CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Tropical roots and tubers crops, which include yam, potato, sweet potato, cassava and edible aroids are staple foods in Africa (FAO, 2015). Root and tuber crops require low inputs for production and contribute significantly to food security by serving as sources of main staple for more than 700 million populations in Latin America,Asia andAfrica (FAO, 2015). Root crops have been noted to make appreciableaddition to the meal of many people in the tropics and are consumed as a basic source of low-cost calories (FAO, 2016a). Furthermore, roots and tubers, including yam, potato, cassava and sweet potato produce more than 240 million tons annually, covering about 23 million hectares, accounting for around 95% of the total root and tuber crops production in Africa (Sanginga, 2015). Nigeria accounts for approximately 40.5 million tons production on 3.2 million hectares. This amount to around68% of global production of yam of about 57 million tons cultivated on 4.7 million ha annually in West Africa (Sanginga, 2015). Otegbayo *et al.* (2017) stated that yams are of nutritional, cultural and economic importance because they produce starchy storage tubers which are edible.

Otegbayo *et al*. (2011) reported that cassava is the most significant root and tuber crop in the tropics,followed by yam. Yam is a significantenergy source for most population in Africa, especially the sub-Saharan region (Akissoe*et al*., 2003). Yam constitutes one of the main sources of important foods in West African sub-region, and is rich in fibre. Hence, it isa probable dietary fibre source (Apara, 2013). It is high in moisture and contains 5-10 mg per 100 g of vitamin C. However, it is limitedin essential amino acids, especially those containing sulphur and isoleucine(Opara, 2003).Dry matter component of yam is made up of about 60 – 80% starch, which is a major determinant of the characteristics of food and products obtainable from yam species (Amani *et al*., 2004).

Yam has found utilisation industrially, in addition to its domestic use. Industrially, yam is being adapted for use in form of flour and starch, in bakery (for high quality bread, biscuits and other pastries), for ice-cream production and thickeners in soups(Iwuoha, 2004;Foraminifera Market Research, 2013). Domestically, yam has various means of being consumed. Yams can be boiled in water and eaten with stew, fried egg or garden egg stew; it can be roasted or fried; traditionally made into flour for *amala*, made into porridge, or otherwise pounded and eaten with vegetable and stew. Boiled yam is a fast yam food product, which is easy to prepare andwidely taken in West Africa. In south-west Nigeria, *amala* is a popular food and widely consumed as an important meal daily. *Amala* is prepared by the reconstitution of fermented yam flour, known as *elubo* in boiling water, which involves stirring until a paste that is smooth and consistent, known as *amala* is obtained. It is an important food at home and for entertaining guests in Yoruba land of Nigeria and some West Africa countries like Benin Republic and Ghana.

Food products quality which conforms to consumer requirements is determined by chemical composition, sensory properties, physical attributes, and the level of toxicological and microbiological contaminants (Molnar, 2011). Evaluation methods using quality indices have been introduced for numerical description of food quality. Food qualities in yam are inherent parameters, which are important in identifying the use and acceptance of yam food products by all concerned personnel. These quality attributes could include: granule morphology, pasting properties,proximate composition, minerals, functional properties and anti-nutritional factors (tannins, phytates, oxalates and saponins) (Otegbayo *et al*., 2010).

1.2 Problem Statement

Fermented yam flour *(elubo*) has been surveyed to be the second popularly important processed form of yam in South-West of Nigeria. *Amala*and pounded yam are the commonest yam food products in parts of Western Nigeria;hence, *amala* is a staple and an important food in this region. However, not all varieties of yam are suitable for different food uses. Yam food products, including *amala* have different quality attributes preferred by consumers. These quality attributes determine the selection and acceptability of yam varieties chosen for different purposes. Breeders often depend on the use of sensory evaluation approach and some other subjective screening tools to screen new breeds of yam (Otegbayo *et al.*, 2007). The sensory evaluation approach is time consuming, cumbersome, and gives inaccurate result, because of the subjectivity of the outcome and the quantity of materials that has to be evaluated. Therefore, the breeding of yam for specific food quality to be acceptable by end users is difficult because of lack of appropriate selection or screening techniques, for evaluating quality attributes of newly bred varieties.

Furthermore, considering the number of varieties of yam available to food processors, selecting yam varieties for food processing is often done at random, since there are no indices that could tell the end product's quality. This often results in low quality end product and at times great loss to food processors, when it is discovered at the end of processing that the particular yam variety that has been selected for usage, would not give food products with quality attributes preferred by the consumers. Hence, there is need to identify the quality indicators for the acceptable quality attributes of product in the yam tubers. This may involve identifying physical, chemical and functional properties intrinsic in yam tubers which could indicate the quality of the end food product.

1.3 Justification

Breedersare lacking in definite and specific quality indices of yam tubers that could be employed to estimate the quality of a resulting food product, such as *amala*. Food quality is often seen in terms of how suitable yam is for specific high-rated food product like pounded yam, the commercial value and sustainable derivable income from cultivating a particular variety (Otegbayo *et al.*,2010 and Sesay *et al.,* 2013). This is because there are multiple lines of yam species that has to be assessed, and lack of appropriate screening tools by yam breeders to be able to identify the line suitable for specific products. Hence, identification of food quality parameters in yam will be necessary, using large varieties from two major yam species which are used to produce *amala*. If these quality indicators are known, breeders will be able to incorporate them in their breeding process; enabling researchers to carry out prompt, effective and efficient selection of varieties for food and industrial uses. This will also help farmers and food processors to make appropriate selection of varieties for specific food uses, such as *amala*, and industrial use of flour and starch.

Quality indicators have previously been identified for pounded yam (Otegbayo *et al.*2006 and 2011); hence this approach can also be used for *amala*, as it is an important diet at household level and a ceremonial food common in the southwestregion of Nigeria, and some other parts of West Africa like Benin Republic and Ghana. Furthermore, the research also employed the use of descriptive sensory evaluation, using trained panelist to be able to assess the food product objectively, combined with laboratory analyses of the raw yam tubers, starch, flour and *elubo*from varieties of two yam species. The results are expected to provide tools or indicators for subsequent rapid screening and selection of varieties.

1.4 Objectives

The main objective was to determine intrinsic attributes in yam tubers (*D. rotundata*Poir.and *D.alata*Linn.) that could be used as indices of food quality in starch, flour and *amala*.

The specific objectives of this studywere to:

1 characterise 19 varieties of *D. rotundata* Poir. and 36 varieties of*D. alata*Linn.speciesin terms of the chemical, physicochemical and functional properties of their flour and starch.

2 determine food quality attributes important for acceptance of *amala* produced from the yam varieties.

3 assess the relationship and association between the sensory properties of *amala*; and the chemical and physicochemical properties of their yam flour and starch; and pasting properties of *elubo*, that can be used to indicate the food quality of *amala*.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Production of Yam in Nigeria

Five main countries in West Africa Belt (Benin, Ghana, Nigeria, Côted'Ivoireand Togo) are responsible for 93% of global yam productions, produced annually on 4.7 million hectares (Sanginga, 2015). Nigeria is the largest producer ofyam worldwide, producingmore than 45.004 million metric tonnes (mmt) annually, followed by 7.119 mmt produced by Ghana, 5.808 mmt by Cote d'Ivoire, 3.220 mmt by Benin republic, 1.448 mmt by Ethiopia and 0.579 mmt by Cameroun (Bassey, 2017). Over 45 years ago, the production of yam in Nigeria has been more than tripled to 39.3 million tons from 6.7 million tons,between 1961 and 2006 (FAO, 2007). However, the average yield declined per hectare from 14.9% to 2.5% between 1986 and 1999, which is as a result of inefficiency in the use and allocation of resources (CBN, 2002, FAO, 2007; Nwosu and Okoli, 2010). Nsikak-Abasi *et al.* (2013) concluded from their research that land manure, family labour and hired labour are important farm resources that increase farm output in the rural areas of Nigeria among poor farmers.

Yam is produced for consumption at household level and as a cash crop in all central and southern states of Nigeria, with Oyo, Benue, Niger and Nassarawa having the highest production (Foraminifera Market Research, 2013). Other yam producing states in Nigeria includeAnambra,Abia,Sokoto, Edo, Niger, Osun,Delta,Enugu, Ebonyi, Tarabaand Plateau states (Foraminifera Market Research, 2013). The higher market value of yam when compared with other root and tuber crops gives farmers the impetus to produce it as against some other root and tuber crops, such as cassava (Fu *et al.*, 2011). The production volume differsfrom state to state, but Niger State is identified as the highest yam producer in Nigeria (Kleih*et al.*, 2012). The distribution of yam production in Nigeria is shown in Figure 2.1.

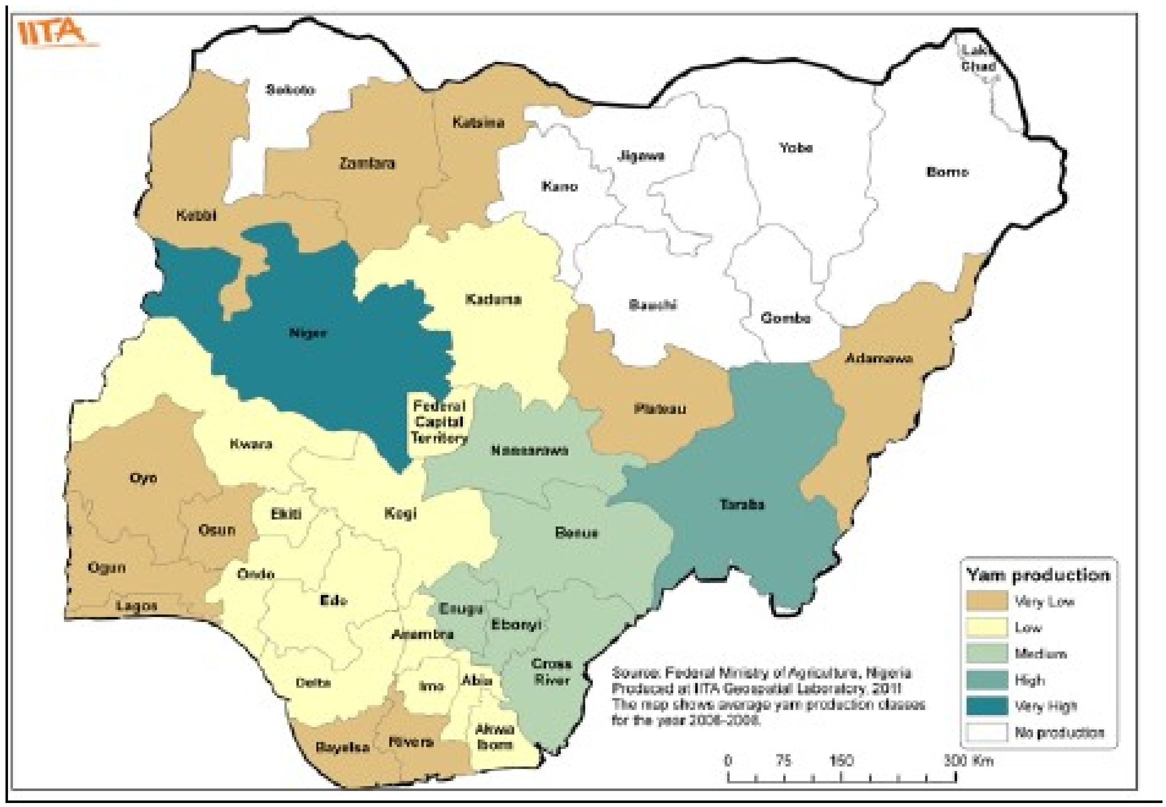


Figure 2.1: Distribution ofYam production in Nigeria (Source: IITA (in Kleih*et al.*, 2012).

2.2 Species of Yam

Yam belongs to the family *Dioscoreaceae*.Six yam species are the most significant economically and socially in relation to cash, medicine and food, out of over 600 species of yams in West Africa (IITA, 2009). These include yellow yam (*D.cayenensis*),aerial yam (*D.bulbifera*),water yam (*D.alata*),bitter yam (*D.dumetorum*), white yam (*D.rotundata*) andlesser yam (*D. esculenta*) (Opara, 1999; IITA, 2009). Others include Chinese yam (*D. opposita*), cush-cush yam (*D.trifida*)(Opara, 1999). Zhu (2015) classified *D. abyssinica, D. Septemloba, D. pseudojaponica, D. bulbifera, D. persimilis* and*D. dumetorum*, as the least species cultivated, however, they have local significance.

White yam,known as *D. rotundata* is the most widely grown variety in West Africa. Adeola *et al.* (2012) reported that*D. rotundata* is a widely cultivated and consumed species in Nigeria.The *D. rotundata* and*D. cayenensis*were noted to be of the same complexbotanically, hencegrouped as *D. cayenensis-rotundata*(Hamon and Toure, 1990). The *D. rotundata*has a fairly cylindrical shape, witha smooth and brown colour of skin. It is popular and widely consumed across Nigeria, hence largely produced in all parts of Nigeria, with the exception of a few states in the North-east region.In Ghana, *D.* rotundata is the most important speciesthat is grown for consumption, and anadvantage when it comes to planting area and production output (Otoo and Asiedu, 2008).

Water yam species are valuable source of carbohydrate in the arid regions, for human needs (Estiasih*et al*., 2013). There are water yam varieties that are purple in colour, known as *D.alata*L. *var. purpurea* (*Roxb*) M. Pouch, and could as well be yellow in colour (*D.alata*L.) (Estiasih*et al*., 2013). Water yam has been observed to contain some bioactive compounds, part of which arewater soluble storage protein of yam as well as dioscorine and diosgenin, which playssignificant function in the management of hypertension (Harijono*et al.,* 2013). The yield of dioscorine and polysaccharides that are water soluble decrease by steam blanching and blanching at a temperature of 97 °C for 7 min have effect on the bioactive content of water yam (Estiasih*et al*., 2013).

D. nipponica Makino is a specie of yam common in China. It is abundant in dioscin, and hence important for pharmaceuticals because of its diosgenin (Yuan *et al.*, 2007). When small molecule bioactive ingredients are isolated and seperated from *D. nipponica*, which is a medicinal plant, it results in losses and waste of its starch component (Yuan *et al.*, 2007).

2.3 Constraints to Yam Production

Yams have been seen to be one of the most expensive crops to cultivate, in terms of planting and harvesting processes as a result of high seed yam cost, expensive labour, use of unimproved yam seed, even limited supply of the seeds, climate condition and bad road network (NBS, 2013; Udemezue and Nnabuife, 2017). In some traditional yam producing areas, the decline in the production of yam was predicted to be due to declining soil fertility, increase in pest pressures and high labour cost (IITA, 2009). Nwosu and Okoli (2010) attributed the increase inoutput rather than increase in productivity to the large area available for planting yam. The cost and availability of healthy seed yam has been a major constrain to the productivity of yam and this makes farmers keep back about one-third of their harvest for planting the following season (IITA, 2013).

Moreover, yams are perishable, requiring high attention due to their physiological processesinfluenced by their high rate of respiration and high moisture content, as well as pest infestation (Noamesi, 2008). The cause of the vulnerability of yam to physical and mechanical damage during processing, handling and storage is its high moisture content and poor mechanical properties, which couldresult (Alvis *et al.*, 2010). This results in its limitation for automation of the production processes to have increased productivity. The development and design of yam handling equipment will be necessary to help reduce the losses recorded in yam production as well as some other limitations, hence need for proper understanding of the engineering properties of yam (Aluko and Koya, 2006).

2.4 Chemical Composition of Yam

Chemical compositions of yam vary bothwithin and between different species. The variation may be caused by differences in maturity stageat harvest, method of storage, duration of storage, cultivation practices, environmental factors, and climatic conditions where the yam is cultivated (Hsu *et al.*, 2003; Amani *et al.*, 2004; Abara*et al*., 2011;Wireko-Manu *et al.,* 2011).

2.4.1 Proximate composition and energy content of yam

The moisture content of raw tubers of *D. esculenta, D. alata, D. cayenensisD. rotundata* and *D. dumetorum*were reported to range from 67.0 – 81.0%, 50.0 – 80.0%, 56.47 - 79.31%, 60.0 – 84.0% and 67.0 - 79.0% respectively (Baah, 2009;Wireko-Manu *et al.,* 2011). The high moisture contents of yam tubers influence their keeping quality by making them prone to increased post-harvest losses. According to Hsu *et al.* (2003) yam flour processed by using different drying methods had varying moisture content. Freeze drying produced *D.alata* yam flour with lower moisture content (0.60 – 1.86%), followed by hot air drying (4.73 - 5.39%) and then drum drying (6.66 - 7.33%) (Hsu *et al.*, 2003). Moisture content of raw yam tubers reduces during storage, signifying higher dry matter content, resulting from water loss by tubers during storage, caused by increased respiratory intensity and perspiration acceleration (Nina *et al.*, 2017).

Yam mainly composes of starch, including some other constituents such as proteins, minerals, lipids (Lasztity*et al.*, 1998). Proximate composition of*D. species*yam floursare presented in Table 2.1. *D. dumetorum* was reported to be the most nutritious yam species because of its fairly high protein content (6.21 – 6.52%) and balanced amino-acid (Afoakwa and Sefa-Dedeh, 2001; Polycarp *et al.*, 2012); whereas, Otegbayo *et al.* (2017) reported *D. bulbifera* to have the highest protein content (4.60 - 8.71%) and Sri-Lanka *D. alata* by Senanayake *et al.* (2012) with a protein content of 10.16%. Protein content of *Dioscorea spp.* is considerably more than that of cassava which ranged from 1.2 – 1.8% (Charles *et al.*, 2005). Nina *et al.* (2017) observed a decreased protein content in*D. alataAzagule* variety, from 8.59 - 6.90 g/100g during a 6 month storage period; which was suggested to be as a result of reduction of the protein synthesis capacity and proteolysis initiated by the proteases during storage.

Yam species have considerably low crude fat which ranged between 0.41 and 1.10%, for different species. Yam species possess crude fibre content varying from 0.53 to 3.47% (Polycarp *et al,* 2012; Otegbayo *et al.*, 2017). Yams contain ash ranging from 1.29 to 8.15%, which is an indicator of mineral presence in a particular food sample

Table 2.1: Proximate composition and energy contents of yam flour species

Components	***D. alata***	***D. rotundata***	***D. bulbifera***	***D. cayenensis***	***D. dumetorum***
Moisture content (%)	6.00 – 12.81	6.66 – 12.82	4.02 – 12.68	8.15 – 11.67	7.44 – 7.59
Crude protein (%)	3.21 – 8.31	4.03 – 5.58	5.30 – 8.71	4.55 – 7.15	6.21 – 6.52
Crude fat (%)	0.75 -1.10	0.41 – 0.46	0.53 – 0.55	0.50 – 0.53	0.61
Crude fibre (%)	0.75 – 1.13	1.25 – 1.68	0.53 – 0.55	1.91 – 2.44	2.10 – 3.47
Ash (%)	2.25 – 6.69	1.29 – 3.60	3.65 – 8.15	2.64 – 5.48	7.79
Carbohydrate (%)	81.53 – 87.84	85.51 – 87.31	81.76 – 82.52	80.01 – 80.75	77.53 – 77.91
Energy (kJ/100g)	1499.0-1511.9	1539.1-1574.7	1501.8-1512.7	1476.8-1482.5	1451.2-1452.6

Source: Udensi*et al*. (2008); Polycarp *et al*. (2012); Otegbayo *et al.* 2017

(Nina *et al.*, 2017). Bamishaiye*et al.* (2011) reported the importance of minerals in biochemical reactions in the human body, which aids physiological functioning of the major metabolic processes. The carbohydrate content of the different species of yam ranged from 77.53 – 87.84% (Table 2.1), which accounts for high calorie, estimated to be 1451.2 to 1574.1 kJ/100g (Udensi*et al.*, 2008; Polycarp *et al.*, 2012; Otegbayo *et al.*, 2017). These carbohydrate content and energy value makes yam tubers suitable as a staple crop for combating food insecurity (Polycarp *et al.*, 2012).

2.4.2 Dietary fibre contents of *Dioscorea species*

Yams also contain dietary fibres, which are defined as remnants of plant cell walls, not hydrolysed by alimentary enzymes; and can be classified into soluble and insoluble fibres having different complimentary functions in the bowel (Abara*et al.*, 2011). Dietary fibres contained in yam include hemicellulose, cellulose and lignin; and these are important sources of dietary fibre for humans, alongside with cereals, fruits and vegetables (Abara*et al.*, 2011). The Neutral Detergent Fibre (NDF), which is the combination of cellulose, lignin and hemicellulose is a measure of the amount of insoluble dietary fibre. NDF indicate bulk and feed intake and also varied from specie to specie as well as variety to variety (Otegbayo *et al.*, 2017). The NDF ranged from 1.40 – 4.74%, 1.08 – 6.31%, 2.57 - 7.14% and 1.35 – 4.40% for *D.alata, D.rotundata, D.bulbifera*and *D. cayenensis*respectively (Udensi*et al.*2008;Abara *et al.* 2011; Polycarp *et al.*2012;Otegbayo *et al.* 2017) (Table 2.2).

The acid detergent fibre (ADF) of the species, which is a measure of digestibility and energy intake was reported to be lower than NDF (Table 2.2). Higher ADF indicate lower digestible energy (Otegbayo *et al.*, 2017). The ADF contents of four species of raw yam tubers evaluated by Abara*et al.* (2011) were significantly different from each other, with the dietary fibre content of *D. bulbifera*signifying the highest, with the exception of lignin content, which was highest in *D.alata*. Moreover, all the species considered had the ADF values of their cooked samples higher than those of the raw tubers.

Hemicellulose is another non-starchy polysaccharide content which gives structural strength to cell walls of plants, as a result of the hydrogen bonding linking cellulose, lignin and pectin with polymers of neutral sugars: xylan and xyloglucan (rod-shaped

Table 2.2: Dietary fibre content of *Dioscoreaspp*

Chemical component	***D. alata***	***D. rotundata***	***D. bulbifera***	***D. cayenensis***
NDF (Neutral Detergent Fibre)	1.40 – 4.74	1.08 – 6.31	2.57 – 7.14	1.35 – 4.40
ADF (Acid Detergent Fibre)	1.20 – 2.85	0.00 – 3.10	2.30 – 3.42	0.92 – 2.48
Hemi-cellulose	0.20 – 1.81	0.21 – 2.06	0.27 – 2.23	0.16 – 1.46
Lignin	0.00 – 1.44	0.00 – 3.18	0.10 – 1.20	0.00 – 1.02
Cellulose	0.86 – 2.32	0.73 – 3.21	1.13 – 3.72	1.04 – 1.92

Source: Abara*et al.* (2011) Polycarp *et al*., (2012) and Otegbayo *et al.*, 2017 polymers) (Otegbayo *et al.*, 2017). The hemicellulose contents of yam species were reported to vary both within varieties and species, and ranged from 0.16 – 2.23% (Table 2.2). Cell walls of plants gain their rigidity and toughness from lignins, which are phenyls propanoid polymers having varying molecular weight (Cho *et al.*, 1997). These ranged from 0.00 to 3.18% in yam varieties of different species (Table 2.2).

Fibre has a number of functional roles in the body system, including bulky stool and increased water holding capacity, as hemicellulose and cellulose take up water and swell, thereby helping to increase the bulk of the stool. It lowers the level of cholesterol of Low Density Lipoprotein (LDL), thereby helping to lower the potential of heart diseases, since it is in the blood, and improves cholesterol ratio (Eastwood and Kritchevsky, 2005; Suter, 2005; Anderson *et al*., 2009). In most tropical Africa, including Nigeria, yam is a major staple food, which could form a major source of dietary fibre for its populace, despite its low amount.

2.4.3 Mineral contents of yam species

The amount of mineral inyam species are presented in Table 2.3. These levels indicate their importance as good source of nutrition for its consumers (Udensi*et al.*, 2008). These levels show that there are differences both within and between the species, linked to genotypic variations, method of determination, cultural practices, and environmental factors as well as chemical composition of the growing soil (Wireko-Manu *et al.*, 2011; Otegbayo, *et al.*, 2017).

Reports have shownthat the most abundant mineral in yam species is potassium (Udensi*et al,*, 2008; Polycarp *et al.*, 2012; Otegbayo *et al.*, 2017), ranging from 240 mg/100g to as high as 1475 mg/100g (Table 2.3), with *D. bulbifera* showing the highest concentration. The appreciable amount of potassium it makes yam meals desirable for people managing high blood pressure, because it is a significant intracellular cation that engage in nerve impulse transmission, muscle contraction, as well as fluid balance maintenance (Baah, 2009; Otegbayo *et al.*, 2017). The appreciable amount of potassium it contains, makes it a good diet for high blood pressure people (Baah, 2009). According to Udensi*et al.* (2008), *D. bulbifera*has the highest component of potassium (1250 – 1475 mg/100g), calcium (103 – 116.5 mg/100g) and magnesium (76.5 – 83.5 mg/100g), while *D.alata*has the highest amount

Table 2.3: Mineral contents of *Dioscoreaspp*

Chemical component	***D. alata***	***D. rotundata***	***D. bulbifera***	***D. cayenensis***	***D. dumetorum***
Potassium (mg/100g)	240 – 400	475 – 900	1250 – 1475	700 – 825	670 – 772.5
Sodium (mg/100g)	190 – 380	70 – 87.5	92.5 – 102.5	62.5 – 70	72.5 – 77.5
Phosphorus (mg/100g)	100 – 340	158 – 211.5	223.5 – 224.5	164.5 – 190.5	269 – 286
Calcium (mg/100g)	20.16 – 80.16	91.50 – 103.25	103 – 116.5	74.5 – 82	27.5 – 29.5
Magnesium (mg/100g)	24.31 – 97.24	35.5 – 53	76.5 – 83.5	38 - 57.5	61.5

Source: Udensi*et al*. (2008); Polycarp *et al*. (2012); Otegbayo *et al.*(2017)

of sodium (190-380 mg/100g) and *D. dumetorum* is highest in terms of phosphorus (269 – 286 mg/100g). Iron, an important component essential for oxidative phosphorylation, for the release of cellular energy, is a result of its oxygen carrier capacity in haemoglobin (Otegbayo *et al.*, 2017). Most yams possess iron content that can meet the range of between 11 and 18 mg per day, which is the recommended daily allowance (RDA). Zinc is important for nucleic acid biosynthesis, cell division and growth; however dietary zinc bioavailability may be reduced by the presence of phytate in yam tubers, as it forms Zn-phytic complex and insoluble mineral chelates, which is difficult to absorb from the gastrointestinal tract (Otegbayo *et al.*, 2017).

2.4.4 Phytochemical composition ofyam

Yams possess a complex phytochemical profile, which makes them useful for medicinal purposes. Yam consists mainly of dioscorine alkaloid and diosgenin saponin (Okwu and Ndu, 2006). However, these components are considered to be toxic but traditionally, washing and cooking may be used to remove it (Eka, 1998). The steroid structure of sapogenins, aglycons of yam saponins, makes them useful for medicinal purposes. These serve as precursors of birth control pillshemisynthesis, as well as similar hormones and corticosteroids (Crabbe, 1979). However, yam has been disregarded as a food that is edible by some people based on religion, belief and culture due to the chemical constituents of yam (Okwu and Ndu, 2006).

D. rotundata (19.46 mg/100g) had the highest content of saponins with *D. alata*(2.98 mg/100g) having the lowest concentration, as shown in Table 2.4 (Okwu and Ndu (2006). Saponin is involved in fighting microbial invasion and infections, acting as a natural antibiotic (Sodipo*et al.*, 2000). Saponins help reducerisk of heart diseases by lowering blood cholesterol, and also fight tumor cells by interfering with cell growth and division of these cells (Ryan and Shattuck, 1994). The range of 1.10 and 9.94 mg/100g was reported for flavonoids content of yams, with *D. alata* and *D. dumetorum*having the lowest and highest values, respectively (Okwu and Ndu,2006; Polycarp *et al.,* 2012). Flavonoids serve as antioxidants in different biological systems, protecting against inflammation, platelet aggregation, allergies, free radicals, hepatoxins, microbial attack, ulcer ailment, tumours and viruses (Okwu, 2004; Okwu

Table 2.4: Phytochemical composition of *Dioscorea species*

Dioscorea sp.	Saponins	Flavonoids	Alkaloids	Phenol	Tannin	Phytates	Oxalates
D. alata	2.98	1.10	0.74	0.00	0.044 – 13.20	0.89 – 3.01	0.45 – 0.50
D. cayenensis	16.48	5.78	0.68	0.0024	0.0047 – 5.76	3.24 – 4.16	0.50 – 0.51
D. bulbifera	14.88	8.04	0.88	0.004	0.08 – 10.98	1.20 – 2.24	0.58 – 0.63
D. rotundata	19.46	6.50	0.48	0.005	0.004 – 6.94	2.54 – 2.60	0.58 – 0.59
D.dumetorum	14.78	9.94	1.68	0.003	0.09 – 9.17	2.10 – 2.50	0.43 – 0.46

(Values are in mg/100g on dry weight basis)

Source: Okwu and Ndu (2006); Polycarp *et al.* (2012)

and Omodamiro, 2005). The alkaloid content varied from 0.48 to 1.68 mg/100g with *D. dumetorum*possessing the largest value and *D. rotundata* having the lowest value. The presence of alkaloid in yam makes it impossible for it to be eaten raw, as this causes itching and the compound is as well toxic (Oliver-Bever, 1983). This compound has been reported to cause central nervous system paralysis in animals, but could however be used in the production of analgesic drugs in pharmaceutical industries (Okwu and Ndu, 2006).

Yam species contain trace amount of phenolic compound, ranging from 0.00 to 0.005 mg/100g (Table 2.4). Phenolic compounds in yam act as anti-microbial agent, preventing the death of crops; it also results in browning reactions when oxidation takes place as a result of injury caused to yam tissues (Okwu and Ndu, 2006). Colour changes occur in freshly damaged plant materials due to the action of PPO(polyphenol oxidase), catalysing polyphenols oxidation to o-quinones (Chilaka*et al.*, 1993). These polyphenol oxidases are involved in catalysing the oxidation of a number of different phenol contents to o-quinones; and they are copper-containing enzymes (Oliveira *et al*., 2011). A secondary reaction that is non-enzymatic occurs with the o-quinones, resulting in brown complex polymers, called melanin and cross linking of polymers with protein functional groups (Taranto *et al.*, 2017). These enzymatic browning reactions changes the organoleptic properties of some food, hence affecting its quality. Other phenolic constituents including cathecholamine, cyaniding-3-glucoside, (+) catechol and procyanidin oligomers, have been observed to be involved inbrowning of edible yams (Akissoe*et al*., 2003).

Enzymatic browning could be eradicated or limited by the use of reaction inhibitors, by-product extracts, modified atmosphere and physical treatments. Physical treatment may involvethe utilization of heat, dehydration, irradiation as well as high pressure (Taranto *et al.*, 2017). However, changes in the colour of yam during processing was observed by Chilaka*et al*. (2002) to result from incomplete inactivation of PPO and peroxidase, which is majorly caused by the regeneration of peroxidase activity after thermo inactivation in processed yams. However, it has been reported that only 40% of browning activity in *D. rotundata* results from PPO activity, while the rest is non-enzyme related (Omidiji and Okpuzor, 1996). However, thiourea could be used to inhibit the action of peroxidase and polyphenol oxidase, thereby reducing browning during and after processing of yam (Chilaka*et al*., 2002)

Tannin content of yam species ranged from 5.76 mg/100g in *D. cayenensis*to 13.20 mg/100g in *D alata.* (Polycarp *et al.* (2012))*,* on the contrastOkwu and Ndu (2006) reported values from 0.004 to 0.09 mg/100g, with *D. rotundata*showing the lowest value and *D. dumetorum*reflecting the highest content.The bitter taste of *D. dumetorum*and *D. bulbifera* has been linked to the tannin content (Okwu and Ndu, 2006). Otegbayo *et al.* (2017) reported a greater tannin content of 56 to 1970 mg/kg for*D. rotundata, D. bulbifera, D. alata*and *D. cayenensis* species, with significant difference among and within species. Tannin contents have been reported to reduce food digestibility and palatability as they produce complexes with proteins (Polycarp *et al*., 2012). Tannin are phenolic compounds which are water soluble and precipitate protein by binding them irreversibly (Otegbayo *et al.,*2017).Tannin content of yam is significantly reduced during processing throughdenaturation, degradation by heat treatment and formation of complexes that are insoluble (Akin-Idowu *et al.*, 2008).

