigidity as crystallites begin to form and phase separation between polymer and solvent also occurs. This phenomenon is known as syneresis (Karim et al., 2000). Freeze-thaw stability expressed as percentage syneresis is also used as an indicator of starch retrogradation. Measurement of freeze-thaw stability involves freezing starch gel for a period, during which phase separation occurs. The frozen gel is then thawed and the water expelled from the gel is measured gravimetrically and expressed as a percentage of the starch gel (Karim et al., 2000; Zheng & Sosulski, 1998). The freeze-thaw stability has been of interest since it plays a critical role in the stability of frozen starch-based foods (Thomas & Atwell, 1999). It provides a measure of the ability of a product to withstand cold temperature cycling and/or prolonged storage at low temperatures of starch gels.

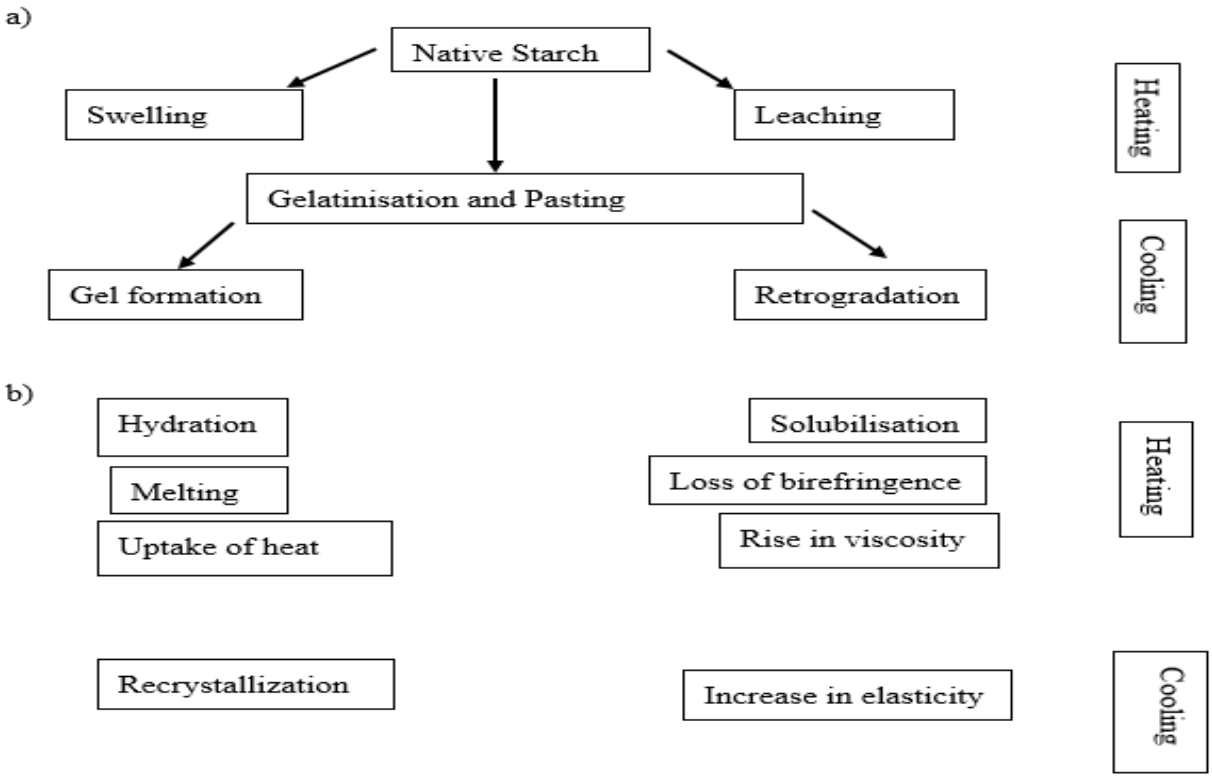

Figure 11: Terms to describe changes induced by heating and cooling (b) Physicochemical changes that take place during heating and cooling**.**

Source**:** (BeMiller & Whistler, 2009)

Retrograded starches show lower gelatinisation temperatures and enthalpy than native starches because of weaker starch crystallinity. The crystalline forms are different in nature from those present in the native starch granules (Karim et al., 2000). Amylose undergoes rapid crystallisation as soon as cooling begins and retrogradation depends on the amylose content in the sample. Amylopectin, on the other hand, recrystallizes slowly and the degree of retrogradation depends on the chain length distribution of amylopectin (Ring et al., 1988). Similar differences in the retrogradation tendencies were also reported by Chen et al. (2003) on three (3) different varieties of Chinese sweet potato starches. All these differences observed were attributed to the differences in amylose content, size and distribution compactness of starch granules. A report by Kaur et al. (2002) showed that low amylose content (approx. 25%) of potato starch from one variety showed high retrogradation tendency (approx. 8%) in comparison with other potato starch from other varieties with high amylose (approx. 30%) content which exhibited low retrogradation rate(approx. 5%). Furthermore, amylopectin and

intermediate components can also influence starch retrogradation during refrigeration storage (Yamin et al., 1999). Other authors have reported that retrogradation can be accelerated by the amylopectin with larger chain length (Tester & Karkalas, 2001).

2.11 Hypothesis

1. Location and genotypes will influence the flour composition e.g. carbohydrates content as well as the functional properties of amadumbe flour. Aboubakar et al. (2008) found variations in total carbohydrate contents among five taro varieties grown in different environments.

2. Genotypes and growth location will influence the starch composition e.g. amylose content, which may impact on starch functionality. Beta and Corke (2001) observed that environmental effect (low temperature) resulted in low amylose content in starch content than genotypic influence.

2.11.1 Aims

To investigate the influence of growth location and genotypes on the physicochemical characteristics of amadumbe flour and starch to promote their utilisation and selection of varieties with desirable characteristics

2.11.2 Objectives

1. To determine the influence of growth location and genotypes on chemical composition (proximate composition, crude mucilage content, and mineral content) of amadumbe flours
2. To determine the functional properties of amadumbe flours as influenced by growing location and genotypes
3. To determine the influence of growth location on starch properties, structure, composition and functionality

CHAPTER THREE

3.0 Effect of genotypes and growth locations on composition and functional properties of amadumbe flour

Abstract

Amadumbe, known as taro is a traditional crop mainly grown for subsistence in Southern Africa. In this study, chemical composition and functional properties of nine (9) amadumbe genotypes grown at two distinct locations were investigated. Carbohydrate contents (73-81%) of amadumbe genotypes were substantially high and varied with growth location. Protein contents ranged from 8-12% and fat was very low (less 1%) in all genotypes. Major minerals in flours were K, P, Mg and Ca, but these were present at varying levels depending on growth locations. Amadumbe flours showed slightly low mucilage content (6-9%) across genotypes. However, genotypes with higher mucilage contents generally had higher water absorption capacity irrespective of growth locations. Genotype and growth location significantly affected the pasting properties of amadumbe flours. Peak viscosities varied between 83-242 RVU among genotypes. The pasting temperature of the genotypes were fairly high approx. 87-94oC across genotypes. This study data suggests that differences in environmental temperatures and amounts of rain falls received at growth location during the growing season could be responsible for the variations in flour composition and consequently their functionality. Findings from this study are important for future improvement programme and for food application of amadumbe flour.

Keywords: Amadumbe genotypes, Growth location, flour, composition, functionality

3.1 Introduction

Amadumbe (*Colocasia esculenta*), also known as taro are grown for their edible corms in the tropics and subtropical parts of the world (Huang et al., 2010). In South Africa, amadumbe is a traditional tuber crop grown for subsistence. The corms are normally boiled, fried or made into a mash to create a variety of dishes. Amadumbe is rich in carbohydrates (75-90%), the bulk of it being starch (approx. 80-96%) making it a reliable source of calories (Aboubakar et al., 2008; Aprianita et al., 2009; Naidoo et al., 2015). The high resistant starch content (approx. 60%) (Naidoo et al., 2015) and mucilage (7-10%) in amadumbe suggests that this crop may play a significant role in digestive health (Guevara-Arauza et al., 2012; Hong & Nip, 1990).

Furthermore, amadumbe corms are fairly good sources of minerals and vitamins such as K, Zn, Mg and Mn with a significant role in the metabolic process (Mergedus et al., 2015). As such, amadumbe flour can be used as a food ingredient in the food formulations for health-conscious individuals i.e. obesity or diabetics (Liu et al., 2006).

Due to their high moisture content (approx. 90%), amadumbe tubers are highly perishable. Hence, they must be processed into stable products such as flours (Falade & Okafor, 2015). The use of flours in the food industry as a food ingredient is primarily governed by their functional and physicochemical properties. Flour composition may be influenced by growth location which may have impact on functionality and application. According to Tester and Karkalas (2001), environmental factors such as growth temperature may significantly influence starch composition e.g. amylose content which in turn can modify the properties of flour. For instance, Tattiyakul et al. (2006) studied the flour composition and functional properties of two taro varieties grown at four different locations in Thailand. The protein contents of the flour (0.9-1.7 g/100 g flour) varied with growth location indicating an environmental influence on the composition of taro flours. Also, the swelling power (11.3-15.9 g/g) and solubility (0.08-0.13 g/g) of the flours also differed with growth location (Tattiyakul et al., 2006). Besides growth location, genotypic differences may also influence flour functionality such as pasting properties. Falade and Okafor (2015) found significant differences in the peak viscosities (97.3-201.2 RVU) of flour isolated from four taro genotypes grown in the same location.

In Southern Africa, amadumbe is regarded as traditional and its utilisation remains largely domestic. However, amadumbe flour has the potential for industrial application, since it has some beneficial physiological effect as previously stated above. Previous studies on amadumbe have investigated water use and drought resistance of locally grown varieties in South Africa (Mabhaudhi et al., 2013). These studies revealed significant variations among amadumbe landraces grown under varying environmental conditions**.** Under different irrigation treatments, amadumbe corm mass reportedly reduced with a decrease in soil water availability (Mabhaudhi et al., 2013). However, the efforts aimed at promoting the utilisation of amadumbe in South Africa has focused on breeding of locally grown varieties largely on the agro-morphological and molecular markers. The integration of breeding for yield and yield-related traits, as well as physicochemical properties, is important for food and nutritional security. Although breeding data was encouraging, breeding can interfere with the good inherent properties of amadumbe flours. Hence, in this study, the composition and functional properties

of flour extracted from amadumbe genotypes grown under different environmental conditions was investigated.

3.2 Materials and Methods

Nine genotypes were obtained from the Agricultural Research Council-Vegetable and Ornamental Plant Institute, Pretoria, South Africa. The genotypes were grown at Roodeplaat Research Farm and Umbumbulu Farmers' Field. The genotypes were evaluated for their agro-morphological characteristics. The altitude of Umbumbulu and Roodeplaat is 597 m and 1168 m above sea level, respectively. The locations receive an annual rainfall of 828 mm and 514 mm for Umbumbulu and Roodeplaat, respectively. The average temperatures for Roodeplaat and Umbumbulu were 19 and 24^{o}C, respectively for the cropping season (Sept/2014- May/2015) (Table 5).

Table 5: Average temperature, humidity and rainfall during the growth season of amadumbe in Roodeplaat and Umbumbulu.

ROODEPLAAT STATION DATA

Month/Year	Tx (^{o}C)	Tn (^{o}C)	RHx (%)	RHn (%)	Rainfall (mm)
Sept/2014	24.9	9.42	73.7	13.3	0.51
Oct/ 2014	22.9	11.9	79.0	19.6	29.9
Nov/ 2014	24.3	14.4	86.4	34.7	92.9
Dec/ 2014	22.4	16.4	89.5	39.8	123
Jan/ 2015	28.4	16.5	89.2	35.3	120
Feb/ 2015	23.2	16.0	88.2	27.0	32.5
Mar/ 2015	22.6	14.7	88.1	29.3	71.6
Apr/ 2015	21.3	10.8	90.8	30.6	42.7
May. 2015	24.3	7.12	83.9	18.6	0.00
Average	23.8	13.1	85.4	27.2	514

UMBUMBULU STATION DATA

Month/ Year	Tx (^{o}C)	Tn (^{o}C)	RHx (%)	RHn (%)	Rainfall (mm)
Sept/2014	29.7	15.5	88.1	45.1	78.0
Oct/ 2014	29.8	14.0	88.7	56.3	127
Nov/ 2014	27.9	16.4	9.35	1.56	107
Dec/ 2014	28.7	18.4	--	--	104
Jan/ 2015	30.1	16.8	--	--	93.4
Feb/ 2015	31.9	19.4	93.4	57.8	164
Mar/ 2015	30.1	19.0	94.1	57.8	90.5
Apr/ 2015	27.4	16.6	93.6	52.1	60.5
May. 2015	27.6	16.5	89.8	39.7	1.02
Average	29.3	17.2	61.9	34.5	828

Tx (^{o}C)-Maximum temperature, Tn (^{o}C)-Minimum temperature, RHx (%)-Maximum humidity, RHn (%)-Minimum humidity

3.2.1 Flour preparation

Freshly harvested amadumbe corms were washed, peeled, and sliced into a thickness of three mm. Peeled sliced corms were dried at 50°C for 48 hr in a hot air oven (D-37520, Thermo Fisher Scientific, Germany). Dried slices were then milled into flour using a warring blender (Model: 8010S, Torrington, USA) and sieved (screen size: 180 mm) to obtained fine flours, which were then stored at 4°C prior to analysis.

3.2.2 Determination of proximate composition

Moisture, fat, ash and protein content of amadumbe flours was determined using AOAC (2000), methods. Protein content (N x 6.25) was determined by Kjeldahl method (6.25 ×N) and total carbohydrate was calculated by difference**.**

3.2.3 Mineral profile determination

Phosphorous content of flours, as a percentage of sample weight (w/w), was determined following the spectrophotometric method of AOAC (2000) while minerals (Ca, Na, Mg, K, Mn, Mg, Fe, Zn, Cu) content, as a percentage of sample weight (w/w), was analysed using an atomic absorption (AA) spectrophotometer.

3.2.4 Water and oil absorption capacity determination

Water absorption capacity was done according to the method described by (Falade & Okafor, 2015). One gram of flour sample was weighed into a dry, clean weighed centrifuge tube. Water (10 ml) was poured into the tube and properly mixed using a vortex. The suspension was allowed to stand for 30 mins at room temperature which was followed by centrifugation (Centrifuge Model: Ependof 5810R, Germany) at 3500 x g for 15 min. The supernatant was discarded and the tube with the sediment was reweighed. The same procedure was repeated for oil absorption capacity by replacing water with oil. The following equation was used to calculate water/ oil absorption capacity:

$$\text{Water/ Oil Absorption [g } H_2O\text{/ oil/g of dry sample weight} = \frac{\text{Wet sample weight} - \text{Dry sample weight}}{\text{Dry sample weight}}$$

3.2.5 Swelling power and Solubility index determination

Swelling power and the solubility index was determined following methods described by (Gebresamuel & Gebre-Mariam, 2011). Briefly, flour samples (0.1 g flour in 10 ml of distilled water) were vortexed for 1 min and placed in a water bath for 30 min at temperatures ranging from 55^{o}C to 85^{o}C with constant shaking. The suspension was then centrifuged at 3500 x g for 15 min and the supernatant was kept for the determination of solubility index. For the determination of solubility index, the supernatant obtained by heating starch in different temperatures was then poured into dry, clean petri dishes and dried to a constant weight in an oven at 105°C. The precipitated paste and the dried supernatant were then weighed. The swelling power (SP) and solubility Index (SI) was calculated using equations (1) and (2), respectively.

Swelling Power [g/g starch/flour] = $\frac{m_{sw}}{(m_{o}-m_{s}}$ ..... (1)

Solubility index [g/g starch/flour] = $\frac{m_{s}}{m_{o}} \times 100\%$..... (2)

Wherem_{sw}, is weight of swollen starch/flour, m_{o} is sample weight and m_{s} is the weight of dried supernatant.

3.2.6 Determination of Pasting property

The pasting properties of the amadumbe flours were determined using the Rapid Visco Analyser (RAV-4, Newport, Scientific, Warriewood, Australia) following an established method followed by (Oyeyinka et al., 2016). Parameters recorded were pasting temperatures, peak viscosity, trough viscosity (min viscosity @ 95°C), final viscosity (viscosity @50°C), breakdown viscosity (peak-trough viscosity) and setback viscosity (final viscosity).

3.2.7 Statistical analysis

The data reported in all the tables are average values of triplicate determinations. The data was analysed using two-way analysis of variance (ANOVA) and the means were compared using the Fisher Least Significant Difference (LSD) test ($p<0.05$).

3.3 Results and Discussion

3.3.1 Proximate composition of amadumbe flours

Proximate composition of flours from amadumbe grown in Roodeplaat (R) and Umbumbulu (U) varied significantly ($p<0.05$) (Table 1). Amadumbe flours produced from genotypes grown in both locations showed high carbohydrate content ranging between 72 and 80% while fats, protein, and ash were very limited (Table 1). The carbohydrate content was generally low compared to previously reported data on taro flours (Aboubakar et al., 2008; Kaur et al., 2013). However, between the two locations, amadumbe flour obtained from genotypes grown in Umbumbulu showed slightly higher carbohydrate content approx. 77% when compared to the same genotypes grown at Roodeplaat (approx. 74%). Higher annual rainfall received in Umbumbulu (828 mm) could have caused higher carbohydrate content due to increased enzymatic activities in starch biosynthesis resulting in accumulation of starch granules compared to lower rainfall received in Roodeplaat (514 mm) which could have resulted in lower CHO content (Zhong-Min et al. (2008). Soil water deficit has been reported to cause reduced enzymatic activities, resulting in lower CHO content due to less accumulation of starch granules (Zhong-Min et al. (2008). Comparable results have been reported by Thitisaksakul et al. (2012), who found out that soil water deficit resulted in decrease of cereal starch accumulation by 40% which consequently result in reduced CHO content. Moreover, the differences in the carbohydrate values may be due to variation in soil composition, agronomic practices in which these amadumbe were grown or possibly genotypic differences. Furthermore, ash content which represents the mineral component and protein content varied from approx. 4-8% and 8-12%, respectively. These values were generally high compared to those reported in literature for taro flours (Aboubakar et al., 2008; Kaur et al., 2013; Naidoo et al., 2015). This difference in composition could be attributed to differences in soils nutrients at two growth locations.

Table 6: Proximate composition of flour isolated from amadumbe genotypes grown in different locations

Locations	Parameters / Genotypes	Moisture (%)	Protein (%)	Ash (%)	ADF (%)	NDF (%)	Fats (%)	CHO (%)
Roodeplaat	G 1	$10.4^{b}\pm0.03$	$8.92^{d}\pm0.03$	$6.81^{b}\pm0.07$	$5.91^{c}\pm0.02$	$50.9^{a}\pm0.04$	$0.77^{b}\pm0.06$	$73.1^{c}\pm0.01$
	G 2	$8.69^{d}\pm0.01$	$7.68^{f}\pm0.02$	$6.21^{c}\pm0.09$	$6.88^{b}\pm0.03$	$50.7^{a}\pm0.03$	$0.50^{f}\pm0.02$	$76.9^{b}\pm0.02$
	G 3	$9.28^{c}\pm0.03$	$8.09^{e}\pm0.08$	$6.80^{b}\pm0.06$	$5.39^{cd}\pm0.01$	$40.9^{b}\pm0.06$	$0.66^{d}\pm0.03$	$75.2^{bc}\pm0.08$
	G 9	$8.32^{d}\pm0.02$	$9.77^{b}\pm0.02$	$6.48^{bc}\pm0.03$	$7.13^{a}\pm0.04$	$29.2^{d}\pm0.05$	$0.28^{g}\pm0.04$	$75.2^{bc}\pm0.01$
	G 20	$11.1^{a}\pm0.02$	$9.31^{c}\pm0.07$	$6.58^{bc}\pm0.01$	$5.24^{cd}\pm0.02$	$51.2^{a}\pm0.02$	$0.71^{c}\pm0.02$	$72.3^{c}\pm0.04$
	G 21	$8.53^{d}\pm0.02$	$9.65^{bc}\pm0.03$	$7.61^{a}\pm0.02$	$6.76^{bc}\pm0.01$	$41.8^{b}\pm0.04$	$0.56^{e}\pm0.08$	$73.7^{c}\pm0.06$
	G 22	$10.2^{bc}\pm0.03$	$6.87^{g}\pm0.02$	$6.50^{bc}\pm0.11$	$5.18^{d}\pm0.03$	$49.0^{ab}\pm0.03$	$0.84^{a}\pm0.09$	$80.6^{a}\pm0.03$
	G 26	$8.68^{d}\pm0.03$	$8.69^{de}\pm0.05$	$6.31^{c}\pm0.03$	$6.66^{bc}\pm0.04$	$26.6^{d}\pm0.09$	$0.62^{d}\pm0.04$	$75.7^{bc}\pm0.02$
	G 29	$6.36^{e}\pm0.03$	$10.3^{a}\pm0.02$	$6.6^{bc}\pm0.10$	$6.15^{c}\pm0.01$	$33.7^{c}\pm0.08$	$0.82^{ab}\pm0.02$	$75.9^{bc}\pm0.09$
	Max	11.1	10.3	7.61	7.13	51,2	0.84	80.6
	Min	6.36	6.87	6.21	5.18	26.6	0.28	72.3
	C.V	0.27	0.42	0.86	0.38	0.12	6.94	0.05
Umbumbulu	G 1	$7.13^{cd}\pm0.02$	$9.83^{c}\pm0.02$	$5.04a^{b}\pm0.01$	$4.94^{c}\pm0.04$	$52.2^{a}\pm0.03$	$0.63^{c}\pm0.01$	$77.4^{a}\pm0.02$
	G 2	$4.42^{f}\pm0.03$	$9.75^{c}\pm0.01$	$5.04a^{b}\pm0.04$	$5.66^{b}\pm0.01$	$33.8^{d}\pm0.05$	$0.61^{c}\pm0.03$	$73.2^{ab}\pm0.03$
	G 3	$7.34^{c}\pm0.05$	$7.97^{de}\pm0.05$	$4.66^{bc}\pm0.02$	$5.28^{bc}\pm0.02$	$27.1^{d}\pm0.03$	$0.42^{e}\pm0.01$	$75.6^{a}\pm0.02$
	G 9	$6.11^{e}\pm0.09$	$8.35^{d}\pm0.03$	$5.13^{a}\pm0.02$	$6.28^{a}\pm0.01$	$30.6^{cd}\pm0.03$	$0.61^{c}\pm0.02$	$77.8^{a}\pm0.03$
	G 20	$6.51^{d}\pm0.12$	$12.0^{a}\pm0.01$	$4.34^{c}\pm0.01$	$5.62^{b}\pm0.01$	$50.3^{ab}\pm0.03$	$0.55^{d}\pm0.02$	$76.6^{a}\pm0.02$
	G 21	$8.69^{b}\pm0.06$	$8.35^{d}\pm0.03$	$4.74b^{c}\pm0.06$	$4.69^{c}\pm0.02$	$46.4^{b}\pm0.01$	$0.76^{b}\pm0.02$	$75.5^{a}\pm0.01$
	G 22	$6.02^{e}\pm0.12$	$7.19^{e}\pm0.02$	$4.69^{bc}\pm0.01$	$5.60^{b}\pm0.02$	$46.8^{b}\pm0.02$	$0.83^{a}\pm0.03$	$75.3^{a}\pm0.01$
	G 26	$7.31^{c}\pm0.02$	$10.8^{b}\pm0.03$	$4.47^{bc}\pm0.01$	$4.55^{c}\pm0.01$	$52.2^{a}\pm0.02$	$0.72^{bc}\pm0.03$	$76.7^{a}\pm0.03$
	G 29	$9.29^{a}\pm0.02$	$11.4^{ab}\pm0.01$	$4.97^{b}\pm0.01$	$6.00^{ab}\pm0.02$	$43.1^{bc}\pm0.01$	$0.47^{e}\pm0.01$	$73.8^{ab}\pm0.02$
	Max	9.29	12.0	5.13	6.28	52.2	0.83	77.8
	Min	4.42	7.19	4.34	4.55	27.1	0.42	73.2
	C.V	0.84	0.21	0.44	0.33	0.06	3.23	0.03

[1]Mean±SD. Mean values with different letters in column are significantly different ($p<0.05$), Max-maximum value, Min-minimum value, C.V-coefficient of value, G-genotype, G with a number is the identification code of the genotype (Gn), ADF- Acid detergent fiber, NDF- Neutral detergent fiber, CHO-Carbohydrates

3.3.2 Mineral composition of amadumbe flours

The mineral composition of amadumbe flours isolated from amadumbe genotypes grown in Roodeplaat and Umbumbulu varied significantly with growth location ($p<0.05$) (Table 7). Generally, the mineral composition showed higher levels of Ca, Mg, K, Na and P in flour obtained from amadumbe genotypes grown in Roodeplaat compared to the same genotype grown in Umbumbulu. In both locations, amadumbe flour showed substantially higher levels of Potassium (K), approx. 2457 mg/100 g and approx. 1952 mg/100 g for Roodeplaat and Umbumbulu respectively. Potassium (K) is a vital nutrient which plays a pivotal role in human health such as relief from stroke, blood pressure, heart and kidney disorders (Ndabikunze et al., 2011). The values of macromineral contents in this study were fairly high when compared to the ones reported in the literature for taro flours (Aboubakar et al., 2008; Polycarp et al., 2012). The values of microminerals such as Zn, Cu, Mn and Fe also varied significantly ($p<0.05$) with genotype and growth location. Flour obtained from amadumbe genotypes from Roodeplaat showed higher amounts of Zn (approx. 137 ppm), Cu (12 ppm) and Fe (31 ppm) when compared to those grown in Umbumbulu. The difference in these mineral elements can be attributed to variations in soil nutritional composition between Roodeplaat and Umbumbulu. However, these micronutrient values are much lower compared to those reported in the literature, which are fairly high (Ndabikunze et al., 2011). The differences in the Ca and Mg in amadumbe flours can be attributed to different environments in which these amadumbe were grown. For instance, according to Ndabikunze et al. (2011), taro grown in swampy areas exhibited higher Ca and Mg content of (110 and 90 mg/100) than taro grown in dry lands which showed (69 and 84 mg/100).

Table 7: Mineral composition of flour extracted from amadumbe genotypes grown in different locations

	Parameters	Ca g/ 100 g	Mg	K	Na	P	Zn mg/kg	Cu	Mn	Fe
Locations	**Genotypes**									
Roodeplaat	G 1	70.0^{cd}±0.01	250^{a}±0.01	2570^{b}±0.02	20.0^{bc}±0.01	770^{a}±0.01	149^{ab}±0.10	13.0^{b}±0.03	5.50^{bc}±0.71	27.5^{b}±0.14
	G 2	80.0^{c}±0.01	240^{a}±0.03	2260^{e}±0.03	50.0^{a}±0.02	730^{ab}±0.02	133^{c}±0.05	12.5^{b}±0.03	7.00^{b}±0.49	26.5^{b}±0.12
	G 3	80.0^{c}±0.01	240^{a}±0.01	2560^{b}±0.02	30.0^{b}±0.01	770^{a}±0.03	135^{c}±0.03	13.5^{b}±0.03	6.50^{b}±0.71	35.0^{a}±0.10
	G 9	120^{a}±0.02	200^{a}±0.03	2360^{d}±0.02	40.0^{ab}±0.02	690^{b}±0.02	151^{ab}±0.11	12.5^{b}±0.03	8.50^{a}±0.71	34.5^{a}±0.12
	G 20	50.0^{d}±0.02	220^{a}±0.02	2410^{cd}±0.02	40.0^{ab}±0.02	750^{a}±0.02	121^{d}±0.14	12.5^{b}±0.03	5.00^{c}±0.43	26.5^{b}±0.11
	G 21	80.0^{c}±0.02	200^{a}±0.02	2870^{a}±0.03	50.0^{a}±0.02	740^{a}±0.02	113^{e}±0.12	9.00^{b}±0.03	5.50^{bc}±0.68	36.5^{a}±0.11
	G 22	80.0^{c}±0.02	220^{a}±0.02	2460^{c}±0.01	20.0^{bc}±0.02	670^{bc}±0.03	138^{c}±0.09	11.5^{b}±0.03	5.00^{c}±0.51	32.5^{a}±0.12
	G 26	120^{a}±0.02	200^{a}±0.02	2320^{d}±0.03	40.0^{ab}±0.02	610^{bc}±0.02	144^{b}±0.12	13.0^{b}±0.03	7.00^{b}±0.62	31.5^{ab}±0.13
	G 29	100^{b}±0.01	240^{a}±0.02	2310^{d}±0.02	40.0^{ab}±0.16	670^{b}±0.01	155^{a}±0.13	25.0^{a}±0.03	9.00^{a}±0.41	32.5^{a}±0.09
	Max	120	250	2870	50.0	770	155	25.00	9.00	36.5
	Min	50.0	200	2260	20.0	610	112.50	9.00	5.00	26.5
	C.V	0.02	0.02	0.00	0.09	0.00	0.07	5.88	8.92	0.37
Umbumbulu	G 1	30.0^{b}±0.01	120^{a}±0.01	2060^{ab}±0.01	20.0^{a}±0.01	180^{b}±0.01	25.5^{b}±0.03	6.50^{b}±0.12	14.0^{c}±0.42	21.5^{c}±0.44
	G 2	40.0^{ab}±0.01	130^{a}±0.01	2040^{b}±0.02	20.0^{a}±0.06	170^{b}±0.01	25.0^{b}±0.03	6.50^{b}±0.10	11.5^{cd}±0.74	16.5^{d}±0.51
	G 3	30.0^{b}±0.01	120^{a}±0.01	1910^{c}±0.02	10.0^{a}±0.02	160^{bc}±0.01	34.0^{a}±0.03	7.00^{b}±0.11	14.0^{c}±0.44	28.0^{b}±0.31
	G 9	50.0^{ab}±0.01	120^{a}±0.01	2100^{a}±0.01	10.0^{a}±0.01	200^{a}±0.02	26.5^{b}±0.03	7.50^{ab}±0.10	22.5^{a}±0.73	20.0^{c}±0.34
	G 20	40.0^{ab}±0.01	140^{a}±0.02	1720^{d}±0.02	20.0^{a}±0.03	170^{bc}±0.01	24.0^{b}±0.03	6.50^{b}±0.13	8.50^{d}±0.71	19.5^{c}±0.32
	G 21	60.0^{a}±0.02	120^{a}±0.02	1920^{c}±0.01	20.0^{a}±0.05	180^{b}±0.02	22.5^{bc}±0.03	4.00^{c}±0.09	13.5^{c}±0.72	20.0^{c}±0.41
	G 22	60.0^{a}±0.01	120^{a}±0.02	1920^{c}±0.01	20.0^{a}±0.01	190^{ab}±0.02	33.0^{a}±0.03	8.00^{ab}±0.15	18.0^{b}±0.43	24.0^{bc}±0.21
	G 26	30.0^{b}±0.01	140^{a}±0.01	1830^{cd}±0.02	10.0^{a}±0.04	140^{c}±0.02	31.5^{ab}±0.03	6.50^{b}±0.12	17.5^{b}±0.74	27.0^{b}±0.31
	G 29	40.0^{ab}±0.01	120^{a}±0.01	2070^{ab}±0.02	20.0^{a}±0.01	190^{ab}±0.02	25.5^{b}±0.03	9.50^{a}±0.11	14.0^{c}±0.43	36.0^{a}±0.41
	Max	60.0	140	2100	20.0	200	34.00	9.50	22.5	36.0
	Min	30.0	120	1720	10.0	140	22.50	4.00	8.50	16.5
	C.V	0.04	0.01	0	0.16	0.08	0.42	8.74	4.02	1.53

[1]Mean±SD. Mean values with different letters in column are significantly different ($p<0.05$), Max-maximum value, Min-minimum value, C.V-coefficient of value, G-genotype, G with a number is the identification code of the genotype (Gn).

3.3.3 Crude Mucilage of amadumbe flours

The crude mucilage content of flours was significantly affected by genotype and growing location. Generally, the crude mucilage was low and ranged between 6 and 9% for amadumbe genotypes grown at both locations (Table 3). On average, amadumbe genotypes grown in Roodeplaat with lower growth temperature (19^{o}C) showed slightly higher mucilage content than their counterparts grown in Umbumbulu with elevated growth temperature (24^{o}C). Slightly higher values of mucilage for taro (approx. 10%) have been previously reported (Hong & Nip, 1990). Differences in mucilage content can be attributed to environmental plant stress response during growth (Jiang & Ramsden, 1999). Some authors have postulated that elevated growth temperatures could result in decrease or increase of mucilage content subject to genotype response to stress (Aprianita, 2010), and this was clearly seen in this study. Mucilage can be used as functional ingredient (soluble fibre) or as a thickener/stabiliser since it exhibits a unique rheological properties.

Table 8: Crude mucilage content for flour extracted from amadumbe genotypes grown in different locations

Parameters	Crude mucilage content (%)	
Locations	**Roodeplaat**	**Umbumbulu**
Genotypes		
G 1	7.26b^{c}±0.11	6.98^{b}±0.55
G 2	7.81^{b}±0.13	7.10^{b}±0.53
G 3	6.63^{cd}±0.11	7.46^{ab}±0.43
G 9	7.34^{bc}±0.12	6.87^{b}±0.39
G 20	7.06^{c}±0.08	6.79^{b}±0.41
G 21	7.64^{b}±0.07	5.80^{c}±0.61
G 22	8.82^{a}±0.10	8.53^{a}±0.62
G 26	7.16^{bc}±0.09	6.60^{b}±0.64
G 29	6.45^{d}±0.15	6.51^{b}±0.46
Max	8.82	8.53
Min	6.45	5.80
C.V	1.45	7.41

[1]Mean±SD. Mean values with different letters in columns are significantly different ($p<0.05$), Max-maximum value, Min-minimum value, C.V-Coefficient of value, G-genotype, G with a number is the identification code of the genotype (Gn)

3.2.4 Water Absorption capacity of amadumbe flours

Water absorption capacity (WAC) of amadumbe flours was almost similar across all genotypes grown in both Roodeplaat (R) and Umbumbulu (U). Only slight differences were observed across all genotypes in both locations (Fig 12). However, genotypes, G1, G9, G26 grown in Roodeplaat showed slightly higher WAC than their counterparts grown in Umbumbulu. High-water absorption of taro flour could be attributed to the presence of higher amounts of carbohydrate (CHO) in the flour. Furthermore, Aboubakar et al. (2008) reported that the non-starch components of flour such as mucilage also contributes immensely to the water absorption capacity of taro flour. In this study amadumbe genotypes from Roodeplaat generally showed high WAC, which can be attributed to high mucilage content, recorded in these flours compared to their counterparts from Umbumbulu. Flour with high WAC may be useful in products such as soups and gravies where higher viscosity is required (Kaushal et al., 2012).

3.3.5 Oil absorption capacity of amadumbe flours

Oil absorption capacity (OAC) of amadumbe flours was generally similar across all genotypes grown in both locations (Fig. 12). Environment or genotype did not have significant influence on the OAC, although minor variation was observed. Oil absorption capacity is useful in structure interaction in food, especially in flavour retention, improvement of palatability and extension of shelf life particularly in bakery or meat products (Kaur et al., 2007).

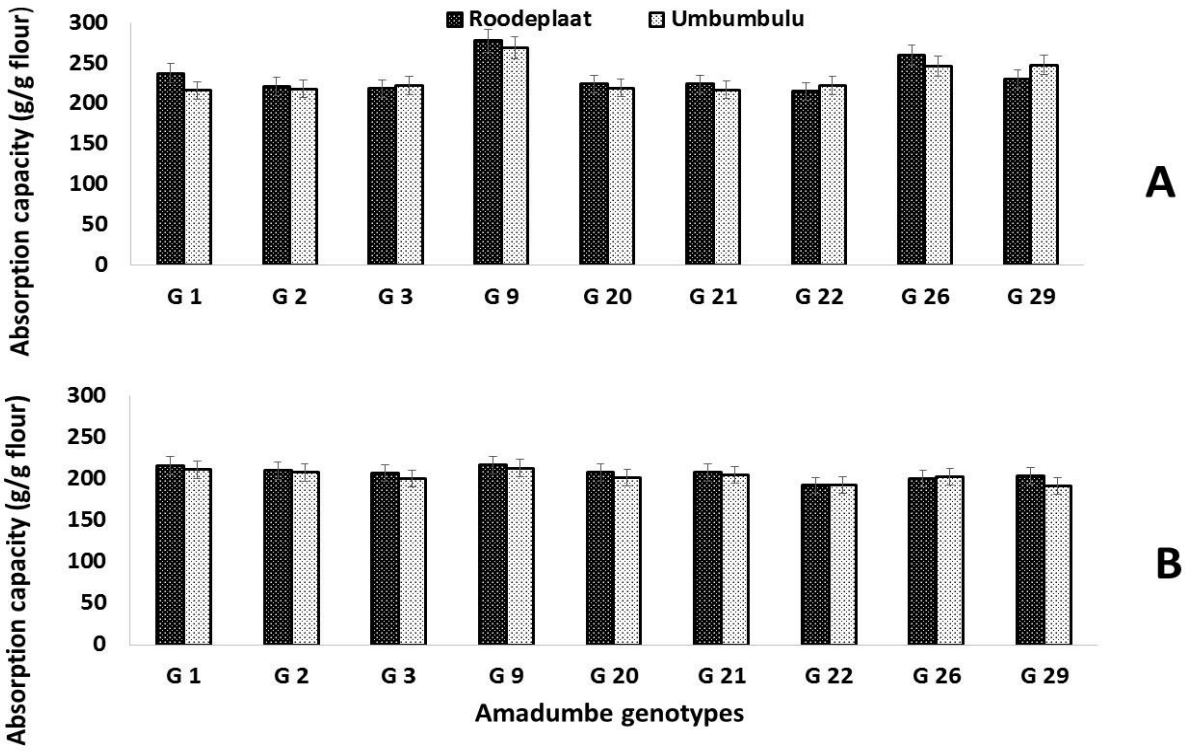

Figure 12: **A**-Water absorption capacity of flour isolates from amadumbe genotypes grown in different locations.
B- Oil absorption capacity of flour isolates from amadumbe genotypes grown in different locations.
Error bars indicate standard deviation, G-genotype, G with a number is the identification code of the genotype (Gn)

3.3.6 Swelling power of amadumbe flours

Swelling power which is an indication of water absorption index of flours during heating was determined between 55 and 85ºC (Fig. 2)(Loos et al., 1981). At temperatures below 65ºC, the swelling power of amadumbe flours across all genotypes was relatively low. Between 65-85ºC degrees, rapid and continuous temperature dependent increase in swelling power was observed which can be attributed to gelatinisation of starch present in the flours (Hoover & Sosulski, 1985). The genotype did not have significant effect on swelling power of amadumbe flours irrespective of growth location. Moorthy and Ramanujam (1986) suggested that the swelling power of granules reflected the extent of the associative forces within the granule. Genotypes from Roodeplaat seem to have higher swelling power than their counterparts grown in Umbumbulu. The higher SP for genotypes grown in Roodeplaat could be linked to inherent small starch granules (1-5 µm) (data not shown) contained within the flour. The smaller starch granules from Roodeplaat could have resulted from little rainfall received (514 mm) compared

to those from Umbumbulu (828 mm). Soil water deficit have been reported to reduce the activities of enzymes involved in starch biosynthesis, resulting in inherent smaller starch granules, which consequently have an effect on swelling power (Zhong-Min et al. (2008). Furthermore, the lower swelling power of amadumbe could be attributed to high protein content in flour isolated from amadumbe genotypes grown in Umbumbulu. According to Aprianita et al. (2009), proteins may cause the starch granules to be embedded within a stiff protein matrix which can subsequently limit access of the starch to water thereby restricting swelling capacity. In this study, a similar observation was also noted. Amadumbe flours with low protein and high carbohydrate content was observed to possess the higher swelling ability as previously reported by Kaur et al. (2013).