2.5 Yam Starch

In yam tuber, starch is the major carbohydrate constituent, and it can be as much as 80% of the dry component of yam, making it a major determinant of food quality and industrial products from yam tubers (Zhu, 2015). Starch isolation from yam tuber involves washing, peeling and dicing of the yam tubers into smaller sizes, followed by homogenizing with water into slurry. The slurry is sieved and allowed to settle, followed by several washing, to clean the starch (Otegbayo *et al.*, 2014). Moreover, the extraction method may vary from species to species, based on differences in their tuber composition and structure. Species with small starch granules are more difficult to extract, because small granules settle slowly than large granules, and are easily held down in the fibrous matrix (Zhu, 2015). Also, the non-starch polysaccharides (NSP) results in trapping of the small granules, as a result of the viscous suspension it gives after homogenisation, thereby carrying them to the portion of the waste, hence impacting difficulty in starch extraction. However, the effect of NSP can greatly be reduced during extraction by addition of 0.03 M NaOH, pectinase and 10% oxalate (Daiuto*et al.*, 2005).

2.5.1 Starch components

Starch comprises of two polymers, namely amylose and amylopectin. Amylose is majorly α-1, 4 glucans,a linear chain of which hasminimal branching points at α-1, 6 positions. This is made up of between 15-30% of common starch, while amylopectin is made up of linear chains of glucose units that islinked by α-1, 4 glycosidic bonds and it is highly branched at the α-1, 6 positions by small glucose chains at intervals of 10 nm along the molecule's axis (Alcázar-Alay and Meireles, 2015). Amylose and amylopectin form a matrix of starch granules when packed in a semi-crystalline structure with the aid of an alternating amorphous (amylose) and crystalline (amylopectin) material, referred to as the growth rings in starch plant which are superior (Alcázar-Alay and Meireles, 2015).

The amylose and amylopectin proportions of yam starches can be measured by different methods including: colorimetry/iodine binding-spectrophotometry, iodine binding-amperometric titration, changes in enthalpy in amylose-lysophospholipid inclusion complex transition measured by size-exclusion chromatography of debranched starch, size-exclusion chromatography by high-performance size-exclusion chromatography and differential scanning calorimetry (Zhu, 2015).

Amylose serves a major role in the characteristic properties, as well as uses of starches (Zhu, 2015).Amylose content greatly influences the pasting and retrogradation behaviours of starch, which influences their use (Wireko-Manu *et al.,* 2011;Ezeocha*et al.*, 2015). The amylose/amylopectin ratio also dictates the basic texture and nature of their resulting products (Baah, 2009). Amylose content of starch from different genotype of yam species varies, which could range from as minimal as 1.4% to as maximal as 50% (Rolland-Sabate*et al.*, 2003; Perez *et al.*, 2011).Otegbayo*et al.* (2011) andKrossmann and Lloyd (2000) reported that *D. rotundata* has lower amylose but higher amylopectin content than *D. alata*, which might be as a result of the activity of enzymes involved in starch biosynthesis of various starches. This has a resulting effect on the swelling power. However, *D. dumetorum*and *D. esculenta* have lower amylose content when compared to *D. alata, D. rotundata, D. cayenensis-rotundata* and *D. cayenensis* (Amani *et al.*, 2004; Otegbayo *et al.*, 2014). Mishra and Rai (2006) reported that the basic nature and texture of food product may be determined by the ratio of amylose/amylopectin, because it impact definite characteristics and functionality to starches. The*D. alata*have a range of 21.69 to 31.56% of amylose (Baah, 2009 and Wireko-Manu *et al.,* 2011) while a range of 17.54 to 29.833%amylose has been reported for *D. rotundata* varieties (Ezeocha*et al.*, 2015).

Reports reflected that the molecular properties of starch components, especially the amylopectin, which correlate with the amylose, strongly influence the gelatinisation temperature, rheological, retrogradation and pasting properties of starch dispersions and the eating quality of starchy food products (Lai *et al.*, 2001; Franco *et al.*, 2002; Lii*et al.*, 2004). It has been reported that starches that contain 32 – 34%of amylose content and significant amount of long chain fractions in amylopectin will have use for rapid-set, elastic gel products, edible films as well as resistant starch components (Wang *et al.*, 2006).

Modification could be done on native starch to promote it functional properties for utilization in non-food and food industries. Starch modification alters the physicochemical properties of native starch, thereby improving its functional properties, including thickening, adhesiveness, gelling properties, binding and film forming characteristics (Kaur *et al*., 2011). Starch modification could be done chemically, physically and /or enzymatically, by oxidation process, acid hydrolysis process, etherification, esterification and cross-linking technique (Zhu, 2015). Dual modification methods have as well been employed to create novel properties of starch (Odeku and Picker-Freyer, 2009). Dual modification methods include heat moisture treatment after debranching, hydroxypropylation-cross linking and ultrasonication-acetylation.

2.5.2 Granule morphology of yam starches

Granules sizes, referred to as the average diameter of starch granules are categorized as large granules (> 25 µm), medium granules (10 – 25 µm), small granules (5 - 10 µm), very small granules (< 5 µm) (Lindeboom*et al.,* 2004). The *D. rotundata* and *D. alata*starch granules could vary from 18.49- 44.29 µm, 10 – 70 µm, 19 - 50µm and 21.5-29.24 µm, 20 - 140µm, 13 – 52 µmrespectively (Moorthy, 2002; Brunnschweiler*et al.,* 2004; Otegbayo *et al.,*2011). The *D. rotundata* and *D. alata*starch granulesmay be reported as varieties with large starch granules, based on the categorization, which is in alignment with the report of Rolland-Sabate*et al.*

(2003). Granules with larger sizes have greater viscosities, swell faster and are more shear-sensitive than small granules (Otegbayo *et al.*, 2014). The granule size is partly responsible for starch properties, such as for variations in their physicochemical, functional as well as pasting properties (Deang and Rosario, 1993; Rolland-Sabate*et al*., 2003;Otegbayo *et al.,*2011, 2014), therefore starch granule morphology is an essential property of consideration for foods and some other industrial applications.

The granule morphology of starch could be obtained using particle size analysis by laser light diffraction, light microscopy and scanning electron microscopy; resulting in variations in the sizes and shapes of starches both within and among species. Yam granules are simple, with the surface having small fissures, with most having mono-modal size distribution (Zhu, 2015). The size of starch granules has great contributions to the swelling power, the rate at which starch gelatinizes and its viscosity, hence generally affecting the functional characteristics of starches (Otegbayo *et al.*, 2011; Addy *et al.*, 2014). However,starch granules sizes depend on the measuring method (Lindeboom*et al.*, 2004). In addition, the biological origin of granules of starch may be responsible for variations in their sizes and shapes, as this depends onthephysiology of the plant as well as the biochemistry of chloroplasts or amyloplasts (Mishra *et al.,* 2006; Singh and Singh, 2001). It has been noted that increased size of starch granules results in higher amylose contents, since amylose has been found to be densed in the boundary of granules (Jane *et al.* 2003; Tang *et al.,*2001). Amylose has been seen to concentrate very much in the boundary of granules, and mostly formed when the growth of granules occurs. According to Otegbayo *et al.* (2011), granule size could be among the determinants of textural quality in pounded yam.

No observable variations in starch granules shapes were noted between*D. rotundata* and *D. alata*, as both appeared smooth without any fissures(Otegbayo *et al.,* 2011). The shapes of *D. rotundata*were mainly oval, oblong, elliptical, triangular and irregular, while those of *D. alata* were ovoid, oblong, elliptical and round. However, shapes of granule have been reported to have no influence on the functional properties of starches, but it could be used as an indicator of starch sources (Otegbayo *et al.*, 2014).

Tetchi*et al.* (2012) observed that starch granules diameter decreased in yam tubers during storage. The size of granules of starch affects the rate of starch extraction.

Report has shown that starches that have large granules will have increased extraction ability and higher settling for decantation during extraction,than those with smaller granules (Xie and Sieb, 2002). Otegbayo *et al.* (2014) reported the difficulty of extracting *D. dumetorum,* having smaller granules as compared with*D. alata,D. cayenensis, D. bulbifera*and *D. rotundata*, with larger granules. This was attributed to the difficulty of small granules settling down when compared with large granules, and the fact that it is easier for small granules to be entrapped in the protein and fibrous matrix (Xie and Sieb, 2002; Zhu, 2015).

There could be variations in the granule's morphology of yam starch within the longitudinal distribution of a tuber. Degbeu*et al.* (2008) observed the variations in the physicochemical properties of yam tuber starches along the longitudinal distribution. The study showed that granule sizes of *D. alata* decreased from the proximal extreme (23.30 µm) toward the distal end (17.90 µm), while for *D. cayenensis*, there were similar sizes for the middle and distal sections and smaller size granules for the proximal section. Variations in granule sizes between different sections of yam tuber and between species have been reported by different authors, and were attributed to environment in which the granules were grown, as well as species variation (Farhat *et al.*, 1999;Amani *et al.*, 2004).

Starch with both large and small granules have their different industrial applications. Starches with large granules can find applications where swelling and good viscosity are required (Otegbayo *et al.*, 2014). Small granules starches have wide industrial applications, including use for replacing fat, since they give a creamy texture that is smooth, showing fat mimetic properties, desired in free-fat and low-fat food formulations, such as frozen desserts and cookies. Starches with small granules can infiltrate fabric, giving high sheen and rigidity in cloth industries, hence use as laundry-stiffening agents; as well as stabilizers in face powders and dusting powder in cosmetic industries; aerosols and baking powder (Jane *et al.*, 1992).

Interaction between the amylopectin external chains forming double helices, results in the crystalline matrix of granules. This results into two types of crystal arrangement known as A or B-type polymorph (Perez and Bertoft 2010). The A-type has its crystal, tightly packed; B-type has minimal tightly packed crystals, while C-type combines A and B-type. WAXS (Wide-angle X-ray scattering) could be utilized to reveal the polymorph patterns with distinct peaks at certain angles (Zhu, 2015). *D. alata* specie has B- or C-polymorph, *D. cayenensis-rotundata* has B- or C-polymorph while *D. opposite* has C-polymorph.

The microstructures of yams as affected by boiling were studied by Otegbayo *et al.* (2005a). The report signified that *D. rotundata* shows rounding off of cells and separation in cooked yam, while *D. alata* shows partial cell separation, without rounding off.Also, boiled yams that were mealy reflect complete rounding off of cells and cell separation, while waxy yams show incomplete retention of textural cell integrity.

2.6 Pasting Properties of Yam Starch

Pasting results from the combined effects of swollen granules of starch and exudation of amylose from granules, leading to formation of a less or more thick paste (Batey and Bason, 2015). Otegbayo *et al.* (2014) also defined pasting as alterationin viscosity just prior, during and after starch gelatinisation. Starch pasting can also be described as the process of significant viscosity development that results after heating a starch suspension to above the gelatinisation temperature (Yongfeng and Jay-Lin, 2015). It is a rheological property of starch, which is determinedby a number of agents including, concentration of starch, starch chemical structure, storage conditions and conditions of pasting (Yongfeng and Jay-Lin, 2015).

Pasting characteristics of roots and tubersis one of the main determinants of their resulting quality of products. Previous reports showed that pasting properties vary both within and among species; the method of pasting properties determination could also give varying results. Pasting characteristics of starch could be analysed by an amylograph such as Rapid Visco-Analyzer (RVA) and BrabenderViscograph (BV), where the parameters measured include: peak viscosity (PV), cool paste viscosity (CPV), hot paste viscosity (HPV), breakdown (BV = PV – HPV), setback viscosity (SB = CPV – HPV) and pasting temperature (Zhu, 2015).

It had been observed that pasting properties of *D. alata* varieties could vary from: 74.80 – 417.67 RVU for peak viscosity, 66.85 – 325.33 RVU for trough viscosity, 19.50 – 311.50 RVU for break down viscosity, 112.25 – 555.13 RVU for final viscosity, 27.45 – 308.10 RVU for setback viscosity, 4.60 – 7.00 min for peak time and pasting temperature of 83.45 – 90.10 °C. The *D. rotundata* varieties could range from 177.42 to 528.88 RVU for peak viscosity, 155.92 – 362.29 RVU for holding strength, 6.67 – 228.88 RVU for breakdown viscosity, 201.25 – 568.96 RVU for final viscosity, 40.00 to 338.92 RVU for setback viscosity, 4.60 – 6.70 minutes for peak time and 79.88 – 86.5 °C for pasting temperature (Wireko-Manu *et al.,* 2011; Otegbayo *et al*., 2014).

It has been reported that *D. dumetorum*varieties have the highest peak viscosity, comparable to those of *D rotundata* varieties, followed by*D.alata, D. cayenensis*and then*D. bulbifera* (Otegbayo *et al*., 2014). Farhat *et al*. (1999) and Amani *et al*. (2004) however reported lower viscosity for *D. dumetorum*and *D. esculenta*, during pasting, which was linked to smaller granule sizes and lower amylose content. Peak viscosities reflect the capability of granules ofstarch toswell freelybefore they physically break down, which is dependent on the swelling power of such granules ofstarch (Wireko-Manu *et al.,* 2011). Otegbayo *et al*. (2014) described peak viscosity as the thickness (viscosity) and water binding capacity of starch paste after cooking. Storage duration also has important effect on the peak viscosity property of *Dioscorea species*, as reported by Ogunlakin*et al.* (2013). Storage period results in loss of water by respiration, thereby increasing ability of starch in flour to bind water molecules, and hence increased peak viscosity (Ogunlakin*et al.*, 2013). However, Rosida*et al.* (2017) reported that starch modification resulted in lower peak viscosity of *D. alata*starches from 106.42 – 128.29 RVU to 12.92 to 82.50 RVU after modification

Varieties of *D.bulbifera*and *D.cayenensis*possess the highest pasting temperatures, which could be a disadvantage in industrial utilization where minimal heating is required. The holding strength of starches of*D.dumetorum* and *D. rotundata*show that the starch granules possess higher stability of pastein the course of heating and shear stress resulting from its resistance to mechanical fragmentation during shearing (Otegbayo *et al*., 2014). Ability of the granules of starch to remain undisrupted after holding at constant mechanical shear stress and temperature is known as the holding strength, which is often followed by a viscosity breakdown (Otegbayo *et al*., 2014). This is of high importance in industrial uses.

Final viscosity is the resulting viscosity afterpaste that has been cooked is cooled to 50 °C. This is very useful in evaluating the level of utilization of starch-based products, because it shows the capability of flour/starch to yield gel after cooking, as a result ofthe high degree of affiliation between water and starch systems which results in higherthickness during the cooling of yam starches that have gelled (Wireko-Manu *et al.,* 2011). Increased peak viscosity is relative to increased final viscosity (Tamiru*et al.,* 2008). Tamiru*et al.* (2008)reported that high breakdown viscosity is as a result ofan increased level of fall of swollen starch granules which also result in lower holding viscosity. Pasting temperature indicates gelatinisation temperature of starch that is measured at the begining of viscosity rise, and this is the degree of hotness to cook starch (Otegbayo *et al.,* 2014). Peak time shows the minimum time for cooking.

A number of parameters influence starch pasting properties of yam, which include agronomic practices, harvesting time, storage duration as well as varieties (Huang *et al.*, 2006; Perez *et al.*, 2011;Ogunlakin*et al.,* 2013; Akinoso and Abiodun, 2013). Other factors that affect the pasting property of starch include minuteparts of starch granules including phosphate-monoester derivativesand lipids, and addition of sugars (Yongfeng and Jay-Lin, 2015). The primary part of starch acccountable for swelling capacity and growth of starch viscosity in the course of cooking has been recounted to be amylopectin. Amylose pose to interact in the presence of lipids with amylopectin and restrict starch granules from swelling (Yongfeng and Jay-Lin, 2015). Inclusion of sugars, for examplemaltose,glucose, galactose, fructose, lactose andsucroseincrease starch viscosity, which is linked to the sugars' water binding ability (Gunaratne*et al.*, 2007; Chantaro and Pongsawatmanit, 2010).

Yam starches, when compared with other root and tubers starches have higher retrogradation ability, resulting in their high set back viscosities, limiting their utilization in food industries (Peroni *et al.*, 2006;Udensi*et al.*, 2008). However, this correlates positively with paste cohesiveness in good pounded yam from yam tubers having higher set back viscosities than those with lower values (Otegbayo et al., 2006).

2.7 Other Functional Properties of Yam Starch

Chandra and Samsher (2013) reported that functional properties are also known as the physicochemical properties, which shows complex reaction between the compositions, molecular conformation and structure of food components combined with the environment where they are associated as well as measured. These properties are affected by numerous factors, which include source of starch or type of starch, ratio of amylopectin andamylose, and starch gelatinisation (Nadia *et al.*, 2014). Yeh *et al.* (2009) added that mucilage and moisture content have effects on the physicochemical properties of yam starch.

The ability of flour to form paste is affected by its water absorption capacity, which is a quantification of the amount of water retained during processing. Ezeocha*et al.* (2015) reported 45 to 155%, as the water absorption capacity for *D. rotundata* varieties. Adebowale *et al.* (2005) showed that the moisture stability of starch is reflected by its water absorption ability, and this is very crutial for the food industry. Storage duration was shown by Ogunlakin*et al.* (2013) not to have any important effect on water absorption capacity of *D. alata*and *D. rotundata*. The water binding capacity of *D. alata*species was observed by Baah (2009) to range between 159. 7 to 202.4%, which is a measure of how loose or firm the structures of the starch polymers are.

Swelling and solubility is another functional property of yam starch that is essential. Swelling and solubility reflects the gelatinization behaviour of granules (Zhu, 2015). Swelling power is the amount of water starch can take up (per gram starch) at a certain starch concentration and temperature, while solubility is the percentage of leached amylose and amylopectin at this temperature (Waterschoot*et al*., 2015). The experimental procedures and parameters include starch slurry and concentration, heating time, elevated temperature,centrifugation conditions and shaking (Li and Yeh, 2001). Swelling power of *D. alata* varies from 6.23 to 11.6% (Baah, 2009; Wireko-Manu *et al.,* 2011), and from 105.03 to 142.86% (Ezeocha*et al.*, 2015) for *D. rotundata*. The swelling power is majorly restrained by the character as well as strength of the micellar networks that is in the starch granules; the associative forces reduced as the swelling power lessens (Ikegwu*et al.*, 2009; Wireko-Manu *et al.,* 2011).

A number of factors could be answerable for variations in the swelling power and solubility; including granule size and amylose content majorly, others could be environmental factors (Zhu, 2015). The greater the amylose contents of starch, the lower the swelling power. This is because amylose molecules tend to be in equally distant location, hence its hydroxyl group are loosely bound, hence the starch form strong crystalline mass, thereby restricting swelling (Riley, 2006). Starch modification that involves heat has been observed to give starch with increased swelling power, as there would be exudation of the amylose (straight chain) in the course of modification, thereby reducing the amylose content responsible for inhibiting swelling (Harijono*et al.*, 2013; Rosida*et al.*, 2017). Additionally, swelling power increases with raising the temperature (Gunaratne and Hoover, 2002; Wang *et al.*, 2006; Tetchi*et al.*, 2007). Presence of mucilage in yam starch has also been stated to affect the swelling power measurement of *D. alata* starch (Yeh *et al*., 2009).

Gelation studies of starches have also shown variations both within and between species. The lower the least gelation capacity (LGC) concentration of starch, the higher its gelation capacity. This implies that starches with low LGC can find wide industrial applications, as they form gel easily and those with higher LGC greater than 10% can be utilised in processing complementary diet, where reduced viscosity, plasticity and elasticity are desired (Otegbayo *et al.*, 2014). Syneresis is another functional property of starch that results from 'reorganisation of amylose' and 'reversible crystallisation of the short external chains of amylopectin' in the longer terms. Starches with high amylose content results in high syneresis, due to more volume of water that will be released during the process of retrogradation (Gunaratne and Hoover, 2002; Singh *et al*., 2003). High syneresis limit the utilization of such starches in custard application, pudding, frozen desserts and pie-fillings, and other products that require storage at low temperature (Otegbayo *et al.*, 2014).

2.8 Utilization of Yam

In Nigeria, a larger portion of cultivated yam is consumed domestically, and the general demand is increasing as population increases (Philips *et al.*, 2013). Harvested yams have been noted to serve different food purposes for the different classes of people in the society. However, yam canalso be processed and utilized industrially for a number of products, such as ice-cream production, thickeners in soupsand dough conditioner in bakery(Iwuoha, 2004). Products from yam could be regarded as a prestigious food in some areas as a food for entertaining special guests, celebrations and also as part of gifts presented to in-laws during wedding ceremonies. Yam can be consumed by boiling, frying, roasting, mashing and pounding, which are the primary means of utilizing yam. FAO (2003) reported that the main purpose of growing yam is for direct human consumption, and are marketed fresh in all growing regions of the country. However, in Europe, yam flour is utilisedin industries for the preparation of biscuits, high quality bread and other pastries (Foraminifera Market Research, 2013).

2.8.1 Roasted yam

In nonruralregions of the Western yam belt area of African, roasted yam has turned a very popular fast food or street food (Osunde, 2008). Roasted yam is achieved by roasting unpeeled yam tubers on coal fire, and then scrapping the burnt skin with knife (Adepoju, 2012). Roasted yam was reported to have a moisture content of 30.63 - 52%, 3.4 – 4.91% crude protein, 1.2 - 2.0% crude fat, 1.21- 10.07% crude fibre, 2.59 - 3.0% ash content, 28.4 – 43.95% carbohydrate and an energy value of 369.6 kcal/100g (Adetunde*et al.*, 2012;Adepoju, 2012).

Research was carried out to see the effects of different roasting methods on the quality of roasted yam; it was found that the methods had no significant effect on the moisture content, but the crude protein and fat content were affected (Adepoju, 2012).Olayaki*et al.*(2007) studied the effect of roasting using open flame on yam, and it was reported to have deleterious effect on some hematologic qualities in male albino rats.

2.8.2 Fried yam

Frying of yam involves washing and slicing of peeled yam to desired size, followed by addition of salt to taste and then frying with vegetable oil with intermittent addition of little water to reduce drying of oil and allowing cooking of the yam. The potential production of deep-fried crisp snack from yam was investigated by Tortoe*et al.* (2014a) to provide a wide array of snacks to meet the demand of the growing urbanised society. Acceptability of fried food products, including fried yam is greatly influenced by the development of a crispy and crunchy texture. Tortoe*et al.* (2014a) reported that taste and texture influenced the selection of preferred choice, while colour and aroma had no significant contribution.

Fried yam has a low moisture content of 33.9%, as compared with other yam food products. The crude protein content was 3.0%, crude fat of 5.3%, crude fibre of 1.2%, ash content of 2.8%, carbohydrates content of 53.8% and gross energy supply of 397.6 kcal/100g (Adepoju, 2012).

2.8.3 *Ikokore*

Ikokore is a special delicacy among the *Ijebu* people of Yoruba land, prepared from water yam. Peeled yam is grated, and then cooked with fish, onions, pepper, crayfish, meat and tomatoes, with other ingredients (Ogundele, 2007). Morakinyo*et al.* (2016) described *ikokore* as 'savoury water-yam porridge with pepper and crayfish'. The grated yam may however be fried with vegetable oil, which is referred to as *ojojo,* common among Oyo people of Yoruba land.

Ikokore contains considerable amounts of mineral contents in relation to the recommended daily allowance, in comparism with commonly consumed local foods in Nigeria. These minerals includepotassium (9.00 mg/100g), sodium (6.90 mg/100g), magnesium (5.20 mg/100g), calcium (10.48 mg/100g), iron (11.63 mg/100g), zinc (4.63 mg/100g), phosphorus (1.06 mg/100g), chlorine (121.90 mg/100g) and manganese (4.18 mg/100g), with low copper content (0.91 mg/100g) (Morakinyo*et al.,* 2016).

2.8.4 Boiled yam

Boiled yam is achieved by the simple process of boiling peeled, sliced and washed yam at a temperature of 100 °C for 30 min (Adepoju, 2012). Reduction of tannin content in yam has been found to be more rapid with boiling method, thereby reducing interference with iron absorption when in the gastro intestinal lumen (Adegunwa*et al.*, 2011). According to Ransford (2012), mealiness and softness are the desired sensory quality attributes of boiled yam.

2.8.5 Pounded yam

In West Africa, the most generally accepted food from yam is pounded, often set aside for unique occasions in both urban and rural areas (Osunde, 2008). Traditional pestle and mortarare used for pounding boiled yam to yield a starchy paste called pounded yam (Adepoju, 2012). The stretchability, cohesiveness, hardness, smoothness and stickiness of pounded yam were reported by Otegbayo *et al.* (2007) to be the determinant attributes of it desired quality. Soluble amylose fraction and the extent of cell fragmentation relates to the chewiness and springiness of pounded yam; where the extensibility and stickiness are affected by the rheological factors or its amylose structure (Konan *et al.*, 2014). Ageing of pounded yam was reported Brunnschweiler*et* *al.* (2006) to yield pronounced textural changes resulting from the reorganisation of amylose fraction or retrogradation.

Preparation of pounded yam involves the use of mechanical energy, leading to process of disintegrating or splitting up of the cells, and thereby exudation of starch granules which areswollenand initiation of a starch phase that iscontinuous, which controls the paste cohesion (Brunnschweiler*et al.,* 2006). Firmness of pounded yam was correlated to the expanse of cell disintegration: moderate cell disintegration was correlated to high firmness.

2.8.6 Fermented yam flour (*Elubo*)

Traditionally, fermented yam flour is the major product processed from yam in southwestern Nigeria. Fermented yam flour is deployed for the preparation of *amala.* There are three main types of dried chunks resulting from different methods of processing yam in Nigeria, followed by milling into flour for *amala*; the dried chunks are: *gbodo, pasa-pasa*and *keso* (Table 2.5). Yam farmers and consuming households have also been known to convert yams that have been eaten by insects or rotten, to fermented yam flour (Kleih*et al*., 2012). From the result of survey carried out by Kleih*et al*. (2012) at a major market in Lagos, *gbodo* has the highest percentage demand and supply for yam flour, approximately 65%, followed by *pasa-pasa*: app. 25% and then keso, app. 10%.

Traditionally, yam flour is processed from yam tubers by peeling, washing and cutting into medium size-chunks or sliced. This is followed by a blanching process to approximately 65 - 70 °C, and the chunks will be left in the blanching water till the following day, after which it will be drained and dried. The dried chunks or slices will be ground into flour using a hammer mill, resulting in a creamish flour which could be stored, and used for preparation of *amala* (Abiodun and Akinoso, 2014; Ojokoh and Gabriel, 2010).Fermented yam flour is reconstituted into paste, known as a*mala,* by stirring the flour in boiled water till a desired consistency is reached, and allowed to cook (Ukpabi*et al.,* 2008).

During the production of *elubo* from yam tubers, a number of reactions occur, resulting in colour change of the white yam tubers to around creamish to deep brown. The colour change processes have been associated with enzymatic browning reactions

Table 2.5: Product characteristics and origin of fermented yam flours

Dried yam chunks	**Product characteristics**	**Origin**
Gbodo	Small sized yam (not sliced) Processed by parboiling	Oyo North, Kwara state.
Pasa-pasa	Sliced and dried tubers	Benue, Taraba state
Keso	Yam flour from water yam (*Ewura*)	Kwara state

Source: adapted from Kleih*et al*. (2012)

of peroxidase and polyphenoloxidase, as well as total phenol contents, which varies between and within species (Chilaka*et al.*, 1993; Oliveira *et al*., 2011; Taranto *et al.*, 2017). Blanching and drying of yam during *elubo*processing have been reported to reduce the peroxidase and polyphenoloxidase (PPO) activity, but increased the total phenol and brown index in the produced *elubo* (Akissoe*et al.*, 2003). However, it was reported by Akissoe*et al.* (2003) that browning of yam was associated to the total phenol present in yam, which is reliant on the peroxidase activity of fresh yam tubers and not on polyphenoloxidase activity. This could be related to the report that browning in yam was partly non-enzymatic and enzymatic (40%) (Omidiji and Okpuzor, 1996).

D. rotundata is the preferred specie of yam for *elubo* (fermented yam flour)*,* however, feasibility of *D. alata* specie for making of *amala* paste has been investigated by Ukpabi*et al.* (2008), especially in areas where they are the major yam species produced. According to Ukpabi*et al.* (2008), the colour of the resulting *amala* from *D. alataelubo*varied from light brown to black, and out of about ten (10) varieties that were evaluated, only two were highly rated in relevant sensory parameters. Furthermore, Abiodun and Akinoso (2014) reported that the pasting and functional properties of *D. dumetorum*were comparable to that of *D. rotundata*, and the fermented yam flour from *D. dumetorum* gave comparable and acceptable *amala*, with those of *D. rotundata*. In the evaluation of *amala*, stickiness, firmness and smoothness have been reported to be the main sensory attributes from both sensory and instrumental measurements (Akissoe*et al.*, 2006).

2.8.7 Industrial products

Industrial products have been obtained from yam, including starch steroids, arrow poison, insecticides, tannin, lagger beer, ice-cream, jellies, candies and chips (Iwuoha, 2004). Yam starch is also utilized for the making of all-purpose-adhesives, used for cartons, shoes and other packaging materials (Foraminifera Market Research, 2013). However, as a result of high cost of yam, non-edible yam species are channelled for industrial starch production (Ike and Inoni, 2006). Yam chips and pellets are useful in livestock feed (Foraminifera Market Research, 2013)

Yams have been reported to have a complex phytochemical profile, with dioscorine alkaloid and diosgenin saponin being the predominant characteristics (Okwu and Ndu, 2006). These are said to be toxic, but are easily removed by washing, boiling and cooking. The use of yam species in herbal medicine, based on its phytochemical characteristics was investigated by Okwu and Ndu (2006), and was concluded to contain nutritive and health advancing substances, prompting their utilization as food and drug.

Yam is majorly starchy in naturewhich supplies energy as it'sprimarily most important nutritional function (Akinwande *et al.*, 2007). The properties of starch in a crop determine it potential uses within the food industry (Aprianita*et al.*, 2009), as well as suitability for processing and the standard of the final product (Abiodun, 2013). Yam starch is about 60 to 80% of the dry content proportion of yam tubers, which determines the textural, functional and rheological properties of food products for varying yam species (Amani *et al.*, 2004). Yam starches have been utilized for various food purposes. Starch of yam was used with brewer's spent using a single screw extruder to make dietary fiber-enriched pasta (Sobukola*et al.*, 2013). Nindjina*et al.* (2011) used yam starch and wheat flour in composite form for bread production; 30% substitution yielded bread with closer loaf volume same as the control (100% wheat flour), with acceptable sensory quality attributes.

Biodegradable starch films have been produced from *D. trifida* and *D. alata* native starch and cross-linked starches (Ferreira *et al.*, 2009). Phase separation was prevented in the starch film by incorporating monoglyceride, which reduced water permeability and alsoimproved stability of the film. Chitosan can as well be added to films to createbetter flexibility compared to LDPE (low-density polyethylene) film and antimicrobial effect against *Salmonella enteritidis* (Durango *et al*., 2006). The microbiological stability of strawberries pack has been reported to be extended from 14 – 21 days by starch film and also give better biodegradability (Ogbobe*et al.*, 1997; Mali and Grossmann, 2003).

Starches have found use in the pharmaceutical industries for tablet formation. Research has been carried out to know the structural basis properties needed for tablet formulation from native starches of *D. alata, D. cayenensis,D. dumetorum, D. oppositifolia, D. polygonoides*, *D. esculenta*and*D. rotundata* (Okunlola and Akingbala, 2013; Odeku and Akinwande, 2012). Modification of starches for use in tablet formation has created a range of properties for wider applications; such as improved efficiency for relaease of the active ingredient (Odeku and Akinwande, 2012), improved crushing force of tablets for direct compressible excipient (Odeku and Picker-Freyer, 2009).

Starches have found use as substrate for fermentation to provide lactic acid, bioethanol and other chemicals, especially from other biological sources such as maize (Zhu, 2015). Yam starch has been used as a substrate in the fermentation of *Penicillium sp.* S-22 for the production of efficient starch degrading enzymes(Sun *et al*., 2006).

2.9 Sensory Evaluation

Sensory evaluation wasdefined as a scientific discipline that encompasses all senses and is used for evoking, measuring, analysing and interpreting reactions to food characteristics, as recognizedusing the senses of smell, sight, taste, hearing and touch (FAO, 2000; Stone and Sidel, 2004). Lawless and Heymann (2010) defined sensory evaluation as a science that is quantitative, where numerical informationisreceived to institute specific and lawful relationships between human perception andproduct characteristics. Watts *et al.* (1989) defined it to be a multidisciplinary science which engages man and womanpanelists with their senses of touch, sight, hearing, taste and smell to determine the sensory properties and acceptableness of products including foods and non-food materials.

Sensory evaluation is the final measure of food quality, but could be expensive and time wasting to evaluate (Akissoe*et al.*, 2006). Colour, aroma, texture, taste and after taste have been observed as expedient evaluators of total acceptability of yams by farmers (Otoo and Asiedu, 2009). Sensory evaluation can be used to obtain information on consumer likes, dislikes and preferences with the aid of consumer-oriented testing methods, which involves sensory panels that were not trrained; as well as getting specific information on sensory properties of food using product-oriented tests (Watts *et al.*, 1989). Product oriented tests make use of small trained panels to identify differences among similar food products.

There is a technique in sensory analyses that helps sensory scientist to get hold of total sensory characterisitics of products, pointing out underlying ingredients, process variables, and alsoidentify which of the sensory properties are significant for acceptance. This is known as descriptive sensory analyses (Lawless and Heymann, 2010).In addition, Gillette (1984) stated that descriptive tests are needed in situations where a whole specification of the sensory properties of a single product or a comparison among several products is needed. Descriptive analysis techniques could include: "quantitative descriptive analysis", "flavour profile analysis", "texture profile analysis" and "sensory spectrum technique". A successful descriptive analysis is achieved by training the judges, determining judge reproducibility and samples evaluation (Lawless and Heymann, 2010).

Texture is an important part of descriptive sensory evaluation, which was explained by Szczesniak (2002) to be 'the functional and sensory manifestation of the mechanical, surface and structural properties of foods identified through the senses oftouch,hearing, vision and kinesthetics'. Texture is very important to consumer as it is frequently used as an index of food quality. A number of texture properties can be quantifiedby the use of standard sensory techniques includingdescriptive techniques, ranking and discrimination testing (Lawless and Heymann, 2010).

Instrumental texture measurements are an alternative mechanical test that can stand in the place of the sensory panelists due to cost of efficiency (Bourne and Szczesniak, 2003; Lawless and Heymann, 2010). Texture Profile Analysis (TPA) techniques have been carried out with texturometer, and done with the "Instron Universal Testing Machine" and other related equipments (Varela*etal*.,2006). Otegbayo *et al.* (2007) reported significant correlation between Sensory Texture Profile Analysis (STPA) and Instrumental Texture Profile Analysis (ITPA) of pounded yam. To minimize errors and achieve desired results, it is of importance to follow the principles of good sensory evaluation practices. Good practices in sensory evaluation covers the areas ofexperimental design, test protocol considerations, panelists considerations, sensory testing surroundings and data analysis (Lawless and Heymann, 2010).

The sensory testing environment is expected to be situated nearer to possible judges, but free of extraneous odours and noise. Use of sensory booths is necessary, but in cases where they are not available, panelist should not seat facing each other (Kimmel *et al*., 1994; Meilgaard*et al.*, 2006). Standardization of sample serving procedures and preparation should be ensured to avoid variations, except for the variable under consideration; as size of sample has been observed to have effect on the intensity scores of textural attributes (De Wijk*et al.*, 2003). Sample serving temperatures and holding time are to be standardized as these also affect some product quality (Lawless and Heymann, 2010); hence use of warm holding containers or storage in styrofoam box, as applicable.

2.10 Quality Indicators in Food

The quality of food items which conforms to consumer prerequisite is evaluated by sensory properties, chemical properties, physical attributes, and the extent of microbiological and toxicological contaminants (Molnar, 2011). Evaluation methods including quality indicators have been introduced for quantitative description of food quality. Food qualities in yam are parameters inherent, which are essential in identifying uses and acceptability of yam food products by every concerned stake-holders. These quality attributes include physicochemical properties (granule sizes and shapes, pasting parameters, swelling power, water binding capacity), nutritional composition (proximate,minerals, vitamins) and anti-nutritional properties (phytates,tannins, saponins and oxalates) (Otegbayo *et al*., 2010). Baah*et al.* (2009) found that physicochemical and pasting characteristics of yam tubers was related to the eating quality of its products. Crosbie (1991) also related the quality of boiled noodle to the starch swelling properties and paste viscosity of the wheat flour that was used. Amylose content and amylograph peak viscosity of starch from cassava were also related to sensory qualities of boiled cassava roots and reconstituted gari (Olorunda*et al*., 1981).

Quality attributes of yam is based on a number of product attributes that determine their level of suitability to a concrete and predetermined use, such includes sensory properties (appearance, colour, texture, taste and flavour), physical properties and chemical composition. Farmers' important criteria for choosing yam genotype for processing into secondary products include low moisture content and reduced percent peel loss (Ukpabi*et al.*, 2010).They also, see food quality in terms of the marketable value, maintainable derivable income from cultivating a specific variety and appropriateness of yam for specific food product like pounded yam (Otegbayo *et al.* 2010; Sesay *et al.* 2013).

2.10.1 Chemical properties of food

The amount and nature of componentts in a specific food item determine the nutritive quality and other properties of the food (Molnar, 2011). High dry matter, that is low moisture content, starch and amylose contents have been attributed to result in good eating quality of *D. alata*varieties (Lebot*et al.*, 2005). Negative correlation was observed between the sugar of yam flour and the smoothness, consistency and hardness of pounded yam of *D. alata*, but positive correlation to elasticity (Baah*et al.,* 2009). Starch has been identifiedto be a prevailingindex in ascertaining the textural, functional and rheological properties of yam food productsbecause it amounts to about 80%of yam carbohydrates on dry weight basis (Baah, 2009).

Ascheri*et al.* (2012) studied the relationship between nutritional content of grain and the pasting characterisitcsof pre-gelatinized red rice flour. There was a strong positive association between the content of crude fibre and the lipid content of polished red rice; and strong negative correlation with the protein content. This implies that the more the bran is withheld in the polished red rice, the more the content of lipid and the lesser the protein content. Non-starchy carbohydrates (lignin, cellulose, hemicellulose) had also been reported to have significant contribution to the creation of doughy and firm texture of pounded yam prepared from fresh and stored varieties of *D. rotundata* (Otegbayo *et al.*, 2017). High calcium, pectin and other insoluble dietary fibre content have been reported to account for smooth texture observed for pounded yam prepared from *D. rotundata* tubers (Otegbayo *et al.*, 2012). Olorunda*et al.* (1981) predicted the quality of boiled cassava roots and reconstituted gari using chemical and rheological properties, and concluded that mealier boiled cassava and most acceptable gari were obtained from cultivars that had higher amylose content and slightly higher amylograph peak viscosity.

2.10.2 Functional properties of food

The water binding capacity and swelling power of *D. alata* werestatedto be more related to the eating quality of pounded yam than other physicochemical properties (Baah, 2009). In 2011, Otegbayo *et al.* stated that there were significant relationships between pounded yam's textural quality and the functional properties of starch samples. This correlation was more evident in *D. rotundata*when compared with*D. alata*.Amylose, amylopectinwater binding capacity and swelling power of yam starches were significantly associated with stickiness and cohesiveness while solubility index was significantly correlated with stretchability of pounded yam.

2.10.3 Rheological properties of food

According to Fayose *et al.* (2015), rheological characterisiticsof food are significant indices ofquality and texture of food products. Baah*et al.* (2009) reported significant associations between the quality of pounded yam and functional as well as pasting characteristics of *D. alata*. There were positive associations between consistency of pounded yam, and the trough viscosity,final viscosity and peak viscosity of yam varieties. Otegbayo *et al.* (2011) reported on the impact of granule size onthe textural quality of foods, as it hadinfluenceon the viscosities and swelling of the yam starch. Konan *et al.* (2014) observed that higher level of granule cell disintegration gives a springy and chewy product, which was associated to the amount of soluble or free amylose in drum-dried yam flakes.Extrudates with high degree of retrogradation resulted from starch with a moderate to high moisture content, extruded at moderate temperature (125 – 190 °C). In addition, there is a decrease in the rate of retrogradation as extrusion time and moisture content increased (Fayose *et al.,* 2015)

2.10.4 Physical and sensory properties of food

Textural quality, colour, aroma and taste are important quality properties of great significance in the choice and acceptance of food products.

2.10.4.1 Colour and appearance

Food quality and appreciation is influenced by colour and other aspects of appearance, especially by the consumer. There are subjective acceptable ranges preferred by man for optima qualities of different food, which can as well be precisely and objectively determined with the use of modern instruments (Molnar, 2011). Since colour communicates freshness, flavour and quality, it requires appropriate attention through objective and repeated measurement, with the aid of an instrument. To ensure consistency and for monitoring consumer preference surveys, instruments and colorimetry are now replacing grading scales based on visual assessment (Konica Minolta, 2015). Mahony(2011) reported how colour was used to evaluate the quality of beverages and food, and this enhanced both thirst quenching and refreshment perception. It also influenced higher product liking scores and inappropriately colour products received lower acceptance scores. Mestres*et al.* (2004) observed that taste, colour and aroma parameters of *amala* could be efficiently predicted from the biochemical characteristics of yam chips flour.

2.10.4.2 Taste and flavour

Flavour is described as the overall sensation that results from taste, odour and textural feeling of a product. For many food products, flavour is the most important sensory property (Molnar, 2011). It was reported that odour/flavour were more correctly identified when colour of product was appropriate (Mahony, 2011). Also, Tortoe*et al.*(2014b) reported that taste and texture attributes of precooked vacuum-packaged yam contributed significantly and was positively correlated to overall preference of yam slices from differentvarieties.

2.10.4.3 Textural quality

The way a consumer will perceive quality is greatly affected by the texture of a food; as there is transmission of information on changesoccurring in texture of a food during chewing, to the brain from mouth sensor, hearing sense and memory, thereby creating a view of the food textural properties (Fellows, 2000). Consumers employ food texture as an index of food quality, not indicator of food safety (Akissoe*et al.,* 2001; Lawless and Heymann, 2010).

2.11 CanonicalCorrelationAnalysis

This is an analysis technique useful for identifying and measuring the relationshipsthat exists among two groups of variables, by determining a set of canonical variates, orthogonal liner combinations of the variables within each set that best explain the variability both between and within sets (UCLA Statistical Consulting Group, 2016). It is a generalization of multiple regression analysis with more than one trait in the independent and dependent trait sets. Unlike, many other techniques, for canonical analysis, any of the two sets can be a probable candidate to be used as dependent or independent traits (Norman *et al.*, 2012). Canonical correlation analysis has found application in different fields of research, including plant sciences, medical sciences, chemistry, and even in the social and management sciences.

Canonical correlation analysis was applied to fluorescence spectra measured for a set of samples composed of binary mixtures of raw materials, and through the canonical variates and spectral pattern, it was made possible to compare the samples and the emission wave-lengths respectively (Devaux*et al.*, 1998). In 2005, Martin *et al.* reported the relationships between site characteristics (soil physical, topography and chemical properties) and performance of soybean plant (yield, canopy development) with the aid of canonical correlation analysis. The results showed that site variables related to soil water retention (organic matter, pH and deep electrical conductivity) were more consistently associated with soybean performance than site variables related to soil fertility (soil phosphorus and soil potassium).

The relationship between the textural quality of pounded yam andfunctional characteristics of yam starch was studied using canonical analysis (Otegbayo *et al.*, 2011). It was revealed that significant correlations existed between the physicochemical properties (amylose, amylopectin, water binding capacity and swelling capcity) of starch and textural quality (cohesiveness, stretchability andadhesiveness) of pounded yam prepared from *D. rotundata* tubers, although, there was weak associations between those of *D. alata*starch and pounded yam.

Norman *et al.*(2012) used canonical correlation analysis to study the interrelationship between the agro-morphological trait and cytological trait of yams. The results revealed that significant association exists between the two sets of variables as shown by the canonical correlation; with the content of DNA (pg) having the largest significanteffect on the differences in the morphological traits (i.e.number of stems per plant, wings presence and colour of wing).

Canonical correlation was used to analyse how the performance of sesame in the market is affected by social capital (Anzaku*et al.*, 2013). It was reported that high degree of relationshipwas observed between social capital variables and market performance, with sizeable contribution made byfarmer's share, net marketing margin and return of investment (market performance) on the variables of social capital: number of marketing information from social relationships and amount of credit.

In general, the use of canonical correlation analysis makes easier the review of relationships between sets of numerousindependent variables and numerousdependent variables (Anzaku*et al.*, 2013). Canonical correlation analysis has beenlargely used in different areas of research.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental design

The two major species of yam in Nigeria were selected for the study. Fifty-five genetically characterised and elite landraces were selected from these: *D. rotundata* (19 varieties) and*D. alata* (36 varieties) (Table 3.1). The varieties were obtained from the yam programs of theInternational Institute of Tropical Agriculture (IITA) and National Root Crops Research Institute (NRCRI), Umudike, Nigeria. The physical, functional, chemical and pasting characterisations of the yam tuber varieties were determined. The resulting *amala* from the *elubo* of the varieties of the yam species were subjected to descriptive sensory evaluation. The relationship and association between these, which can serve as determinant of quality of the resulting food product, were identified.

3.2 Sample Preparations

Minimum of three to five tubers (3.8 – 4.8 kg) per variety of the yam tubers, stored for three months were used. Each was split into four sections, with the tip of the proximal and distal end cut off, resulting in four sub-samples. The first set was used for granule morphology and dry matter content determination, the second sub-sample was processed into fermented yam flour (*elubo*) for *amala*, the third sub-sample was used for yam flour preparation, and the fourth set was used for starch extraction. Plate 3.1 and 3.2 present representations of varieties of *D. rotundata* and *D. alata* species respectively.

3.2.1 Yam flour processing

The processing of yam flour was done by the method described by Wireko-Manu *et al.* (2011). Theprocessing steps involved peeling, washing, dicing and then drying at 60 °C for a period of 72 hours in a forced draft oven. The dried cubes were ground (Panasonic mixer grinder, MX-AC210S), packed and kept in ziplock bags, prior to analysis. Figure 3.1 presents the flow diagram for the preparation.

Table 3.1: List of varieties of *D. rotundata* and *D. alata*species used for the study

S/No	Varieties of *D. rotundata*	S/No	Varieties of *D. alata*
1.	Agbanwobe	**1.**	TDa11/00011
2.	TDr95/18531	**2.**	TDa11/00014
3.	TDr89-02665	**3.**	TDa11/00020
4.	TDrUfenyi	**4.**	TDa11/00022
5.	TDr97-00917	**5.**	TDa11/00024
6.	TDr99-02607	**6.**	TDa11/00063
7.	TDr89-21-3	**7.**	TDa11/00102
8.	Agba	**8.**	TDa11/00110
9.	Agboyo-abbi	**9.**	TDa11/00138
10	Ameh	**10**	TDa11/00162
11.	Fakinsa	**11.**	TDa11/00164
12.	Lagos	**12.**	TDa11/00167
13.	Nwopoko	**13.**	TDa11/00179
14.	PAA-IITA	**14.**	TDa11/00189
15.	Pampas	**15.**	TDa11/00225
16.	Ogoja	**16.**	TDa11/00232
17.	Sandpaper	**17.**	TDa11/00242
18.	Takalafia	**18.**	TDa11/00247
19.	2665	**19.**	TDa11/00275
		20.	TDa11/00287
		21.	TDa11/00292
		22.	TDa11/00299
		23.	TDa11/00305
		24.	TDa11/00317
		25.	TDa11/00324
		26.	TDa11/00368
		27.	TDa11/00370
		28.	TDa11/00374
		29.	TDa11/00424
		30	TDa11/00426
		31.	TDa11/00428
		32.	TDa11/00434
		33.	TDa11/00493
		34.	TDa11/00495
		35.	TDa11/00541
		36.	TDa11/00555

a. TDr89/02665

b. Agba

c. TDrAgboyo-abbi

d. Pampas

e. Ogoja

f. Fakinsa

g. Nwopoko   h. TDr Pampas

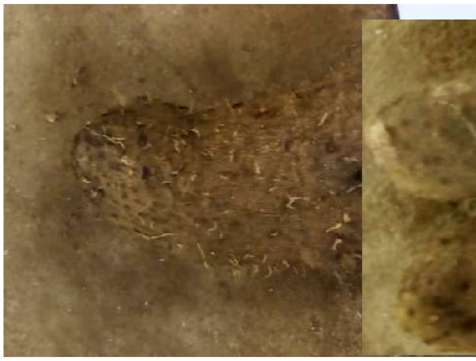
Plate 3.1: Representations of fresh yam tubers of *D. rotundata* species

a. TDa11/00022

b. TDa11/00024

c. TDa11/00063

d. TDa11/00102




e. TDa11/00110 f. TDa11/00162

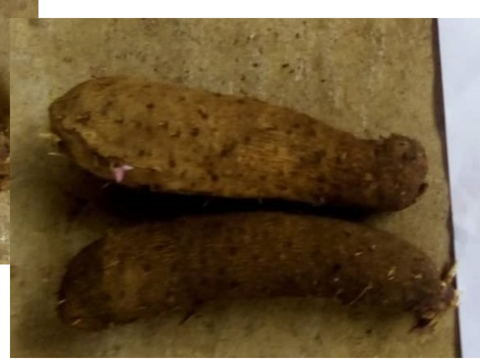

g. TDa11/00167 h. TDa11/00164

i. TDa11/00179

j. TDa11/00189

k. TDa11/00225

l. TDa11/00232



m. TDa11/00242

n. TDa11/00247

o. TDa11/00275 p. TDa11/00287

q. TDa11/00292 r. TDa11/00299

s. TDa11/00305

Plate 3.2: Representations of fresh yam tubers of *D. alata*species

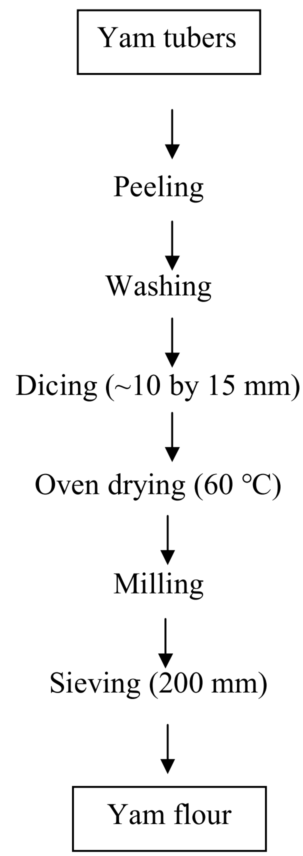


Figure 3.1: Yam flour processing

3.2.2. Yam Starch extraction

Starch was extracted from yam tubers by wet method, using the method described by Otegbayo *et al.* (2011). The yam tubers were peeled, washed to clean off all dirts, and then diced into smaller sizes. These were milled into slurry with water using a warring blender (Panasonic mixer grinder, MX-AC210S) with intermittent stopping to prevent heating up the starch, followed by sieving using triple layers of muslin cloth, and then washed until the residue was free of starch. The filtrate was left to settle, drained and re-washed numerously with water. The extracted settled starch was dried in shallow trays at a temperature range of 20 – 25 °C, followed by blending into fine powder packed and kept in ziplock bags, prior to analysis. Figure 3.2 reflects the flow chart for the starch extraction process.

3.2.3 Fermented yam flour (*Elubo*) processing

According to processors interviewed and observed in Oyo north (Igbeti, Saki and Igboho of Oyo State), fermented yam flour production principally involves a blanching (70°C) and drying process, after the yam tubers have been peeled, and the size of the tubers reduced. Hammer mill was used ti mill the dried chips into flour.

The fermented yam flour (*elubo*) for preparation of *amala* was processed from yam tubers adopting the traditional methods used by local processors. The method involved peeling the yam tubers, chipping, and then blanching in water on a heat source, till the temperature reached 70°C, and the source of heat removed (Fig. 3.3). The yam was left in the steeping water, decanted after 24 h, and dried until the inner core of the flabby yam were dried. Hammer mill was used to finely grind the resulting dried cores, packed and kept in ziplock bags.

3.2.4*Amala p*reparation from fermented yam flour by standardized laboratory method

The standard method of *amala* preparation was employed, but modified to ensure consistency in the preparation, by the use of a locally fabricated yam pounding machine (S. Adiss engineering company, Ibadan, Oyo State, 1420 rev/min) which was adapted for *amala* preparation (shown in Plate 3.3). The fermented yam flour (200 g) was reconstituted into *amala* by adding it into boiling water (500 ml). This was stirred

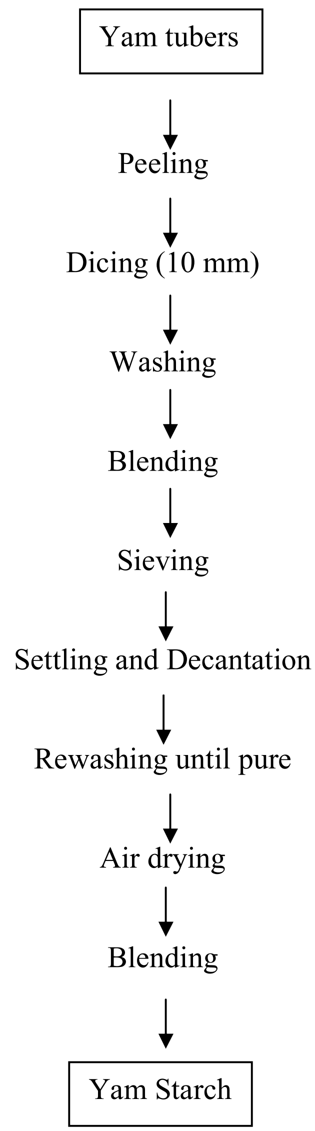


Figure 3.2: Starch extraction from yam tubers

Yam tubers

↓

Peeling

↓

Size reduction (~15 mm by 80 mm)

↓

Heating (up to 70 °C)

↓

Steeping (24 h)

↓

Draining

↓

Sun Drying (5 - 6 days)

↓

Milling

↓

Sieving

↓

Fermented yam flour (*elubo*)

Figure 3.3: Processing of '*elubo*' from yam tubers

Plate 3.3: Adapted *amala* preparation machine

uniformly by the blade of the mixer into a smooth paste. This was stopped intermittently after 10 seconds (this was done three times). The metal bowl of the machine was placed on a heat source and cooked for 5 minutes after adding 40 ml of boiling water. The cooked paste was further mixed for 10 s into a smooth paste, known as *amala*. This was wrapped in aluminium foil and kept in a polystyrene foam box for sensory evaluation. These were done to simulate how it is usually reconstituted when being prepared conventionally at household level.

3.3 Analysis on Fresh Tubers

3.3.1 Morphology of starch granules of the fresh yam tubers

Light microscopy (Fisher Micromaster) was used to examine and measure the granule size and shapes of yam starch granules of the fresh yam tubers, as depicted by Otegbayo *et al.* (2011). It was carried out by cutting very thin section of parts of the yam tuber which has been sliced. A glass slide with the dimension of 75 mm by 25 mm was used on the light microscope. The thinly cut section was placed carefully on the glass slide and drops of water was bestowed to reduce evaporation and movement of starch granules. After these, a glass cover slip with the dimension 22 mm by 22 mm was used to cover the sample, after which it was placed under the microscope lens. The granule sizes of the yam starches were measured and the shapes were viewed under the microscope using the scientific imaging tools (Westover scientific, Micron 2.0) of the connected computer. Ten (10) granules were measured per variety.

3.3.2 Instrumental colour evaluation of raw yam tuber

Hunter colorimeter (Konica Minolta CR 410 chromameter) by the aid of the Commission Internationale de l'Eclairage (CIE) tristimulus was used for the evaluation. This evaluated the L*-signifying lightness, a*- red-green axis and b*-the yellow-blue axisas the colour parameters of the raw yam tubers. Standardization of the instrument was carried out with a white tile according to Lui-ping *et al*. (2005). The parameters evaluated were L*, a* and b* axis of the CIE scale. Where, *L**(lightness) axis showed 0 is black, while 100 is white; *a**(red-green) axis signified positive values indicates red while negative values are green and 0 is neutral; *b**(yellow-blue) axis showed positive values indicates yellow, while negative values are blue and 0 is neutral.

3.3.3 Determination of dry matter content

The dry matter content determination was carried out by oven drying method. Two grams (2.00 g) of the tuber sample was weighed with the aid of an analytical balance (Pioneer OHAUS corp. Pine Brook NJUSA) in a pre-dried and pre-cooled moisture can, and then placed in a forced draft oven (Memmert digital oven) at 130 °C for 1 h. After drying, the moisture cans with samples were cooled in a dessicator, after which the moisture cans were weighed (modified AOAC, 2010). This was carried out in triplicates. The dry matter and moisture content were calculated as shown in equation 3.1 and 3.2.

$$Dry\ matter\ (\%) = \frac{Weight\ of\ sample\ after\ drying}{weight\ of\ sample\ before\ drying} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 3.1$$

$$Moisture\ content\ \ (\%) = \ 100\ - dry\ matter \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3.2$$

3.4. Analyses on Yam Flour

3.4.1 Chemical properties of yam flour

NIR (Near Infrared Reflectance) spectroscopy was used to assess the flour samples for crude fat, fibre, ash, crude protein, sugar, starch, amylose, amylopectin, tannin and phytate content with the aid of the NIRS monochromator (model FOSS XDS, near infrared rapid content analyser, solid module) and a ring cell cup. Each sample of yam flour was examined two times by NIRS in the range of 400 – 2498 nm, registering the absorbable values log (1/R) at 0.5 nm. The measurement of the samples was done in duplicates and the mean value was obtained and reported.

3.4.2 Oxalate determination

High Performance Liquid Chromatography was used to evaluate the oxalate content of the yam flour samples, as described by Bhatia *et al.* (2016). Column 18 (C-18) of the instrument was used, and methanol: 0.1% TrifluoroAcetic Acid in water (40: 60, v/v) as the mobile phase.

Two grams of sample to be evaluated was dissolved in 20 ml of 6 N HCl, which was then allowed to stand for 1 hour. This was passed through a filter paper of Whatman

No 2, and the pH of the filtrate checked and adjusted to pH 6 with dilute NaOH solution. Distilled water was used to make up to the mark of 50 ml, and the solution was refrigerated to keep at low temperature till the solution was read with the HighPerformance Liquid Chromatography machine (Agilent 1200 infinity series).

The sample solution (20 µg) was injected, using rheodyne injector at a flow rate of 1.0 ml/min and wavelength of analysis, 254 nm. The oxalate was resolved at 1.47 min with good retention parameters under the above chromatographic conditions. The peak area of the oxalate was recorded for each sample by software, after that of a standard solution of oxalic acid has been recorded. The oxalate content was calculated by equation 3.3

$$\text{Oxalate content (mg/100g)} = \frac{(PA\ of\ sample) \times C \times \text{V}}{PA\ of\ standard \times 10 \times \text{W}} \quad \ldots\ldots\ldots\ldots\ldots\ldots..3.3$$

Where; P/A = Peak Area

C = Concentration of standard (100 ppm)

V = total extract volume

W = weight of the sample

3.4.3 Mineral content

The mineral contents, magnesium (Mg), potassium (K) and sodium (Na)were evaluated using atomic absorption spectrophotometer (PG 990) and flame photometer (Jenway PFP 7) (AOAC, 2010). The samples were prepared by ashingat 550 °C for 3 h. The cooled ash was mixed with 6N hydrochloric acid (5 ml), filtered and the filtrate was made up with distilled waterto 50 ml. Atomic absorption spectrophotometer was used to analyse Mg whileK and Na were evaluated by flame photometer. The concentration of Mg, K and Na were calculated as shown in equation 3.4.

$$\text{Concentration (mg/100g)} = \frac{(a-b) \times V}{weight\ of\ sample} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...... 3.4$$

Where: a = concentration of sample solution (ppm)

b = concentration of blank solution (ppm)

V = volume in mL of the extract

Phosphorus (P) was evaluated by stannous chloride colorimetric method (Method of Dickman and Bray (1940) and Bray and Kurtz (1945), adapted by Bowen University Central Laboratory). Two millilitres of the digest were mixed with 5 ml of distilled water, and then addition of 2 ml ammonium molybdate solution and 1 ml of mixed stannous chloride. The resulting solution was read for absorbance on a spectrophotometer after 5 – 6 min, before 20 min at a wavelength of 660 nm. The stannous chloride was prepared from a constantly cooled stock every 3 h.

The concentrations of phosphorus were extrapolated using a standard graph of known concentrations of standard phosphorus (0 ppm, 0.1 ppm, 0.25 ppm, 0.5 ppm and 1.0 ppm) and their corresponding absorbance.

Phosphorus concentration (mg/100g) = $\frac{\{(A \times B) + I]\, V}{W \times 10}$ ………………………….3.5

Where:

A- Absorbance of sample

I- Intercept of standard curve

V- Total extracts volume

B- Slope of the standard curve

W- Sample weight.

3.5 Analyses on Yam Starch

3.5.1 Determination of pasting properties

The yam starch varieties were evaluated for their pasting properties with the aid of a Rapid Visco Analyzer (RVA4500) connected to a PC running ThermoCline for windows (TCW) version 3 software (Perten Instruments of Australia, 2015).The parameters that were evaluated include: final viscosity, set back viscosity, pasting temperature,peak time, break down viscosity, trough viscosity also known as holding strength and peak viscosity, from the pasting profile. The sample calculator of the analyser was used to calculate the weight of the sample to be used for the analysis, based on it moisture content. This could be calculated manually as shown in eqn. 3.2.

The estimated sample weight and volume of water was weighed to prepare the starch suspension, amounting to a sum of 28.0 g slurry in the canister of theRVA. This was mounted in a central manner with the paddle in the canister unto the RVA machine, followed by pressing the motor tower of the instrument, once initiated. The progress of the pasting activities, showing the pasting profile was monitored and viewed on the monitor of the connected computer, till the end of each experimental run.