3.3.7 Solubility index of amadumbe flours

The solubility index was also determined within the temperature range of (55-85^{o}C). Temperature dependent increase in solubility was also observed across all amadumbe flours in both locations. The genotype appeared to influence the solubility index of flours within the temperature range of 70-80^{o}C in both locations (Fig. 13). It was observed that the solubility pattern had a correlation with the swelling power. With the increase in swelling power, starch solubility also increased. Highest solubility and swelling power of starches were in the temperature range of 80-85°C, which suggests maximum water penetration into the granules at elevated temperatures. The lower value of solubility of amadumbe flour might be due to the protein-amylose complex formation in amadumbe flour which agrees with the findings reported in literature. Furthermore, Shimelis et al. (2006) also reported that starch (in flour) and protein can interact due to the attraction of their opposite charges and form inclusion complexes during gelatinisation and this restricts swelling.

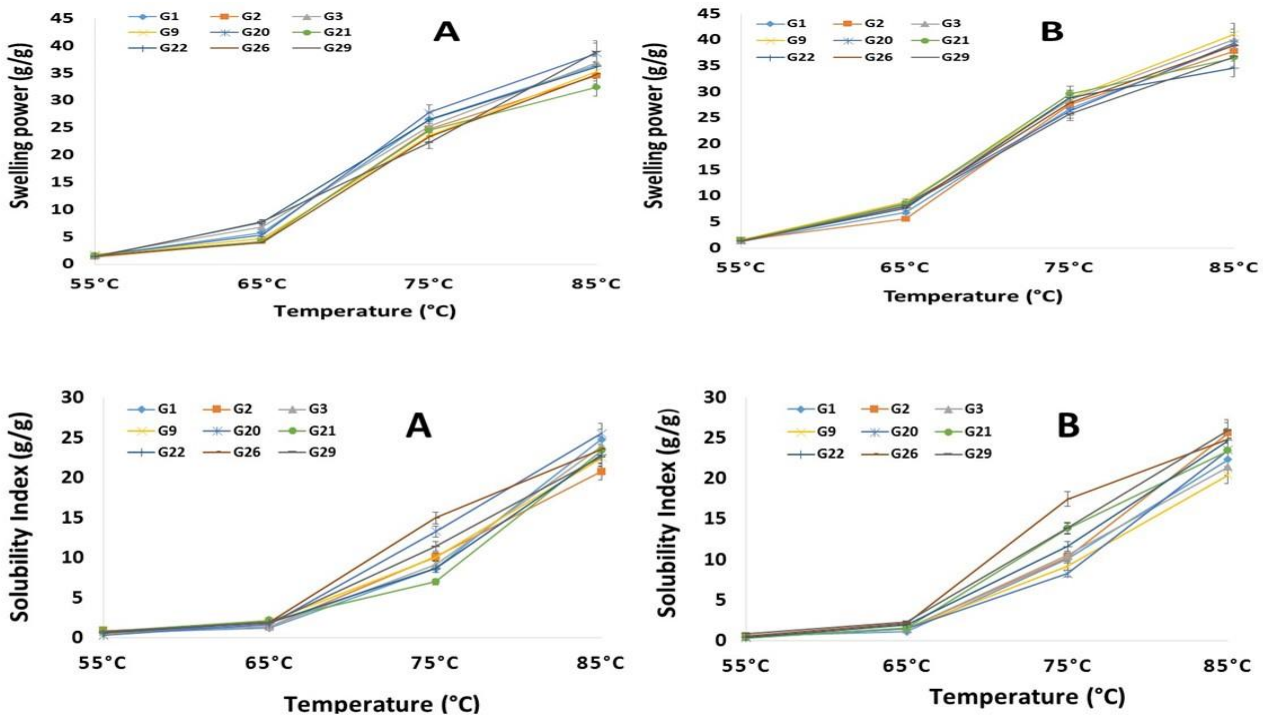

Figure 13: Swelling power and Solubility index of flours isolated from amadumbe genotypes grown in different locations

*A: Amadumbe genotypes from Roodeplaat, *B: Amadumbe genotypes from Umbumbulu, G-genotype, and G with a number is the identification code of the genotype (Gn).

3.3.8 Pasting properties of amadumbe flours

The pasting temperatures (PT) of flours from amadumbe genotypes grown in both Roodeplaat and Umbumbulu ranged from approx 85-95^{o}C (Table 4). Flours obtained from amadumbe genotypes grown at Roodeplaat showed slightly higher PT (approx 91^{o}C) compared to the same genotypes from Umbumbulu (89^{o}C). The higher PT of flours from Roodeplaat could be attributed inherent small starch granules contained within flours (Data not shown). Smaller starch granules could have resulted from lower annual rainfall (514 mm) received in Roodeplaat compared to those granules from Umbumbulu which received higher rainfall (829 mm). Lower rainfall has been attributed to decrease in the activity of enzymes involved in starch biosynthesis which has a major impact on granule size development. Comparable results where smaller starch granules impacted on PT have been also previously reported (Sit et al., 2013; (Falade & Okafor, 2015). Furthermore, higher PT of flours from Roodeplaat can also be attributed to high mucilage content of flours (Table 4). Mucilage has been reported to increase the pasting temperature of flour when it interacts with smaller amount of amylose released by the limited swelling of starch granules in flour (Jane et al., 1992; Liu et al., 2006). The higher pasting temperature of amadumbe flours in comparison to other flours indicate the presence of starch that is highly resistant to swelling and rupturing (Jane et al., 1992). Pasting temperature generally provides an indication of the minimum temperature required for sample cooking (Kaur et al., 2010)

The peak viscosity (PV) of amadumbe flours varied significantly from approx. 83-243 RVU and 55-197 RVU for Roodeplaat and Umbumbulu, respectively (Table 4). On average, PV values of flour obtained from genotypes grown at Roodeplaat were higher (169 RVU) than those grown at Umbumbulu (152 RVU). Higher PV of flours from Roodeplaat can be attributed to lower temperatures (approx 19^{o}C) recorded during the growth season. Lower temperature has been reported to cause decrease in amylose content of the inherent starch molecules contained in the flour. Comparable results were found by Noda et al. (2001) who observed that PV of sweet potatoes clearly decreased with increase in soil temperature from (15-33^{o}C). Peak viscosity correlates with the quality of end-product and provides an indication of the viscous load likely to be encountered by a mixing cooker. Starch, mucilage and lipid contents of flours have been reported to influence the peak viscosity (Ragaee & Abdel-Aal, 2006). In this study, genotypes, G1, G2, G9 and G22 grown at Roodeplaat and G3, G21 grown at Umbumbulu showed higher PV values, which can be attributed to high mucilage content in those flours

(Table 9). Increased peak viscosity in the presence of a hydrocolloid has been reported in the literature (Huang et al., 2010; Liu et al., 2003). Flours with high PV are desirable especially in bread making since they produce a dough with great strength as previously reported in literature (Singh et al., 2016).

The breakdown viscosity (BD) of amadumbe flour was generally low in all genotypes grown in both locations. Genotypes, G9, G26 and G29 grown in both Roodeplaat and Umbumbulu generally showed lower BD compared to the rest of the genotypes from both locations. Previous studies have reported that lower breakdown viscosity showed greater resistance which is normally expected of flours with lower peak viscosities, and this was also evident in this study. Hence, the higher the breakdown in viscosity, the lower the ability of the sample to withstand heating and shear stress during cooking (Adebowale et al., 2005).

The final viscosity of amadumbe flour varied significantly among the genotypes grown in the same location or in different locations. On the average, amadumbe flour produced from genotypes grown in Roodeplaat showed slightly higher final viscosity of approx. 163 RVU in comparison to those grown in Umbumbulu (approx. 159 RVU). Final viscosity is used to define the quality of flour and indicates the stability of the cooked paste (Ikegwu et al., 2010). High final pasting viscosity values of amadumbe flour suggests that these flours can be potentially used as a thickening agent in food applications.

Setback viscosity (SV) is associated with the tendency of starch to retrogradation (Owuamanam et al., 2010). The SV was generally low and varied significantly from approx. 23- 67 RVU for genotypes grown in the same or different environments. On the average, flour isolated from genotypes grown in Roodeplaat showed lower setback viscosity approx. 46 RVU compared to the same genotypes grown in Umbumbulu which had approx. 56 RVU. When comparing with other tuber flours elsewhere, amadumbe flours in this study showed a lower setback indicating a lower tendency to retrograde (Kaushal et al., 2012). Lowest setback viscosity of amadumbe flours suggests high resistance to retrogradation which is a positive indication for the formation of stable pastes. Lower SV is most likely to be caused by higher amylose content and shorter amylose chains present which cause intermolecular bonding associations (Hoover & Sosulski, 1991).

Table 9: Pasting profile of flours extracted from amadumbe genotypes grown in different locations

Parameters	Pasting temperature (°C)		Peak Viscosity (RVU)		Breakdown (RVU)		Final Viscosity (RVU)		Setback (RVU)	
Location	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**
Genotypes										
G 1	$92.4^{ab} \pm 0.61$	$85.7^{b} \pm 0.54$	$218^{ab} \pm 0.56$	$188^{ab} \pm 0.75$	$49.4^{bc} \pm 0.47$	$70.9^{ab} \pm 0.42$	$166^{c} \pm 0.62$	$214^{a} \pm 1.14$	$45.3^{c} \pm 1.03$	$66.5^{a} \pm 0.77$
G 2	$87.3^{c} \pm 0.54$	$86.1^{b} \pm 0.86$	$159^{c} \pm 0.77$	$151^{b} \pm 0.67$	$47.2^{bc} \pm 0.42$	$32.6^{c} \pm 0.54$	$155^{cd} \pm 0.96$	$174^{b} \pm 1.12$	$46.1^{c} \pm 1.06$	$56.5^{bc} \pm 1.18$
G 3	$91.1^{bc} \pm 0.65$	$85.9^{b} \pm 0.53$	$195^{b} \pm 0.24$	$197^{a} \pm 0.50$	$57.3^{b} \pm 0.47$	$53.3^{bc} \pm 0.66$	$188^{b} \pm 1.02$	$100^{cd} \pm 0.91$	$52.3^{b} \pm 0.87$	$66.5^{a} \pm 0.78$
G 9	$94.1^{a} \pm 0.99$	$94.5^{a} \pm 0.71$	$191^{b} \pm 0.68$	$150^{b} \pm 0.81$	$6.73^{f} \pm 0.57$	$16.4^{e} \pm 0.42$	$95.5^{e} \pm 0.82$	$129^{c} \pm 1.03$	$37.9^{d} \pm 0.93$	$56.1^{bc} \pm 1.07$
G 20	$91.7^{b} \pm 0.42$	$86.9^{b} \pm 0.49$	$161^{c} \pm 0.38$	$133^{c} \pm 0.68$	$41.5^{c} \pm 0.36$	$22.8^{d} \pm 0.53$	$176^{bc} \pm 0.95$	$168^{b} \pm 1.12$	$46.6^{c} \pm 1.13$	$54.9^{bc} \pm 1.01$
G 21	$90.9^{b} \pm 0.29$	$86.8^{b} \pm 0.64$	$139^{d} \pm 0.65$	$148^{b} \pm 0.51$	$44.4^{c} \pm 0.77$	$78.5^{a} \pm 0.82$	$129^{d} \pm 1.09$	$215^{a} \pm 1.18$	$33.8^{d} \pm 1.15$	$64.8^{ab} \pm 1.05$
G 22	$88.5^{c} \pm 0.76$	$85.3^{b} \pm 0.60$	$242^{a} \pm 0.64$	$195^{a} \pm 0.53$	$86.8^{a} \pm 0.41$	$57.9^{b} \pm 0.24$	$215^{a} \pm 1.00$	$198^{ab} \pm 0.94$	$61.3^{a} \pm 1.18$	$61.9^{abc} \pm 1.17$
G 26	$93.4^{ab} \pm 0.59$	$94.5^{a} \pm 0.35$	$83.4^{e} \pm 0.99$	$54.5^{d} \pm 0.95$	$17.7^{d} \pm 0.54$	$10.3^{f} \pm 0.45$	$124^{d} \pm 0.60$	$76.1^{d} \pm 1.16$	$45.5^{c} \pm 1.09$	$22.9^{c} \pm 1.03$
G 29	$92.8^{ab} \pm 0.8$	$94.3^{a} \pm 0.46$	$130^{d} \pm 0.26$	$149^{b} \pm 0.84$	$11.6^{e} \pm 1.60$	$14.8^{e} \pm 0.32$	$184^{b} \pm 0.0.2$	$190^{ab} \pm 0.86$	$46.3^{c} \pm 0.86$	$52.8^{bc} \pm 1.07$
Max	94.1	94.5	242	197	86.8	78.5	215	215	61.3	66.5
Min	87.3	85.3	83.4	54.5	6.73	10.3	95.5	76.1	33.8	22.9
C.V	0.67	0.65	0.34	0.41	0.33	1.22	0.56	0.64	2.29	1.82

[1]Mean±SD. Mean values with different letters in a column are significantly different ($p<0.05$), Max-maximum value, Min-minimum value, C.V-coefficient of value, G-Genotype, G with a number is the identification code of the genotype (Gn).

3.3.9 Conclusions

Amadumbe flour is an excellent source of carbohydrates, minerals and mucilage. Mineral composition varied significantly with genotypes and growth location. Functional properties such as swelling power, water absorption or pasting properties of flours were greatly influenced by carbohydrate and mucilage content. Amadumbe flour is a reliable source of mucilage and resistant starch which has low glycaemic index. Thus, the flour can be potentially used as food ingredient in food formulations for health-conscious individuals.

CHAPTER FOUR

4.0 Physicochemical properties of starch isolates from amadumbe (*Colocasia esculenta* (L.) Schott) genotypes

Abstract

Amadumbe, commonly known as taro is a traditional Southern African tuber crop mainly grown for domestic consumption. In this study, the influences of genotypes and growth environment on the physicochemical properties of starches extracted from nine amadumbe genotypes grown at two different locations were investigated. The genotypes had smaller sized (1-5 µm) and polygonal starch granules from both locations. The amylose contents (0-14%) of amadumbe starches were low and varied significantly with growth location and genotypes. Three genotypes, G2, G20, and G21 had undetected levels of the amylose content. The crystallinity pattern of starch was not significantly affected by genotype and environment. All amadumbe starches showed reflective peaks at $2\theta=15^{o}$ and a doublet at 17^{o} and 18^{o}, typical of A-type starches irrespective of genotype and/growth location. Functional properties including water absorption, swelling power, peak viscosity significantly and positively correlated with amylose contents. Findings from this study are important for future improvement programme for industrial production of amadumbe starch.

Keywords: amadumbe genotypes, starch, growth location, functionality

4.1 Introduction

Amadumbe (*Colocasia esculenta* (L.) Schott), commonly known as taro, is a traditional Southern African tuber crop that is grown for its edible corms (Mabhaudhi & Modi, 2013). Nutritionally, amadumbe contain an appreciable amount of carbohydrates (approx. 72%). Starch is the major carbohydrate in amadumbe and its content ranges between 80 and 96% (Aboubakar. et al., 2008; Aprianita et al., 2009; Naidoo et al., 2015). A high proportion of amadumbe starch is reportedly resistant to digestion (Aprianita, 2010; Naidoo et al., 2015). Further, amadumbe contains mucilage (7-10%) (Hong & Nip, 1990; Huang et al., 2010), a soluble fiber, that is good for human digestive health (Guevara-Arauza et al., 2012). Hence, amadumbe starch and mucilage could be used as functional ingredients in food formulations (Liu et al., 2006). However, many factors including processing and growing conditions can influence the properties of major components of amadumbe.

Several studies have demonstrated the influence of genotypes and growing conditions on physicochemical properties of starch. According to Tester and Karkalas (2001), growth temperature contributes significantly to change in physicochemical properties of starch than does the varietal difference. Amylose content and the branch chain length distribution of amylopectin have been found to significantly influence starch pasting (Jane et al., 1999; Jane et al., 1992) and gelatinisation (Aboubakar et al., 2008; Jane et al., 1992). Starch with high amylose content and abundant short chain amylopectin reportedly showed low pasting viscosity and high pasting temperature (Jane et al., 1992). Furthermore, (Noda et al., 2001) studied the physicochemical properties of starches from sweet potato grown at four different soil temperatures (15, 21, 27 or 33^{o}C). The amylose contents (13-17%) of these starches increased with increasing soil temperature. The peak gelatinisation of sweet potato starch increased by approx. 40% when the soil temperature was raised from 15 to 33^{o}C (Noda et al., 2001).

However, amadumbe grown in Southern Africa has received less research attention. Previous studies on amadumbe grown in South Africa has focused on DNA fingerprinting of wild and cultivated amadumbe Mabhaudhi and Modi (2013), water-use and drought resistance of locally grown varieties (Mabhaudhi et al., 2013). These studies revealed significant variations among amadumbe landraces grown under varying environmental conditions**.** According to Mabhaudhi et al. (2013), different irrigation treatments were found to have an effect on harvested amadumbe corm mass, which reduced with a decrease in water availability. Recent efforts to promote the utilisation of locally grown South African amadumbe genotypes has focussed on breeding these tubers specifically on the agro-morphological and molecular markers. The integration of breeding for yield and yield related traits as well as physicochemical properties is important for food and nutritional security. Hence, in this study, the composition, microstructure and functionality of starches extracted from amadumbe genotypes grown in different environmental conditions were determined.

4.2 Materials and methods

Nine genotypes were obtained from the Agricultural Research Council-Vegetable and Ornamental Plant Institute, Pretoria, South Africa. The genotypes were grown at Roodeplaat

Research Farm and Umbumbulu Farmers' Field. The genotypes were evaluated for their agro-morphological characteristics. The altitude of Umbumbulu and Roodeplaat is 597 m and 1168 m above sea level, respectively. The locations receive an annual rainfall of 828 mm and 514 mm for Umbumbulu and Roodeplaat, respectively. The average temperatures for Roodeplaat and Umbumbulu were 19 and 24^{o}C, respectively for the cropping season (Sept/2014- May/2015) (Table 5).

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4.2.1 Starch extraction

Starch was isolated from amadumbe corms following the method described by Singh et al. (1989). Amadumbe flour was suspended in water (1:10), stirred at room temperature for 6 hr. The mixture was separated using a screen size of 180 mm to remove non-starch components and the resulting filtrate was left at an ambient temperature for 24 hr. Thereafter, the slurry was washed repeatedly using a centrifuge (Ependorf 5810R Centrifuge, Germany) at 14000 × g for 20 min until the supernatant was colourless. The remaining sediment which is starch fraction was dried at 50°C for 24 hr in a hot air oven (D-37520, Thermo Fisher Scientific, Germany). The starch yield was calculated as the ratio of the starch obtained to the amount of flour used. Dried starch was packed, sealed and kept at 4°C until analysed.

4.2.2 Colour determination

Tristimulus L* a* b* parameters of amadumbe starch were determined after standardisation using a calorimeter (Color Flex EZ Eco 150, HunterLab, Virginia, USA). Snapshots in triplicates were taken and values were read directly from a digital print. Averages of the readings were computed and reported. Hue angle (H) and the total colour difference (ΔE) were calculated using Eqns. (1) and (2) respectively (Falade and Okafor, 2014)

$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$ …….. …… . (1)

Huge angle $= Tan^{-1}(b)$ ……..….. (2)

4.2.3 Microscopy

Starch granule shape and size was viewed using Scanning Electron Microscope (EVO 15 HD SEM) following standard laboratory procedures. A thin layer of amadumbe starch granule was mounted on the aluminium specimen holder by double-sided tape. The starch sample was coated with a thin film of gold up to a thickness of about 30 nm and the micrographs were obtained (Li et al., 2014).

4.2.4 FTIR

Starch spectra were obtained following a method described by Oyeyinka et al. (2015). Dry potassium bromide (0.15 g) was mixed with 0.0015 g of the dried starch sample and compressed for 5 min using a 10 MPa mechanical compressor system to obtain a clear pellet. The pellets were then analysed in a Bruker Tensor 27 FTIR spectrophotometer (Bruker Optics, Inc., Billerica, MA). The frequency range used was between 400 and 4000 cm^{-1}.

4.2.5 X-ray diffraction

X-ray diffraction pattern of amadumbe starch was done following an established method used by Li et al. (2014). The relative crystallinity of the starch was calculated using the following equation:

$$\text{Relative crystallinity (\%)} = \frac{100Ac}{Ac + Aa} \quad \text{……………………………………….} \ (1)$$

Ac is the crystalline area and Aa is the amorphous area on the X-ray diffractogram.