RVA sample weight (S) = $\frac{A \times 100}{100 - M}$ ………………..…………………….…..... 3.6

Volume of distilled water (V) = 28 – S

Where A = 3 g

S = Calculated sample weight for RVA

M = Moisture content of the sample

V = Volume of water

3.5.2. Determination of swelling and solubility index

Leach *et al.* method, as cited by Zakpaa*et al.* (2010) was modified for the evaluation of swelling and solubility index. The method involved weighing 0.5 gram of the starch sample into a previously weighed centrifuge tube with cap, followed by the addition of 10 ml distilled water and then proper mixing. The samples in the centrifuge tubes were subjected to heating at 85 ℃ with constant shaking for 30 min in a water bath. After the heating period, the tubes were brought out and the temperature allowed to lower-down, and then centrifuging at 2,200 rpm for 15 minutes. The supernatant was drained into pre-weighed moisture cans and then heated at 105 ℃ to constant weight, after which the weight was noted, as well as the weight of the residue left in the centrifuge tubes. The swelling power and percentage solubility were estimated (eqn 3.7 and 3.8)

$$\text{Swelling power} = \frac{\text{weight of sediment}}{Weight\ of\ sample - weight\ of\ solubles} \qquad \text{........………………….. 3.7}$$

$$\%\ \text{Solubility index} = \frac{\text{weight of solubles}}{Weigh\ \ of\ sample} \times 100 \qquad \text{…………………… 3.8}$$

3.5.3 Determination of WBC (water binding capacity)

Medcalf and Gilles (1965) method of determining water binding capacity was used, with slight modification by Zakpaa*et al.* (2010). The determination was carried out by weighing 1 g of yam starch in a centrifuge tube of known weight, and then adding 15 ml of distilled water to dissolve the starch. The starch suspension was agitated on a shaker for 1 hour, followed by centrifugation at a revolution of 2,500 rpm for 20 minutes. After this, the centrifuge was tilted for 10 minutes to drain the free water, and the remainder weighed, from which the bound water and the WBC were calculated.

$$\text{WBC} = \frac{\text{weight of bound water}}{\text{weight of sample}} \times 100\ (\%) \qquad \text{.......................... 3.9}$$

3.5.4. Determination of WAC (water absorption capacity)

The method of Anderson (1982) was used for the determination with slight modification. The yam starch (1 g) was dispersed in 10 ml distilled water in a pre-weighed centrifuge tube and shaken rigorously, and then allowed to stand for 30 minutes. The starch suspension was centrifuge at 2000 rpm for 30 min. The centrifuge tube was tilted to eliminate the supernatant and the weight of the sediment taken (Deshpande and Poshadri, 2011).

$$\text{WAC} = \frac{\text{weight of absorbed water}}{\text{weight of dry solids}} \times 100 \qquad \text{.................................... 3.10}$$

3.5.5 Determination of pH

Mbaeyi-Nwaoha and Onweluzo (2013) method was adopted for determining the pH. About 10 g of the sample was weighed and mixed well with100 ml of deionized water, and then filtered using a Whatman No 2 filter paper. The electrode of the pH meter was inserted in the filtrate to evaluate the pH.

3.5.6.Determination of titratable acidity

A suspension of 1 g of sample (1 g) and 20 ml of distilled water was prepared inside a 100 ml conical flask, shaken forcefully and passed through a filter paper. The filtrate was titrated with 0.1 N NaOH, by using 2-3 drops of phenolphthalein as the indicator (AOAC,2010). The percentage titratable acidity was calculated using equation 3.11.

$$\%\ \text{Titratable acidity} = \frac{Normality\ of\ NaOH \times volume\ of\ NaOH}{weight\ of\ sample} \times 100 \qquad \text{.................3.11}$$

3.6 Analyses on Fermented Yam Flour (Elubo*)*

3.6.1 Pasting properties of fermented yam flour

The pasting properties of the fermented flour (elubo) was determined as earlier described in 3.5.1.

3.6.2 Instrumental colour evaluation of *eluboand amala*

The instrumental colour parameters of *eluboand amala* were determined as earlier described in 3.3.2. The brown index (BI) was as well calculated from the L* value, as described by Babajide*et al.* (2006) (Equation 3.13).

Where, Brown Index = 100 – L* ……………………………………3.13

3.7Descriptive Sensory Evaluation

The method of Otegbayo *et al*. (2005b) was modified to carry out the descriptive sensory evaluation of *amala* prepared from *elubo*.

3.7.1 Selection of panelists

A set of fifteen panelists were selected from staff of Faculty of Agriculture, Bowen University, based onavailability, interest, familiarity with the consumption of the food product and previous experience on sensory evaluation.

3.7.2 Training of panelists

To achieve an objective and reproducible results, panelists used for the evaluations were trained. They were trained on the basics of sensory quality profile as applicable to *amala*. There were three sessions of training, which covered: introduction of the objectives of the research work, discussion on sensory attributes of *amala:* whichinvolved description of sensory property terms, identification of the quality attributes of the food products using local food descriptors and development of standard scales using local foods, based on contributions made by panelists. Lastly, sensory analysis practice by the panelists.

The actual descriptive sensory evaluation sessions began a week after the training sessions. The descriptive sensory attributes that were presented and described to the panelists, as applied to *amala* included:

a. Stretchability: the extent to which a material can be extended or stretched
b. Stickiness: the extent to which the *amala*sample sticks or gums to the fingers
c. Smoothness: this is described based on the absence or presence of lumps
d. Hardness: the amount or force required to press the sample
e. Taste: the gustatory perception of how astringent, bland or slightly sweet it is
f. Aroma: how pleasant or unpleasant the samples are.
g. Colour: observable range of lightness or darkness of the samples

Standard rating scales were developed together with the panelists for the sensory attributes of *amala*, using properties of common foods. During one of the training sessions, the food items from the developed rating scales were presented to panelists for evaluation. Table 3.2 reflects the standard rating scales developed with the panelists for *amala*.

3.7.3 Sample presentation for descriptive sensory evaluation

Freshly prepared *amala* samples were served and presented to panelists in small white sample plastic plates, labelled with three-digit numbers, in replicates (with different codes). The samples were given to the panelists in a random order placed in partitioned sensory booths, to make individual assessment without influence from each other. It was ensured that the sensory room was well lit, and it took place at room temperature. They were supplied with a bowl of water to wash their hands, as well as serviette paper to wipe their hands. Each panelist had a form for the sensory evaluation, used to assess the quality attribute of the food product (amala), based on scoring method, using different anchor points, as they had been trained to do. The panelists were given incentives at the end of each evaluation session.

3.8. Statistical analysis

The data were analysed using SPSS version 20 statistical software (2004). Analysis of variance (ANOVA) and mean separation were evaluated. Differences ($p < 0.05$) between variables were evaluated by duncan. Canonical correlation analysis

Table 3.2: Standard rating scales for *amala* developed from common foods in Nigeria

Attribute	Level		Food Descriptor
Strechability	Very stretchable	1	Lafun
	Stretchable	2	Fufu
	Slightlystretchable	3	Eba Yoruba
	Non-stretchable	4	Eko/agidi
Stickiness	Very sticky	1	Unproperly cooked semovita
	Sticky	2	Eko/agidi
	Slightly sticky	3	Egg albumin
	Non-sticky	4	Egg white
Smoothness	Lumpy	1	Ebaonikoko
	Coarse	2	Coaker oat
	Smooth	3	Fufu
Hardness	Very Hard	1	Akpu
	Hard	2	Eba/ pounded yam
	Soft	3	Semo
	Very soft	4	Overripe pawpaw
Taste	Sweet	1	Slightly sweet corn
	Bland	2	Tasteless
	Bitter/astringent	3	
Aroma	Pleasant	1	
	Bland	2	
	Unpleasant	3	
Colour	Dark brown	1	Dark chocolate
	Brown	2	Light chocolate
	Light Brown	3	Egg shell/Carton brown
	Grey	4	Dark fufu
	Light grey	5	
	Very light brown	6	Lafun

(CANCORR) was also done by SPSS to determine the interrelationship between the properties of the yam tubers and the sensory quality of the resulting food products, which could serve as their quality indicators. PAST version 2.17c software was employed to do the principal component analysis (PCA) of the descriptive sensory evaluation results; and cluster analysis, using ward's method for characterising the properties of the yam tubers and the sensory evaluation of the resulting *amala* (Hammer *et al.,* 2001).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Granule Morphology of Starch in Fresh Yam Tubers

There were variations in sizes and shapes of the starch granules both within and between species. Light microscope showed that starch granule size from varieties of *D. rotundata* (32.40 – 57.01 µm by 22.38 – 35.70 µm) were bigger than those of *D.alata*varieties (18.33 - 48.91 μm by 13.38 – 33.10 µm) (Tables 4.1 and 4.2). These observations are comparable to that Otegbayo *et al.* (2011) (18.49 - 44.29 µm for *D. rotundata*species and 21.5 - 29.24 µm for *D. alata*species), showing larger sizes for *D. rotundata* than *D. alata*. The varieties of both species could be classified as large starch granules, based on Lindeboom*et al.* (2004) classification scale for sizes > 25μm. Samples Agboyo-abbi and TDa11/00374 had the smallest granule sizes for *D. rotundata* and *D. alata*respectively while samples TDr-Ufenyi and TDr99-02607; TDa11/00232 and TDa11/00299 had the largest sizes for *D. rotundata* and *D. alata*species respectively.

The variations in the granules size of yam species could be responsiblefor variations in their physicochemical and functional properties. This variation was reported by Sanguanpong*et al.*(2004) to be responsible for the differences in the sensitivity of different species to shear, affecting the texture of food products prepared from them. Otegbayo *et al.* (2011) also reported that the higher viscosity and swelling of starches from *D. rotundata* species as compared with those of *D. alata* resulted from the larger starch granules of *D. rotundata*, contributing to its pasting properties, swelling capacity and pasting temperature; hence, larger starch granules swell faster and also build higher viscosity. Morevover, Jane *et al.* (2003) observed that as the granules grow larger, amylose component is mostly formed, because it has been found to be concentrated in the periphery of granules. Hence, the influence of granule sizes on the functionality of food, as a result of the amylose, which is an important component that contributes to food properties. Thus, granule size of starches, molecular make-up of polymers of starch including structural characteristics of these starch polymers

Table 4.1: Sizes of starch granules of *D. rotundata*varieties

Sample	Granule length (µm)	Granule breadth (µm)
Agbanwobe	36.22^{abc}	26.89^{bcde}
TDr95/18531	42.77^{defg}	30.79^{fghi}
TDr89-02665	45.68^{fg}	30.15^{efghi}
TDrUfenyi	46.71^{g}	35.70^{j}
TDr97-00917	43.74^{efg}	29.30^{defgh}
TDr99-02607	57.01^{h}	31.73^{ghi}
TDr89-21-3	35.26^{abc}	26.84^{bcde}
Agba	44.01^{efg}	32.82^{ij}
Agboyo-abbi	32.40^{a}	22.38^{a}
Ameh	40.88^{cdef}	27.55^{bcdef}
Fakinsa	45.82^{fg}	32.75^{ij}
Lagos	34.97^{ab}	28.28^{cdefg}
Nwopoko	46.13^{fg}	26.41^{bcd}
PAA-IITA	37.67^{abcd}	32.15^{hi}
Pampas	38.79^{bcde}	24.99^{abc}
Ogoja	37.45^{abcd}	24.61^{ab}
Sandpaper	37.85^{abcd}	30.39^{fghi}
Takalafia	37.64^{abcd}	28.78^{defgh}
2665	35.19^{abc}	25.32^{abc}
Mean	**40.85**	**28.83**
STD	5.91	3.40

*Values are average of 10 replicates results. Significant difference($p < 0.05$) is shown by values having different superscriptsin a column.

Table 4.2:Sizes of starch granules of *D. alata*varieties

Sample	Granule length (µm)	Granule breadth (µm)
TDa11/00011	$32.65^{bcdefgh}$	21.92^{efgh}
TDa11/00014	30.46^{bcdef}	22.27^{efgh}
TDa11/00020	30.02^{bcde}	21.40^{cdefgh}
TDa11/00022	$32.22^{bcdefgh}$	18.58^{bcde}
TDa11/00024	$33.97^{cdefghijk}$	22.10^{efgh}
TDa11/00063	38.98^{jklm}	23.64^{ghi}
TDa11/00102	29.49^{bcd}	21.19^{cdefgh}
TDa11/00110	$32.62^{bcdefgh}$	23.60^{ghi}
TDa11/00138	42.33^{mn}	28.29^{jk}
TDa11/00162	$37.00^{ghijklm}$	23.35^{fghi}
TDa11/00164	$35.95^{fghijkl}$	19.45^{bcdefg}
TDa11/00167	31.37^{bcdefg}	23.40^{fghi}
TDa11/00179	37.17^{hijklm}	24.74^{hij}
TDa11/00189	30.72^{bcdef}	16.14^{ab}
TDa11/00225	$33.18^{cdefghi}$	24.85^{hij}
TDa11/00232	48.91^{o}	27.01^{ijk}
TDa11/00242	$35.05^{defghijk}$	21.09^{cdefgh}
TDa11/00247	28.76^{bc}	21.96^{efgh}
TDa11/00275	26.92^{b}	17.62^{bcd}
TDa11/00287	$33.46^{cdefghij}$	19.21^{bcdef}
TDa11/00292	$32.13^{bcdefgh}$	21.78^{efgh}
TDa11/00299	46.81^{no}	33.10^{l}
TDa11/00305	39.17^{klm}	21.63^{defgh}
TDa11/00317	30.94^{bcdef}	22.25^{efgh}
TDa11/00324	$34.10^{cdefghijk}$	22.76^{efgh}
TDa11/00368	$34.91^{defghijk}$	24.70^{hij}
TDa11/00370	29.44^{bcd}	24.59^{hij}
TDa11/00374	18.33^{a}	13.38^{a}
TDa11/00424	$35.67^{efghijkl}$	22.89^{fgh}
TDa11/00426	38.80^{ijklm}	21.41^{cdefgh}
TDa11/00428	36.81^{ghijkl}	29.15^{k}
TDa11/00434	28.29^{bc}	20.30^{cdefg}
TDa11/00493	40.82^{lm}	21.44^{cdefgh}
TDa11/00495	30.62^{bcdef}	18.65^{bcde}
TDa11/00541	30.69^{bcdef}	17.49^{bc}
TDa11/00555	$31.72^{bcdefgh}$	22.36^{efgh}
Mean	**33.90**	**22.21**
STD	5.61	3.66

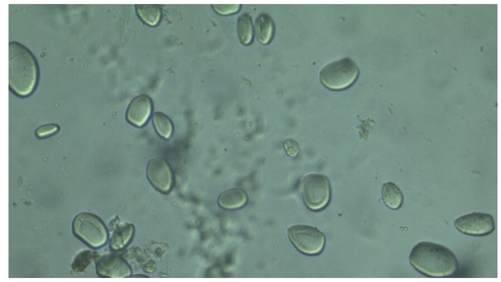
*Values are average of 10 replicates results. Significant difference($p < 0.05$) is shown by values having different superscriptsin a column.

determine the properties of gel made from different starches (Wickramasinghe*et al*., 2009).

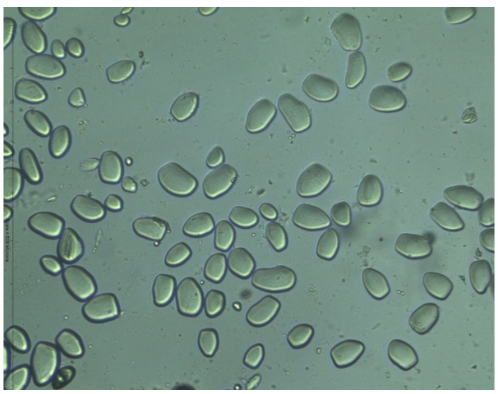
The results of granule sizes of this study are similar to earlier findings for *D. alata*varieties by Otegbayo *et al.* (2014) (29 – 41 μm) and Baah (2009) (29.5 – 41.5 μm). The values are however higher than the report given by Fauziah*et al.* (2016) (13.3 – 26.0 μm), Tetchi*et al.*, (2012) (22.09 – 23.00μm) and Otegbayo *et al.* (2011) (21.5 – 29.24 μm). The *D. rotundata* species also had similar results with those of Otegbayo *et al.* (2011) (18.49 – 44.29 μm). The granules shape of the starch as seen under the microscope for *D. rotundata* and *D. alata* species are shown in Figures 4.1 and 4.2 respectively, with few observable differences in the shapes. The *D. rotundata* varieties were majorly oblong, oval and irregular in shape, while those of *D. alata*varieties were more triangular and oblong. The shapes are comparable to previous observations by Baah (2009), Otegbayo *et al.* (2011), Tetchi*et al.* (2012), Sahore*et al.* (2013) and Fauziah*et al.* (2016) for both species. However, the shapes have no functional roles they contribute, but could be used to establish the source of the starch (Otegbayo *et al.*, 2004).

The cluster analysis emerged two major clusters for both species of *D. rotundata* and *D. alata*, as shown in Figure 4.3. Cluster A comprises of two sub-groups- I and II, made up of both *D. rotundata* and *D. alata* varieties. Sub-group I comprises 10 varieties of *D. alata*species and 9 varieties of *D. rotundata* varieties, which indicated average or medium granule sizes when compared with others. Cluster A sub-group II is made up of majorly *D. rotundata* varieties (TDr99/02607 to TDr95/18531, nine varieties) and three *D. alata* varieties (TDa11/00232 TDa11/00299 and TDa11/00138), with distinctly larger granule sizes. Cluster B showed varieties with relatively small granule sizes, comprising of majorly *D. alata*- 23 varieties and one*D. rotundata* variety. Hence, it can be noted that varieties in the same cluster may have comparable contributions to pasting viscosities, swelling power and gelatinization temperature; as granule sizes influence the viscosity and swelling of their starches. The granule sizes of both yam species studied falls within the group of large starch granules as those of Florido, smooth pea, Kponan and potato starches, which have found utilization in industries where high viscosities and swelling power are needed (Tetchi*et al.*, 2007

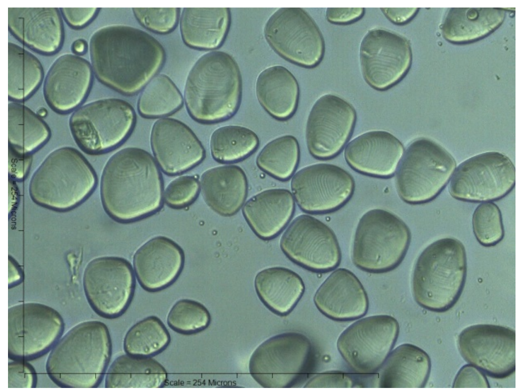
(i) Agbanwobe (mag ×20)



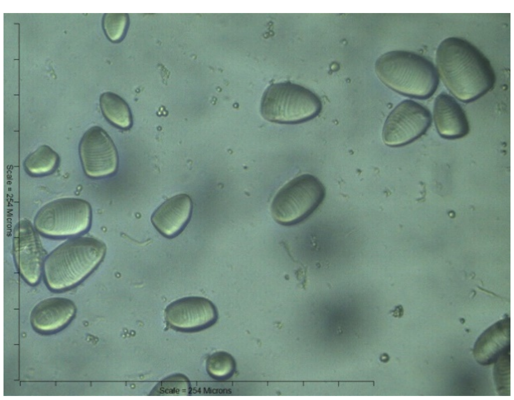
(ii) TDr95/18531 (mag ×20)



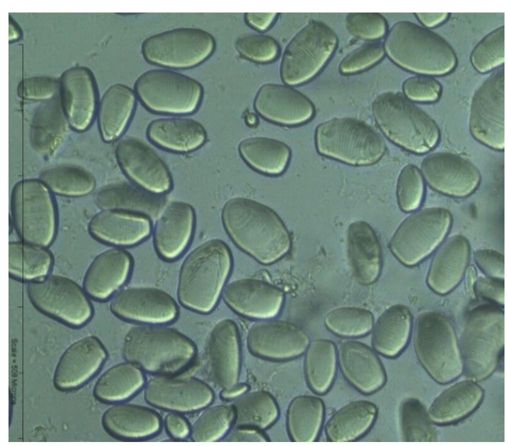
(iii) TDr89-02665 (mag ×20)



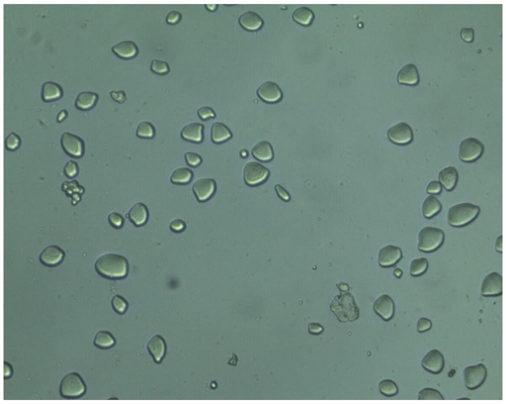
(iv) TDrUfenyi (mag ×20)



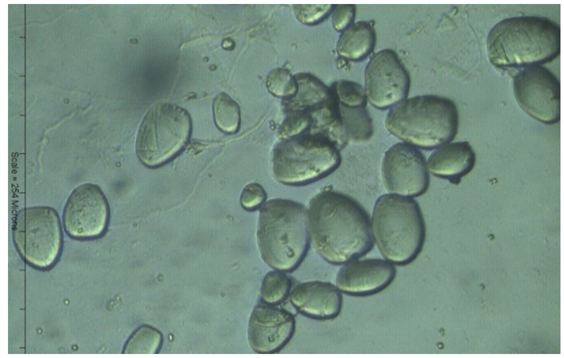
(v) TDr97-00917 (mag ×20)



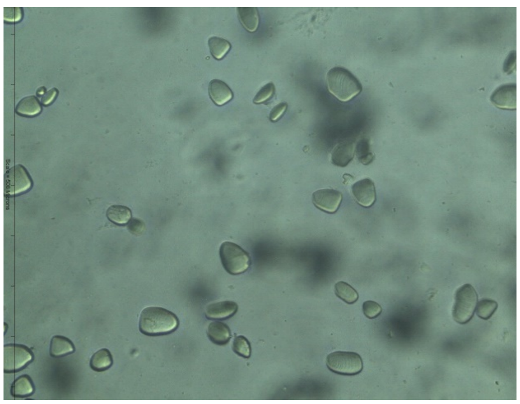
(vi) TDr99-02607 (mag ×20)



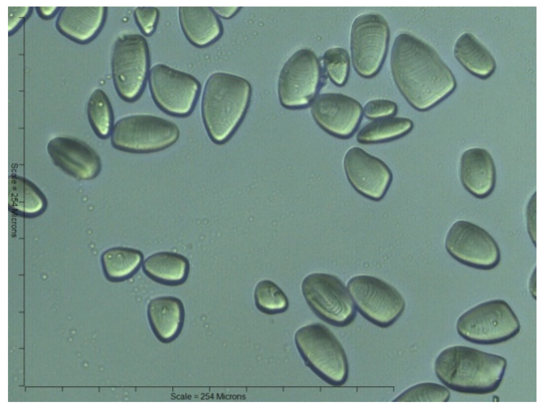
(vii) TDr89 21-3 (mag ×20)



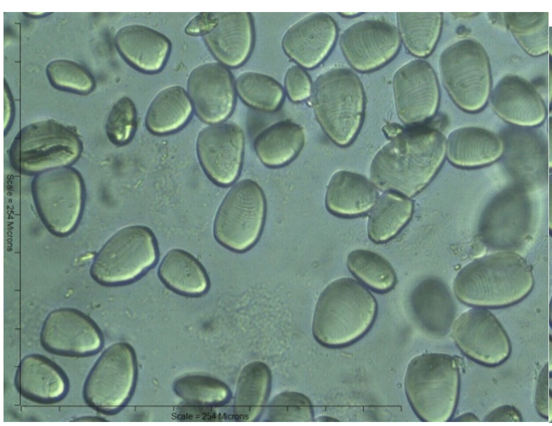
(viii) Agba (mag ×20)



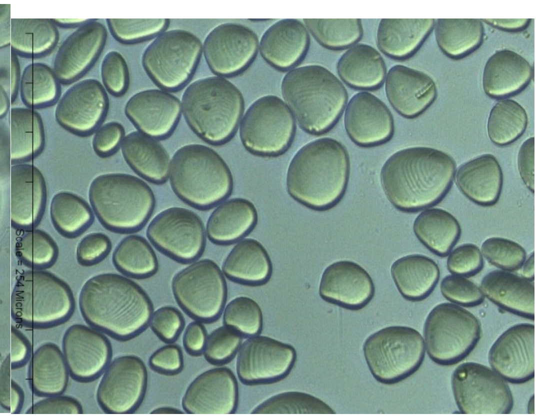
(ix) Agboyo-abbi (mag ×20)



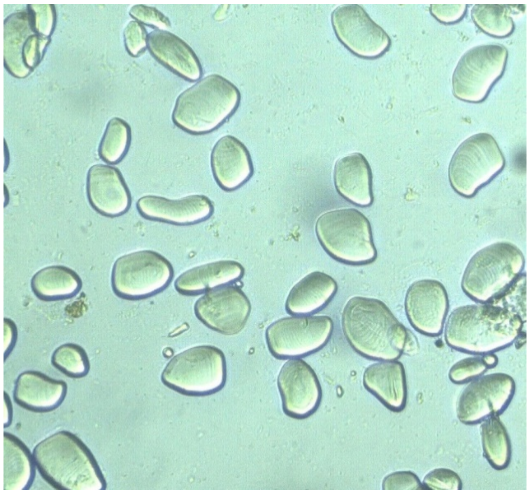
(x) Ameh (mag ×20)

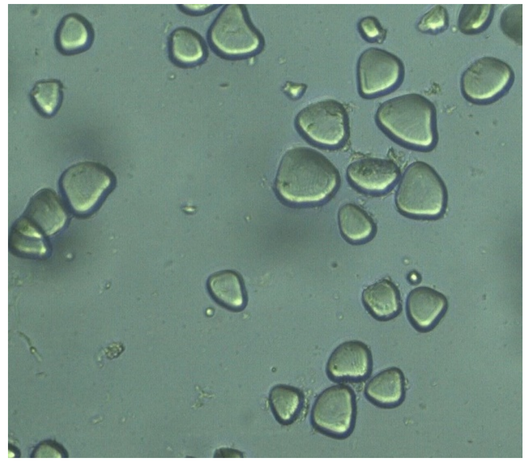


(xi) Fakinsa (mag ×20)



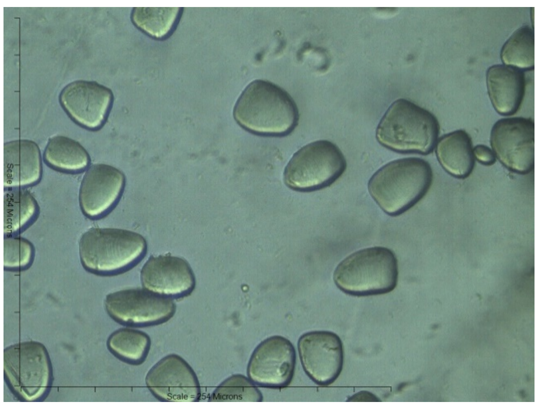
(xii) Lagos (mag ×20)

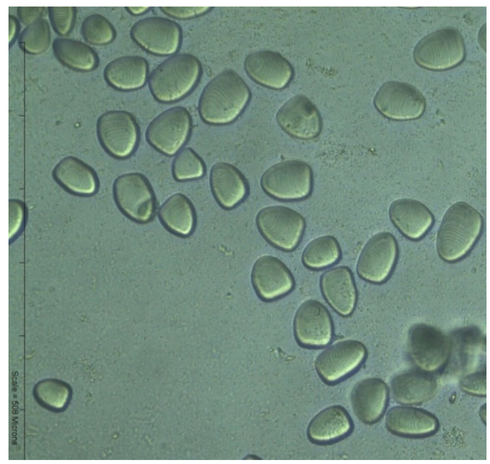




(xiii) Nwopoko (mag ×20)

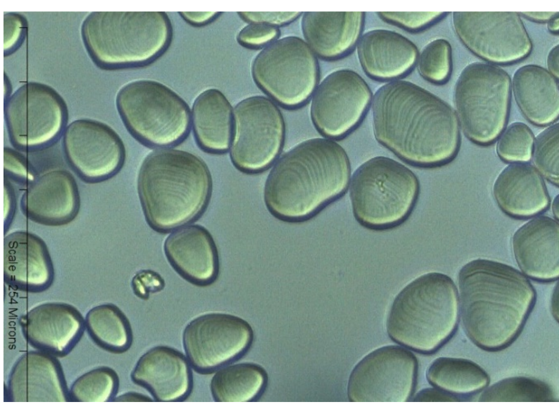
(xiv) PAA-IITA (mag ×20)

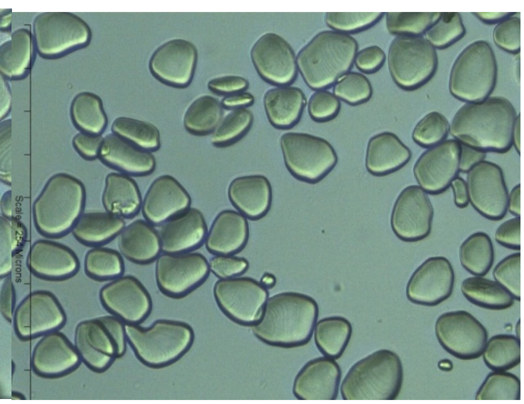




(xv) Pampas (mag ×20)

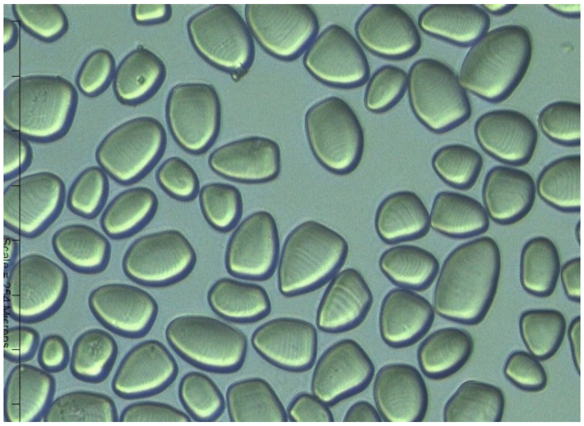
(xvi) Ogoja (mag ×20)





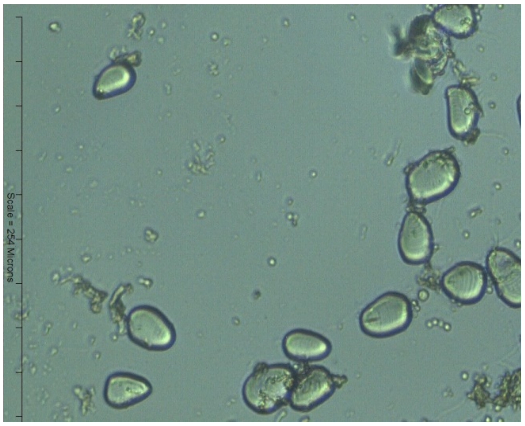
(xvii) Sandpaper (mag ×20)

(xviii) Takalafia (mag ×20)

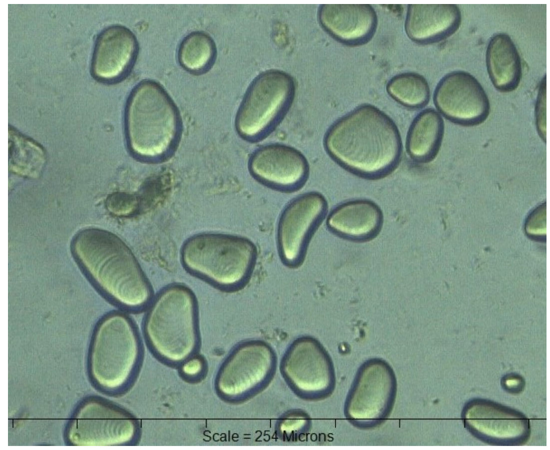


(xix) 2665 (mag ×20)

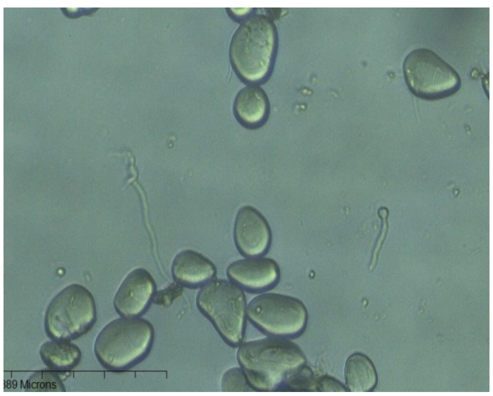
Figure 4.1: Starch granule shapes of *D. rotundata*varieties



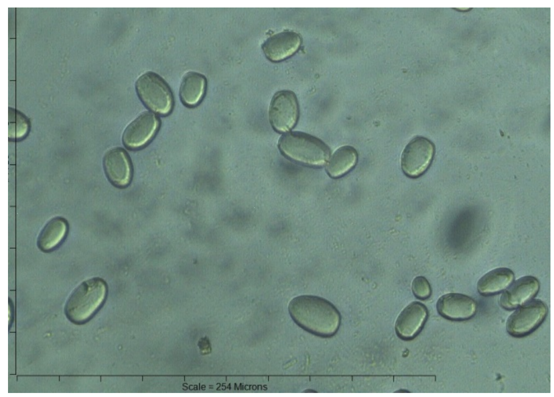
(i) TDa11/00011



(ii) TDa11/00014

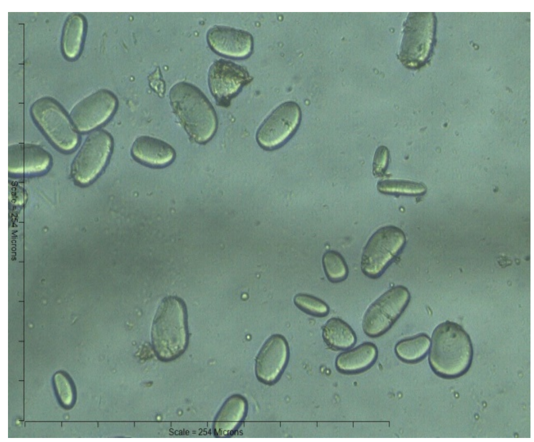


(iii) TDa11/00020



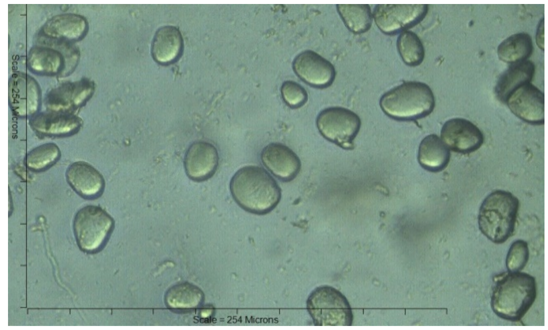
(iv) TDa11/00022

(v) TDa11/00024



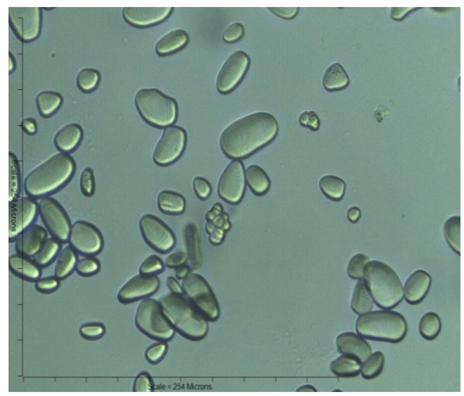
(vi) TDa11/00063

(vii) TDa11/00102 (mag x40)



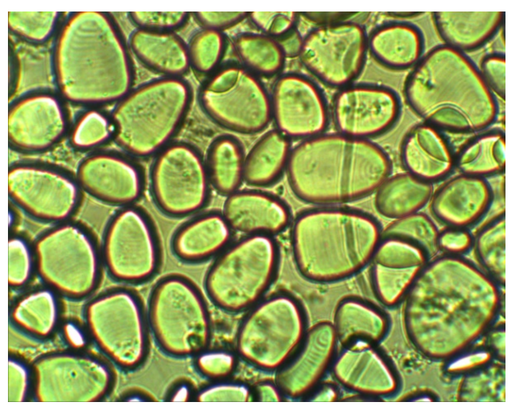
(viii) TDa11/00110

(ix) TDa11/00138



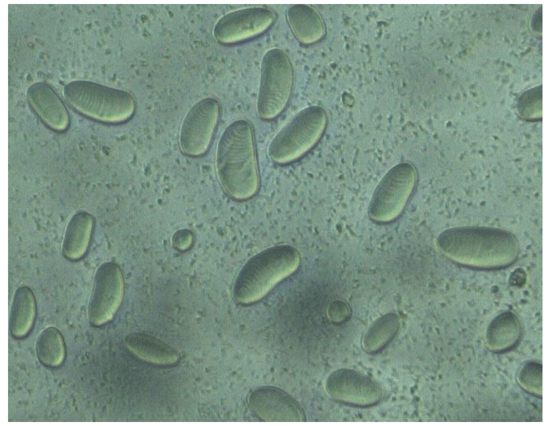
(x) TDa11/00162

(xi) TDa11/00164

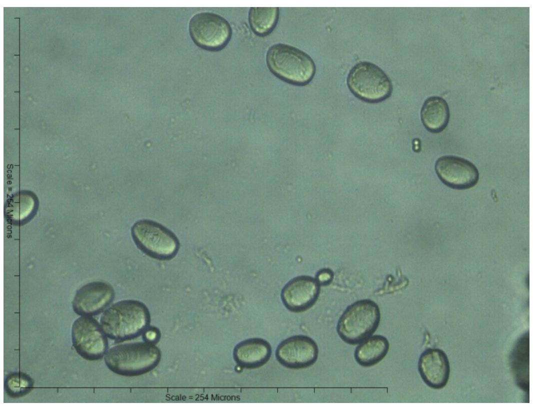


(xii) TDa11/00167

(xiii) TDa11/00179



(xiv) TDa11/00189



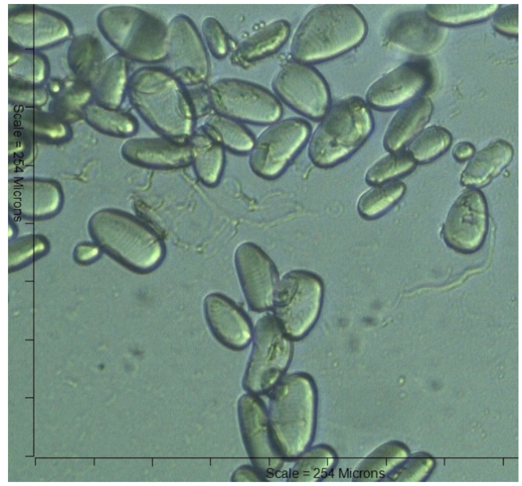
(xv) TDa11/00225

(xvi) TDa11/00232

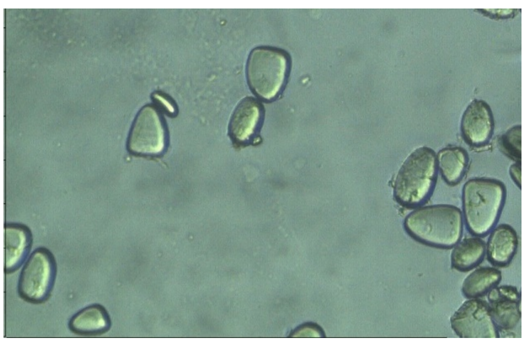
(xvii) TDa11/00242

(xviii) TDa11/00247

(xix) TDa11/00275



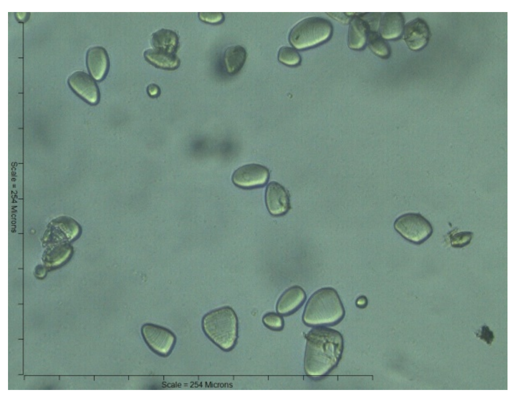
(xx) TDa11/00287



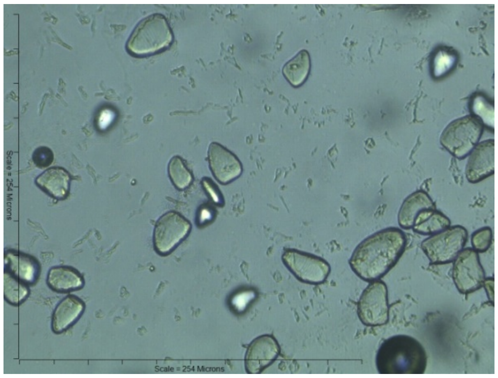
(xxi) TDa11/00292

(xxii) TDa11/00299

(xxiii) TDa11/00305

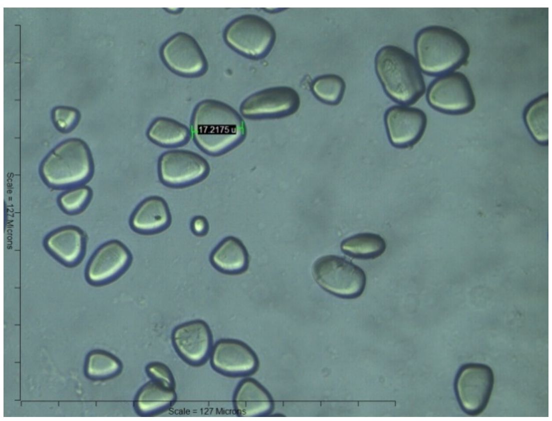


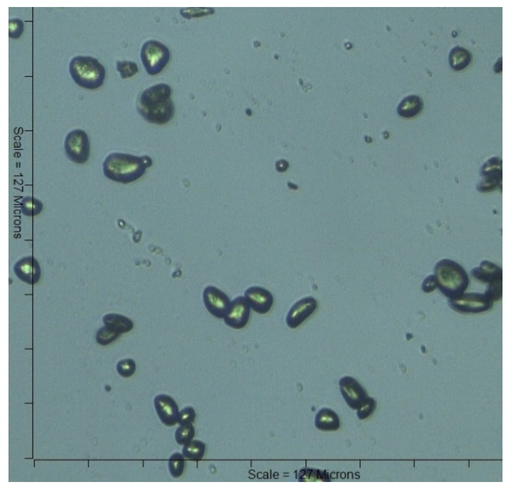
(xxiv) TDa11/00317



(xxv) TDa11/00324

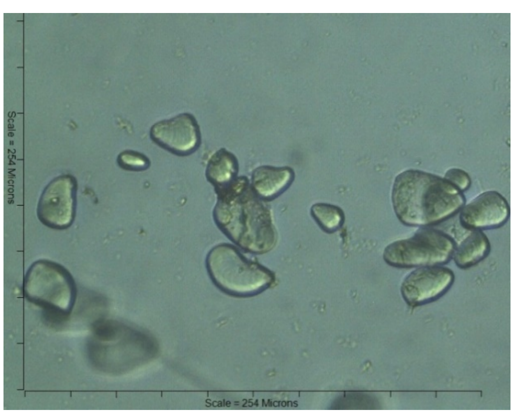
(xxvi) TDa11/00368

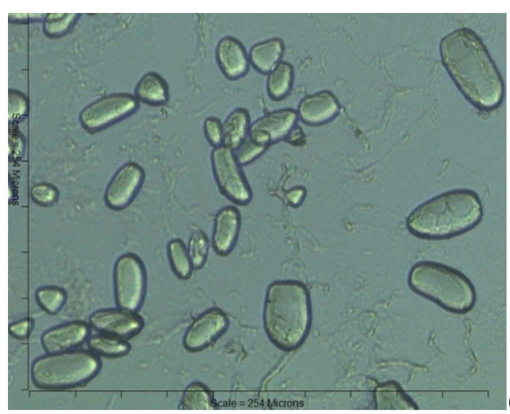




(xxvii) TDa11/00370

(xxviii) TDa11/00374

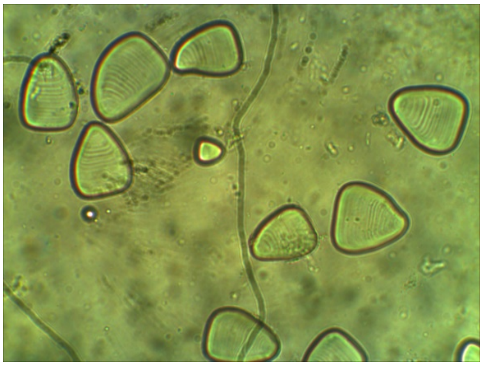




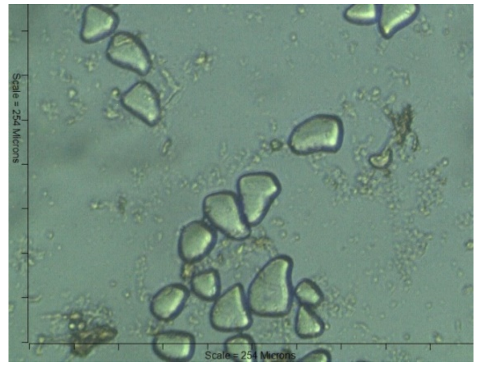
(xxix)

TDa11/00424

(xxx) TDa11/00426



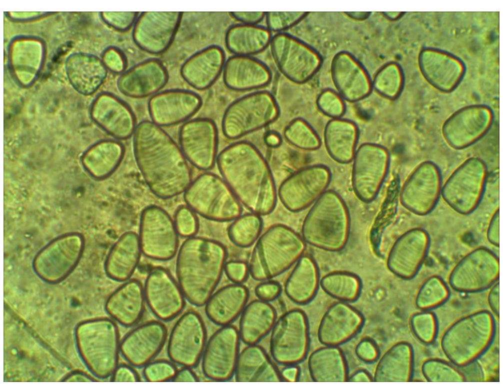
(xxxi) TDa11/00428



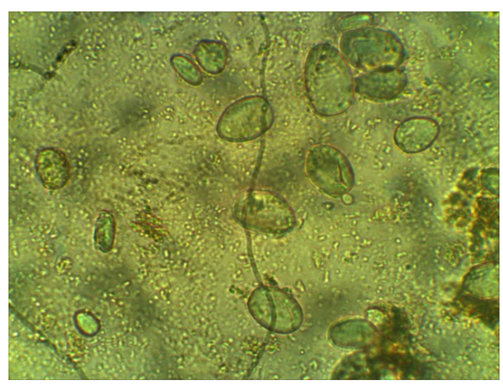
(xxxii) TDa11/00434

(xxxiii) TDa11/00493

(xxxiv) TDa11/00495



(xxxv) TDa11/00541



(xxxvi) TDa11/00555

Figure 4.2: Starch granule shapes of *D. alata* varieties

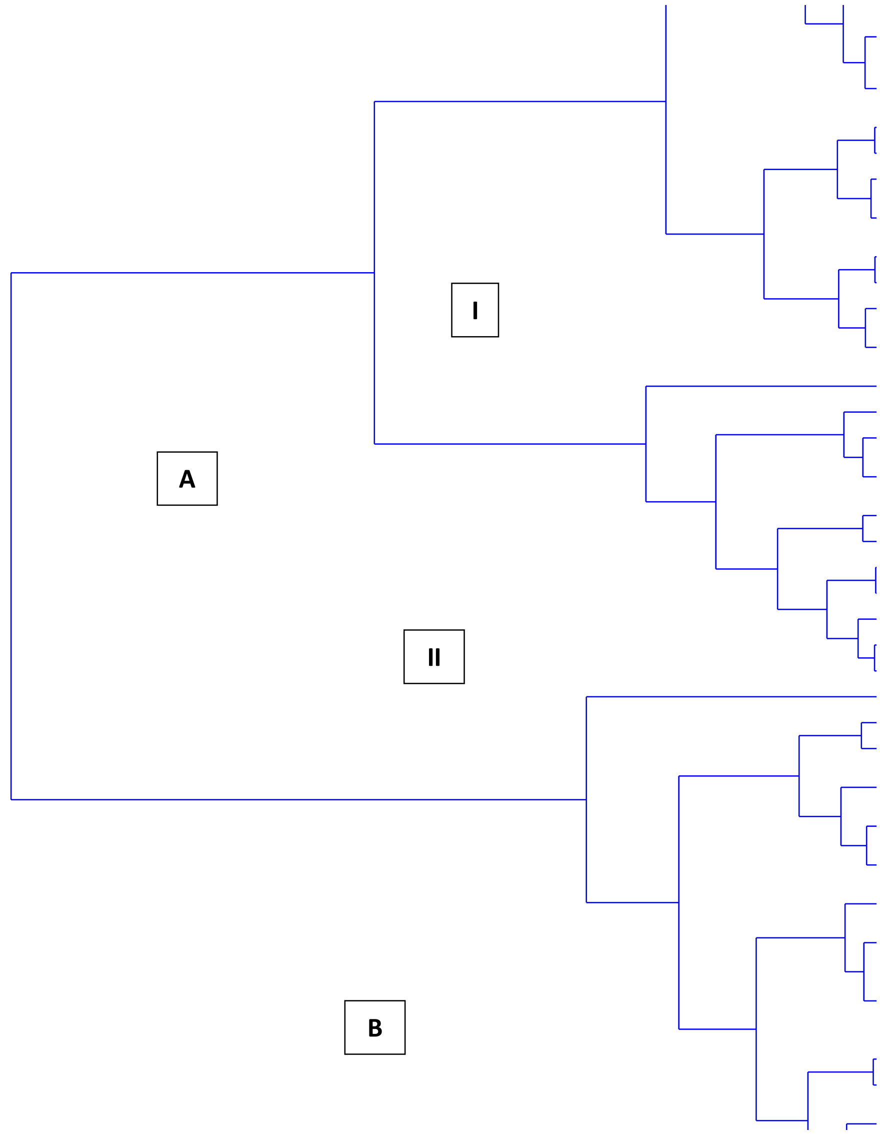


Figure 4.3: Cluster analysis of granule morphology for *Dioscoreaspp*

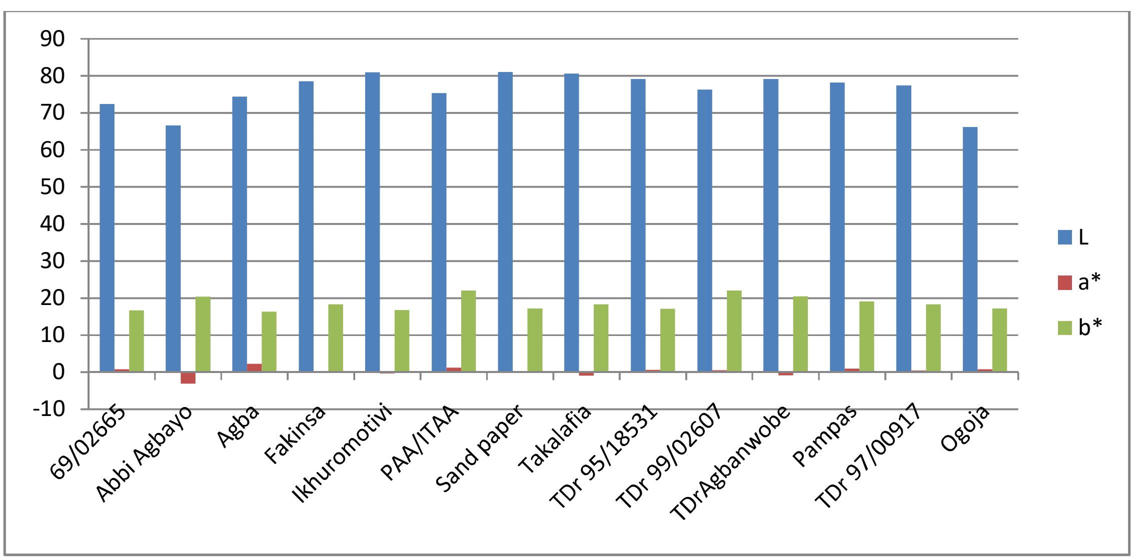
and Otegbayo *et al.*, 2014). Hence, varieties in cluster A, sub-group II could find use in food that requires high viscosity.

4.2 Colour Parameters of Fresh *D. alata*and *D. rotundata* Varieties

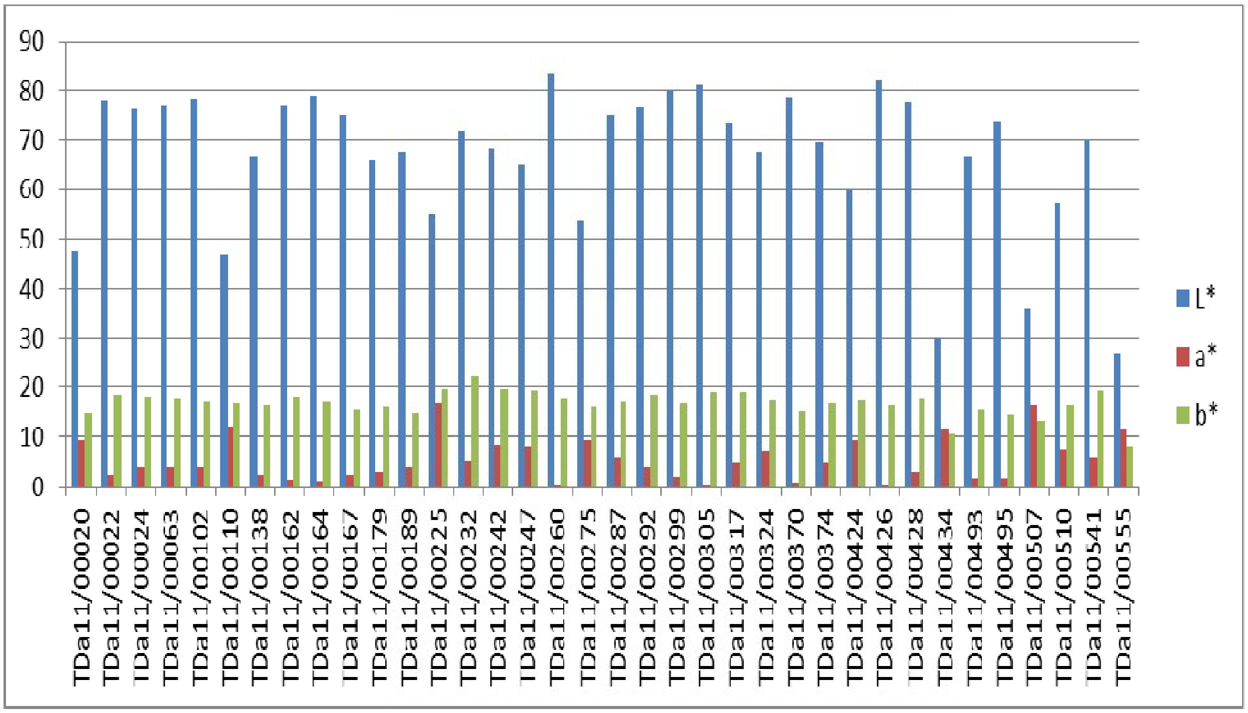
The CIE tristimulus (L: lightness, *a axis: red-green, *b axis: yellow-blue) variables presents the average colour characteristics estimates of the fresh yam tuber varieties. The colour of a food product is the first point of quality parameter assessed by users, which is a factor that determines the acceptance of such a product. The colour parameters of the fresh yam tubers for *D. rotundata* and *D. alata*varieties are shown in

Figure 4.4. *D. rotundata* had an average L* value of 76.18, ranging between 66.19 and 81.06. Variety *Ogoja*had the lowest L* value while sandpaper had the highest value. The L* parameter of the fresh *D. alata* had an average value of 67.09, ranging from 26.88 to 83.40, with variety TDa11/00555 having the lowest, while variety TDa11/00260 had the highest. The higher L* of *D. rotundata* species reflects lighter colours of the fresh yam tubers than those of *D. alata*, which could be a factor of higher phenolic contents and higher rate of browning on exposure to air of *D. alata* species. Hence, *D. alata* species possess more polyphenol contents and presence of cyaniding glycosides responsible for the higher discoloration of fresh yam tubers (Mestres*et al.*, 2004).

For *D. rotundata,* the a* values ranged from -3.08 to 2.28, having an average value of 0.15, with varieties *Abbi Agbayo* and *Agba* having the lowest and highest values respectively. The a* coordinate of species of *D. alata* had an average value of 5.40, ranging from 0.20 to 16.80, with sample TDa11/00260 having the lowest and sample TDa11/00225, the highest. These positive values are indication of the yam varieties tending more towards red rather than green. *D. rotundata* had an average b* value of 18.59, with a range of values from 17.16 to 22.03, showing that the samples tend more towards yellow than blue. The b* coordinate of the fresh *D. alata* had an average value of 16.84, which ranged from 8.07 to 22.19. The colour tends more towards yellow than blue because of their positive values. The colour analysis showed that fresh yam tubers of *D. rotundata* species were creamish-white in colour, while those of *D. alata* species were creamish-brown in colour.



(a) ***D. rotundata***



(a) ***D. alata***

Figure 4.4: Colour parameters of fresh tubers *Dioscoreaspp*

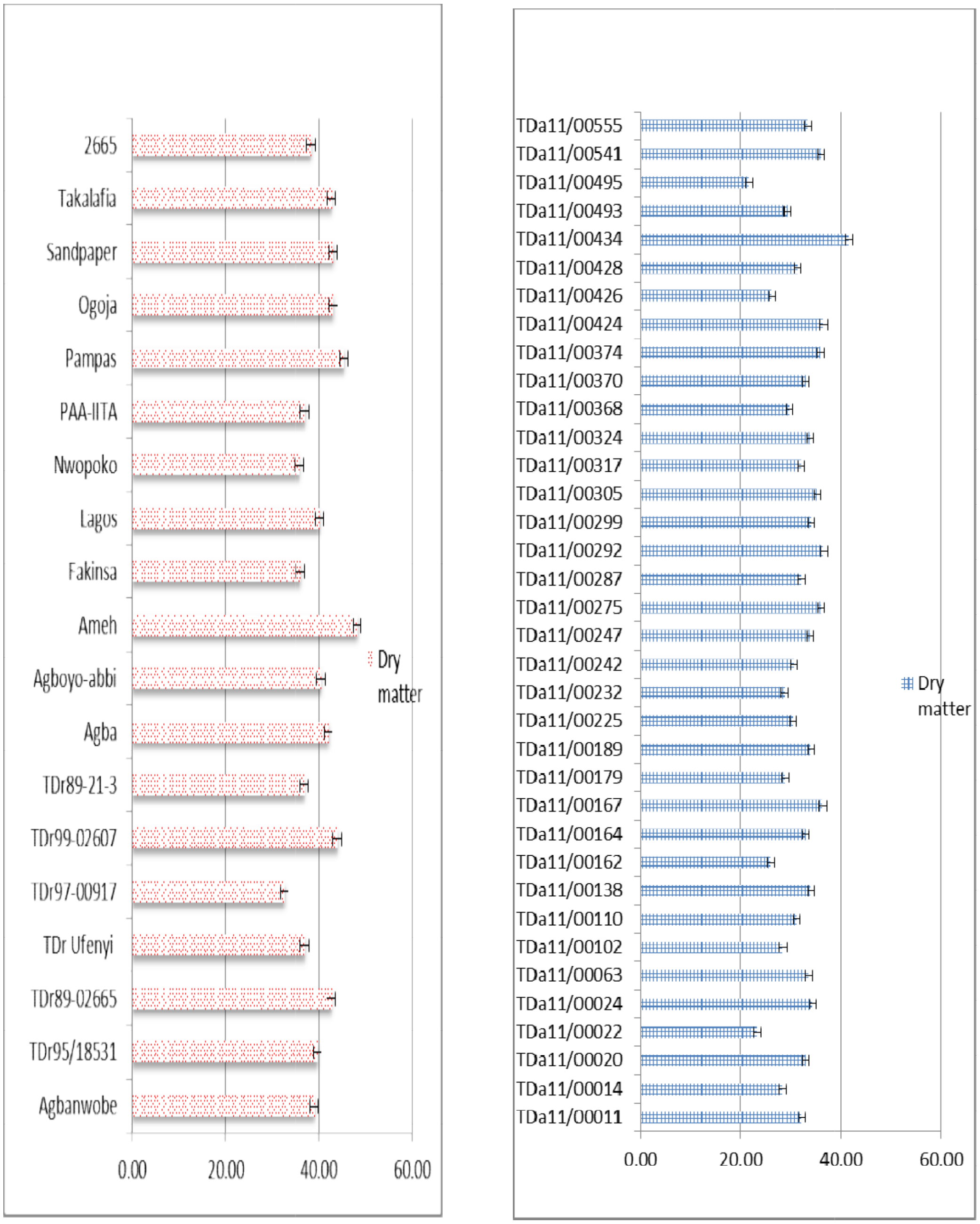
4.3 Dry Matter Contents of the Yam Species

The dry matter contents of the fresh yam tubers are as presented in Figure 4.5 for *D. rotundata* and *D. alata.* It ranged from 32.55 to 48.19% and 21.59 to 41.60% for *D. rotundata* and *D. alata* varieties respectively. This is similar to the report of Wireko-Manu *et al.* (2011) for *D. alata* (20.70 – 43.53%), and Behera *et al*. (2009) for *D. alata* found in Orissa, India (24.91 – 33.33%). Similar results were also given by Ezeocha*et al.* (2015) (30.50 – 36.78%) and Chukwu *et al.* (2007) (27.9 to 38.8%) for *D. rotundata* species. Izutsu and Wani (1985) reported that good eating quality attributes of root and tuber products and their textural quality are due to high dry matter content. Hence, *D. rotundata* species yielding food of good eating and textural quality than those of *D. alata*. Lebot*et al.* (2005) observed good eating quality for food product made from *D. alata*with high dry matter content. Higher dry matter composition as well signify greater yield per constituent, which invariably implies greater economic value (Fakir *et al.,* 2012). Dry matter composition variations could as well be due to variations in the genotype and species of the yam.

4.4 Chemical Composition of yam flour

The results of the crude fat, fibre, ash, crude protein, sugar, starch, amylose and amylopectin content of the yam flour for varieties of *D. rotundata* and *D. alata* are shown in Table 4.3 and Table 4.4 respectively. This study showed low values of crude fat content for *Dioscoreaspp,* which ranged from 0.22 – 0.37% for *D. rotundata* varieties and 0.29 – 0.41% for *D. alata* (Table 4.3 and 4.4), with insignificant difference ($p \geq 0.05$) between the average of *D. rotundata* and *D. alata* species (Table 4.5). Polycarp *et al.* (2012) gave similar report of low fat content of less than 1% for yam varieties. However, slightly higher values were observed for *D. alata* (0.67 – 1.24%) by Behera *et al.* (2009), *D. alata*(1.62 to 2.41%) by Oko and Famurewa (2015), *D. rotundata* (0.36 – 3.39%) by Alamu*et al.* (2014).