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4.2.6 Thermal property of amadumbe starch

The gelatinisation temperatures of the starch samples were determined using a differential scanning calorimeter (SDT Q600, USA) coupled with a thermal analysis data station and data recording software. Starch (3 mg) was weighed into the aluminium DSC pan and distilled water (12 µl) added with a micro syringe before the pan was sealed using a DSC punch sealer. The pans were equilibrated at 25°C for 2 hr prior to the DSC analysis. Samples were scanned at 10–

110^{o}C with an interval heating rate of 5^{o}C/min. An empty pan was used as a reference for all measurements

4.2.7 Amylose content

Amylose content of the isolated amadumbe starch was determined following an established iodine binding method as described by Williams et al. (1970).

4.2.8 Water and oil absorption capacity

Water absorption capacity was done following the method described by Falade and Okafor (2015). One gram of starch sample was weighed into a dry, clean weighed centrifuge tube. Water (10 ml) was poured into the tube and properly mixed using a vortex. The suspension was left to stand for 30 min at room temperature. The suspension was then centrifuged using (Centrifuge Model: Ependof 5810R, Germany) at 3500 x g for 15 min. The supernatant was discarded and the tube with its sample was reweighed. The same procedure was repeated for oil absorption capacity by replacing water with oil. The following equation was used to calculate water/ oil absorption capacity:

Water/ Oil Absorption [g H_2O/ oil/g] of dry sample weight = $\frac{\text{Wet sample weight} - \text{Dry sample weight}}{\text{Dry sample weight}}$

4.2.9 Swelling power and Solubility index

Swelling power and solubility index were determined following methods described by Gebresamuel and Gebre-Mariam (2011). Briefly, 1% starch suspension was boiled in a water bath for 30 min at temperatures ranging from 55^{o}C to 85^{o}C with constant shaking. The suspension was centrifuged for 15 min at 3500 x g and the supernatant was kept for the determination of solubility index.

For the determination of solubility index, the supernatant obtained by heating starch at different temperatures was then poured into dry, clean petri dishes and dried to a constant weight in an oven at 105°C. The precipitated paste and the dried supernatant were then weighed. The swelling power (SP) and solubility index (SI) was calculated using equations (1) and (2), respectively.

Swelling Power [g/g starch/flour] = $\frac{m_{sw}}{(m_{o-}m_s}$ ……. (1)

Solubility index [g/g starch/flour] = $\frac{m_s}{m_o} \times 100\%$ ….…… (2)

Wherem_{sw}, is weight of swollen starch/flour, m_o is sample weight and m_s is the weight of dried supernatant.

4.2.10 Pasting property

The pasting properties of extracted amadumbe starches were determined using the Rapid Visco Analyser (RAV-4, Newport, Scientific, Warriewood, Australia) following an established method described by Oyeyinka et al. (2016). Parameters recorded were pasting temperatures, peak viscosity, trough viscosity (min viscosity @ 95°C), final viscosity (viscosity @50°C), breakdown viscosity (peak-trough viscosity) and setback viscosity (final viscosity).

4.2.11 Statistical analysis

Data was analysed using two-way analysis of variance (ANOVA) and the means were compared using the Fisher Least Significant Difference (LSD) test ($p<0.05$). The variations observed in the functional and pasting properties of the starches from different growth locations were examined by principal component analysis (PCA). Using PCA, it was possible to reduce the dimension and large raw data and identify several correlations between various starch properties and the contribution of the traits to variation among the genotypes.

4.3 Results and Discussion

4.3.1 Starch yield

The starch yield of amadumbe was significantly affected by genotype and growing location. Generally, the starch yield was low and ranged between 8-23% for amadumbe genotypes grown in both Roodeplaat and Umbumbulu (Table 10). In this study, the starch yield of amadumbe genotypes, G1, G2, G3, G9, G20, G22, and G26 showed higher starch yield when grown in Umbumbulu compared to the same genotype grown in Roodeplaat. This could be attributed to the variation in the environmental conditions prevailed during the growing season at both locations, i.e. high rainfall was received in Umbumbulu (828 mm) compared to

Roodeplaat (514 mm). Similarly, high starch yield was reported for Pinto Durango bean variety which was constantly irrigated compared to the same variety which was receiving inconsistent rain water (Ovando-Martínez et al., 2011). Other genotypes, G21 and G29 showed a lower starch yield when grown in Umbumbulu, suggesting that amadumbe genotypes responded differently to the environmental conditions such as temperature and rainfall patterns. Variations in starch yield could also be due to genotypic differences (Falade & Okafor, 2013; Noda et al., 2001; Tester & Karkalas, 2001). Previous studies have reported significant differences in the starch yield (10-19%) for taro genotypes grown in the same environment (Falade & Okafor, 2013).

4.3.2 Amylose content

The amylose contents of amadumbe starches were generally low for both genotypes grown in Roodeplaat and Umbumbulu (Table 10). Amongst the studied genotypes, G1, G2, G3, G9, and G22 showed high amylose content when grown in Umbumbulu compared to the same genotype grown in Roodeplaat. This can be attributed to a fairly high environment average temperature in Umbumbulu (24^{o}C) compared to Roodeplaat (19^{o}C). Noda et al. (2001) similarly reported high amylose content for starch extracted from sweet potato grown at higher environmental temperature. Other genotypes, G26 and G29 showed higher amylose content when grown in Roodeplaat. This finding agrees with those found by Asaoka et al. (1985), who observed that cold weather environments caused higher amylose content in the same variety of rice. However, for some genotypes, G2, G20, G21 grown in both Roodeplaat and Umbumbulu did not have any detected level of amylose content suggesting that these starches are waxy starches. This was also observed in starch from genotype G20 which had no amylose content even after being grown in separate locations. These results suggest that amadumbe genotypes show varying degree of adaptation to environmental temperature. However, other authors found no significant changes in amylose content. According to Hizukuri (1969), no variation was observed in the amylose content of potato starch when the environmental growth temperature was raised from (10-25^{o}C)

Table 10: Starch yield and apparent amylose content of starches isolated from amadumbe genotypes grown in different locations.

Parameters	Starch yield (%)		Apparent amylose (%)		Granule size (µm)		Relative crystallinity (%)	
Locations	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**
Genotypes								
G 1	13.5^{c}±0.03	15.6^{d}±0.62	8.91^{bc} ± 0.04	10.3^{a} ± 0.32	3.04^{a} ± 0.02	3.87^{ab} ± 0.01	27.9^{bc} ± 0.03	23.5^{b} ± 0.01
G 2	13.2^{c}±0.02	14.5^{d}±0.21	N.d	7.04^{c} ± 0.45	1.42^{d} ± 0.01	1.76^{d} ± 0.02	38.2^{a} ± 0.02	31.4^{a} ± 0.01
G 3	18.6^{a}±0.08	19.9^{b}±0.32	0.43^{e} ± 0.14	10.8^{a} ± 0.22	1.91^{bc} ± 0.01	3.10^{ab} ± 0.01	39.5^{a} ± 0.01	28.2^{ab}± 0.02
G 9	13.9^{c}±0.11	23.1^{a}±0.21	5.38^{c} ± 0.02	8.08^{b} ± 0.46	1.62^{c} ± 0.01	1.33^{e} ± 0.01	35.2^{ab} ± 0.01	29.4^{ab} ± 0.02
G 20	18.7^{a}±0.54	18.6^{b}±0.71	N.d	N.d	2.01^{bc} ± 0.01	2.81^{b} ± 0.03	39.3^{a} ± 0.02	33.2^{a} ± 0.01
G 21	17.4^{ab}±0.12	16.9^{c}±0.12	N.d	5.85^{d} ± 0.48	1.86^{bc} ± 0.01	2.01^{c} ± 0.01	38.7^{a} ± 0.01	32.4^{a} ± 0.02
G 22	16.7^{b}±0.09	20.9^{ab}±0.17	4.44^{d} ± 0.94	7.85^{bc} ± 0.86	3.27^{a} ± 0.04	3.75^{ab} ± 0.02	32.4^{b} ± 0.01	29.4^{ab} ± 0.01
G 26	8.21^{d}±0.12	8.97^{e}±0.04	9.99^{b} ± 0.11	2.86^{ef} ± 0.86	2.29^{b} ± 0.02	4.57^{a} ± 0.01	28.9^{bc}± 0.03	29.7^{ab}± 0.02
G 29	15.6^{b}±0.06	15.0^{d}±0.76	14.1^{a} ± 0.56	3.18^{e} ± 0.00	1.58^{c} ± 0.01	2.56^{b} ± 0.01	22.0^{c} ± 0.04	23.5^{b} ± 0.02
Max	18.7	23.1	14.1	10.8	3.27	4.57	39.5	33,2
Min	8.21	8.97	0.43	2.86	1.42	1.33	22.0	23.5
C.V	0.8	2.21	4.18	6.41	0.71	0.52	0.08	0.04

[1]Mean±SD. Mean values with different letters in column are significantly different ($p<0.05$)

N.d- not detected, C.V-Coefficient of variance, Max-Maximum value, Min-Minimum value, G-Genotype, G with a number is the identification code of the genotype (Gn),

4.3.3 Starch morphology and purity

Amadumbe genotypes from both Roodeplaat (R) and Umbumbulu (U) showed more polygonal structures with individuals appearing spherical or irregular, suggesting that these are compound starches (Fig. 14). Generally, amadumbe starch granules were very small with a diameter varying between 1-5 µm in all the genotypes (Table 10). Previous studies similarly reported compound and very small sized granules for amadumbe (Naidoo et al., 2015) and taro starches (Aboubakar et al., 2008; Moorthy, 2002). According to Zhong-Min et al. (2008), soil water deficit resulted in many smaller starch granules and few larger starch granules for a variety of wheat grown under rain-fed and irrigated conditions respectively. Possibly, differences in rainfall patterns between the two locations (R and U) could have played a role in varying starch granule size of amadumbe corms. Also, the smaller granule size of amadumbe starch from genotypes grown in Roodeplaat (with lowest annual rainfall) could be due to a decrease in the activity of enzymes involved in starch biosynthesis**.** Furthermore, some genotypes showed a decrease in average starch granule size while others showed an increase when grown at the location of higher environmental temperature. Hence, the influence of environmental temperature on starch granule size may depend on the botanical origin of the starch and possibly inherent genetic differences.

Furthermore, microscopic image results showed clean starch granules which suggest that the granules are relatively pure (Fig. 14). The purity of the extracted starches was further confirmed by the high lightness values (approx. 96.7%) (Table 11) which was comparable to the control potato starch (approx. 94.0%). A low value for chroma and a high value for lightness are desired for the starch to meet the consumer preference.

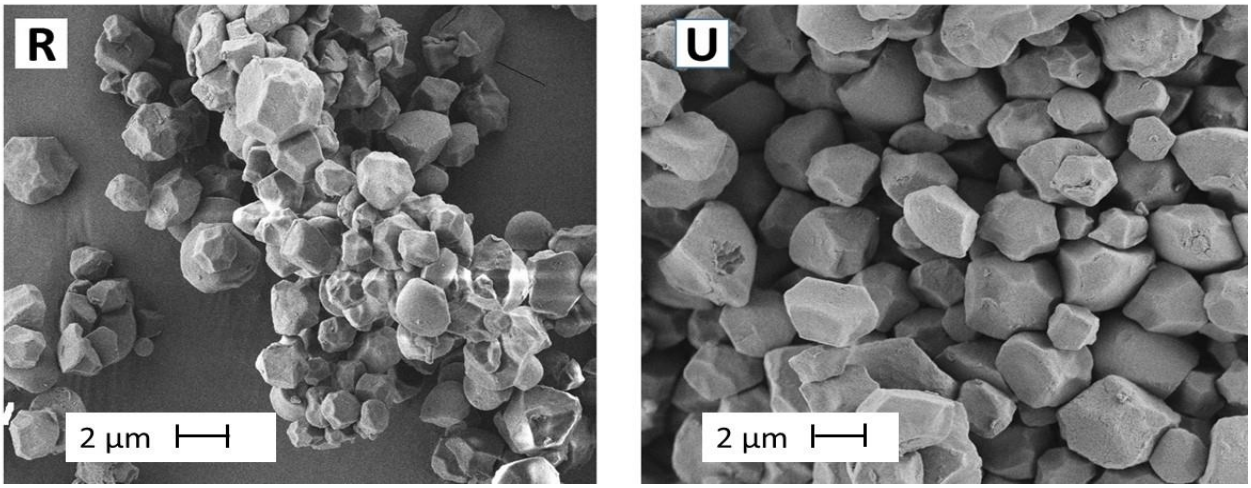

Figure 14: Representative micrograph of starch isolated from amadumbe grown in different locations

*R: Amadumbe genotypes from Roodeplaat, *U: Amadumbe genotypes from Umbumbulu

Table 11: Colour parameters of starches isolated from amadumbe genotypes grown in different locations

Parameters	L		a*		b*		ΔE		Hue angle	
Locations	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**
Genotypes										
*Control	96.9^{a}±0.01	94.0^{a}±0.02	0.82^{a}±0.01	-0.81±0.01	1.27±0.01	2.50±0.03				
G 1	96.6^{a}±0.01	95.7^{a}±0.01	0.17^{c}±0.01	1.75^{a}±0.02	1.16^{b}±0.01	1.71^{a}±0.02	3.16^{b}±0.01	3.35^{a}±0.02	57.7^{c}±0.01	43.8^{c}±0.02
G 2	97.2^{a}±0.01	97.1^{a}±0.02	0.17^{c}±0.01	0.24^{d}±0.01	1.24^{ab}±0.01	1.16^{d}±0.01	3.52^{a}±0.01	3.07^{ab}±0.01	82.2^{ab}±0.01	77.9^{ab}±0.04
G 3	96.5^{a}±0.02	97.0^{a}±0.01	0.40^{b}±0.01	0.29^{c}±0.01	1.39^{a}±0.01	1.36^{bc}±0.01	3.36^{ab}±0.00	3.41^{a}±0.01	82.7^{ab}±0.01	77.6^{ab}±0.02
G 9	96.9^{a}±0.01	96.8^{a}±0.01	0.19^{c}±0.01	0.23^{d}±0.01	1.26^{ab}±0.01	1.47^{b}±0.01	3.12^{b}±0.01	3.00^{ab}±0.01	74.3^{b}±0.01	80.8^{a}±0.01
G 20	96.7^{a}±0.01	96.6^{a}±0.02	0.18^{c}±0.01	0.32^{c}±0.01	1.30^{a}±0.01	1.28^{c}±0.01	3.04^{bc}±0.01	3.35^{a}±0.01	80.9^{ab}±0.01	75.4^{ab}±0.01
G 21	96.5^{a}±0.01	96.4^{a}±0.01	0.08^{d}±0.01	0.65^{b}±0.01	1.20^{b}±0.01	1.42^{b}±0.01	2.96^{bc}±0.01	3.11^{ab}±0.01	82.1^{ab}±0.01	65.6^{bc}±0.01
G 22	96.2^{a}±0.01	96.9^{a}±0.01	0.20^{c}±0.01	0.37^{c}±0.01	1.16^{b}±0.01	1.16^{g}±0.01	3.44^{a}±0.01	2.92^{b}±0.00	85.8^{a}±0.01	71.9^{b}±0.01
G 26	96.9^{a}±0.01	96.6^{a}±0.01	0.20^{c}±0.01	0.30^{c}±0.01	1.08^{c}±0.01	1.35^{bc}±0.01	3.07^{bc}±0.01	2.72^{b}±0.01	80.2^{ab}±0.01	76.9^{ab}±0.01
G 29	96.9^{a}±0.01	97.0^{a}±0.01	0.82^{a}±0.01	0.28^{c}±0.01	1.27^{ab}±0.01	1.24^{c}±0.01	3.43^{a}±0.01	3.35^{a}±0.01	79.9^{ab}±0.01	77.8^{ab}±0.01
Max	97.2	97.1	0.82	1.75	1.39	1.71	3.52	3.41	85.8	80.8
Min	96.2	94.0	0.08	0.23	1.08	1.16	2.96	2.92	57.7	43.8
C. V	0.01	0.01	3.70	2.27	0.81	0.82	0.31	0.32	0.01	0.02

[1]Mean±SD. Mean values with different letters in column are significantly different ($p<0.05$)

*Control-Potato starch, G-genotype, G with a number is the identification code of the genotype (Gn), Max-maximum value, Min-minimum value, C.V-Coefficient of variance

4.3.4 Water absorption capacity

Generally, the water absorption capacities (WAC) of amadumbe starch were not significantly affected by genotypes or growth location (Fig. 15). Among studied genotypes, G3 grown in Umbumbulu and G29 grown in Roodeplaat showed the highest WAC irrespective of growth location (Fig. 15). The highest water absorption capacity can be attributed to the high amylose content in these genotypes (Table 10). The hydroxyl groups in amylose may have contributed to the increase in water uptake by starch samples. Naidoo et al. (2015) similarly observed higher WAC for starches extracted from wild amadumbe with high amylose content (20%) compared to starches from cultivated amadumbe with low amylose content (12%). Also, a similar observation has been reported for Chinese yam starch with high amylose content (Shujun et al., 2006). However, some authors found a negative correlation between amylose content with water absorption capacity (Falade & Okafor, 2013). Hence, differences in WAC may be attributed to other factors such as strong interactions of hydroxyl groups of starches through covalent bonding between starch molecules than with water.

4.3.5 Oil absorption capacity

The oil absorption capacity (OAC) of amadumbe starches was almost similar across all genotypes and appeared to be interdependent of the growth location. (Fig. 15). There was no notable effect of environment or genotypes on OAC although slight differences were observed. Oil absorption capacity is useful in structure interaction in food systems especially in flavour retention, improvement of palatability and extension of shelf life particularly, in bakery or meat products.

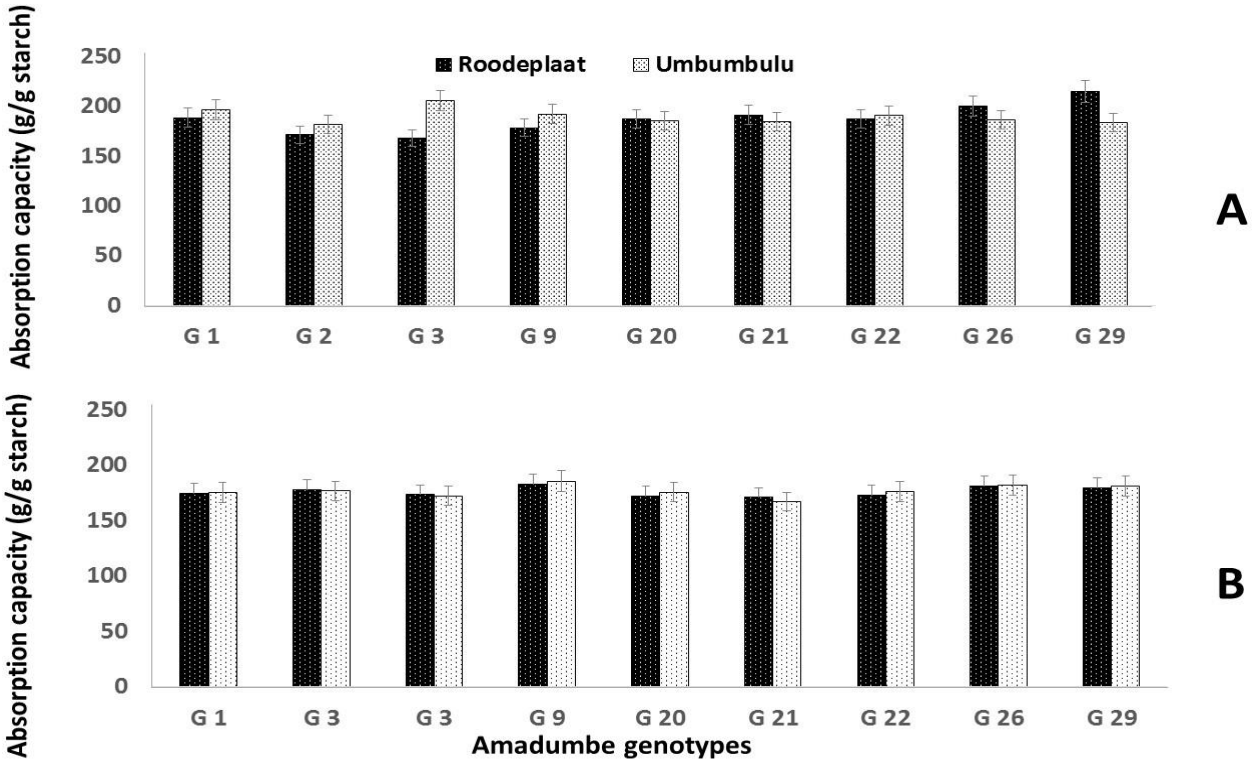

Figure 15: **A**- Water absorption capacity of starches isolated from amadumbe genotypes grown in Roodeplaat and Umbumbulu.

B- Oil absorption capacity of starches isolated from amadumbe genotypes grown in Roodeplaat and Umbumbulu.

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Error bars indicate standard deviation, G-genotype, G with a number is the identification code of the genotype (Gn).

4.3.6 Swelling power

All amadumbe starches showed a similar swelling trend irrespective of growth location or genotype. Swelling power of amadumbe starches was determined between 55 and 85ºC (Fig. 16). At temperatures below 65ºC, amadumbe starches showed relatively low swelling power. This was followed by a rapid and continuous increase in swelling power with increasing temperature between 65 and 85ºC which could be associated with melting of starch crystallites (Hoover & Sosulski, 1985). The genotype had a significant effect on swelling power which was evident and noted at temperatures ranging from 70-85ºC. This can be attributed to difference in amylose content between the genotypes. Starch from amadumbe genotypes, G2, G3, G20 and G21 grown in Roodeplaat with less or no amylose showed higher swelling power than other respective genotypes with higher amylose content. These results agree which those

reported by Tester and Morrison (1990), where high amylose was found to restrict swelling. Variation in starch swelling could also be due to the molecular structure of amylopectin, the magnitude of interaction within the amorphous and crystalline region, as well as minor components such as lipids and phosphorous (Singh et al., 2003).

4.3.7 Solubility index

The solubility index of amadumbe starches from both locations similarly increased with increasing temperature across all the amadumbe genotypes (Fig. 16). Significant variation was observed between 75 and 85ºC. This can be due to differences in the starch granule size. Previous studies have reported that starches with smaller sized granules normally exhibit high solubility index than those with large starch granules (Moorthy, 2002; Naidoo et al., 2015).

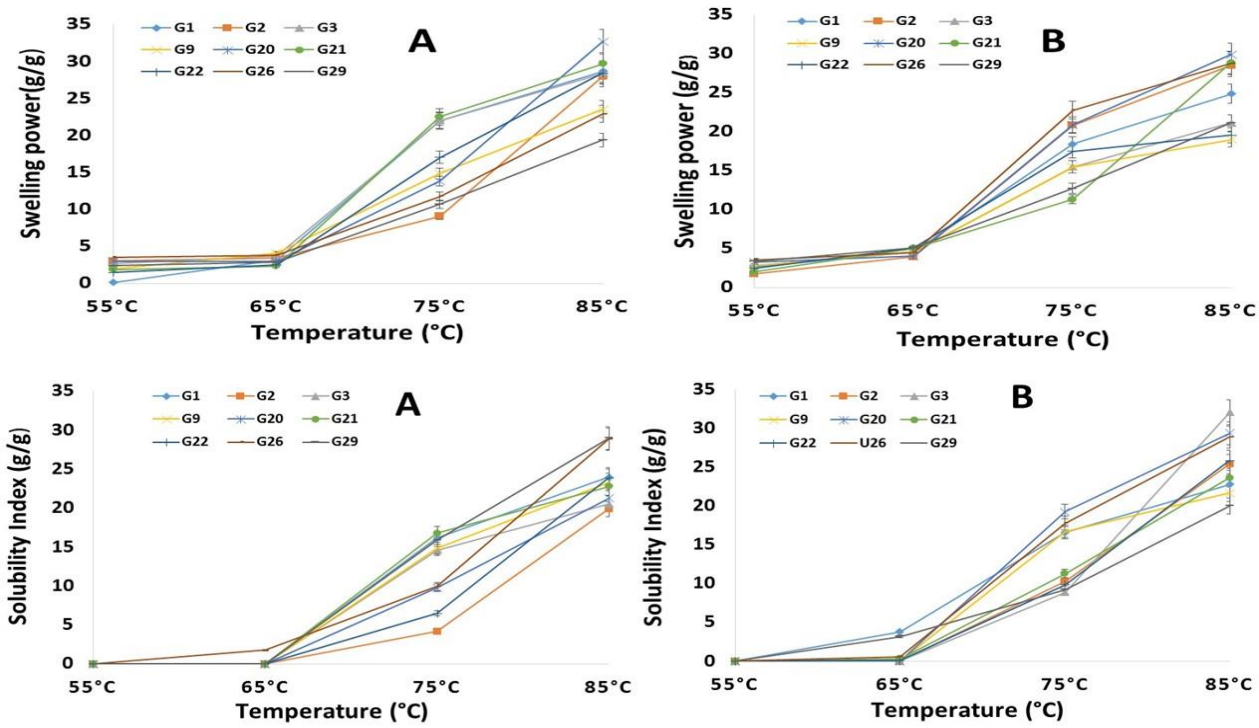

Figure 16: Swelling power and Solubility index of starches isolated from amadumbe genotypes grown in different locations

*A: Amadumbe genotypes from Roodeplaat, *B: Amadumbe genotypes from Umbumbulu, G-Genotype, and G with a number is the identification code of the genotype (Gn)

4.3.8 Pasting temperature

The pasting temperature of amadumbe starches from both locations was generally high and varied between 79 and 84^{o}C (Table 12). In comparison with other tubers, the pasting temperature of amadumbe starch was higher (approx. 81^{o}C) than that reported for potato starch (approx. 67^{o}C) (Gałkowska et al., 2014). Smaller starch granules are reportedly resistant to rupture and loss of molecular order (Dreher & Berry, 1983). Difference in pasting temperature could be attributed to small size (1-5 µm) granules of amadumbe starch (Table 10) as reported in literature. Pasting temperature is a useful indicator which provides the minimum temperature required for a sample cooking, energy costs involved and other component stability. The pasting temperatures of amadumbe starch compared favourably with reports from literature (Naidoo et al., 2015) and taro starches (Falade & Okafor, 2013; Sefa-Dedeh & Sackey, 2002; Sit et al., 2014).

The peak viscosity measures the ability of starch to swell freely before their physical breakdown. It also indicates the water binding capacity of starch. The peak viscosity (86-271 RVU) of amadumbe starches varied significantly among genotypes grown in both locations (Table 12). Genotypes G3, G20, G21 and G22 grown in Roodeplaat showed significantly higher PV when compared to other genotypes grown in both locations. This can be attributed to their relatively low or no amylose content (Table 11). Previous authors postulated that amylose content of starches restricts swelling during pasting (Tester & Morrison, 1990). Similar studies where starch with low amylose content exhibit high peak viscosity were also reported by (Noda et al., 2004). Relatively high PV starch may be suitable for products requiring high gel strength and elasticity. Genotypes G9 and G29 showed relatively low PV when compared to other genotypes grown at both locations which could be attributed to other factors other than amylose content The amylopectin branch chain length distribution has also been found to affect peak viscosity of starch (Chung et al., 2008; Jane et al., 1999). Starches with a high amount of long amylopectin chains would show high peak viscosity. In general, the distributions of amylopectin chain length have been found to be sensitive to environmental temperatures. Noda et al. (2001), found that higher soil temperatures resulted in few amylopectin short chains, with many medium and long amylopectin chains in sweet potato starch. Hence, the environmental temperature may influence the proportion or distribution of amylopectin chain length in starches in diverse ways which can cause variation in PV of starches.

Breakdown viscosity (BV) of amadumbe starch genotypes grown in Roodeplaat and Umbumbulu varied significantly ($p<0.05$). High BV with an average of 105 RVU was generally observed on starch samples from amadumbe genotypes grown in Umbumbulu in comparison to those grown in Roodeplaat (96 RVU). Genotypes G9, G26, and G29 showed relatively low BV when grown either in Roodeplaat or Umbumbulu. According to Falade and Okafor (2013), lower breakdown viscosity showed greater resistance which is normally expected of starches with lower peak viscosities, and this was the case in this study. These findings showed that starch extracted from amadumbe genotypes grown in Umbumbulu or Roodeplaat have high resistance to the shear and are less susceptible to disintegration. These results are comparable with those that have been previously reported for cocoyam (Falade & Okafor, 2013; Sit et al., 2014)

The final viscosity of the extracted amadumbe starch ranged from 105-237 RVU. When comparing the two locations, starch samples from amadumbe grown in Umbumbulu showed a higher final viscosity (199 RVU) compared to those grown in Roodeplaat (189 RVU). Final viscosity is used to define the quality of starch and indicates the stability of the cooked paste. It also indicates the ability of starch to form various paste or gel after cooling. Less stability of starch paste is commonly accompanied with a high value of breakdown (Ikegwu et al., 2010). The high final pasting viscosity observed for amadumbe starches suggest that these can be potentially used as a thickening agent in food applications.

Setback viscosity (SV) is associated with the tendency of starch to retrogradation (Owuamanam et al., 2010). The setback viscosity of amadumbe starches was generally low and ranged between 41 and 100 RVU across all genotypes. However, genotypes G1, G2, G3, G21, G26 starches from Umbumbulu showed higher setback viscosity compared to those grown in Roodeplaat (Table 13). The higher setback for these starches suggests that they will retrograde faster and may exhibit a high stalling tendency when used in food applications (Falade & Okafor, 2013; Idowu et al., 1993). Furthermore, starch with higher setback viscosity tend to have stiffer pastes, and also susceptible to weeping when used in frozen product such as a filling than low setback viscosity starches (Seog et al., 1987).

Table 12: Pasting profile of starches isolated from amadumbe genotypes grown in different locations

Parameters	Pasting temperature (°C)		Peak viscosity (RVU)		Breakdown (RVU)		Final Viscosity (RVU)		Setback (RVU)	
Location	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**
Genotypes										
G 1	$82.4^{a} \pm 0.00$	$78.8^{ab} \pm 0.57$	$241^{b} \pm 0.47$	$251^{ab} \pm 0.18$	$116^{c} \pm 0.41$	$127^{a} \pm 0.62$	$208^{a} \pm 1.18$	$227^{a} \pm 0.78$	$83.4^{ab} \pm 1.23$	$103^{a} \pm 1.89$
G 2	$84.4^{a} \pm 0.13$	$79.2^{ab} \pm 0.04$	$212^{c} \pm 0.77$	$263^{a} \pm 0.17$	$97.9^{d} \pm 0.41$	$132^{a} \pm 1.24$	$202^{a} \pm 0.94$	$226^{a} \pm 1.12$	$87.5^{ab} \pm 0.89$	$95.1^{ab} \pm 1.18$
G 3	$81.9^{ab} \pm 0.15$	$79.1^{ab} \pm 0.04$	$252^{ab} \pm 1.36$	$133^{c} \pm 0.90$	$125^{b} \pm 2.71$	$116^{b} \pm 2.66$	$219^{a} \pm 1.42$	$236^{a} \pm 2.95$	$92.7^{ab} \pm 1.77$	$100^{a} \pm 2.71$
G 9	$81.7^{ab} \pm 0.03$	$83.1^{a} \pm 0.04$	$90.0^{de} \pm 0.53$	$146^{c} \pm 0.60$	$25.3^{g} \pm 1.30$	$66.9^{cd} \pm 1.01$	$117^{c} \pm 2.95$	$129^{c} \pm 1.03$	$52.9^{c} \pm 1.58$	$50.1^{c} \pm 1.44$
G 20	$81.6^{ab} \pm 0.07$	$78.3^{ab} \pm 0.14$	$250^{ab} \pm 0.06$	$160^{c} \pm 0.78$	$124^{b} \pm 2.36$	$129^{a} \pm 1.07$	$220^{a} \pm 1.03$	$220^{c} \pm 1.36$	$94.8^{a} \pm 1.73$	$89.2^{ab} \pm 2.65$
G 21	$82.0^{a} \pm 0.19$	$78.4^{ab} \pm 0.04$	$256^{ab} \pm 0.51$	$242^{ab} \pm 0.21$	$124^{b} \pm 2.77$	$131^{a} \pm 0.82$	$223^{a} \pm 2.19$	$227^{a} \pm 0.98$	$91.0^{ab} \pm 1.95$	$96.3^{ab} \pm 1.35$
G 22	$80.8^{ab} \pm 0.00$	$79.9^{ab} \pm 0.04$	$266^{a} \pm 0.30$	$251^{ab} \pm 0.53$	$137^{a} \pm 2.01$	$130^{a} \pm 0.54$	$230^{a} \pm 2.12$	$235^{a} \pm 1.77$	$101^{a} \pm 1.83$	$95.1^{ab} \pm 2.47$
G 26	$81.5^{ab} \pm 0.21$	$81.1^{a} \pm 0.04$	$142^{d} \pm 0.65$	$199^{b} \pm 0.31$	$36.3^{f} \pm 0.65$	$89.1^{c} \pm 2.53$	$171^{b} \pm 1.83$	$189^{b} \pm 2.96$	$65.1^{b} \pm 1.11$	$79.0^{b} \pm 2.18$
G 29	$82.1^{a} \pm 0.08$	$80.0^{a} \pm 0.06$	$107^{de} \pm 0.18$	$86.3^{d} \pm 0.11$	$43.1^{e} \pm 0.18$	$27.9^{d} \pm 2.06$	$104^{c} \pm 1.16$	$100^{d} \pm 1.66$	$41.0^{c} \pm 0.92$	$42.4^{c} \pm 1.61$
Max	84.4	83.1	266	263	137	132	230	236	101	103
Min	80.8	78.3	107	86.3	25.3	27.9	104	100	41.0	42.4
C. V	0.12	0.14	0.65	0.34	1.54	1.32	0.87	0.81	1.83	2.33

[1]Mean±SD. Mean values with different letters in a column are significantly different ($p<0.05$). G-Genotype, C.V-Coefficient of variance, Max-maximum value, Min-minimum value, G with a number is the identification code of the genotype (Gn).

4.3.9 FTIR

Typical FTIR of amadumbe starches is shown in (Fig. 19). The broad band at 3414 cm^{-1} could be attributed to O-H bond vibrations (Zhang & Han, 2006). In this study, different peak intensities were observed on amadumbe starches with different amylose content. A characteristic band with a peak at 2931 cm^{-1} in the region of 2800-3000 cm^{-1} shown in the FTIR spectra can result as C-H bond stretching. At wavenumber 1655 cm^{-1} and 1642 cm^{-1} in the region of 1000-2000 cm^{-1}, the sharp band produced can be due to water molecule bending vibrations in the non-crystalline region of starch (Kizil et al., 2002; Zeng et al., 2011). The peaks occurring at 1164cm^{-1} in amadumbe starches may be due to C-O and C-C stretching, while peaks at 860 and 928 cm^{-1}could be attributed to C-O stretching (Capron et al., 2007; Kizil et al., 2002). Amadumbe starches showed complex vibrations at a low wavenumber (< 800cm^{-1}) which can be attributed to the skeletal vibration mode of glucose pyranose ring.

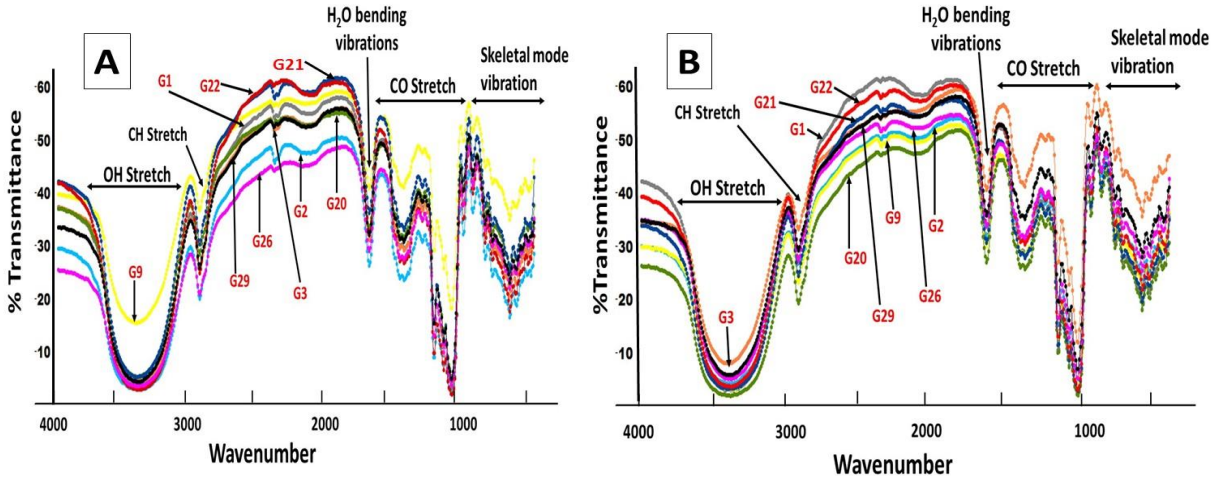

Figure 17: FTIR spectra of starches isolated from amadumbe genotypes grown in different locations

*A: Amadumbe genotypes from Roodeplaat, *B: Amadumbe genotypes from Umbumbulu, G-Genotype, and G with a number is the identification code of the genotype (Gn)

4.3.10 Thermal Properties

Starches isolated from amadumbe grown in both locations varied significantly in onset gelatinisation temperature (T_o), peak gelatinisation temperature (T_p), conclusion temperature (T_c) and gelatinisation enthalpy (ΔH_{gel}) (Table 13). The onset gelatinisation temperature of starches isolated from amadumbe genotypes grown in Umbumbulu was slightly higher approx. 83^{o}C when compared to those grown in Roodeplaat (77^{o}C). These results are slightly higher when compared to those reported for amadumbe and taro elsewhere (Naidoo et al., 2015; Sit et al., 2014). The T_p of starches isolated from amadumbe genotypes ranged from 66-104^{o}C for genotypes grown in both Roodeplaat and Umbumbulu. Generally, starches from genotypes grown in Umbumbulu showed higher T_p (91.4^{o}C) when compared to those grown in Roodeplaat (83.7^{o}C) (Table 13). This could be attributed to high amylose content in this starch (Table 10). In comparison to similar crops, T_p values of starch from this study were significantly higher than those reported for six taro varieties (approx. 62^{o}C) (Aboubakar et al., 2008). These results clearly showed that amylose is not the only factor that can affect starch gelatinisation. According to Noda et al. (1996), the distribution of amylopectin short chain can also influence the melting temperature of starch rather than the ratio of amylose to amylopectin only. The differences in the T_p can also be attributed to the difference in the relative crystallinity of starches from different genotypes (Hoover, 2001). Starch granule size and purity after

extraction may also have influenced the difference in T_p. However some of these results are comparable to those reported for taro starch reported elsewhere (Naidoo et al., 2015; Sit et al., 2014).

Gelatinisation enthalpy (ΔH_{gel}) of starches isolated from amadumbe ranged from (10-22 J/g) for genotypes grown in both Roodeplaat and Umbumbulu. Starches isolated from amadumbe genotypes grown in Umbumbulu showed slightly higher gelatinisation enthalpy (approx. 16 J/g) (ΔH_{gel}) than those grown in Roodeplaat (approx. 14 J/g). These results compare well to those reported for taro (Sit et al., 2014). However, these findings are lower compared to those reported for wild and cultivated amadumbe which are much higher (approx. 28 J/g)(Naidoo et al., 2015). Differences in the enthalpy gelatinisation temperature values may be due to differences in the extent of interactions between the double helices from the crystalline region of the respective starches (Zhou et al., 2004).