The crude fibre content of flour from species of *D. rotundata*varieites (1.14 to 2.26%) were significantly lower than those of *D. alata*varieties (2.05 to 4.48%) (Table 4.5). These findings are slightly greater than values presented by Polycarp *et al.* (2012) for*D. alata*(1.59 – 1.75%) and similar for *D. rotundata* (1.25 – 1.68%) of Ghanaian yam germplasm, Behera *et al.* (2009) for *D. alata* (1.31 – 2.60%) as well as



(a) *D. rotundata* (b) *D. alata*

Figure 4.5: Dry matter contents of fresh *Dioscoreaspp*

Table 4.3: Chemical composition of yam flour from *D. rotundata* varieties

Sample	% Crude fat	% Crude Fibre	% moisture content	% Ash	% Protein	% Starch	% Sugar	Other components
Agbanwobe	0.31^{ef}	1.67^{i}	5.41^{g}	3.10^{hij}	5.08^{d}	50.01^{e}	4.72^{c}	29.73
TDr95/18531	0.29^{cd}	1.39^{cde}	3.78^{a}	2.32^{d}	5.09^{d}	53.69^{fg}	5.05^{ef}	28.42
TDr89-02665	0.26^{b}	1.14^{a}	4.51^{cde}	3.02^{ghi}	5.22^{de}	50.93^{e}	5.40^{j}	29.53
TDrUfenyi	0.29^{cd}	1.24^{b}	4.28^{bcd}	2.52^{e}	5.11^{d}	55.40^{h}	4.67^{c}	26.51
TDr97-00917	0.37^{i}	2.26^{l}	4.22^{bc}	3.94^{l}	6.89^{gh}	41.34^{b}	5.07^{efg}	35.94
TDr99-02607	0.32^{fg}	1.60^{hi}	4.56^{cde}	2.93^{gh}	5.19^{d}	33.57^{a}	4.26^{a}	47.59
TDr89-21-3	0.34^{h}	1.62^{hi}	4.51^{cde}	3.17^{ij}	4.60^{b}	48.73^{d}	4.85^{d}	32.19
Agba	0.34^{h}	2.15^{k}	3.55^{a}	2.77^{f}	4.11^{a}	48.27^{d}	5.08^{efgh}	33.75
Agboyo-abbi	0.30^{e}	1.53^{gh}	6.16^{h}	3.04^{ghi}	7.71^{i}	65.97^{l}	4.70^{c}	10.60
Ameh	0.33^{g}	1.64^{i}	4.48^{cde}	1.63^{a}	4.71^{bc}	43.41^{c}	4.51^{b}	39.31
Fakinsa	0.22^{a}	1.29^{bc}	6.59^{i}	3.02^{ghi}	4.97^{cd}	51.11^{e}	4.54^{b}	28.28
Lagos	0.31^{ef}	1.47^{efg}	4.82^{ef}	2.07^{c}	5.73^{f}	52.76^{f}	4.85^{d}	28.01
Nwopoko	0.32^{g}	2.05^{j}	5.31^{g}	2.34^{d}	5.18^{d}	53.93^{fg}	5.20^{i}	25.69
PAA-IITA	0.26^{b}	1.34^{bcd}	6.59^{i}	2.88^{fg}	5.49^{ef}	63.70^{k}	4.67^{c}	15.10
Pampas	0.30^{e}	1.52^{fgh}	5.09^{fg}	3.34^{k}	7.44^{i}	53.75^{fg}	5.13^{fghi}	23.44
Ogoja	0.30^{de}	1.42^{def}	4.28^{bcd}	1.91^{b}	6.66^{g}	59.55^{j}	5.14^{ghi}	20.76
Sandpaper	0.34^{h}	1.34^{bcd}	3.53^{a}	1.59^{a}	5.63^{f}	62.78^{k}	5.16^{hi}	19.64
Takalafia	0.28^{c}	1.52^{fgh}	4.72^{def}	3.23^{jk}	6.98^{h}	54.33^{fg}	5.21^{i}	23.75
2665	0.33^{g}	1.61^{hi}	3.95^{ab}	2.21^{cd}	6.70^{gh}	56.58^{i}	5.01^{e}	23.63
Mean	**0.30**	**1.57**	4.75	**2.68**	**5.71**	**52.62**	**4.90**	**27.46**
STD	0.04	0.30	0.92	0.62	1.03	7.83	0.30	8.44

*Values are average of replicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.

Table 4.4: Chemical composition of yam flour from *D. alata* varieties

Sample	% Crude Fat	% Crude Fibre	% moisture content	% Ash	% Protein	% Starch	% Sugar	Other component (%)
TDa11/00011	0.40^{k}	4.48^{q}	6.44^{j}	6.73^{q}	9.38^{st}	38.83^{mn}	4.99^{r}	28.76
TDa11/00014	0.37^{i}	4.12^{p}	7.58^{m}	6.60^{p}	8.87^{q}	31.94^{g}	4.50^{jk}	36.04
TDa11/00020	0.33^{de}	2.21^{b}	5.46^{f}	3.34^{a}	6.27^{b}	43.41^{rs}	4.58^{lm}	34.41
TDa11/00022	0.33^{cd}	2.69^{g}	6.90^{l}	3.87^{b}	5.84^{a}	38.19^{lmn}	4.42^{h}	37.79
TDa11/00024	0.38^{j}	2.05^{a}	4.48^{b}	4.87^{hi}	9.12^{r}	37.89^{lm}	4.74^{op}	36.49
TDa11/00063	0.36^{fg}	2.74^{gh}	6.21^{i}	5.32^{j}	6.99^{e}	30.29^{f}	4.44^{hi}	43.67
TDa11/00102	0.40^{k}	3.76^{n}	4.81^{c}	6.18^{n}	8.56^{mno}	33.75^{i}	4.85^{q}	37.71
TDa11/00110	0.32^{c}	2.69^{g}	7.87^{no}	5.91^{m}	8.72^{opq}	22.30^{b}	4.00^{c}	48.20
TDa11/00138	0.29^{a}	2.07^{a}	8.52^{p}	3.88^{b}	6.95^{e}	42.80^{qr}	4.21^{e}	31.29
TDa11/00162	0.37^{i}	2.06^{a}	4.81^{c}	4.95^{i}	8.83^{pq}	36.37^{jk}	4.73^{op}	37.90
TDa11/00164	0.38^{j}	3.04^{j}	6.69^{k}	6.39^{o}	9.90^{u}	36.10^{j}	4.51^{jk}	33.00
TDa11/00167	0.35^{f}	2.59^{ef}	5.93^{gh}	4.17^{d}	7.50^{g}	41.82^{p}	4.55^{kl}	33.11
TDa11/00179	0.38^{j}	3.25^{l}	5.74^{g}	5.84^{m}	8.54^{lmn}	36.87^{jk}	4.72^{o}	34.67
TDa11/00189	0.31^{b}	2.65^{fg}	8.83^{q}	4.87^{hi}	9.32^{s}	33.21^{hi}	4.07^{d}	36.75
TDa11/00225	0.35^{f}	2.87^{i}	5.32^{ef}	4.45^{e}	5.76^{a}	39.01^{n}	4.60^{m}	37.66
TDa11/00232	0.34^{e}	3.47^{m}	7.91^{no}	5.92^{m}	8.03^{j}	28.59^{e}	4.09^{d}	41.67
TDa11/00242	0.36^{gh}	2.78^{h}	7.08^{l}	5.56^{k}	11.20^{x}	36.75^{jk}	4.55^{kl}	31.75
TDa11/00247	0.29^{a}	2.49^{d}	10.16^{s}	4.77^{gh}	8.69^{nop}	36.50^{jk}	3.84^{a}	33.28
TDa11/00275	0.35^{f}	2.59^{ef}	7.82^{n}	5.43^{j}	11.06^{x}	40.78^{o}	4.34^{g}	27.64
TDa11/00287	0.38^{j}	2.86^{i}	5.02^{cd}	4.17^{d}	7.18^{f}	50.65^{t}	5.15^{s}	24.62
TDa11/00292	0.36^{gh}	3.89^{o}	7.01^{l}	7.61^{s}	8.88^{q}	17.29^{a}	4.07^{d}	50.90
TDa11/00299	0.41^{l}	2.91^{i}	3.39^{a}	5.71^{l}	7.86^{ij}	32.58^{gh}	4.77^{p}	42.38
TDa11/00305	0.37^{hi}	3.69^{n}	6.11^{hi}	6.24^{n}	8.02^{j}	33.52^{hi}	4.40^{h}	37.66
TDa11/00317	0.32^{c}	3.20^{kl}	7.74^{mn}	5.34^{j}	8.32^{k}	32.91^{ghi}	4.27^{f}	37.91
TDa11/00324	0.31^{b}	3.14^{k}	8.05^{o}	5.72^{l}	6.75^{d}	23.69^{c}	3.92^{b}	48.46
TDa11/00368	0.32^{c}	2.29^{bc}	8.09^{o}	3.82^{b}	8.39^{kl}	51.98^{u}	4.53^{kl}	20.58
TDa11/00370	0.33^{de}	4.08^{p}	9.21^{r}	3.86^{b}	9.23^{rs}	42.07^{pq}	4.51^{jk}	26.73
TDa11/00374	0.36^{gh}	2.49^{d}	5.20^{de}	4.68^{fg}	7.61^{gh}	38.61^{mn}	4.83^{q}	36.24
TDa11/00424	0.37^{hi}	2.32^{c}	6.08^{hi}	3.99^{c}	7.72^{hi}	43.05^{qr}	4.51^{jk}	31.98
TDa11/00426	0.35^{f}	2.27^{bc}	5.42^{ef}	4.61^{f}	6.57^{c}	24.52^{cd}	4.28^{f}	52.01
TDa11/00428	0.35	2.51^{de}	7.10^{l}	4.76^{gh}	8.52^{lm}	44.26^{s}	4.47^{ij}	28.04
TDa11/00434	0.36^{gh}	4.45^{q}	8.74^{q}	5.56^{k}	9.49^{t}	50.39^{t}	4.36^{g}	16.66
TDa11/00493	0.36^{gh}	3.19^{kl}	6.48^{j}	5.83^{m}	7.97^{j}	33.90^{i}	4.67^{n}	37.61
TDa11/00495	0.35^{f}	4.09^{p}	7.70^{mn}	7.44^{r}	10.28^{v}	24.73^{d}	4.19^{e}	41.22
TDa11/00541	0.40^{k}	3.27^{l}	6.10^{hi}	6.45^{o}	10.88^{w}	38.59^{mn}	4.76^{op}	29.56
TDa11/00555	0.40^{k}	3.54	7.13^{l}	6.47^{o}	10.14^{v}	37.23^{kl}	4.29^{f}	30.82
Mean	0.35	3.02	6.75	5.31	8.42	36.26	4.46	35.42
STD	0.03	0.69	1.49	1.07	1.39	7.79	0.30	7.78

*Values are average of replicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.

Table 4.5: Chemical composition of yam flour from *Dioscoreaspp*

Species	**Crude fat content (%)**	**Crude Fibre content (%)**	**Moisture content (%)**	**Ash content (%)**	**Protein content (%)**	**Starch content (%)**	**Sugar content (%)**
D. rotundata	0.30±0.04a	1.57±0.30a	4.75±0.92a	2.68±0.62a	5.71±1.03a	52.62±7.83b	4.90±0.30a
D. alata	0.35±0.03a	3.02±0.69b	6.75±1.49b	5.31±1.07b	8.42±1.39b	36.26±7.79a	4.46±0.30a

Means ± std

those of traditional yam flour (1.23 to 1.38%) from *D. rotundata* (Ojokoh and Gabriel, 2010).

Ash content, which is a function of the aggregate of minerals available in a component, ranged from 1.59 to 3.94% and 3.34 to 7.61% for *D. rotundata* and *D. alata*varieties respectively, with *D. alata*varieties having significant higher ash content (Table 4.5). This implies that *D. alata*varieties are higher in mineral contents than *D. rotundata* varieties. Comparable observations were reported by Ezeocha*et al.* (2015) (1.25 to 2.50% for *D. rotundata*), Polycarp *et al.* (2011) (1.29 – 2.54% and 6.19 – 6.29%: *D. rotundata* and *D. alata*resp.) for Ghanaian germplasm, Diegbeu*et al.* (2009) (0.42 to 4.68%, *D. rotundata*) for Cote d'Ivoire land races, Baah (2009) (2.9 to 4.3%), Behera *et al.* (2009) (1.89 to 7.08%) for *D. alata* from India, as well as for *D. rotundata* as reportedbyAlamu*et al.* (2014) 1.39 to 2.93%.

The result showed significant differences both within and among species of *D.* for the crude protein content. The crude protein content of *D. alata* varieties (5.76 – 11.20%) (Table 4.3) were significantly higher than those of *D. rotundata* varieties (4.11 – 7.71%) (Table 4.4) on the average (Table 4.5), similar to previous observations by Polycarp *et al.* (2011) (4.03 – 4.42% for *D. rotundata* and 5.91 – 6.08% for *D. alata*), Baah (2009) (5.2% for species of *D. rotundata* and 4.3 – 8.7% for *D. alata* species). Behera *et al.* (2009) also recorded protein content of 7.31 to 9.67% for *D. alata*collections found in India.

The starch content of species of *D. rotundata* and *D. alata* varied from 33.57% (TDr99-02607) to 65.97% (Agboyo-abbi) and 17.29% (TDa11/00292) to 51.98% (TDa11/00368) (Tables 4.3 and 4.4) respectively. Higher contents of starch were observed by Wireko-Manu *et al.* (2011) (60.42 – 72.56% for species of *D. alata* and 70.26% for *D. rotundata*), Lebot*et al.*, 2005 (63.6 – 78.6%), Baah*et al.*, 2009 (60.3 to 74.4% for varieties of *D. alata*and 78.3% for *D. rotundata* varieties. Varieties of *D. rotundata* species had the sugar content ranging from 4.26% (TDr99-02607) to 5.40% (TDr89-02665), and those of *D. alata*varieties ranging from 3.84% (TDa11/00247) to 5.15% (TDa11/00287). Similar observations of 2.43 to 6.91% were made for the sugar contents of *D. alata* by Wireko-Manu *et al.* (2011), lower values of 3.36% for *D. rotundata* (Alamu *et al.*, 2014), 0.97 to 4.61% for *D. rotundata* and 1.02 to 4.14% for

D. alata reported by Otegbayo *et al*. (2017) but higher values of 3.60 to 11.0% for*D. alata* was reported by Baah*et al.* (2009).

Starch and sugar components of yam have been reported to contribute to the suitability of yam for varying products, because they affect the taste, textural and rheological properties of products from yam (Baah*et al.*, 2009; Wireko-Manu *et al.*, 2011; Otegbayo *et al.*, 2017). In addition to the eating quality, these components could also influence preference of yam varieties by consumers (Otegbayo *et al.,* 2017). The starch component is a significant index in determining the characteristics of food products from yam because it amount to about 80% of yam carbohydrate on a dry weight basis. Sugar makes meaningful contribution to the eating quality of boiled yam as it imparts the sweet taste. It also has effect on the taste of *amala*, as increasing sugar content improves the taste of *amala*. However, it could vary greatly with respect to their species, varieties, cultural practices, agro-climatic and genetic stock (Behera *et al*., 2009; Wireko-Manu *et al.,* 2011; Otegbayo *et al.,* 2017).

The amylose/amylopectin ratio, which impact definite characteristics and functionality to starches, (Mishra and Rai, 2006), varied both within and between the *Dioscorea species* (Figures 4.6 and 4.7). Amylose content of starches from yam have been observed to serve an important role in the resulting textural properties of root and tuber products, as they influence the swelling, gelatinization and pasting properties of yam starches (Otegbayo *et al.*, 2014). This study reflected that the amylose content of yam flour in *D. rotundata*varieties ranged from 27.78 to 41.88% (Figure 4.6), with sample Agboyo-abbi and TDr89-02665 having the lowest and highest values respectively. On the other hand, varieties TDa11/00555 and TDa11/00426 had the lowest (26.27%) and highest (33.40%) values for *D. alata*varieties respectively (Figure 4.7). *D. rotundata* varieties have slightly higher amylose content and lower amylopectin content than those of *D. alata* varieties, which is in contrast to previous observations of *D. rotundata* having lower amylose content and higher amylopectin content of starch than those of *D. alata* (Otegbayo *et al.,* 2011; Baah, 2009).

The amylose contents observed in this research are higher than those reported by Lebot*et al.* (2006) for *D. alata*accessions from Vanuatu (13.4 –20.7%) andEzeocha*et al.* (2015) for *D. rotundata* varieties (17.54 – 29.83%). The values obtained in this study for amylose are similar to those of Baah*et al.* (2009) for *D. alata* varieties (27.2 – 32.

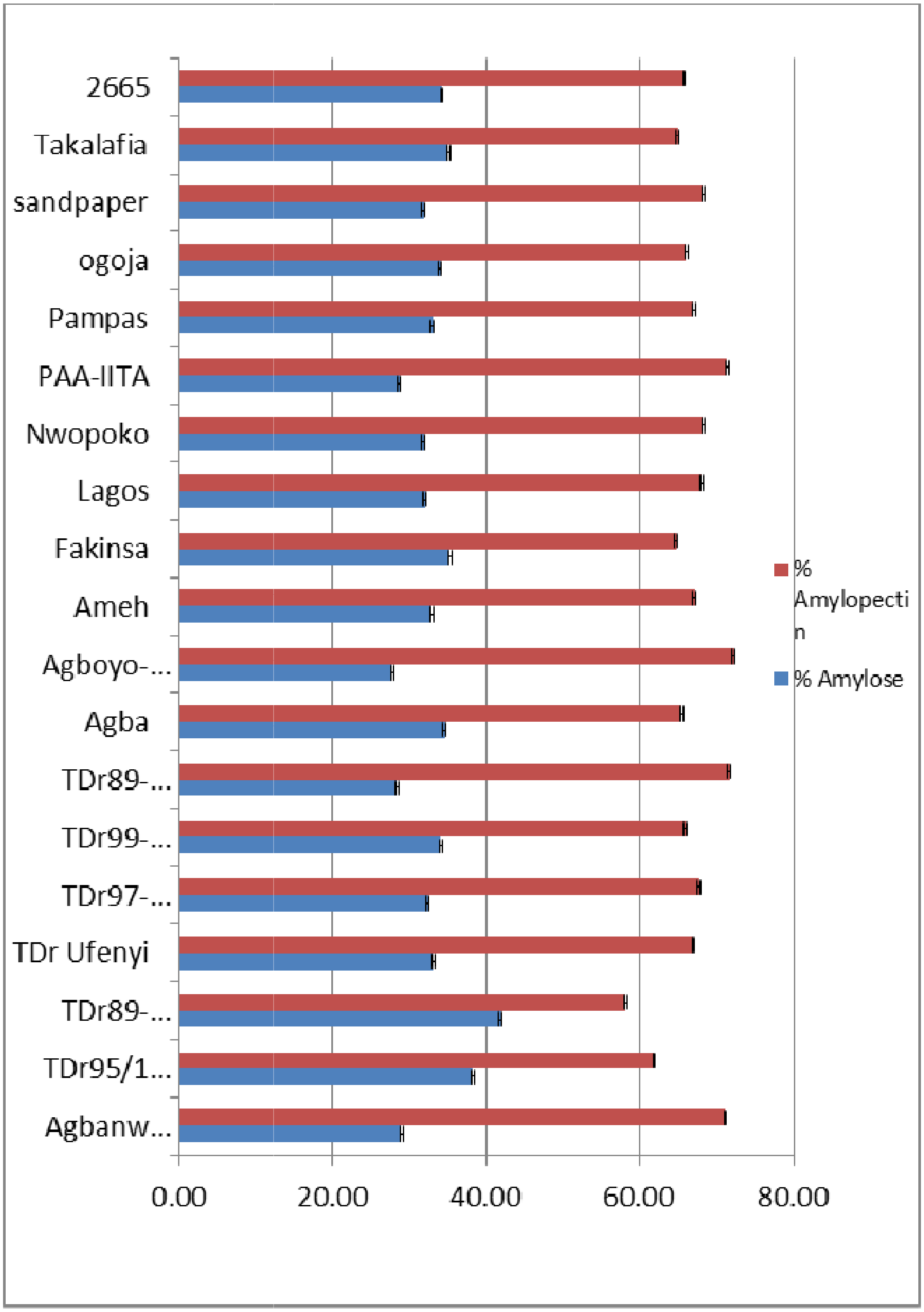


Figure 4.6: Amylose and amylopectin contents of *D. rotundata* varieties

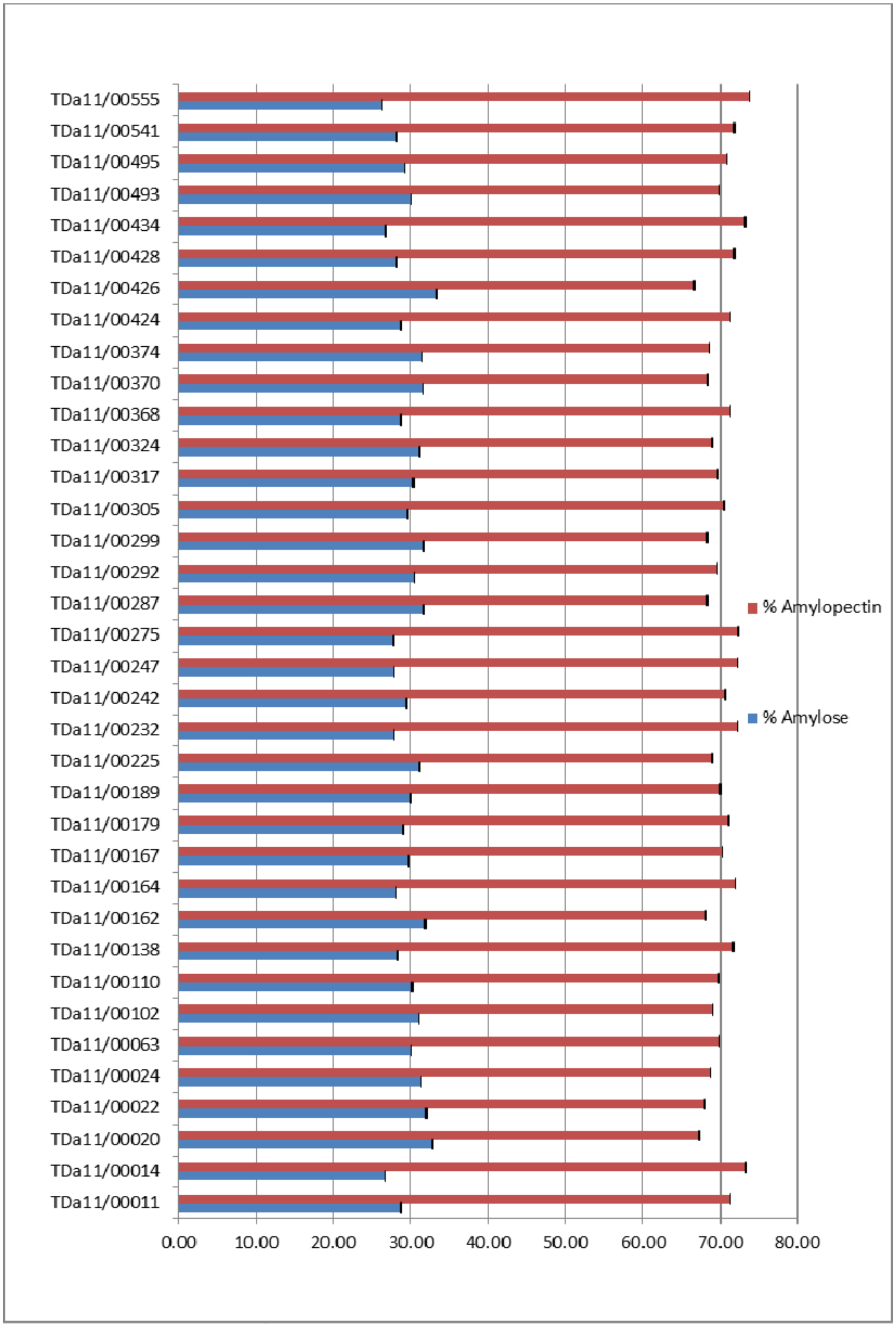


Figure 4.7: Amylose and amylopectin contents of *D. alata* varieties

3%) and *D. rotundata* (26.6%); Otegbayo *et al.* (2011) for *D. rotundata* (27.44 – 33.03%). These variabilities in the content of amylose evaluated in the present study, as well as in comparism with previous studies could be due to a number of factors. Cultural practices and environmental factors could greatly affect the amylose content of yam starch (Akinoso and Abiodun, 2013). Other factors reported by Zhu (2015) include, variation in the quantification method, harvesting year and period, as well as other compositon of the yam tubers. According to Zhu (2015), the endogenous lipid matter is a critical factor that can cause variation in the amylose content of starch, as this can cause inclusion complexes with amylose. Jayakody *et al.* (2007) reported that about 5.6 – 8.3% of amylose in *D. alata*was bound to lipid.

4.5 Anti-nutritional Composition of Yam Flour

Anti-nutrients are known as secondary metabolites, that reduce nutrient use and ingestion of plants or plants products that serve as human food or animal feed (Kumar, 1992). The anti-nutritional compositions of the yam varieties in each species are presented in Tables 4.6 and 4.7. The phytate content range from 0.97 to 1.38% and 0.99 to 1.56% for *D. rotundata* and *D. alata*varieties respectively. Oxalates and phytates have been found to unfavorably affect bioavailability of mineral (Bhandari and Kawabata, 2006), as phytic acid is the form in which phosphorus is stored, and it forms insoluble complexes with positively charged components including trace elements and minerals, which leads to lowered bioavailability of such, including iron, zinc and calcium (Kumar *et al.*, 2010; Otegbayo *et al.*, 2017).

Tannin contents, which are water soluble compounds, (forming insoluble precipitates) forms precipitate with protein by irreversibly binding them, leading to reduced palatability and digestibility (Chung *et al.*, 1998). *D. alata*specie (8.64%) had significantly higher tannin contents than that of *D. rotundata* specie (0.72%), ranging from 0.06 to 1.66% and 3.28 to 17.77% for *D. rotundata* varieties and *D. alata*varieties respectively (Table 4.8) The oxalate contents ranged from 1.75 to 9.85 mg/100g and 4.73 to 35.96 mg/100g for *D. rotundata* and *D. alata*species respectively. Oxalate in yam is present in soluble or insoluble calcium oxalate form. Excessive irritation of the mucous membrane and the skin result when there is close

Table 4.6 Anti-nutritional properties of *D. rotundata* varieties

Sample	Phytate (%)	Tannin (%)	Oxalate (mg/100g)
Agbanwobe	1.19^{g}	1.10^{c}	9.54
TDr95/18531	1.14^{f}	0.33^{a}	6.24
TDr89-02665	1.03^{b}	0.33^{a}	9.26
TDrUfenyi	1.25^{h}	0.12^{a}	4.67
TDr97-00917	1.05^{bc}	1.56^{d}	2.75
TDr99-02607	1.38^{k}	1.58^{d}	4.82
TDr89-21-3	1.12^{ef}	1.46^{d}	5.88
Agba	1.07^{cd}	1.66^{d}	5.96
Agboyo-abbi	1.27^{hi}	0.10^{a}	8.22
Ameh	1.29^{i}	0.97^{bc}	4.81
Fakinsa	1.33^{j}	0.36^{a}	7.45
Lagos	1.20^{g}	0.10^{a}	1.94
Nwopoko	0.97^{a}	1.06^{c}	8.17
PAA-IITA	1.26^{hi}	0.06^{a}	5.89
Pampas	1.09^{de}	0.36^{a}	5.63
Ogoja	1.13^{f}	0.33^{a}	2.95
Sandpaper	1.02^{b}	0.80^{bc}	4.69
Takalafia	1.08^{cd}	0.72^{b}	9.85
2665	1.12^{ef}	0.73^{b}	1.75
Mean	**1.15**	**0.72**	**5.81**

STD	**0.11**	**0.55**	**2.47**

*Values are average of replicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.

Table 4.7 Anti-nutritional properties of *D. alata* varieties

Sample	Phytate (%)	Tannin (%)	Oxalate (mg/100g)
TDa11/00011	1.04^{b}	15.19^{t}	22.12
TDa11/00014	1.28^{jk}	11.95^{p}	16.44
TDa11/00020	1.23^{h}	3.87^{b}	14.92
TDa11/00022	1.30^{kl}	7.22^{h}	17.27
TDa11/00024	1.16^{ef}	3.78^{b}	5.27
TDa11/00063	1.29^{kl}	8.19^{j}	15.06
TDa11/00102	1.08^{c}	11.60^{o}	8.46
TDa11/00110	1.46^{q}	6.98^{h}	11.88
TDa11/00138	1.41^{o}	3.28^{a}	16.84
TDa11/00162	1.15^{ef}	4.05^{b}	7.97
TDa11/00164	1.26^{ij}	10.17^{m}	8.35
TDa11/00167	1.25^{i}	4.55^{c}	9.58
TDa11/00179	1.16^{fg}	7.90^{i}	10.30
TDa11/00189	1.45^{pq}	6.43^{f}	4.73
TDa11/00225	1.21^{h}	9.44^{kl}	5.17
TDa11/00232	1.44^{p}	10.53^{n}	10.24
TDa11/00242	1.26^{ij}	6.72^{g}	8.76
TDa11/00247	1.56^{s}	5.67^{e}	6.77
TDa11/00275	0.99^{a}	7.70^{i}	14.81
TDa11/00287	1.42^{o}	15.14^{t}	9.01
TDa11/00292	1.14^{de}	10.40^{mn}	35.96
TDa11/00299	1.29^{kl}	13.61^{r}	11.69
TDa11/00305	1.35^{m}	10.13^{m}	9.02
TDa11/00317	1.50^{r}	9.60^{l}	21.40
TDa11/00324	1.28^{jk}	5.21^{d}	11.79
TDa11/00368	1.22^{h}	5.31^{d}	14.31
TDa11/00370	1.13^{d}	4.39^{c}	7.41
TDa11/00374	1.30^{l}	4.56^{c}	9.88
TDa11/00424	1.34^{m}	5.77^{e}	7.23
TDa11/00426	1.28^{jk}	5.81^{e}	6.78
TDa11/00428	1.34^{m}	17.77^{u}	10.44
TDa11/00434	1.18^{g}	9.30^{k}	6.93
TDa11/00493	1.40^{o}	12.59^{q}	22.50
TDa11/00495	1.39^{o}	12.58^{q}	8.58
TDa11/00541	1.14^{def}	9.30^{k}	13.69

TDa11/00555	1.37[n]	14.59[s]	12.31
Mean	**1.28**	**8.64**	**12.42**
STD	**0.13**	**3.79**	**6.51**

*Values are average of replicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.

Table 4.8: Anti-nutritional properties of *D. rotundata* and *D. alata*species

Species	Phytate (%)	Tannin (%)	Oxalate (mg/100g)
D. Rotundata	1.15 ± 0.11[a]	0.72 ± 0.55[a]	5.81 ± 2.47[a]
D. alata	1.28 ± 0.13[b]	8.64 ±3.79[b]	12.42±6.51[b]

Mean ± standard deviation

contact between calcium oxalate crystal (raphides) and yam mucilage (Otegbayo *et al.*, 2017).

The tannin, phytate and oxalate contents observed in this research are greater than those reported by Okwu*et al.* (2006), Polycarp *et al.* (2012), and Otegbayo *et al.* (2017), but lower than their lethal doses. The reported lethal dose of tannin in plants is between 7.6 – 9.0g/kg (Alecto, 1993) or 1.5 – 2.5g daily (Sharma *et al.*, 2019) and that of oxalate falls between 3-5g for man (Ekop*et al.*, 2007). However, food processing operations including soaking, washing, heat treatment, play significant roles in reducing these anti-nutrients prior to consumption. It has been reported that food preparation by heating or other hydrothermal treatment reduces phytate content by de-phosphorylation; and tannin by denaturation and thermal degradation, as well as oxalates by washing and thermal treatments (Akin-Idowu *et al.*, 2008; Kumoro*et al.* 2014 and Otegbayo *et al.*, 2017). Lewu*et al.* (2009) observed significant drop in the level of anti-nutrients in cocoyam on boiling for 5 minutes: 16 – 78% lessening in oxalate, 28 – 61% lessening in the content of tannin and 17 – 41% lessening in the contnets of phytate. Hence, heat treatment plays a significant role in reducing levels of anti-nutrients in food.