Table 13: Thermal properties of starches isolated from amadumbe genotypes grown in different locations

Parameters	Onset (T_o)		Peak (T_p)		End (T_c)		Enthalpy (ΔH_{gel})	
Locations	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**	**Roodeplaat**	**Umbumbulu**
Genotypes								
G1	$56.3^{c}\pm0.04$	$71.5^{bc}\pm0.01$	$75.7^{b}\pm0.03$	$90.7^{ab}\pm0.01$	$73.9^{b}\pm0.03$	$110^{a}\pm0.02$	$16.9^{a}\pm0.01$	$21.9^{a}\pm0.01$
G2	$80.5^{b}\pm0.01$	$79.9^{b}\pm0.01$	$86.5^{ab}\pm0.03$	$94.4^{a}\pm0.06$	$91.8^{ab}\pm0.03$	$109^{a}\pm0.01$	$15.1^{a}\pm0.03$	$14.9^{b}\pm0.01$
G3	$60.3^{c}\pm0.02$	$91.3^{a}\pm0.02$	$71.1^{b}\pm0.04$	$100^{a}\pm0.01$	$81.8^{b}\pm0.02$	$104^{a}\pm0.01$	$12.0^{ab}\pm0.02$	$12.2^{bc}\pm0.02$
G9	$65.2^{c}\pm0.05$	$82.1^{ab}\pm0.02$	$76.3^{b}\pm0.02$	$87.4^{b}\pm0.02$	$86.2^{b}\pm0.04$	$91.8^{ab}\pm0.02$	$16.4^{a}\pm0.02$	$15.7^{b}\pm0.02$
G20	$101^{a}\pm0.01$	$84.6^{ab}\pm0.04$	$103^{a}\pm0.01$	$92.5^{ab}\pm0.03$	$105^{a}\pm0.02$	$95.8^{ab}\pm0.01$	$16.2^{a}\pm0.01$	$21.1^{a}\pm0.01$
G21	$93.0^{ab}\pm0.02$	$78.4^{b}\pm0.06$	$98.8^{a}\pm0.03$	$84.8^{b}\pm0.02$	$101^{a}\pm0.01$	$89.0^{b}\pm0.02$	$15.4^{a}\pm0.01$	$13.7^{b}\pm0.04$
G22	$95.2^{ab}\pm0.01$	$96.2^{a}\pm0.02$	$99.2^{a}\pm0.02$	$98.5^{a}\pm0.02$	$102^{a}\pm0.03$	$100^{a}\pm0.01$	$12.7^{ab}\pm0.03$	$16.8^{b}\pm0.04$
G26	$71.2^{bc}\pm0.03$	$95.2^{a}\pm0.01$	$75.7^{b}\pm0.01$	$98.2^{a}\pm0.01$	$78.8^{b}\pm0.03$	$100^{a}\pm0.02$	$13.1^{ab}\pm0.02$	$10.4^{c}\pm0.01$
G29	$70.6^{bc}\pm0.01$	$67.7^{bc}\pm0.03$	$65.9^{c}\pm0.01$	$75.1^{c}\pm0.02$	$74.9^{b}\pm0.02$	$63.8^{c}\pm0.01$	$12.0^{ab}\pm0.02$	$17.5^{ab}\pm0.02$
Max	101	96.2	103	100	105	110	16.9	21.9
Min	56.3	67.7	65.7	75.1	73.9	63.8	12.0	10.4
C.V	0.04	0.03	0.03	0.02	0.03	0.02	0.11	0.12

[1]Mean±SD. Mean values with different letters in a column are significantly different ($p<0.05$). G-Genotype, C.V-Coefficient of variance, Max-maximum value, Min-minimum value, G with a number is the identification code of the genotype (Gn).

4.3.11 XRD

All amadumbe starches show diffractograms with strong single t peak at 2θ= 15°, a single duplet at 17°, other peak at 18° and 24° typical of A-type starch (Fig. 20). Similar peak positions have been previously reported for taro starch (Moorthy, 2002; Sit et al., 2014). Genotypic differences did not seem to have any influence on the crystallinity of starch as the same configuration was observed on all starch samples from both locations. The relative crystallinity for starches ranged from 28-39% for amadumbe genotypes grown at both Roodeplaat and Umbumbulu (Table 10). On the average, starches extracted from genotypes grown at Roodeplaat site generally showed low relative crystallinity (approx. 26%) compared to those grown at Umbumbulu site (approx. 34%). As previously reported, side chains of amylopectin forms the crystalline structure in starch granules, therefore it is expected that the relative crystallinity will be directly proportional to amylopectin content (Kaur et al., 2010; Naidoo et al., 2015). Higher relative crystallinity can be attributed to low amylose contents of starch (Table 10). Similar results where starches with low amylose exhibit high relative crystallinity have been reported for taro starches (Sit et al., 2014), or legume starches (Kaur et al., 2010; Oyeyinka et al., 2015).

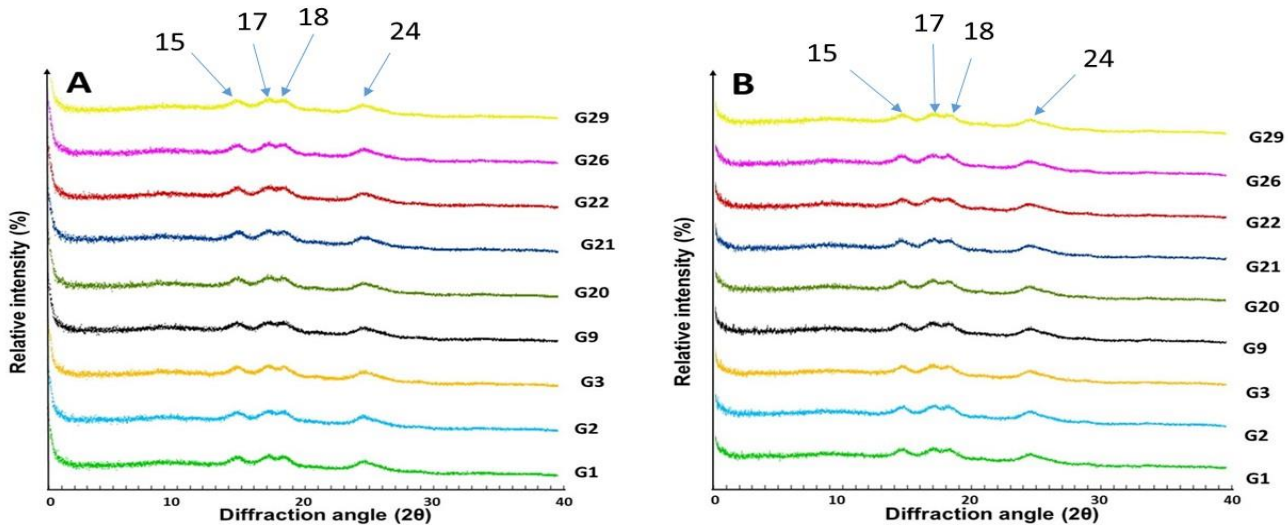

Figure 18: Diffractograms of starches isolated from amadumbe genotypes grown in different locations

*A: Amadumbe genotypes from Roodeplaat, *B: Amadumbe genotypes from Umbumbulu, G-Genotype, and G with a number is the identification code of the genotype (Gn)

4.3.12 Principal Component Analysis (PCA) of starch properties

To view the differences in the properties of starches isolated from amadumbe genotypes grown in both locations (Roodeplaat and Umbumbulu), PCA was employed in the analysis (Fig. 19). Using this statistical tool, a large dataset with many variables was reduced to few variables called principal components (PCs) which describe the greatest variance in the data analysed. PCA biplot illustrates an overview of the similarities and differences in starches from amadumbe on all measured properties. The distance existing between the locations of any two starch samples on the score plot is directly proportional to the level of difference or similarity between them. The 1st and 2nd PCs denotes 54.64% and 13.85% of the variance respectively. Combining the two PCs represents 68.29% of the total variability.

From the first principal component (PC), 55% of the overall variation was explained. The starch samples extracted from amadumbe genotypes from Roodeplaat and Umbumbulu in a cluster on the right side of the plot were separated from other starch samples clustered on the left side of the plot. Starch samples on the right side of the plot were characterised by high peak viscosity, breakdown, final viscosity and setback viscosity. Starch samples on the left side of the plot were characterised by high pasting temperature, high water, and oil absorption capacities. The 2nd PC, in addition, explained 14% of the total variation and separated G26 from Umbumbulu with high swelling power and high solubility index to G2 from Roodeplaat which was characterised by a higher pasting temperature than other starch samples. The 3rd PC finally explained 12% making it a total of 80% of the total variation and clearly differentiated G2 grown in Roodeplaat which had high pasting temperature, smallest granule size to G26 grown in Umbumbulu which had slightly high amylose content, high swelling power and solubility index.

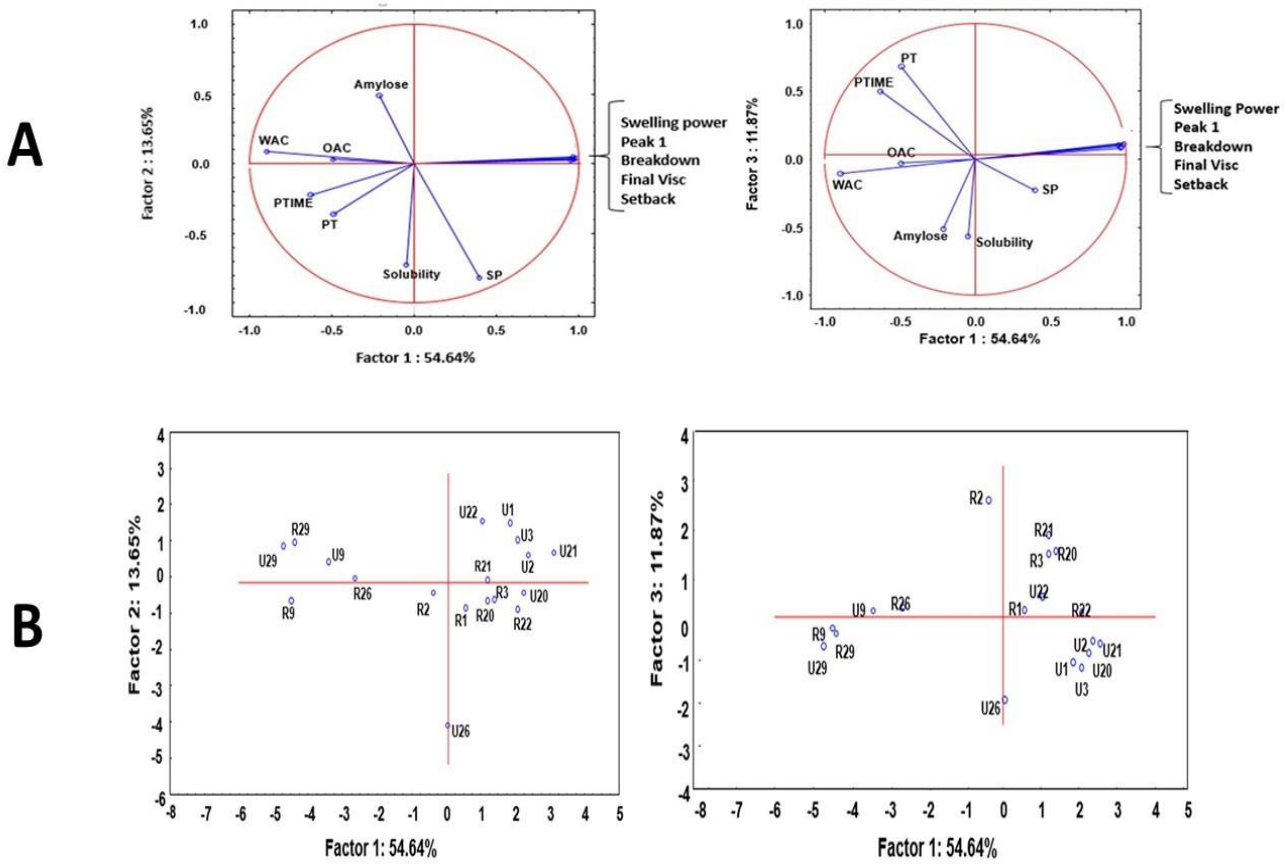

Figure 19: Principal component analysis for amadumbe starch

A: showing vector loading for functional properties, PT-Pasting temperature, OAC-Oil absorption capacity, WAC- Water absorption capacity, SP-Swelling power, PTIME-Peak time

B: showing the loading plot for genotypes from two locations, U-Umbumbulu, R- Roodeplaat

Conclusions

Amadumbe genotypes are excellent sources of starch. The starches appeared polygonal and small size granules. The amylose contents varied across all amadumbe genotypes and had a significant effect on swelling power, pasting properties, water absorption or XRD. All amadumbe genotypes displayed the A-type starches. Growth environments and genotypes significantly affected starch properties. Extracted amadumbe starch can be used in food industries as a bulking agent during product development.

CHAPTER FIVE

5.0 General Discussions

Amadumbe flour prepared from all genotypes grown in both locations showed high carbohydrate content which ranged between 72 and 80% while fats, protein, and ash were very limited. The differences in the carbohydrate values may be attributed to different varieties which were grown and cultivated under different agricultural conditions such as soil composition, different climatic and agronomic practices or genotypic differences. Furthermore, ash content which represents the mineral component varied from (approx. 4-8%) across all the genotypes grown in both locations. The crude mucilage content (6-9%) of flour was generally comparable to values previously reported on taro flour though it was affected by genotype and growing location. Differences in mucilage content can be attributed to variation in mucilage formation by plant stress response during growth and therefore related to environmental conditions.

Water absorption capacity of amadumbe flour was almost similar across all genotypes grown in both Roodeplaat (R) and Umbumbulu (U). Slight differences were observed across all genotypes in both locations. However, genotypes, G1, G9, G26 and G29 grown in Umbumbulu showed slightly higher WAC than those grown in Roodeplaat. The high-water absorption capacity of taro flour could be attributed to the presence of higher amount of CHO in this flour. The OAC of amadumbe flour was almost similar across all genotypes and appeared to be independent of the growth location. In both locations, the genotype did not seem to have any influence on the swelling power which was evident and noted along the heating temperature range of 55-85^{o}C on all amadumbe flour across all genotypes. Low protein and high CHO contents of potato and taro flour resulted in the higher swelling ability of some amadumbe flours. The solubility index was also determined within the temperature range of (55-85^{o}C). A temperature dependent increase in solubility was also observed across all amadumbe flour in both locations. The genotype seemed to influence the solubility index of flour within the temperature of 70-80^{o}C in both Roodeplaat and Umbumbulu.

On the average, the pasting temperature of flours was generally high (approx. 90^{o}C) for all amadumbe genotypes grown in both locations. Flour prepared from amadumbe genotypes grown in Roodeplaat showed slightly higher pasting temperature (approx. 91^{o}C) compared to

those grown in Umbumbulu which had (approx. 89^{o}C). The slightly higher pasting temperature of flour from Roodeplaat can be attributed to high mucilage content present in the flour. The peak viscosity of amadumbe flour varied significantly among genotypes grown in either the same environment or different environment. This can be attributed to lowest protein and highest carbohydrate present in these flour samples which have been reported to result in higher swelling ability. The breakdown viscosity of amadumbe flours was generally low across all genotypes grown in both locations. Genotypes, G9, G26 and G29 grown in both Roodeplaat and Umbumbulu generally showed lower BD compared to the rest of the genotypes from both locations. The setback viscosity varied significantly among genotype grown in the same or different environments. The setback viscosity of amadumbe flour from all genotypes grown in both locations was generally low. The lower setback viscosity of amadumbe flour suggests that amadumbe flour from these genotypes has high resistance to retrogradation and will be desirable in forming stable pastes. Higher setback indicates higher retrogradation tendency which is most likely to be caused by higher amylose content present and shorter amylose chains which can lead to intermolecular bonding associations

The starch yields were significantly affected by genotype and growing location. Generally, the starch yield was low for amadumbe genotypes grown in Roodeplaat and Umbumbulu. Amadumbe genotypes, G1, G2, G3, G9, G22, and G26 showed higher starch yields when grown in Umbumbulu compared to the same genotypes grown in Roodeplaat. This can be attributed to high rainfall received in Umbumbulu compared to Roodeplaat. Other genotypes, G21 and G29 showed a lower starch yield when grown in Umbumbulu, suggesting that amadumbe genotypes responded differently to environmental conditions such as temperature and rainfall patterns. Variations in starch yields could also be due to genotypic differences. The amylose content of amadumbe starches was generally low for genotypes grown in Roodeplaat and Umbumbulu. Amongst studied genotypes, G1, G2, G3, G9, and G22 showed high amylose content when grown in Umbumbulu compared to the same genotype grown in Roodeplaat. This can be attributed to fairly higher environmental average temperature in Umbumbulu (24^{o}C) compared to that of Roodeplaat (19^{o}C).

Starch from amadumbe genotypes from both Roodeplaat and Umbumbulu showed more polygonal structures with individuals appearing spherical or irregular, suggesting that these are compound starches. Generally, amadumbe starch granules were very small with a diameter varying between 1 and 5 µm across all the genotypes. Possibly, differences in rainfall patterns between the two locations could have played a role in varying starch granule diameter. Also,

the reduction in the granule size in amadumbe starch grown in Roodeplaat (with the lowest annual rainfall) could be because of a decrease in the activity of enzymes involved in starch biosynthesis.

The growth location seems not to have significant effect on the WAC of starches. Generally, the water absorption capacity (WAC) of amadumbe starches was almost similar across all genotypes grown in both Roodeplaat (R) and Umbumbulu (U). However, among studied genotypes, G3 grown in Roodeplaat and G29 grown in Umbumbulu showed the highest WAC irrespective of growth location. The highest water absorption capacity can be attributed to the high amylose content in these genotypes. The hydroxyl groups in amylose may have contributed to the increase in water uptake by starch samples. Swelling power of amadumbe starches was determined between 55 and 85^{o}C. At temperatures below 65^{o}C, amadumbe starches showed relatively low swelling power. This was followed by a rapid and continuous increase with increasing temperatures between 65 and 85^{o}C which could be associated with melting of starch crystallites. The genotype had a significant effect on swelling power which was evident and noted in temperatures ranging from 70-85^{o}C irrespective of growth location. Starch from amadumbe genotypes, G2, G3, G20 and G21 grown in Roodeplaat with no amylose, showed higher swelling power than other respective genotypes with higher amylose content.

The pasting temperature of amadumbe starches (approx. 81^{o}C), was not significantly affected by genotype and growth location. Only a minor variation was observed. Pasting temperature is a useful indicator which gives an idea of the minimum temperature required for a sample cooking. The peak viscosity of amadumbe starches varied significantly among genotypes grown in the same or different environments. Genotypes G3, G20, G21 and G22 grown in Roodeplaat showed significantly higher PV when compared to other genotypes grown in both locations. This can be attributed to their relatively low or no amylose content. Relatively high PV starch may be suitable for products requiring high gel strength and elasticity.

High BV was generally observed on starch samples from amadumbe genotypes grown in Umbumbulu in comparison to starch samples extracted from the same amadumbe genotypes grown in Roodeplaat. Genotypes G9, G26, and G29 showed relatively low BV when grown either in Roodeplaat or Umbumbulu. Lower breakdown viscosity is an indication of greater resistance which is normally expected of starches with lower peak, and this was the case in this study. Comparing the two locations, starch samples from amadumbe grown in Umbumbulu

showed a higher final viscosity compared to those grown in Roodeplaat. Final viscosity is used to define the quality of starch and indicates the stability of the cooked paste. Setback viscosity (SV) is associated with the tendency of starch to retrogradation. However, starches extracted from genotypes G1, G2, G3, G21, G26 grown in Umbumbulu showed high setback viscosity compared to those grown in Roodeplaat. The higher setback for these starches suggests that they can retrograde faster and exhibit a high stalling tendency when used in food applications. All amadumbe starches show diffractograms with strong singlet peak at $2\theta=15^{o}$, a duplet at 17^{o}, 18^{o} and 24^{o} typical of A-types starches. Genotype did not seem to have any influence on the crystallinity of starch as the same configuration was observed on all starch samples from both locations. The relative crystallinity for starches was comparable to previously reported data on taro starches. Amadumbe starches extracted from genotypes grown in Roodeplaat generally showed low relative crystallinity compared to those counterparts grown in Umbumbulu.

PCA biplot illustrates an overview of the similarities and differences in starches from different locations and the interrelationships between the measured properties. The 1^{st} and 2^{nd} PCs denoted 54.64% and 13.85% of the variance respectively. Combining the two PCs represents 68.29% of the total variability. Starch samples on the right side of the plot were characterised by high peak viscosity, breakdown, final viscosity and setback viscosity. Starch samples on the left side of the plot were characterised by high pasting temperature, high water, and oil absorption capacities. The second PC, in addition, explained 14% of the total variation and separated G26 from Umbumbulu, with high swelling power and high solubility index to G2 from Roodeplaat which was characterised by the highest pasting temperature than other starch samples.

5.1 Conclusions

Amadumbe represents a very good source of carbohydrate including starch. Growth location and genotype generally influenced the chemical composition of amadumbe flours and starches. Amadumbe tubers grown in Roodeplaat showed higher mineral composition and crude mucilage content than those grown in Umbumbulu. Amadumbe starches generally had low levels of amylose, while some genotypes grown in Roodeplaat and Umbumbulu had no amylose, suggesting that they are waxy starches. Amadumbe starch granules were very small in size and mostly polygonal in shape. The growth location seemed not to have any large effect on the WAC and OAC of starches. Amadumbe starch with no amylose showed higher swelling

power than their respective genotypes with higher amylose content. The pasting temperature of amadumbe starches was fairly high for all genotypes grown in both locations. The peak viscosity of amadumbe starches varied significantly among genotypes grown in either the same or different environments. On the average, genotypes grown in Umbumbulu showed slightly higher PV compared to those grown in Roodeplaat. Relatively high PV starch may be suitable for products requiring high gel strength and elasticity. Higher breakdown viscosity (BV) of amadumbe starch was observed for individual genotypes grown in Roodeplaat and Umbumbulu resembling unique characteristics of high resistance to the shear, and less susceptible to disintegration during processing. Genotype did not seem to have any influence on the crystallinity of starch as the same configuration was observed on all starch samples from both locations. Amadumbe starches with low amylose content appeared to have higher relative crystallinity than those with higher amylose. To view the differences in the properties of starches isolated from amadumbe genotypes grown in both locations (Roodeplaat and Umbumbulu), PCA was employed in the analysis. PCA was able to group genotypes with similar characteristics in a cluster which can be further used to identify similar genotypes from the large data set. This study clearly demonstrated that there exists tremendous potential application for amadumbe flour and starch, in the food industry. Each of these constituents displayed unique physicochemical and functional properties, which can be further investigated for new product development. For instance, flour or starch with high viscosity can be very useful in food where high thickening power or gel strength is desirable. Small granule size of amadumbe can be useful in noodle, bread or as fat replacers.

References

Abad-García, B., Berrueta, L. A., Garmón-Lobato, S., Gallo, B., & Vicente, F. (2009). A general analytical strategy for the characterization of phenolic compounds in fruit juices by high-performance liquid chromatography with diode array detection coupled to electrospray ionization and triple quadrupole mass spectrometry. *Journal of Chromatography A, 1216*(28), 5398-5415.

Aboubakar, Y., Njintang, N., Scher, J., & Mbofung, C. (2008). Physicochemical, thermal properties and microstructure of six varieties of taro (Colocasia esculenta L. Schott) flours and starches. *Journal of Food Engineering, 86*(2), 294-305.

Aboubakar., Njintang, Y. N., Scher, J., & Mbofung, C. M. F. (2008). Physicochemical, thermal properties and microstructure of six varieties of taro (Colocasia esculenta L. Schott) flours and starches. *Journal of Food Engineering, 86*(2), 294-305.

Achille, T. F., Georges, A. N. G., & Alphonse, K. (2007). Contribution to light transmittance modelling in starch media. *African Journal of Biotechnology, 6*(5), 569.

Adebowale, A., Sanni, L., & Awonorin, S. (2005). Effect of texture modifiers on the physicochemical and sensory properties of dried fufu. *Food Science and Technology International, 11*(5), 373-382.

Adebowale, K. O., Afolabi, T. A., & Lawal, O. S. (2002). Isolation, chemical modification and physicochemical characterisation of Bambarra groundnut (Voandzeia subterranean) starch and flour. *Food chemistry, 78*(3), 305-311.

Agbor-Egbe, T., & Rickard, J. E. (1990). Identification of phenolic compounds in edible aroids. *Journal of the Science of Food and Agriculture, 51*(2), 215-221.

Akpan, E. J., & Umoh, I. (2004). Effect of heat and tetracycline treatments on the food quality and acridity factors in cocoyam [Xanthosoma sagittifolium (L) Schott]. *Pak J Nutr, 3*(4), 240-243.

AOAC, I. (2000). In Williams, S. (Ed.), Official methods of analysis. Washington DC: Association of Official Analytical Chemists.

Aprianita, A. (2010). *Assessment of underutilized starchy roots and tubers for their applications in the food industry.* Victoria University.

Aprianita, A., Purwandari, U., Watson, B., & Vasiljevic, T. (2009). Physico-chemical properties of flours and starches from selected commercial tubers available in Australia. *International Food Research Journal, 16*(4), 507-520.

Asaoka, M., Okuno, K., & Fuwa, H. (1985). Effect of environmental temperature at the milky stage on amylose content and fine structure of amylopectin of waxy and nonwaxy endosperm starches of rice (Oryza sativa L.). *Agricultural and Biological Chemistry, 49*(2), 373-379.

BeMiller, J. N. (2007). arbohydrate chemistry for food scientists: American Association of Cereal Chemists, Inc (AACC).

BeMiller, J. N., & Whistler, R. L. (2009). *Starch: chemistry and technology*: Academic Press.

Beta, T., & Corke, H. (2001). Genetic and environmental variation in sorghum starch properties. *Journal of Cereal Science, 34*(3), 261-268.

Blanshard, J. M. V. (1987). Starch granule structure and function: a physicochemical approach. In T. Galliard (Ed.), Starch Properties and Potential. Chichester: John Wiley and Sons. 17-54.

Buléon, A., Colonna, P., Planchot, V., & Ball, S. (1998). Starch granules: structure and biosynthesis. *International journal of biological macromolecules, 23*(2), 85-112.

Bultosa, G., Hall, A. N., & Taylor, J. (2002). Physico-chemical Characterization of Grain Tef [Eragrostis tef (Zucc.) Trotter] Starch. *Starch-Stärke, 54*(10), 461-468.

Bultosa, G., & Taylor, J. (2003). Chemical and physical characterisation of grain Tef [Eragrostis tef (Zucc.) Trotter] starch granule composition. *Starch-Stärke, 55*(7), 304-312.

Capron, I., Robert, P., Colonna, P., Brogly, M., & Planchot, V. (2007). Starch in rubbery and glassy states by FTIR spectroscopy. *Carbohydrate polymers, 68*(2), 249-259.

Chen, X., Du, X., Chen, P., Guo, L., Xu, Y., & Zhou, X. (2017). Morphologies and gelatinization behaviours of high-amylose maize starches during heat treatment. *Carbohydrate polymers, 157*, 637-642.

Chen, Z., Schols, H., & Voragen, A. (2003). Physicochemical properties of starches obtained from three varieties of Chinese sweet potatoes. *Journal of Food Science, 68*(2), 431-437.

Chiang, W., & Chen, K. (1988). Comparison of physicochemical properties of starch and amylolytic enzyme activity of various sweet potato varieties. *Shih P'in K'o Hsueh (Taipei), 15*, 1-11.

Chung, H.-J., Liu, Q., Donner, E., Hoover, R., Warkentin, T. D., & Vandenberg, B. (2008). Composition, molecular structure, properties, and in vitro digestibility of starches from newly released Canadian pulse cultivars. *Cereal Chemistry, 85*(4), 471-479.

Collado, L. S., Mabesa, R., & Corke, H. (1999). Genetic variation in the physical properties of sweet potato starch. *Journal of agricultural and food chemistry, 47*(10), 4195-4201.

Cooke, D., & Gidley, M. J. (1992). Loss of crystalline and molecular order during starch gelatinisation: origin of the enthalpic transition. *Carbohydrate research, 227*, 103-112.

Crabtree, J., & Baldry, J. (1982). Technical note: The use of taro products in bread making. *International Journal of Food Science & Technology, 17*(6), 771-777.

Craig, S. A., Maningat, C. C., Seib, P. A., & Hoseney, R. (1989). Starch paste clarity. *Cereal chemistry (USA)*.

de Oliveira, C. M., Azevedo, L. K. A., Botarelli, G. R., de Sousa, M. V., Moreira, R. A., & Negreiros, A. N. M. (1977). Studies on trypsin and chymotrypsin inhibitors from the tubers of *colocasia esculenta.* in).

Deo, P. C., Tyagi, A. P., Taylor, M., Becker, D. K., & Harding, R. M. (2009). Improving taro (Colocasia esculenta var. esculenta) production using biotechnological approaches. *The South Pacific Journal of Natural and Applied Sciences, 27*(1), 6-13.

Diarra, M. (2016). Proximate Composition of Danwake from Sorghum, Wheat and Cassava Bases. *EC Nutrition, 4*, 921-926.

Dreher, M., & Berry, J. (1983). Buffalo gourd root starch. Part I. Properties and structure. *Starch-Stärke, 35*(3), 76-81.

Ebrahimzadeh, H., Niknam, V., & Maassoumi, A. (2000). Mucilage content and its sugar composition in Astragalus species from Iran. *Pakistan Journal of Botany, 32*(1), 131-140.

Ejoh, A. R., Mbiapo, F. T., & Fokou, E. (1996). Nutrient composition of the leaves and flowers ofColocasia esculenta and the fruits ofSolanum melongena. *Plant Foods for Human Nutrition, 49*(2), 107-112.

Ellis, R. P., Cochrane, M. P., Dale, M. F. B., Duffus, C. M., Lynn, A., Morrison, I. M., Prentice, R. D. M., Swanston, J. S., & Tiller, S. A. (1998). Starch production and industrial use. *Journal of the Science of Food and Agriculture, 77*(3), 289-311.

Emiri, U. (2015). Influence of Soil Types on the Performance of Cocoyams in the Humid Environment of Rivers and Bayelsa States of Nigeria.

Falade, K. O., & Okafor, C. A. (2013). Physicochemical properties of five cocoyam (Colocasia esculenta and Xanthosoma sagittifolium) starches. *Food Hydrocolloids, 30*(1), 173-181.

Falade, K. O., & Okafor, C. A. (2015). Physical, functional, and pasting properties of flours from corms of two Cocoyam (Colocasia esculenta and Xanthosoma sagittifolium) cultivars. *Journal of Food Science and Technology, 52*(6), 3440-3448.

FAO. (1990). Roots, tubers, plantains and bananas in human nutrition. FAO Food and Nutrition Series.

FAO. (1998). Functional Properties of Starches. FAO Agricultural and Food Engineering Technologies Service Bulletin. Available online: www.fao.org/ag/magazine/pdf/starches.pd.

FAO. (2003). Statistics, Food and Agriculture Organization, Data base results.

Ferreres, F., Gonçalves, R. F., Gil-Izquierdo, A., Valentão, P., Silva, A. M., Silva, J. o. B., Santos, D., & Andrade, P. B. (2012). Further knowledge on the phenolic profile of Colocasia esculenta (L.) Shott. *Journal of agricultural and food chemistry, 60*(28), 7005-7015.

Fredriksson, H., Silverio, J., Andersson, R., Eliasson, A.-C., & Åman, P. (1998). The influence of amylose and amylopectin characteristics on gelatinization and retrogradation properties of different starches. *Carbohydrate polymers, 35*(3), 119-134.

Frost, K., Kaminski, D., Kirwan, G., Lascaris, E., & Shanks, R. (2009). Crystallinity and structure of starch using wide angle X-ray scattering. *Carbohydrate polymers, 78*(3), 543-548.

Gałkowska, D., Pycia, K., Juszczak, L., & Pająk, P. (2014). Influence of cassia gum on rheological and textural properties of native potato and corn starch. *Starch-Stärke, 66*(11-12), 1060-1070.

Gebresamuel, N., & Gebre-Mariam, T. (2011). Comparative physico-chemical characterization of the mucilages of two Cactus Pears (Opuntia spp.) obtained from Mekelle, Northern Ethiopia.

Goodfellow, B., & Wilson, R. (1990). A Fourier transform IR study of the gelation of amylose and amylopectin. *Biopolymers, 30*(13-14), 1183-1189.

Griffin, G. (1979). Non-food applications of starch, especially potential uses of taro. *Small-Scale Processing and Storage of Tropical Root Crops, Westview Tropical Agricultural Series, 1*, 275-301.

Guevara-Arauza, J. C., de Jesús Ornelas-Paz, J., Pimentel-González, D. J., Mendoza, S. R., Guerra, R. E. S., & Maldonado, L. M. T. P. (2012). Prebiotic effect of mucilage and pectic-derived oligosaccharides from nopal (Opuntia ficus-indica). *Food Science and Biotechnology, 21*(4), 997-1003.

Guilbot, A., & Mercier, C. (1985). Starch. In G.O. Aspinall (Ed.). Polysaccharide New York. Academic Press Inc. 209-243.

Hanson, J., & Imamuddin, H. (1983). Germination of Colocasia gigantean.Hook.f Paper presented at the Proceedings of the 6th Symposium of the International Society for Tropical Root Crops, Peru.

Hari, P., Garg, S., & Garg, S. (1989). Gelatinization of starch and modified starch. *Starch-Stärke, 41*(3), 88-91.

Herrero-Martínez, J. M., Schoenmakers, P. J., & Kok, W. T. (2004). Determination of the amylose–amylopectin ratio of starches by iodine-affinity capillary electrophoresis. *Journal of Chromatography A, 1053*(1), 227-234.

Hirst, E., & Jones, J. (1955). The analysis of plant gums and mucilages. In *Modern Methods of Plant Analysis/Moderne Methoden der Pflanzenanalyse*, (pp. 275-294): Springer.

Hizukuri, S. (1969). The effect of environment temperature of plants on the physicochemical properties of their starches. *Journal of Food Science and Technology, 17*(1), 73-88.

Hizukuri, S. (1986). Polymodal distribution of the chain lengths of amylopectins, and its significance. *Carbohydrate research, 147*(2), 342-347.

Hong, G., & Nip, W. (1990). Functional properties of precooked taro flour in sorbets. *Food chemistry, 36*(4), 261-270.
Hoover, R. (2001). Composition, molecular structure, and physicochemical properties of tuber and root starches: a review. *Carbohydrate polymers, 45*(3), 253-267.
Hoover, R., Hughes, T., Chung, H., & Liu, Q. (2010). Composition, molecular structure, properties, and modification of pulse starches: A review. *Food Research International, 43*(2), 399-413.
Hoover, R., & Sosulski, F. (1985). Studies on the functional characteristics and digestibility of starches from Phaseolus vulgaris biotypes. *Starch-Stärke, 37*(6), 181-191.
Hoover, R., Swamidas, G., Kok, L., & Vasanthan, T. (1996). Composition and physicochemical properties of starch from pearl millet grains. *Food chemistry, 56*(4), 355-367.
Huang, A. S., & Tanudjaja, L. S. (1992). Application of anion-exchange high-performance liquid chromatography in determining oxalates in taro (Colocasia esculenta) corms. *Journal of agricultural and food chemistry, 40*(11), 2123-2126.
Huang, C.-C., Lai, P., Chen, I.-H., Liu, Y.-F., & Wang, C.-C. (2010). Effects of mucilage on the thermal and pasting properties of yam, taro, and sweet potato starches. *LWT-Food Science and Technology, 43*(6), 849-855.
Hung, P., & Duy, T. (2012). Effects of drying methods on bioactive compounds of vegetables and correlation between bioactive compounds and their antioxidants. *International Food Research Journal, 19*(1), 327-332.
Idowu, M., Adeyemi, I., & David, M. (1993). Sensory evaluation and nutrient composition of weaning food from pregelatinized maize-sweet potato mixtures. *Plant Foods for Human Nutrition, 44*(2), 149-155.
Ikegwu, O., Okechukwu, P., & Ekumankana, E. (2010). Physico-chemical and pasting characteristics of flour and starch from achi Brachystegia eurycoma seed. *Journal of Food Technology, 8*(2), 58-66.
Ikpeme-Emmanuel, C., Okoi, J., & Osuchukwu, N. (2009). Functional, anti-nutritional and sensory acceptability of taro and soybean based weaning food. *African Journal of Food Science, 3*(11), 372-377.
Ivancic, A. (1992). Breeding and genetics of taro (Colocasia esculenta (L.) Schott). *Ministry of Agriculture and Lands, Solomon Islands UNDP, Food and Agriculture Organizations of the United Nations*, 1-97.
Jane, J.-L., & Chen, J.-F. (1992). Effect of amylose molecular size and amylopectin branch chain length on paste properties of starch. *Cereal Chemistry, 69*(1), 60-65.
Jane, J., Chen, Y., Lee, L., McPherson, A., Wong, K., Radosavljevic, M., & Kasemsuwan, T. (1999). Effects of amylopectin branch chain length and amylose content on the gelatinization and pasting properties of starch 1. *Cereal Chemistry, 76*(5), 629-637.
Jane, J., Kasemsuwan, T., Chen, J., & Juliano, B. (1996). Phosphorus in rice and other starches. *Cereal Foods World, 41*(11), 827-832.
Jane, J., Shen, L., Chen, J., Lim, S., Kasemsuwan, T., & Nip, W. (1992). Physical and chemical studies of taro starches and flours1 2. *Cereal Chem, 69*(5), 528-535.
Jiang, G., & Ramsden, L. (1999). Characterisation and yield of the arabinogalactan–protein mucilage of taro corms. *Journal of the Science of Food and Agriculture, 79*(5), 671-674.
Jobling, S. (2004). Improving starch for food and industrial applications. *Current opinion in plant biology, 7*(2), 210-218.
Kaptso, G. K., Njintang, N. Y., Nguemtchouin, M. G. M., Amungwa, A. F., Scher, J., Hounhouigan, J., & Mbofung, C. M. (2016). Characterization of Morphology and Structural and Thermal Properties of Legume Flours: Cowpea (Vigna unguiculata L.

Walp) and Bambara Groundnut (Vigna subterranea L. Verdc.) Varieties. *International Journal of Food Engineering, 12*(2), 139-152.
Karim, A., Toon, L., Lee, V., Ong, W., Fazilah, A., & Noda, T. (2007). Effects of phosphorus contents on the gelatinization and retrogradation of potato starch. *Journal of food science, 72*(2), C132-C138.
Karim, A. A., Norziah, M., & Seow, C. (2000). Methods for the study of starch retrogradation. *Food chemistry, 71*(1), 9-36.
Katayama, K., Komae, K., Kohyama, K., Kato, T., Tamiya, S., & Komaki, K. (2002). New sweet potato line having low gelatinization temperature and altered starch structure. *Starch-Stärke, 54*(2), 51-57.
Kaur, L., Singh, N., & Sodhi, N. S. (2002). Some properties of potatoes and their starches II. Morphological, thermal and rheological properties of starches. *Food chemistry, 79*(2), 183-192.
Kaur, M., Kaushal, P., & Sandhu, K. S. (2013). Studies on physicochemical and pasting properties of Taro (Colocasia esculenta L.) flour in comparison with a cereal, tuber and legume flour. *Journal of Food Science and Technology, 50*(1), 94-100.
Kaur, M., Sandhu, K. S., & Lim, S.-T. (2010). Microstructure, physicochemical properties and in vitro digestibility of starches from different Indian lentil (Lens culinaris) cultivars. *Carbohydrate polymers, 79*(2), 349-355.
Kaur, M., Singh, N., & Sandhu, K. S. (2007). Preparation and characterization of protein isolates from different lentil (Lens culinatis) cultivars. *JOURNAL OF FOOD SCIENCE AND TECHNOLOGY-MYSORE, 44*(3), 327-329.
Kaushal, P., Kumar, V., & Sharma, H. (2012). Comparative study of physicochemical, functional, antinutritional and pasting properties of taro (Colocasia esculenta), rice (Oryza sativa) flour, pigeonpea (Cajanus cajan) flour and their blends. *LWT-Food Science and Technology, 48*(1), 59-68.
Kaushal, P., Kumar, V., & Sharma, H. (2015). Utilization of taro (Colocasia esculenta): a review. *Journal of Food Science and Technology, 52*(1), 27-40.
Kizil, R., Irudayaraj, J., & Seetharaman, K. (2002). Characterization of irradiated starches by using FT-Raman and FTIR spectroscopy. *Journal of agricultural and food chemistry, 50*(14), 3912-3918.
Kossmann, J., & Lloyd, J. (2000). Understanding and influencing starch biochemistry. *Critical Reviews in Plant Sciences, 19*(3), 171-226.
Lawton, J. W. (2004). Native starch; uses of. Encyclopaedia of Grain Science. *1-3*, 195-202.
Lebot, V. (2009). *Tropical root and tuber crops: cassava, sweet potato, yams and aroids*: Cabi.
Lewu, M. N., Yakubu, M. T., Adebola, P. O., & Afolayan, A. J. (2010). Effect of accessions of Colocasia esculenta-based diets on the hepatic and renal functional indices of weanling Wistar rats. *Journal of medicinal food, 13*(5), 1210-1215.
Li, J.-Y., & Yeh, A.-I. (2001). Relationships between thermal, rheological characteristics and swelling power for various starches. *Journal of Food Engineering, 50*(3), 141-148.
Li, W., Xiao, X., Zhang, W., Zheng, J., Luo, Q., Ouyang, S., & Zhang, G. (2014). Compositional, morphological, structural and physicochemical properties of starches from seven naked barley cultivars grown in China. *Food Research International, 58*, 7-14.
Liu, H., Eskin, N. M., & Cui, S. W. (2003). Interaction of wheat and rice starches with yellow mustard mucilage. *Food Hydrocolloids, 17*(6), 863-869.
Liu, H., Eskin, N. M., & Cui, S. W. (2006). Effects of yellow mustard mucilage on functional and rheological properties of buckwheat and pea starches. *Food chemistry, 95*(1), 83-93.