Two major clusters emerged from the dendogram: cluster A and cluster B (Figure 4.8). Cluster A consists of two subgroups I and II, made up of *D. alata* (21 varieties) and *D. rotundata* varieties (19 varieties) respectively. These yam varieties were characterised by the level of oxalate, phytate and tannin content present in the yam tubers. Varieties under cluster A have distinctly lower anti-nutrients contents than those of cluster B. Moreover, cluster A, subgroup II, consisting exclusively of *D. rotundata*, have the lowest contents of anti-nutrients. Cluster B, composed of fifteen (15) varieties of *D. alata*, have the highest anti-nutrients content than those of cluster A sub-group I and II.

4.6 Mineral Contents of Yam Flour

The mineral compositions of yam varieties from *D. rotundata* and *D. alata* species are shown in Tables 4.9 and 4.10 respectively. The results of the macro mineral composition showed that these yam species are relatively significant, nutritionally. The phosphorus (P) content ranged from 22.05 to 62.96 mg/100g in *D. rotundata* (Table 4.9) and 13.37 to 202.31 mg/100g for *D. alata* (Table 4.10) varieties, similar to the

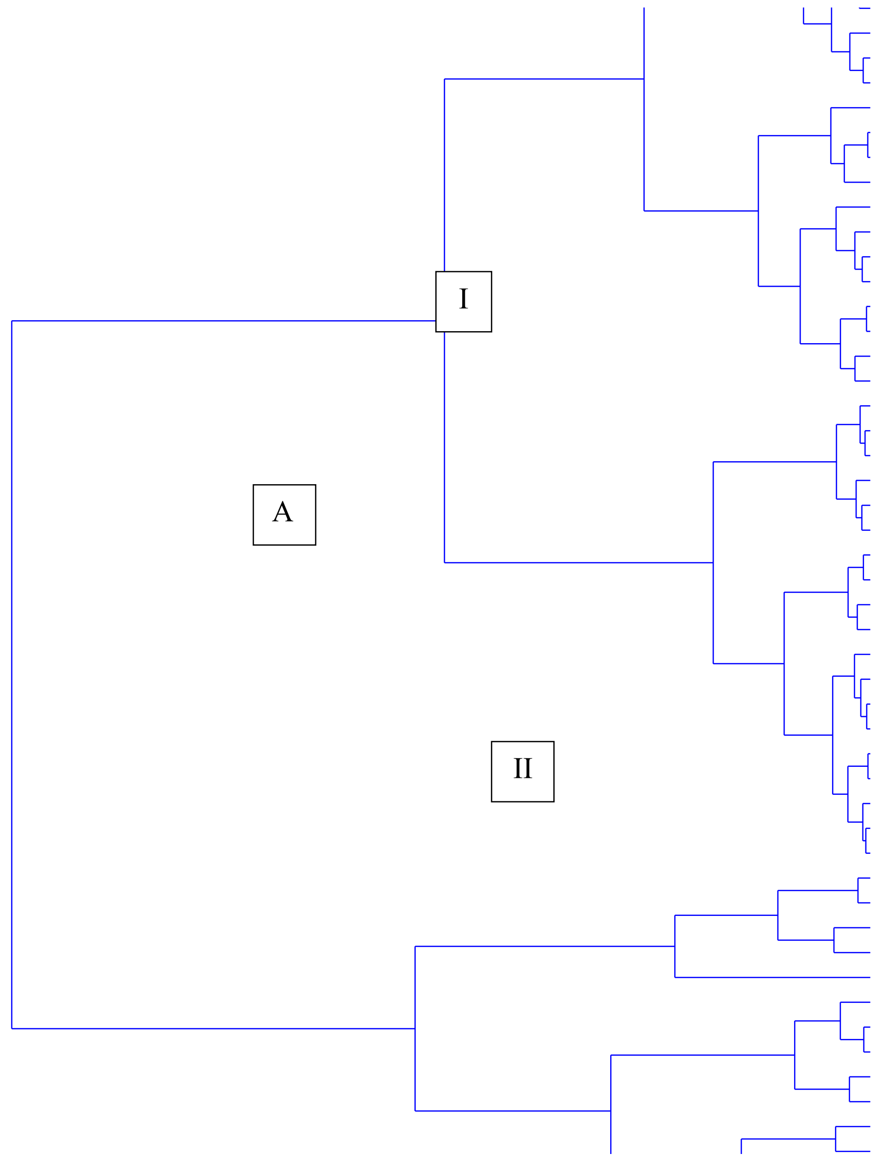


Figure 4.8: Cluster analysis of anti-nutritional properties from *Dioscoreaspp*

B

Table 4.9: Mineral contents of *D. rotundata* varieties

Variety	Magnesium (mg/100g)	Sodium (mg/100g)	Potassium (mg/100g)	Phosphorus (mg/100g)
Agbanwobe	31.98	143.58	324.66	43.97
TDr95/18531	37.76	193.78	246.89	33.29
TDr89-02665	34.92	188.76	347.61	22.05
TDrUfenyi	37.20	158.64	375.02	42.75
TDr97-00917	33.07	198.80	297.89	35.50
TDr99-02607	25.66	168.68	309.36	36.68
TDr89-21-3	36.47	156.13	410.09	46.55
Agba	28.89	176.21	331.67	36.68
Agboyo-abbi	23.76	131.03	215.01	62.96
Ameh	36.93	148.60	267.29	36.81
Fakinsa	27.29	168.68	304.26	44.38
Lagos	42.91	126.01	258.36	42.61
Nwopoko	27.38	163.66	290.24	37.26
PAA-IITA	29.76	118.48	496.79	48.85
Pampas	28.74	133.54	301.07	51.12
Ogoja	38.25	123.50	302.99	55.80
Sandpaper	37.79	178.72	275.57	45.01
Takalafia	38.25	131.03	280.04	31.76
2665	35.50	173.70	313.82	41.74
Mean	**33.29**	**156.93**	**313.09**	**41.88**

Table 4.10: Mineral contents of *D. alata*varieties

Varieties	Magnesium (mg/100g)	Sodium (mg/100g)	Potassium (mg/100g)	Phosphorus (mg/100g)
TDa11/00011	37.16	196.29	314.46	49.50
TDa11/00014	37.02	166.17	320.2	45.72
TDa11/00020	37.72	133.54	277.49	44.66
TDa11/00022	35.99	156.13	300.44	13.37
TDa11/00024	39.69	208.84	306.81	46.62
TDa11/00063	35.58	183.74	307.45	44.73
TDa11/00102	38.93	131.03	276.85	42.75
TDa11/00110	30.7	213.86	325.94	46.97
TDa11/00138	28.7	128.52	212.46	65.49
TDa11/00162	29.43	123.5	209.27	54.55
TDa11/00164	42.23	178.72	309.36	50.16
TDa11/00167	36.03	146.09	262.82	48.41
TDa11/00179	24.27	113.46	210.55	54.24
TDa11/00189	27.53	115.97	226.49	54.08
TDa11/00225	39.73	158.64	313.82	43.08
TDa11/00232	38.01	163.66	278.76	61.26
TDa11/00242	37.47	138.56	302.99	44.67
TDa11/00247	43.24	153.62	302.99	202.31
TDa11/00275	36.69	151.11	287.05	36.81
TDa11/00287	36.89	183.74	310.64	44.73
TDa11/00292	38.22	161.15	309.36	48.69
TDa11/00299	29.03	138.56	205.45	66.11
TDa11/00305	38.77	158.64	294.06	55.64
TDa11/00317	13.72	163.66	383.95	37.13
TDa11/00324	38.75	186.25	422.84	32.58
TDa11/00368	34.64	156.13	324.02	34.02
TDa11/00370	24.98	156.13	201.62	56.12
TDa11/00374	22.6	108.44	190.79	51.12
TDa11/00424	38.16	156.13	313.19	41.80
TDa11/00426	39.54	176.21	279.4	44.59
TDa11/00428	29.67	126.01	213.74	64.08
TDa11/00434	36.4	158.64	317.65	187.61
TDa11/00493	33.42	213.86	286.41	29.51
TDa11/00495	41.18	126.01	315.1	51.95
TDa11/00541	44.48	123.5	262.19	21.16
TDa11/00555	40.43	161.15	301.07	46.26
mean	**34.92**	**155.99**	**285.49**	**54.51**

observations of Otegbayo *et al*. (2017). However, higher values were reported by Polycarp *et al*. (2012) for species of *D. rotundata* and *D. alata* (158.0 – 211.5 mg/100g and 219.0 to 239.0 mg/100g respectively); Udensi*et al.* (2008) for *D. alata* (120.00 – 340.00 mg/100g); Baah (2009) for *D. alata*(877 to 2053 mg/kg. Lower phosphorus content in yam has been attributed to the phytic acid present in yams, as these bind with phosphorus, preventing its availability for nutritional and biochemical utilization (Otegbayo *et al.*, 2017).

The potassium content varied from 215.01 to 496.79 mg/100g and 190.79 to 422.84 mg/100g in the *D. rotundata* and *D. alata*species respectively, with the potassium values of *D. rotundata*species significantly greater than those of *D. alata*species (Table 4.11). Potassium is the most abundant mineral in all the varieties for both species, and this is similar to previous observations (Udensi*et al.*, 2008; Baah 2009; Polycarp *et al.,* 2012; Otegbayo *et al.*, 2017).

The work showed that the sodium (Na) content of *D. rotundata* and *D. alata*species ranged from 118.48 – 198.80 mg/100g and 108.44 – 213.86 mg/100g respectively, with insignificant difference between the sodium components of both species (Table 4.11). This observation is comparable to previous report by Udensi*et al.* (2008): 190.00 to 250.00 mg/100g. However, the sodium contents observed for this research are higher than those observed by Polycarp *et al.* (2012): 70.0 – 87.5 mg/100g for *D. rotundata* and 62.5 – 95.0 g/100g for *D. alata;*Baah (2009): 84 – 131 mg/kg for *D. alata.* The magnesium content of the yam species varied from 25.66 to 42.91 mg/100g and 13.72 to 44.48 mg/100g for species of *D. rotundata* and *D. alata* respectively (Table 4.9 and 4.10). The magnesium contents observed in this research are lower than those given by Udensi*et al.* (2008); Baah (2009) and Polycarp *et al.* (2012).

The values reflected that there were differences in the mineral contents, both between and within the species. These variations in mineral contents compared with previous reports could be attributed to genetic components, environmental properties, method of determination, cultural practices as well as chemical composition of the soil (Oluwatosin, 1998; Otegbayo *et al.*, 2017). However, the variations in the result of the current study may be a function of differences in genetic components of each variety, as well as the soil components.

Table 4.11: Mineral content of yam flour from *Dioscoreaspp*

Species	Mg (mg/100g)	Na (mg/100g)	K (mg/100g)	P (mg/100g)
D. rotundata	33.29±5.28[a]	156.93± 25.02[a]	313.09± 62.96[b]	41.88 ± 9.21[a]
D. alata	34.92±6.51[a]	155.99± 27.77[a]	285.49± 50.75[a]	54.51± 36.34[b]

(means ± standard deviation)

4.7 Pasting Properties of Yam Starch

Resulting product quality of crops of root and tuber is significantly determined by its pasting properties. Texture and cooking quality of varieties of food products have been associated with the pasting characteristics of starches (Otegbayo *et al.*, 2006; Moorthy, 2002). Pasting results where there is creation of a more or less thick paste from starch granules that have swollen up, resulting in leaching of amylose from the granules (Batey and Bason, 2015). Zhu (2015) also described pasting as the heating-up and cooling of starch-water suspension between 50 and 95 ℃ to a cycle that has been programmed under a shearing force that isregular. Tables 4.12 and 4.13 present the pasting parameters evaluated for each variety during the pasting cycle. The pasting parameters include peak viscosity, breakdown viscosity, holding strength, final viscosity, setback viscosity, peak time and pasting temperature. Pasting properties of starches dictate, to a great level, their use as ingredient in foods and other industrial applications, hence they have great impact on the resulting product quality.

The degree to which the starch granules can liberarily swell before breaking down, reflected by peak viscosity (Singh *et al.*, 2003; Wireko-Manu *et al.*, 2011) ranged from 291.08 to 654.79 RVU and 252.42 to 467.46 RVU for *D. rotundata* and *D. alata* varieties respectively (Table 4.5 and 4.6). *D. rotundata* varieties gave a significantly higher mean peak viscosity value of 518.50 RVU than those of *D. alata* varieties (336.01 RVU), as shown in Figure 4.9. This could be due to the granule size; as peak viscosity is higher in starches with larger granules (Wickramasinghe*et al.*, 2009). High peak viscosity has been noted to have influence on the water binding capacity of granules of starch, thereby improving the strength of formed paste during processing (Adebowale *et al.*, 2005). This could make them useful in products with high viscosity such as thickeners, fillers and binders (Otegbayo *et al.*, 2014).

Similar trends of higher peak viscosity for *D. rotundata*have been observed by Baah*et al*. (2009) (*D. rotundata*- 322 RVU; *D. alata*- 99 – 296 RVU), Wireko-Manu *et al.* (2011) (*D. rotundata*- 291.17RVU; *D. alata*- 74.80 – 284.60 RVU), Otegbayo *et al.* (2014) (*D. rotundata* 360.51 RVU; *D alata* 341.17 RVU). The lower peak viscosity of *D. alata*could be linked to the lower swelling capacity of it starch in comparism to that of *D. rotundata* (Otegbayo *et al.*, 2006; Baah*et al.*, 2009 andWireko-Manu *et al.,*

Table 4.12: Pasting properties of starch from *D. rotundata* varieties

Sample	Peak viscosity (RVU)	Holding strength (RVU)	Break down viscosity (RVU)	Final Viscosity (RVU)	Setback viscosity (RVU)	Peak Time (min)	Pasting Temp (^{o}C)
Agbanwobe	571.58^{ijk}	310.38^{i}	261.21^{cdef}	420.96^{g}	110.58^{cd}	4.83^{def}	81.63^{bcd}
TDr95/18531	585.79^{jk}	262.08^{efg}	323.71^{ghi}	372.88^{ef}	110.79^{cd}	4.77^{cd}	79.58^{a}
TDr89-02665	642.96^{m}	281.79^{ghi}	361.17^{i}	378.75ef	96.96^{abc}	4.73^{bcd}	79.38^{a}
TDrUfenyi	499.08^{efg}	219.13^{cd}	279.96^{defg}	326.13^{cd}	107.00^{cd}	4.70^{bcd}	82.40^{def}
TDr97-00917	534.29^{ghi}	362.58^{j}	171.71^{a}	493.58^{i}	131.00^{d}	4.97^{fg}	83.28^{f}
TDr99-02607	654.79^{m}	349.79^{j}	305.00^{fgh}	483.38^{hi}	133.58^{d}	4.70^{bcd}	80.90^{b}
TDr89-21-3	426.25^{bc}	202.21^{bc}	224.04^{bc}	272.92^{b}	70.71^{ab}	4.60^{b}	81.63^{bcd}
Agba	631.33^{lm}	285.58^{ghi}	345.75^{hi}	393.54^{fg}	107.96^{cd}	4.73^{bcd}	81.65^{bcd}
Agboyo-abbi	406.04^{b}	241.08^{de}	164.96^{a}	375.96^{ef}	134.88^{d}	5.07^{g}	82.43^{def}
Ameh	604.21^{kl}	362.29^{j}	241.92^{cd}	458.08^{h}	95.79^{abc}	4.97^{fg}	82.38^{def}
Fakinsa	453.25^{cd}	193.38^{bc}	259.88^{cdef}	265.58^{b}	72.21^{ab}	4.60^{b}	82.55^{def}
Lagos	471.33^{de}	248.33^{def}	223.00^{bc}	353.50^{de}	105.17^{cd}	4.97^{fg}	81.93^{bcde}
Nwopoko	464.33^{de}	269.58^{efg}	194.75^{ab}	364.29^{ef}	94.71^{abc}	5.00^{g}	82.83^{ef}
PAA-IITA	291.08^{a}	140.33^{a}	150.75^{a}	209.63^{a}	69.29^{a}	4.40^{a}	82.00^{cde}
Pampas	562.25^{ij}	238.00^{de}	324.25^{ghi}	328.25^{cd}	90.25^{abc}	4.67^{bc}	79.63^{a}
Ogoja	510.71^{fgh}	257.46^{efg}	253.25^{cde}	352.50^{de}	95.04^{abc}	4.73^{bcd}	82.40^{def}
Sandpaper	477.92^{def}	176.63^{b}	301.29^{efgh}	310.29^{c}	133.67^{d}	4.70^{bcd}	83.23^{f}
Takalafia	519.92^{gh}	265.83^{efg}	254.08^{cde}	380.21^{ef}	114.38^{cd}	4.80^{cde}	81.20^{bc}
2665	544.29^{hi}	291.63^{hi}	252.67^{cde}	393.88^{fg}	102.25^{bcd}	4.93^{efg}	81.98^{cde}
Mean	518.50	260.95	257.54	364.96	104.01	4.78	81.73
SD	90.89	60.34	60.52	71.97	20.36	0.17	1.16

*Values are average of triplicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.

Table 4.13: Pasting properties of starch from *D. alata*varieties

Sample	Peak viscosity (RVU)	Holding strength (RVU)	Break down viscosity (RVU)	Final Viscosity (RVU)	Setback viscosity (RVU)	Peak Time (min)	Pasting Temp (^{O}C)
TDa11/00011	283.96^{abcde}	263.13^{mn}	20.83^{a}	456.96^{l}	193.83^{jk}	5.33^{m}	83.60^{b}
TDa11/00014	300.00^{bcdefg}	220.96^{hij}	79.04^{defg}	421.29^{jk}	200.33^{jk}	4.87^{hij}	84.43^{b}
TDa11/00020	351.75^{ijklm}	166.08^{cde}	185.67^{s}	236.92^{bc}	70.83^{b}	4.40^{bcd}	80.45^{b}
TDa11/00022	435.79^{pq}	315.00^{p}	120.79^{lkmno}	419.71^{jk}	104.71^{de}	5.03^{kl}	83.10^{b}
TDa11/00024	282.88^{abcde}	236.63^{jkl}	46.25^{abc}	458.04^{l}	221.42^{lm}	5.03^{kl}	83.33^{b}
TDa11/00063	353.75^{jklm}	261.46^{lm}	92.29^{efghijk}	403.67^{ij}	142.21^{gh}	4.90^{ijk}	67.10^{a}
TDa11/00102	329.46^{ghijk}	286.38^{no}	43.08^{ab}	524.04^{op}	237.67^{no}	5.30^{m}	84.50^{b}
TDa11/00110	330.58^{ghijkl}	233.33^{ijk}	97.25^{fghijk}	451.29^{l}	217.96^{lm}	4.73^{fgh}	84.45^{b}
TDa11/00138	363.79^{lmn}	237.67^{jkl}	126.13^{lmno}	346.04^{f}	108.38^{ef}	4.93^{ijkl}	84.03^{b}
TDa11/00162	444.96^{qr}	289.96^{o}	155.00^{pqr}	382.79^{hi}	92.83^{cd}	5.07^{l}	83.00^{b}
TDa11/00164	281.25^{abcde}	186.13^{defg}	95.13^{efghijk}	307.17^{e}	121.04^{f}	4.67^{efg}	83.15^{b}
TDa11/00167	321.38^{fghij}	190.38^{efg}	131.00^{mnopq}	346.17^{f}	155.79^{h}	4.50^{cde}	82.40^{b}
TDa11/00179	277.67^{abc}	173.75^{cdef}	103.92^{ghijklm}	365.17^{fgh}	191.42^{j}	5.07^{l}	85.65^{b}
TDa11/00189	318.08^{fgh}	106.54^{a}	211.54^{t}	159.54^{a}	53.00^{a}	4.23^{a}	82.88^{b}
TDa11/00225	354.17^{jklm}	247.29^{klm}	106.88^{ghijklmn}	439.83^{kl}	192.54^{jk}	4.87^{hij}	84.10^{b}
TDa11/00232	343.25^{hijklm}	287.67^{no}	55.58^{bcd}	494.71^{mn}	207.04^{kl}	5.03^{jkl}	83.63^{b}
TDa11/00242	467.46^{r}	368.63^{q}	98.83^{fghijkl}	504.21^{no}	135.58^{g}	5.23^{m}	82.40^{b}
TDa11/00247	356.33^{klm}	238.58^{jkl}	117.75^{jklmno}	456.92^{l}	218.33^{lm}	4.60^{ef}	83.30^{b}
TDa11/00275	308.17^{cdefg}	194.50^{fg}	113.67^{ijklmno}	369.46^{gh}	174.96^{i}	4.87^{hi}	85.20^{b}
TDa11/00287	319.54^{fghi}	208.42^{ghi}	111.13^{hijklmno}	319.42e	111.00^{ef}	4.63^{ef}	81.20^{b}
TDa11/00292	272.92^{ab}	190.42^{efg}	82.50^{efgh}	364.29^{fgh}	173.88^{i}	4.80^{ghi}	83.68^{b}
TDa11/00299	435.79^{pq}	327.71^{p}	108.08^{hijklmn}	504.54^{no}	176.83^{i}	4.67^{efg}	82.35^{b}
TDa11/00305	322.63^{fghij}	270.58^{mno}	52.04^{bc}	533.54^{p}	262.96^{p}	5.07^{l}	84.40^{b}
TDa11/00317	313.13^{efgh}	209.21^{ghi}	103.92^{ghijklm}	435.88^{kl}	226.67^{mn}	4.83^{hi}	82.73^{b}
TDa11/00324	312.33^{defgh}	226.75^{hijk}	85.58^{efghi}	493.33^{mn}	266.58^{p}	4.73^{fgh}	83.63^{b}
TDa11/00368	252.42^{a}	161.29^{bc}	91.08^{efghij}	306.42^{e}	145.21^{gh}	4.82^{ghi}	83.00^{b}
TDa11/00370	278.46^{abcd}	139.54^{b}	138.92^{opqr}	224.79^{b}	85.25^{c}	4.37^{abc}	82.03^{b}
TDa11/00374	363.25^{lmn}	205.00^{gh}	158.25^{qr}	314.54^{e}	109.54^{ef}	4.50^{cde}	82.43^{b}
TDa11/00424	406.21^{op}	271.42^{mno}	134.79^{nopqr}	392.17^{i}	120.75^{f}	4.93^{ijkl}	81.65^{b}
TDa11/00426	394.25^{no}	233.00^{ijk}	161.25^{r}	351.54^{fg}	118.54^{ef}	4.67^{efg}	81.68^{b}
TDa11/00428	292.50^{bcdef}	163.54^{bcd}	128.96^{mnop}	267.67^{d}	104.13^{de}	4.50^{cde}	82.60^{b}
TDa11/00434	301.50^{bcdefg}	205.63^{gh}	95.88^{efghijk}	359.08^{fg}	153.46^{h}	4.60^{ef}	82.88^{b}
TDa11/00493	345.33^{hijklm}	188.75^{efg}	156.58^{qr}	310.04^{e}	121.29^{f}	4.53^{de}	81.83^{b}
TDa11/00495	371.04^{mn}	158.21^{bc}	212.83^{t}	247.63^{cd}	89.42^{c}	4.30^{ab}	80.25^{b}
TDa11/00541	307.71^{cdefg}	237.17^{jkl}	70.54^{cdef}	457.33^{l}	220.17^{lm}	5.07^{l}	84.48^{b}
TDa11/00555	302.67^{bcdefg}	233.88^{ijk}	68.79^{bcde}	479.92^{m}	246.04^{o}	4.93^{ijkl}	84.78^{b}
Mean	**336.01**	**225.96**	**110.05**	**386.28**	**160.32**	**4.80**	**82.67**
Std	**52.64**	**55.22**	**44.18**	**92.66**	**57.93**	**0.28**	**2.94**

* Values are average of triplicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.

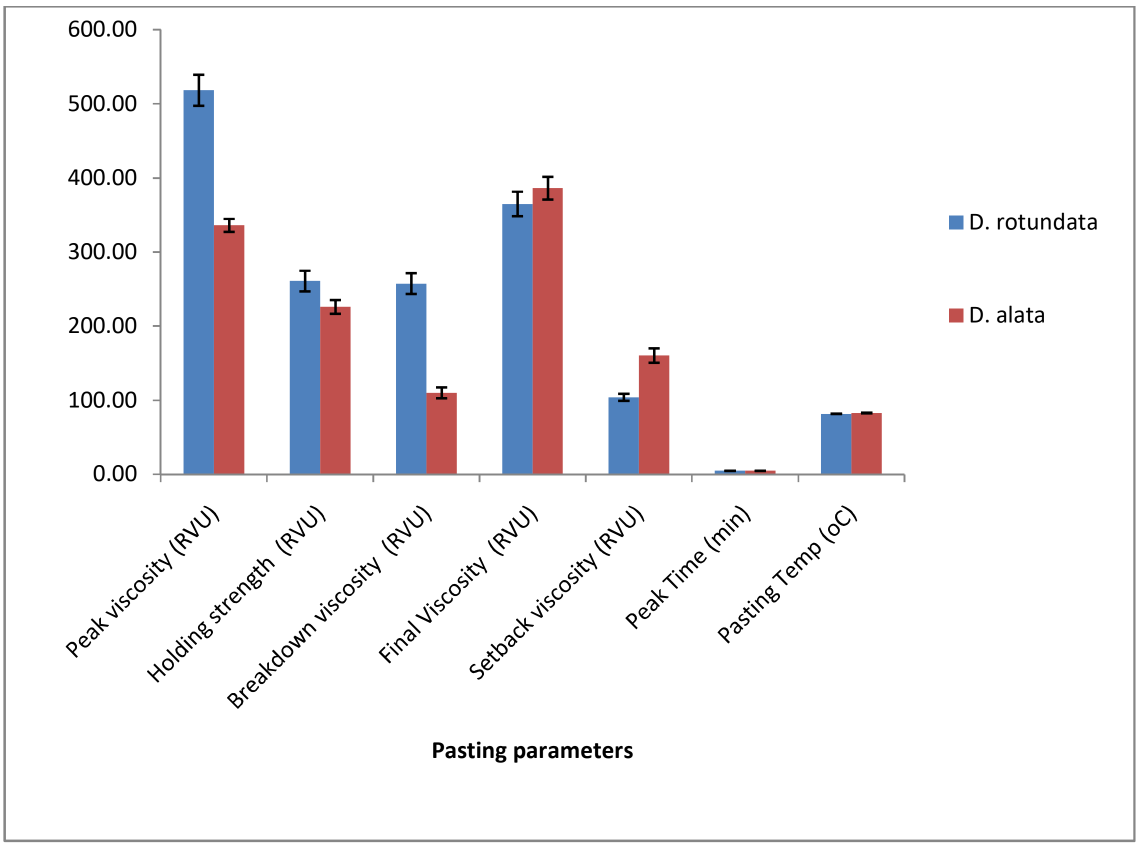


Figure 4.9: Summary of Pasting properties of starch from *Dioscoreaspp*

2011). However, this research observed higher peak viscosity than those reported by Wireko-Manu *et al.* (2011), Baah*et al*. (2009) and Otegbayo *et al.* (2014).

Holding strength, also known as trough viscosity ranged from 140.33 to 362.58 RVU and 106.54 to 368.63 RVU (Table 4.12 and 4.13) for species of *D. rotundata* and *D. alata* respectively, with significant difference among the varieties for each species. The mean value for holding strength in *D. rotundata* species (260.95 RVU) was significantly higher than the mean value for *D. alata* species (225.9 6 RVU) (Figure 4.9), hence *D. rotundata* can remain intact and undisrupted over a hold period and temperature than those of *D. alata,* which is of industrial advantage. This holding strength is the capability of a paste to withstand stress, or remain uninterrupted when brought under a hold duration of regular high mechanical shear stress and temperature (Madsen *et al.,* 1996; Kinn-Kabari*et al*., 2015).

The breakdown viscosity varied from 150.75 to 361.17 RVU and 20.83 to 212.83 RVU with an average of 257.54 RVU and 110.05 RVU for *D. rotundata* and *D. alata* species respectively. The significantly higher breakdown viscosity (Figure 4.9) of *D. rotundata* starch implies stronger ability to oppose shear thinning by resisting breakdown in viscosity, as a result of minimum starch granule rupture, hence, resulting in more stable cooked paste than those of *D. alata* (Otegbayo *et al*., 2006). The high break down viscosity often accompanies holding strength; an indication of the resistance of starch granules to mechanical fragmentations during shearing and heating, hence increased paste stability (Otegbayo *et al*., 2014).

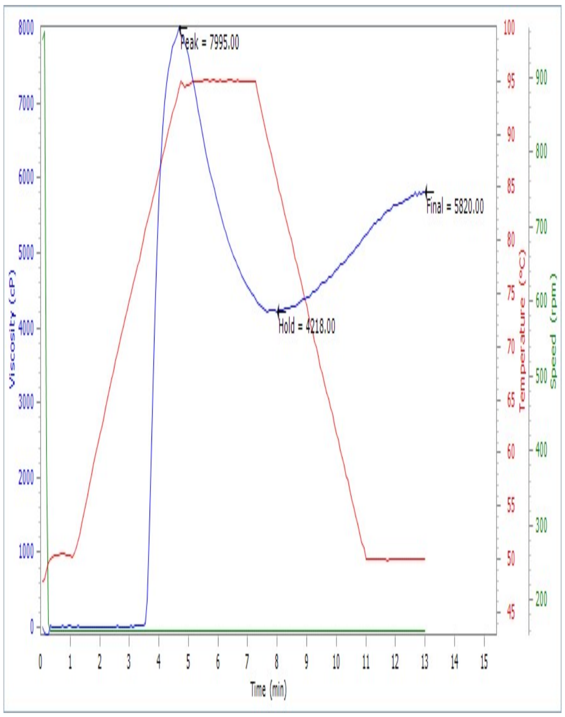
The resulting thickness of cooked paste, after cooling it down to 50 ℃, and its ability to form gel after cooking is known as final viscosity (Wireko-Manu *et al*., 2011). This is an important pasting property useful in determining the level of quality for starch-based product, as higher final viscosity shows that the formed paste has greater strength to resist mechanical shear, thereby forming more stiff gel (Zhang *et al*., 2011). The final viscosity of *D. rotundata* varieties ranged from 209.63 to 493.58 RVU and an average of 364.96 RVU (Table 4.12), with insignificant difference with those of *D. alata*varieties, ranging from 159.54 to 533.54 RVU with a mean value of 386.28 RVU (Table 4.13). Hence, both species have the ability to form gel after cooking with the mean value of varieties of*D. alata* insignificantly higher than those of *D. rotundata*(Figure 4.9).

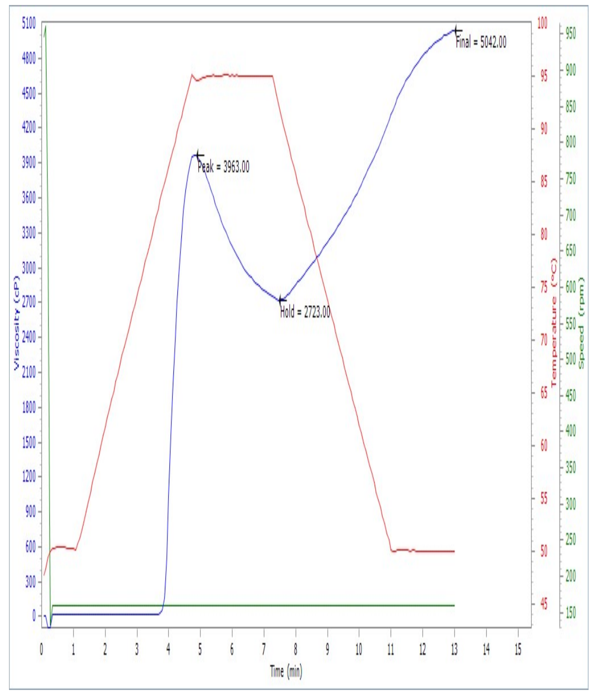
The results signified that there was increase in viscosity of *D. alata* varieties upon further heating and then cooling, showing a more stable viscosity when compared with starches of cassava and potato (Brunnschweiler*et al.*, 2005). Moreover, with the exception of varieties TDr89/21-3 and PAA-IITA for *D. rotundata* and TDa11/00189, these yam species gave similar values with those of kponan (409.75 RVU), smooth pea (512.08 RVU) and maize (340.33 RVU) which have found use in the commercial world (Tetchi*et al.*, 2007). Furthermore, there were varieties within both species (TDr89-21-3, Fakinsa, PAA-IITA, TDa11/00020, TDa11/00189 and TDa11/00370) that exhibited low viscosities after cooling, comparable to those of potato and cassava starches, which make them fit for application in dessert creams as thickening agents (Tetchi*et al.*, 2007).