Liu, Q. (2005). Understanding starches and their role in foods. *Food carbohydrates: Chemistry, physical properties and applications, 30*.
Loos, P. J., Hood, L., & Graham, H. (1981). Isolation and characterization of starch from breadfruit [Artocarpus communis]. *Cereal Chemistry*.
Lu, T.-J., Chen, J.-C., Lin, C.-L., & Chang, Y.-H. (2005). Properties of starches from cocoyam (Xanthosoma sagittifolium) tubers planted in different seasons. *Food chemistry, 91*(1), 69-77.
Mabhaudhi, T., Modi, A., & Beletse, Y. (2013). Response of taro (Colocasia esculenta L. Schott) landraces to varying water regimes under a rainshelter. *Agricultural water management, 121*, 102-112.
Mabhaudhi, T., & Modi, A. T. (2013). Preliminary assessment of genetic diversity in three taro (Colocasia esculenta L. Schott) landraces using agro-morphological and SSR DNA characterisation. *Journal of Agricultural Science and Technology B, 3*, 265-271.
Madamba, L., Bustrillos, A., & San Pedro, E. (1975). Sweet potato starch: physicochemical properties of the whole starch. *Philippine Agriculturist (Philippines)*.
Maga, J. A., Liu, M. B., & Rey, T. (1993). Taro (Colocasia esculenta) extrusion. *Carbohydrate polymers, 21*(2-3), 177-178.
McEwan, R., Shangase, F., Djarova, T., & Opoku, A. (2014). Effect of three processing methods on some nutrient and anti-nutritional factor constituent of Colocasia esculenta (Amadumbe). *African Journal of Food Science, 8*(5), 287-292.
McPherson, A., & Jane, J.-l. (1999). Comparison of waxy potato with other root and tuber starches. *Carbohydrate polymers, 40*(1), 57-70.
Mergedus, A., Kristl, J., Ivancic, A., Sober, A., Sustar, V., Krizan, T., & Lebot, V. (2015). Variation of mineral composition in different parts of taro (Colocasia esculenta) corms. *Food chemistry, 170*, 37-46.
Mishra, S., & Rai, T. (2006). Morphology and functional properties of corn, potato and tapioca starches. *Food Hydrocolloids, 20*(5), 557-566.
Moorthy, S., Pillai, P. T., & Unnikrishnan, M. (1993). Variability in starch extracted from taro. *Carbohydrate polymers, 20*(3), 169-173.
Moorthy, S., & Ramanujam, T. (1986). Variation in properties of starch in cassava varieties in relation to age of the crop. *Starch-Stärke, 38*(2), 58-61.
Moorthy, S. N. (2002). Physicochemical and functional properties of tropical tuber starches: a review. *Starch-Stärke, 54*(12), 559-592.
Morrison, W. R., & Karkalas, J. (1990). Starch. In: Methods in Plant Biochemistry. . New York. Academic Press, Inc. 323-452.
Mweta, D. E. (2009). *Physicochemical, functional and structural properties of native Malawian cocoyam and sweetpotato starches.* University of the Free State.
Mweta, D. E., Labuschagne, M. T., Bonnet, S., Swarts, J., & Saka, J. D. (2010). Isolation and physicochemical characterisation of starch from cocoyam (Colocasia esculenta) grown in Malawi. *Journal of the Science of Food and Agriculture, 90*(11), 1886-1896.
Naidoo, K., Amonsou, E., & Oyeyinka, S. (2015). In vitro digestibility and some physicochemical properties of starch from wild and cultivated amadumbe corms. *Carbohydrate polymers, 125*, 9-15.
Nara, S., Mori, A., & Komiya, T. (1978). Study on relative crystallinity of moist potato starch. *Starch-Stärke, 30*(4), 111-114.
Ndabikunze, B., Talwana, H., Issa-Zacharia, A., & Palapala, V. (2011). Proximate and mineral composition of cocoyam (Colocasia esculenta L. and Xanthosoma sagittifolium L.) grown along the Lake Victoria Basin in Tanzania and Uganda. *African Journal of Food Science, 5*(4), 248-254.

Nguimbou, R. M., Boudjeko, T., Njintang, N. Y., Himeda, M., Scher, J., & Mbofung, C. M. (2014). Mucilage chemical profile and antioxidant properties of giant swamp taro tubers. *Journal of Food Science and Technology, 51*(12), 3559-3567.

Noda, T., Kobayashi, T., & Suda, I. (2001). Effect of soil temperature on starch properties of sweet potatoes. *Carbohydrate Polymers, 44*(3), 239-246.

Noda, T., Takahata, Y., Sato, T., Hisamatsu, M., & Yamada, T. (1995). Physicochemical properties of starches extracted from sweet potato roots differing in physiological age. *Journal of agricultural and food chemistry, 43*(12), 3016-3020.

Noda, T., Takahata, Y., Sato, T., Ikoma, H., & Mochida, H. (1996). Physicochemical properties of starches from purple and orange fleshed sweet potato roots at two levels of fertilizer. *Starch-Stärke, 48*(11-12), 395-399.

Noda, T., Tsuda, S., Mori, M., Takigawa, S., Matsuura-Endo, C., Saito, K., Mangalika, W. H. A., Hanaoka, A., Suzuki, Y., & Yamauchi, H. (2004). The effect of harvest dates on the starch properties of various potato cultivars. *Food chemistry, 86*(1), 119-125.

Odebunmi, E., Oluwaniyi, O., Sanda, A., & Kolade, B. (2007). Nutritional compositions of selected tubers and root crops used in Nigerian food preparations. *Int J Chem, 17*(1), 37-43.

Oladebeye, A., Oshodi, A., & Oladebeye, A. (2009). Physicochemical properties of starches of sweet potato (Ipomea batata) and red cocoyam (Colocasia esculenta) cormels. *Pakistan Journal of Nutrition, 8*(4), 313-315.

Onwueme, I. (1999). Taro cultivation in asia and the pacific. in: organization, F. A. A. (ed.). Thailand.

Ovando-Martínez, M., Bello-Pérez, L. A., Whitney, K., Osorio-Díaz, P., & Simsek, S. (2011). Starch characteristics of bean (Phaseolus vulgaris L.) grown in different localities. *Carbohydrate polymers, 85*(1), 54-64.

Owuamanam, C., Ihediohanma, N., & Nwanekezi, E. (2010). Sorption isotherm, particle size, chemical and physical properties of cocoyam corm flours. *Researcher, 2*(8), 11-19.

Oyeyinka, S. A., Singh, S., Adebola, P. O., Gerrano, A. S., & Amonsou, E. O. (2015). Physicochemical properties of starches with variable amylose contents extracted from bambara groundnut genotypes. *Carbohydrate polymers, 133*, 171-178.

Oyeyinka, S. A., Singh, S., & Amonsou, E. O. (2016). Physicochemical properties of starches extracted from bambara groundnut landraces. *Starch-Stärke*.

Padula, M. C., Lepore, L., Milella, L., Ovesna, J., Malafronte, N., Martelli, G., & de Tommasi, N. (2013). Cultivar based selection and genetic analysis of strawberry fruits with high levels of health promoting compounds. *Food chemistry, 140*(4), 639-646.

Peroni, F., Rocha, T., & Franco, C. (2006). Some structural and physicochemical characteristics of tuber and root starches. *Food Science and Technology International, 12*(6), 505-513.

Polycarp, D., Afoakwa, E., Budu, A., & Otoo, E. (2012). Characterization of chemical composition and anti-nutritional factors in seven species within the Ghanaian yam (Dioscorea) germplasm. *International Food Research Journal, 19*(3), 985-992.

Prajapati, R., Kalariya, M., Umbarkar, R., Parmar, S., & Sheth, N. (2011). Colocasia esculenta: A potent indigenous plant. *International Journal of Nutrition, Pharmacology, Neurological Diseases, 1*(2), 90.

Prajapati, V. D., Jani, G. K., Moradiya, N. G., & Randeria, N. P. (2013). Pharmaceutical applications of various natural gums, mucilages and their modified forms. *Carbohydrate polymers, 92*(2), 1685-1699.

Ragaee, S., & Abdel-Aal, E.-S. M. (2006). Pasting properties of starch and protein in selected cereals and quality of their food products. *Food chemistry, 95*(1), 9-18.

Ratnayake, W., Hoover, R., Shahidi, F., Perera, C., & Jane, J. (2001). Composition, molecular structure, and physicochemical properties of starches from four field pea (Pisum sativum L.) cultivars. *Food chemistry, 74*(2), 189-202.

Rice-evans, C. A., Miller, N. J., Bolwell, P. G., Bramley, P. M., & Pridham, J. B. (1995). The relative antioxidant activities of plant-derived polyphenolic flavonoids. *Free radical research, 22*(4), 375-383.

Ring, S. G., Gee, J. M., Whittam, M., Orford, P., & Johnson, I. T. (1988). Resistant starch: its chemical form in foodstuffs and effect on digestibility in vitro. *Food chemistry, 28*(2), 97-109.

Robyt, J. F. (2008). Starch: Structure, properties, chemistry, and enzymology. In *Glycoscience*, (pp. 1437-1472): Springer.

Rouphael, Y., Cardarelli, M., Bassal, A., Leonardi, C., Giuffrida, F., & Colla, G. (2012). Vegetable quality as affected by genetic, agronomic and environmental factors. *Journal of Food, Agriculture & Environment, 10*(3&4), 680-688.

Sasaki, T., & Matsuki, J. (1998). Effect of wheat starch structure on swelling power. *Cereal Chemistry, 75*(4), 525-529.

Sefa-Dedeh, S., & Sackey, E. K.-A. (2002). Starch structure and some properties of cocoyam (Xanthosoma sagittifolium and Colocasia esculenta) starch and raphides. *Food chemistry, 79*(4), 435-444.

Seog, H.-M., Park, Y.-K., Nam, Y.-J., Shin, D.-H., & Kim, J.-P. (1987). Physicochemical properties of several sweet potato starches. *Journal of the Korean Society for Applied Biological Chemistry, 30*(2), 179-185.

Shange, L. P. (2004). *Taro [Colocasia Esculenta (L.) Schott] Production by Small-scale Farmers in KwaZulu-Natal: Farmer Practices and Performance of Propagule Types Under Wetland and Dryland Conditions*: University of KwaZulu-Natal.

Shibanuma, Y., Takeda, Y., & Hizukuri, S. (1996). Molecular and pasting properties of some wheat starches. *Carbohydrate polymers, 29*(3), 253-261.

Shimelis, E. A., Meaza, M., & Rakshit, S. K. (2006). Physico-chemical properties, pasting behavior and functional characteristics of flours and starches from improved bean (Phaseolus vulgaris L.) varieties grown in East Africa. *Agricultural Engineering International: CIGR Journal*.

Shujun, W., Hongyan, L., Wenyuan, G., Haixia, C., Jiugao, Y., & Peigen, X. (2006). Characterization of new starches separated from different Chinese yam (Dioscorea opposita Thunb.) cultivars. *Food chemistry, 99*(1), 30-37.

Singh, N., Inouchi, N., & Nishinari, K. (2006). Structural, thermal and viscoelastic characteristics of starches separated from normal, sugary and waxy maize. *Food Hydrocolloids, 20*(6), 923-935.

Singh, N., Kaur, A., Katyal, M., Bhinder, S., Ahlawat, A. K., & Singh, A. M. (2016). Diversity in quality traits amongst Indian wheat varieties II: Paste, dough and muffin making properties. *Food chemistry, 197*, 316-324.

Singh, N., Singh, J., Kaur, L., Sodhi, N. S., & Gill, B. S. (2003). Morphological, thermal and rheological properties of starches from different botanical sources. *Food chemistry, 81*(2), 219-231.

Singh, U., Voraputhaporn, W., Rao, P., & Jambunathan, R. (1989). Physicochemical characteristics of pigeonpea and mung bean starches and their noodle quality. *Journal of Food Science, 54*(5), 1293-1297.

Sit, N., Misra, S., & Deka, S. C. (2014). Characterization of Physicochemical, Functional, Textural and Color Properties of Starches from Two Different Varieties of Taro and Their Comparison to Potato and Rice Starches. *Food Science and Technology Research, 20*(2), 357-365.

Sivak, M., & Preiss, J. (1998). Physicochemical structure of the starch granule. *Advance Food Nutrition Research, 41*, 13-32.
Sugimoto, Y., Yamamoto, M., Abe, K., & Fuwa, H. (1987). Developmental Changes in Starch Properties of the Chinese yam (Dioscorea batatas Decne). *Journal of the Japanese Society of Starch Science, 34*(1), 11-20.
Swinkels, J. (1985). Composition and properties of commercial native starches. *Starch-Stärke, 37*(1), 1-5.
Takeda, C., & Hizukuri, S. (1974). Studies on the gelatinization of starches. I. Characterization of the heat dependent pasting behavior of starches. *J Agric Chem Soc Jap*.
Tattiyakul, J., Asavasaksakul, S., & Pradipasena, P. (2006). Chemical and physical properties of flour extracted from taro Colocasia esculenta (L.) Schott grown in different regions of Thailand. *Science Asia, 32*(3), 279-284.
Tester, R., South, J., Morrison, W., & Ellis, R. (1991). The effects of ambient temperature during the grain-filling period on the composition and properties of starch from four barley genotypes. *Journal of Cereal Science, 13*(2), 113-127.
Tester, R. F., Debon, S. J. J., Davies, H. V., & Gidley, M. J. (1999). Effect of temperature on the synthesis, composition and physical properties of potato starch. *Journal of the Science of Food and Agriculture, 79*(14), 2045-2051.
Tester, R. F., & Karkalas, J. (1996). Swelling and gelatinization of oat starches. *Cereal Chemistry, 73*(2), 271-277.
Tester, R. F., & Karkalas, J. (2001). The effects of environmental conditions on the structural features and physico-chemical properties of starches. *Starch-Stärke, 53*(10), 513-519.
Tester, R. F., Karkalas, J., & Qi, X. (2004). Starch—composition, fine structure and architecture. *Journal of Cereal Science, 39*(2), 151-165.
Tester, R. F., & Morrison, W. R. (1990). Swelling and gelatinization of cereal starches. I. Effects of amylopectin, amylose, and lipids. *Cereal Chem, 67*(6), 551-557.
Thitisaksakul, M., Jiménez, R. C., Arias, M. C., & Beckles, D. M. (2012). Effects of environmental factors on cereal starch biosynthesis and composition. *Journal of Cereal Science, 56*(1), 67-80.
Thomas, D., & Atwell, W. (1999). Gelatinization, pasting and retrogradation. *Starches. St Paul: American Association of Cereal Chemists*.
Thomas, D., & William, A. (1977). Gelatinization, Pasting, and Retrogradation. Starches. Eagen Press. 25-30.
Tian, S. J., Rickard, J. E., & Blanshard, J. M. V. (1991). Physicochemical properties of sweet potato starch. *Journal of the Science of Food and Agriculture, 57*(4), 459-491.
Ugwu, F. (2009). The potentials of roots and tubers as weaning foods. *Pakistan Journal of Nutrition, 8*(10), 1701-1705.
USDA. (2001). Crop profile for taro in American Samoa. Washington,DC: National Agricultural Statistics Service.
Van Hung, P., Maeda, T., & Morita, N. (2006). Waxy and high-amylose wheat starches and flours—characteristics, functionality and application. *Trends in Food Science & Technology, 17*(8), 448-456.
Villordon, A. Q., Ginzberg, I., & Firon, N. (2014). Root architecture and root and tuber crop productivity. *Trends in plant science, 19*(7), 419-425.
Vinson, J. A., Hao, Y., Su, X., & Zubik, L. (1998). Phenol antioxidant quantity and quality in foods: vegetables. *Journal of agricultural and food chemistry, 46*(9), 3630-3634.
Waduge, R., Hoover, R., Vasanthan, T., Gao, J., & Li, J. (2006). Effect of annealing on the structure and physicochemical properties of barley starches of varying amylose content. *Food Research International, 39*(1), 59-77.

Wang, T. L., Bogracheva, T. Y., & Hedley, C. L. (1998). Starch: as simple as A, B, C? *Journal of Experimental Botany, 49*(320), 481-502.

Weightman, B. (1989). *Agriculture in Vanuatu: a historical review*.

Wickramasinghe, H. A. M., Takigawa, S., Matsuura-Endo, C., Yamauchi, H., & Noda, T. (2009). Comparative analysis of starch properties of different root and tuber crops of Sri Lanka. *Food chemistry, 112*(1), 98-103.

Williams, P., Kuzina, F., & Hlynka, I. (1970). Rapid colorimetric procedure for estimating the amylose content of starches and flours. *Cereal Chemistry*.

Yamin, F., Lee, M., Pollak, L., & White, P. (1999). Thermal properties of starch in corn variants isolated after chemical mutagenesis of inbred line B73 1. *Cereal Chemistry, 76*(2), 175-181.

Yuan, Y., Zhang, L., Dai, Y., & Yu, J. (2007). Physicochemical properties of starch obtained from Dioscorea nipponica Makino comparison with other tuber starches. *Journal of Food Engineering, 82*(4), 436-442.

Zaidul, I., Norulaini, N. N., Omar, A. M., Yamauchi, H., & Noda, T. (2007). RVA analysis of mixtures of wheat flour and potato, sweet potato, yam, and cassava starches. *Carbohydrate polymers, 69*(4), 784-791.

Zeng, J., Li, G., Gao, H., & Ru, Z. (2011). Comparison of A and B starch granules from three wheat varieties. *Molecules, 16*(12), 10570-10591.

Zhang, G., Ao, Z., & Hamaker, B. R. (2008). Nutritional property of endosperm starches from maize mutants: A parabolic relationship between slowly digestible starch and amylopectin fine structure. *Journal of agricultural and food chemistry, 56*(12), 4686-4694.

Zhang, Y., & Han, J. (2006). Plasticization of pea starch films with monosaccharides and polyols. *Journal of Food Science, 71*(6), E253-E261.

Zheng, G., & Sosulski, F. (1998). Determination of Water Separation from Cooked Starch and Flour Pastes after Refrigeration and Freeze-thaw. *Journal of Food Science, 63*(1), 134-139.

Zhong-Min, D., Yan-Ping, Y., ZHANG, M., Wen-Yang, L., Su-Hui, Y., Rui-Guo, C., & Zhen-Lin, W. (2008). Distribution of starch granule size in grains of wheat grown under irrigated and rainfed conditions. *Acta Agronomica Sinica, 34*(5), 795-802.

Zhou, Y., Hoover, R., & Liu, Q. (2004). Relationship between α-amylase degradation and the structure and physicochemical properties of legume starches. *Carbohydrate polymers, 57*(3), 299-317.

Zobel, H. (1988). Molecules to granules: a comprehensive starch review. *Starch-Stärke, 40*(2), 44-50.