Generally, yam starch has a high setback viscosity than other root and tuber crops, showing higher capacity for retrogradation (Peroni *et al.*, 2006). The setback viscosity of *D. rotundata* species and *D. alata* specie ranged from 69.29 – 134.88 RVU and 53.00 – 266.58 RVU respectively (Tables 12 and 13). On the average, *D. alata*species (160.32 RVU) had significantly higher setback visocity than that of *D. rotundata* (104.01 RVU) (Figure 4.9) has significantly higher setback viscosity than that of, within a range of 69.29 – 134.88 RVU and 53.00 – 266.58 RVU for *D. rotundata* and *D. alata*species respectively. However, this is in contrast with previous observations by some researchers, that *D. rotundata* has higher set back viscosity than *D. alata*(Otegbayo *et al.*, 2006; Baah*et al.*, 2009; Wireko-Manu *et al.*, 2011). High set back viscosity of *D. alata* and *D. rotundata* could find usein product like noodles where high retrogradation is desired (Kaur and Singh, 2005). Retrogradation process helps fix noodles structure, as this impact noodles strength from increased gel formation due to sufficient leaching out of amylose, as the aging time of the gelatinised starch increased (Thao and Noomhorm, 2011). The peak time, which relates to the cooking time during the pasting cycle, ranged from 4.40 to 5.07 min for *D. rotundata* varieties and 4.23 to 5.33 min for *D. alata*varieties, with mean values of 4.78 min and 4.80 min, respectively.

The pasting temperatures for species of *D. rotundata* and *D. alata*ranged from 79.38 to 83.28 °C and 67.10 to 85.65 °C, and an average of 81.73 °C and 82.67 °C respectively (Tables 4.12 and 4.13). The pasting temperature of *D. rotundata* species, which is lower, when compared with those of *D. alata* signifies lower gelatinisation temperature, indicating shorter cooking time (Otegbayo *et al.*, 2014). It is also a pointer to the strength of associative forces within starch granules, relating to stability of the paste (Afoakwa and Sefa-Dedeh, 2002), as well as restriction to swelling (Kaur and Singh, 2005). High pasting temperatures of *D. species* may limit it utilization in industries, since starches with low pasting temperatures are of more advantage, however, this is advantageous in canned and sterilized foods, which require high temperature for processing. Starch granules of *D. rotundata*species are larger than those of *D. alata*, hence less molecular bonding, making it to swell faster, and building higher viscosity. This contributes to the lower pasting temperature of *D. rotundata*. Figure 4.10 gives the typical pasting graph for *D. rotundata* and *D. alata* starch. Pasting properties has shown that yam starches exhibit good pasting properties, which could be said to be intermediate when compared with other starches that have been accepted for industrial uses, from which the exceptional varieties can be selected. These could be useful as thickeners, fillers and gelling agents for industrial use. However, these starches can as well be modified using suitable methods, to achieve different purposes.

On subjecting the results of the pasting properties to cluster analysis, three major groups emerged (Figure 4.11). Cluster I comprised of exclusively 16 *D. rotundata* varieties which have higher capacity to swell freely during heating, as shown by the peak viscosities, as well as high break-down viscosity and holding strength; and low set back viscosity, with the exception of two varieties. This implies that these varieties with high peak viscosity could form viscous paste, resist stress as well as have low ability to retrograde; thereby useful in high viscous product such as thickener and binders. This result implies that starches with larger granule sizes swell more, reflecting larger percentage of varieties with larger granules possessing higher peak viscosity (Figure 4.3). Cluster II consist of mainly *D. alata* (16 varieties) and 1 *D. rotundata*, showing slightly low peak viscosity, low holding strength as well as low final viscosity. Cluster III is made up of 21 varieties of *D. alata*species and 1 variety of *D. rotundata* species, showing generally low breakdown viscosity and peak viscosity. Varieties in cluster II and III could be useful for less viscous product, for examples soups; however, starches of these varieties could be modified for optimum industrial application.





a. TDr99-02607 b. TDa11/00225

Figure 4.10: Typical pasting graphs for starch of: (a) *D. rotundata* and (b) *D. alata*

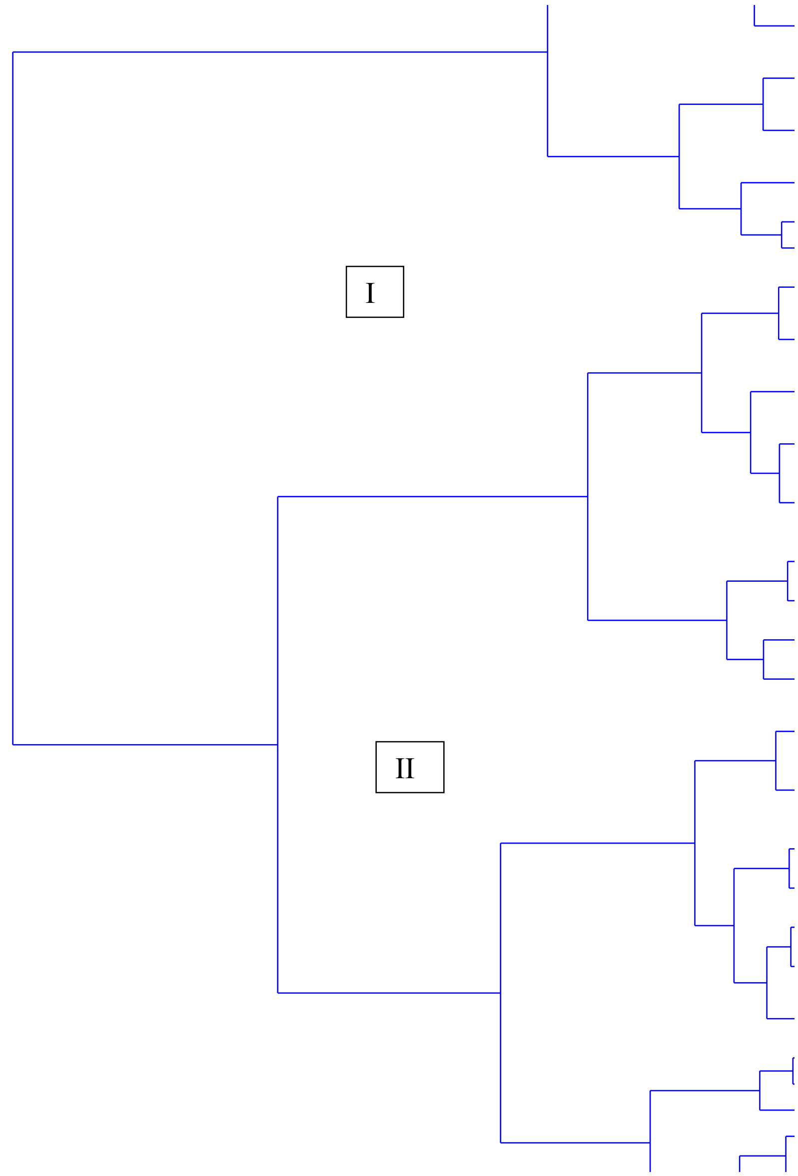


Figure 4.11: Cluster analysis of pasting properties of starch from *Dioscoreaspp*

4.8 Functional Properties of Yam Starch

III

These are properties that exhibit complex reactions among the compositions, structure and molecular conformation of food components, combined with the nature of environment (Chandra *et al.*, 2013). Tables 4.14 and 4.15 present the functional properties of the two *Dioscorea species* extracted starch. The swelling power of *D. rotundata* and *D. alata* varieties varied from 4.97 to 8.86 g/g and 2.15 to 8.45 g/g respectively. The swelling power of *D. rotundata* varieties on the average (7.50 g/g) were significantly higher than those of *D. alata*varieties (5.36 g/g) (Figure 4.12).

The larger granule sizes of *D. rotundata* varieties could be accountable for this higher swelling power, as the size increased in proportion to the initial size under the influence of heat and water (Tetchi*et al.*, 2007 and Wickramasinghe*et al.*, 2011), which could be a pointer of weak internal bonding within the granules (Otegbayo *et al.*, 2014). This study observed lower swelling power compared to reports of Baah (2009) of 8.0 to 11.6 for *D. alata* and 11.0 for *D.rotundata*; Wireko-Manu *et al.* (2011) of 6.23 to 9.75 for *D. alata* and 12.05 for *D. rotundata*; 9.00 g/g for *D. rotundata* and 7.15 g/g for *D. alata* by Otegbayo *et al*. (2014).

In addition, the higher swelling power of *D. rotundata* specie than those of *D. alata*specie is comparable to previous reports (Baah *et al.*, 2009; Walter *et al.*, 2000; Wireko-Manu *et al.*, 2011). Swelling power is majorly monitored by the character and strength of the micellar networks (amylose molecules) that exists within the starch granules; the stronger the associative forces, the lesser the swelling power (Hoover, 2001; Ikegwu*et al.*, 2009;Wireko-Manu *et al.,* 2011). Moreover, this study signified that *D. rotundata* varieties havehigher amylose content and swelling power than *D. alata*. Ai and Jane (2015) reported that swelling capacity and viscosity build-up of starch during cooking is primarily due to amylopectin component; as amylose with the availability of lipids interact with amylopectin thereby restricting swelling of starch granules. Yamstarches with generally low swelling capacity, as observed for *D. alata* and *D. rotundata varieties* when compared with commercially utilized starches, could be suitable for use in complementary foods where very thick gruels are not desired (Otegbayo *et al*., 2014).

Table 4.14: Functional properties of starch from *D. rotundata* varieties

Sample	Swelling Power (g/g)	Solubility Index (%)	WBC (%)	WAC (%)
Agbanwobe	7.27^{cdef}	0.96^{ab}	51.67^{abc}	68.48^{g}
TDr95/18531	7.79^{efghi}	2.65^{h}	53.84^{bcde}	65.21^{ef}
TDr89-02665	8.56^{ij}	0.55^{a}	57.09^{defg}	60.79^{bc}

TDrUfenyi	8.86[j]	1.72[cde]	70.90[j]	74.57[i]
TDr97-00917	7.62[defgh]	1.16[bc]	60.70[ghi]	67.30[g]
TDr99-02607	7.39[cdefg]	1.27[bcd]	52.63[bcd]	70.70[h]
TDr89-21-3	8.52[hij]	1.91[ef]	64.83[i]	61.28[bcd]
Agba	6.93[cde]	0.78[ab]	62.59[hi]	71.59[h]
Agboyo-abbi	6.95[cde]	2.42[fgh]	64.75[i]	56.31[a]
Ameh	7.26[cdef]	0.89[ab]	46.79[a]	57.16[a]
Fakinsa	8.06[fghij]	2.07[efg]	56.46[cdefg]	66.89[fg]
Lagos	8.07[fghij]	1.34[bcd]	52.27[bcd]	61.89[cd]
Nwopoko	8.74[j]	1.36[bcd]	54.80[cdef]	56.35[a]
PAA-IITA	8.31[hij]	2.18[efgh]	65.04[i]	62.93[d]
Pampas	8.22[ghij]	1.30[bcd]	51.87[bcd]	78.68[j]
Ogoja	4.97[a]	0.87[ab]	59.48[fgh]	64.88[e]
Sandpaper	5.91[b]	2.57[gh]	56.28[cdefg]	82.59[k]
Takalafia	6.82[cd]	1.74[de]	58.18[efgh]	59.48[b]
2665	6.30[bc]	1.46[bcd]	45.89[ab]	70.72[h]
Mean	**7.50**	**1.54**	**57.16**	**66.20**
SD	**1.03**	**0.63**	**6.54**	**7.37**

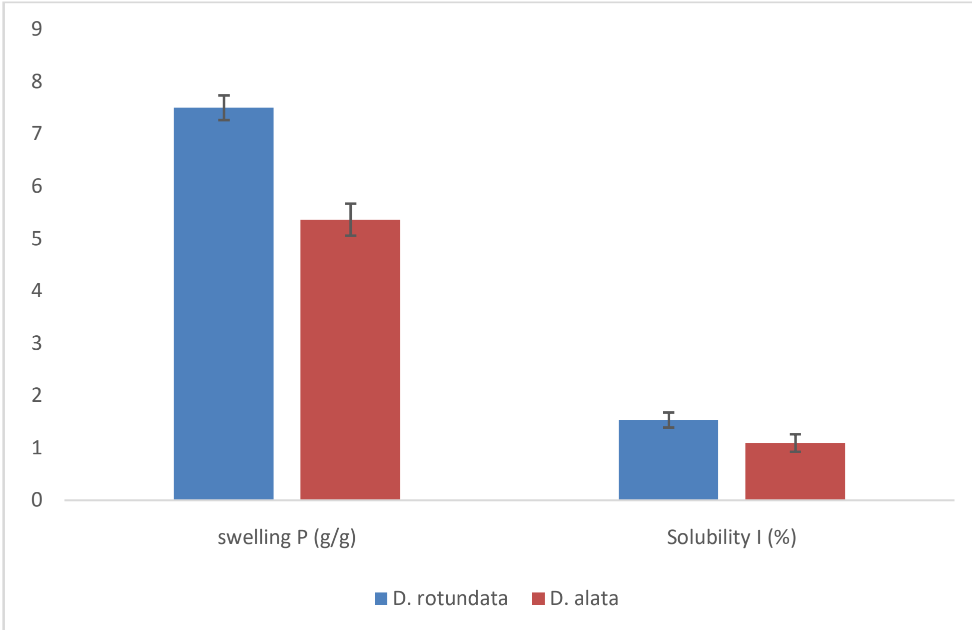
*Values are average of replicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.

Table 4.15: Functional properties starch from *D. alata* varieties

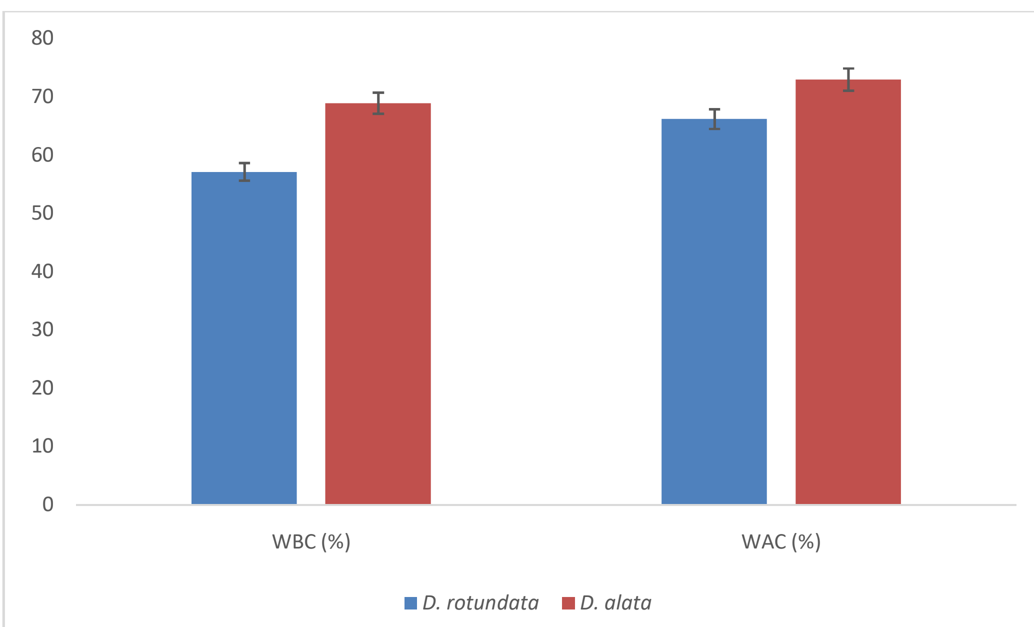
Sample	Swelling Power (g/g)	Solubility Index (%)	WBC (%)	WAC (%)
TDa11/00011	5.45[efg]	0.59[abcd]	64.71[efghij]	67.69[e]
TDa11/00014	3.29[bc]	0.13[a]	67.62[ghijkl]	72.79[f]
TDa11/00020	8.11[nop]	5.72[k]	67.32[fghijk]	85.25[o]
TDa11/00022	7.49[mno]	1.63[fgh]	63.48[defghi]	54.69[b]
TDa11/00024	6.31[ghijkl]	1.37[efg]	78.97[no]	76.58[hij]
TDa11/00063	4.43[d]	0.47[abcd]	58.09[bcde]	51.14[a]
TDa11/00102	6.08[ghijk]	0.78[abcde]	74.28[lmn]	68.76[e]

TDa11/00110	4.17^{cd}	0.16^{ab}	69.46^{hijklm}	67.93^{e}
TDa11/00138	3.26^{bc}	0.29^{abc}	62.89^{cdefgh}	71.82^{f}
TDa11/00162	4.64^{de}	0.87^{cde}	75.37^{mn}	50.18^{a}
TDa11/00164	6.55^{ijklm}	0.88^{cde}	69.93^{ijklm}	77.44^{ijk}
TDa11/00167	5.50^{efgh}	1.87^{ghi}	63.45^{defghi}	74.60^{g}
TDa11/00179	2.35^{ab}	0.62^{abcd}	56.08^{bc}	70.93^{f}
TDa11/00189	2.71^{ab}	2.71^{j}	61.01^{bcdefg}	75.54^{gh}
TDa11/00225	4.06^{cd}	0.84^{cde}	60.61^{bcdef}	75.85^{ghi}
TDa11/00232	4.04^{cd}	1.09^{def}	83.64^{op}	72.16^{f}
TDa11/00242	4.02^{cd}	1.59^{fg}	84.29^{op}	83.04n
TDa11/00247	3.19^{bc}	0.87^{cde}	58.12^{bcde}	62.54^{d}
TDa11/00275	2.15^{a}	0.63^{abcd}	71.07^{jklm}	81.48^{mn}
TDa11/00287	2.75^{ab}	2.37^{ij}	63.77^{efghi}	81.64^{mn}
TDa11/00292	5.80^{fghij}	0.69^{abcd}	85.64^{p}	105.38^{q}
TDa11/00299	6.48^{hijklm}	2.22^{hij}	64.34^{efghi}	62.68^{d}
TDa11/00305	5.60^{efghi}	0.63^{abcd}	72.99^{klmn}	81.10^{m}
TDa11/00317	6.86^{klm}	0.24^{abc}	73.43^{klmn}	78.21^{jk}
TDa11/00324	4.88^{def}	0.70^{abcd}	67.52^{ghijkl}	78.89^{kl}
TDa11/00368	6.47^{hijklm}	0.48^{abcd}	83.17^{op}	76.85^{hij}
TDa11/00370	7.14^{lm}	0.80^{abcde}	60.00^{bcde}	57.73^{c}
TDa11/00374	7.13^{lm}	1.07^{def}	56.67^{bcd}	63.98^{d}
TDa11/00424	8.39^{op}	1.45^{efg}	55.76^{b}	58.60^{c}
TDa11/00426	6.66^{jklm}	0.80^{abcde}	84.71^{op}	81.02^{m}
TDa11/00428	7.35^{mn}	0.83^{bcde}	46.56^{a}	63.70^{d}
TDa11/00434	6.85^{klm}	1.08^{def}	85.77^{p}	90.48^{p}
TDa11/00493	7.11^{lm}	0.47^{abcd}	62.74^{cdefgh}	80.41^{lm}
TDa11/00495	8.45^{p}	1.12^{def}	73.18^{klmn}	64.37^{d}
TDa11/00541	2.66^{ab}	0.64^{abcd}	58.74^{bcde}	72.10f
TDa11/00555	4.87^{def}	0.87^{cde}	95.59^{q}	89.34^{p}
Mean	**5.36**	**1.10**	**68.91**	**72.97**
Std	**1.84**	**0.99**	**10.89**	**11.52**

*Values are average of replicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.



a. Swelling power and solubility index of *D. rotundata* and *D. alata*species



b. WBC and WAC of *D. rotundata* and *D. alata*species

Figure 4.12: Summary of functional properties of *Dioscorea*spp

Solubility was defined by Singh *et al*. (2005) to be the percentage aggregate of starch that escaped out into the supernatant during swelling power determination. The solubility index ranged from 0.55 to 2.65% and 0.13 to 5.72% for *D. rotundata* and *D. alata*species (Tables 4.14 and 4.15) respectively. *D. rotundata* (1.54%) had higher mean solubility index than that of *D. alata*(0.99%), and this is comparable to the report of Otegbayo *et al.* (2011; 2014). However, solubility index of yam flour of*D. alata*were reportedly more than that of *D. rotundata*by Ogunlakin*et al.* (2013). The result of this research implies that there is ease of solubility of amylose, the linear portion of *D. rotundata* starch than those of *D. alata*starches. The amylose is loosely linked to the remaining of the macro molecular structure, which gets escaped or released during swelling, contributing to the high solubility index of *D. rotundata* (Hoover, 2001). In addition to the relationship between starch chains within the amorphous and crystalline domain, specie, variety and the extent of starch granular structure modification can also influence the extent of swelling and solubility of yam starch (Otegbayo *et al.*, 2014).

*D. alata*varieties had significantly higher WBC (water binding capacity)and WAC (water absorption capacity) than *D. rotundata* varieties (Figure 4.12b). The water binding capacity has been defined by Otegbayo *et al*. (2014) to be the aggregate of water which an insoluble starch can contain relative to its own weight, while water absorption capacity was defined to be a function of the quantity of water held down in yam flour at the time of processing, affecting the suitability of the yam flour to form paste (Ezeocha*et al.,* 2015). The water binding capacity reported in this study for *D. rotundata* varieties (46.79 – 70.90%) (Table 4.14) and *D. alata*(46.56 – 95.59%) (Table 4.15) are lower than 72.97 – 80.01% (*D. rotundata*) and 21 – 120% (*D. alata*) reported by Otegbayo *et al.* (2011 and 2014 respectively); 108 – 144% by Alamu*et al.* (2014) for *D. rotundata* varieties; as well as those reported by Baah (2009) for *D. alata*varieties (159.7 – 202.4%). Some varieties of *D. alata*species and few of *D. rotundata* starches in this study could be useful in frozen desserts to improve viscosity and slow down the formation of large ice crystals, since starches with high water binding capacity bind more water, thereby preventing syneresis (Otegbayo *et al*., 2014).

WBC has been reported to be an image of the extentof interrelations between polymers of starch in their native granules, hence high WBC is a reflection of loose affiliation of amylopectin and amylose in the starch granules, while low WBC is related to a high affiliation between the starch's polymers present in the granules (Otegbayo *et al*., 2014). Decrease in WBC has been stated to be influenced by increase in association of polymers of starch in native starch granules (Soni*et al*., 1993); hence *D. rotundata* varieties have closer starch polymer associations than those of *D. alata* varieties with loose associative forces. The variations could also be due to differences in genotype, cultivation practices, origin and the fact that yam is a multi-variant specie crop. Water binding capacity has been stated to be important in influencing the quality of finished product or starch end product. High water binding capacity and low swelling power has been reported by Otegbayo *et al.* (2011) to contribute to the adhesiveness, extreme soft nature and in-cohesive nature of pounded yam from *D. alata*, hence water binding capacity and swelling power could be important quality indicators of yam food product such as *amala*.

Two major clusters emerged from the functional properties' characterisation of both species of *D. rotundata*and *D. alata* (Figure 4.13). Cluster A is composed of two sub-clusters, I and II, made up of varieties of both *D. rotundata* and *D. alata* species. Sub-group I is composed of seven (7) *D. rotundata* varieties and two (2) *D. alata* varieties, significantly high in swelling power. This is similar to the findings on pasting properties of starch (Figure 4.11) as varieties under cluster A, sub-group I with high swelling power, are also those with high peak viscosity, hence, the association between granule size, swelling power and peak viscosity. Sub-group II is made up of fourteen (14) *D. alata* and five (5) varieties of *D. rotundata* with fairly high swelling power and WBC. Cluster B is made up of mainly *D. alata* (23 varieties) and 4 *D. rotundata* varieties, showing distinctly high water absorption capacity.

4.9 Acidity of Yam Starch

The acidity content of the starch of the yam species as expressed by the pH and titratable acidity (TTA) are presented in Figures 4.14 and 4.15. The results reflected that significant differences exist among some varieties for both the pH and titratable acidity of species of *D. rotundata* and *D. alata* varieties. The pH and titratable acidity ranged from 6.29 to 7.26 and 0.14 to 1.99 for *D. rotundata* respectively, and 5.59 to

7.71and 0.74 to 2.00 for *D. alata* respectively. Varieties TDa11/00426, TDa11/00428 and TDa11/00434 had the lowest pH of less than 6 among both species. The pH is

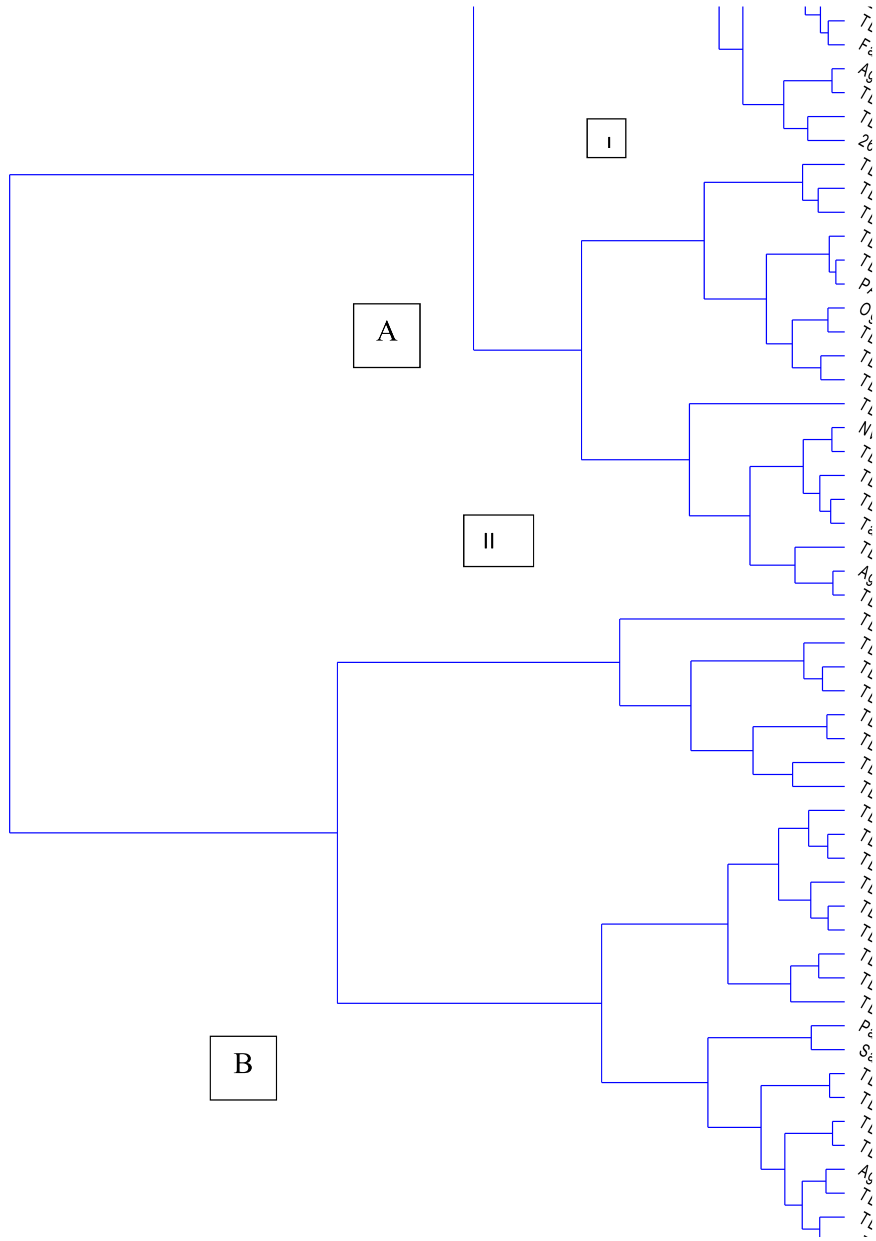


Figure 4.13: Cluster analysis of functional properties for *Dioscoreaspp*

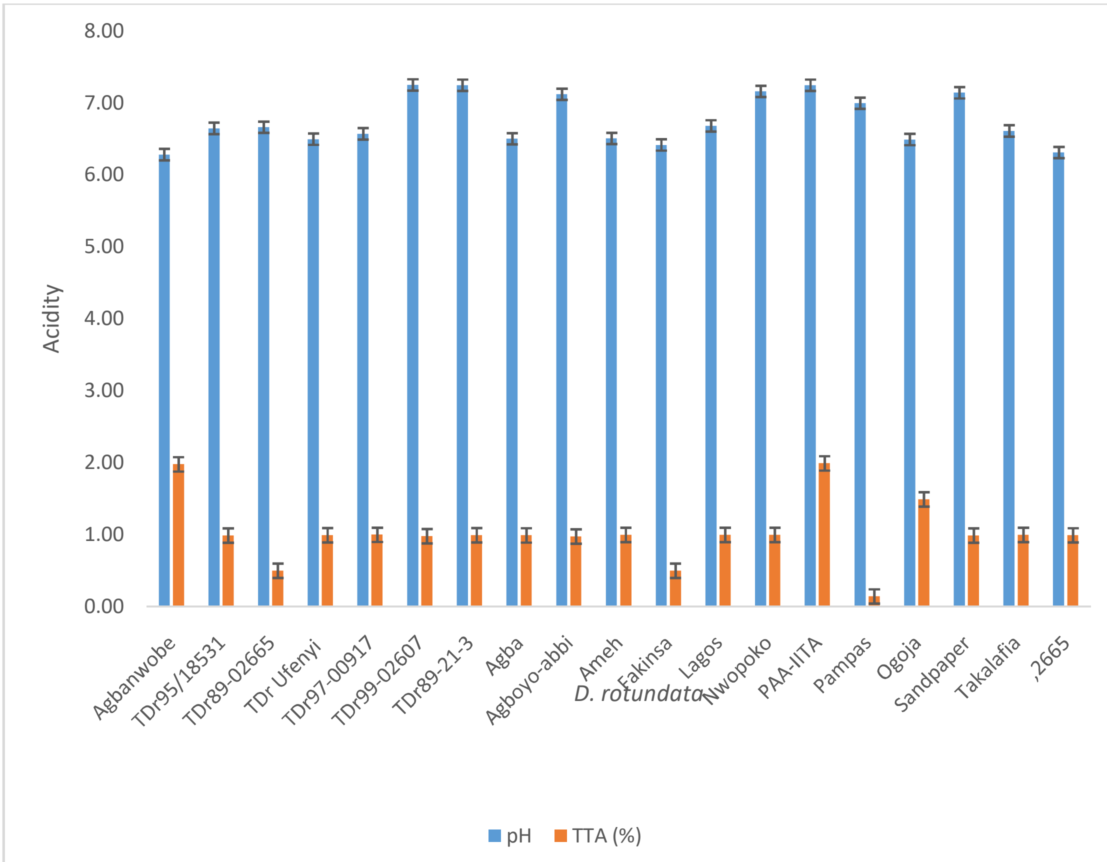


Figure 4.14: pH and Titratable Acidity of starch from *D. rotundata* varieties

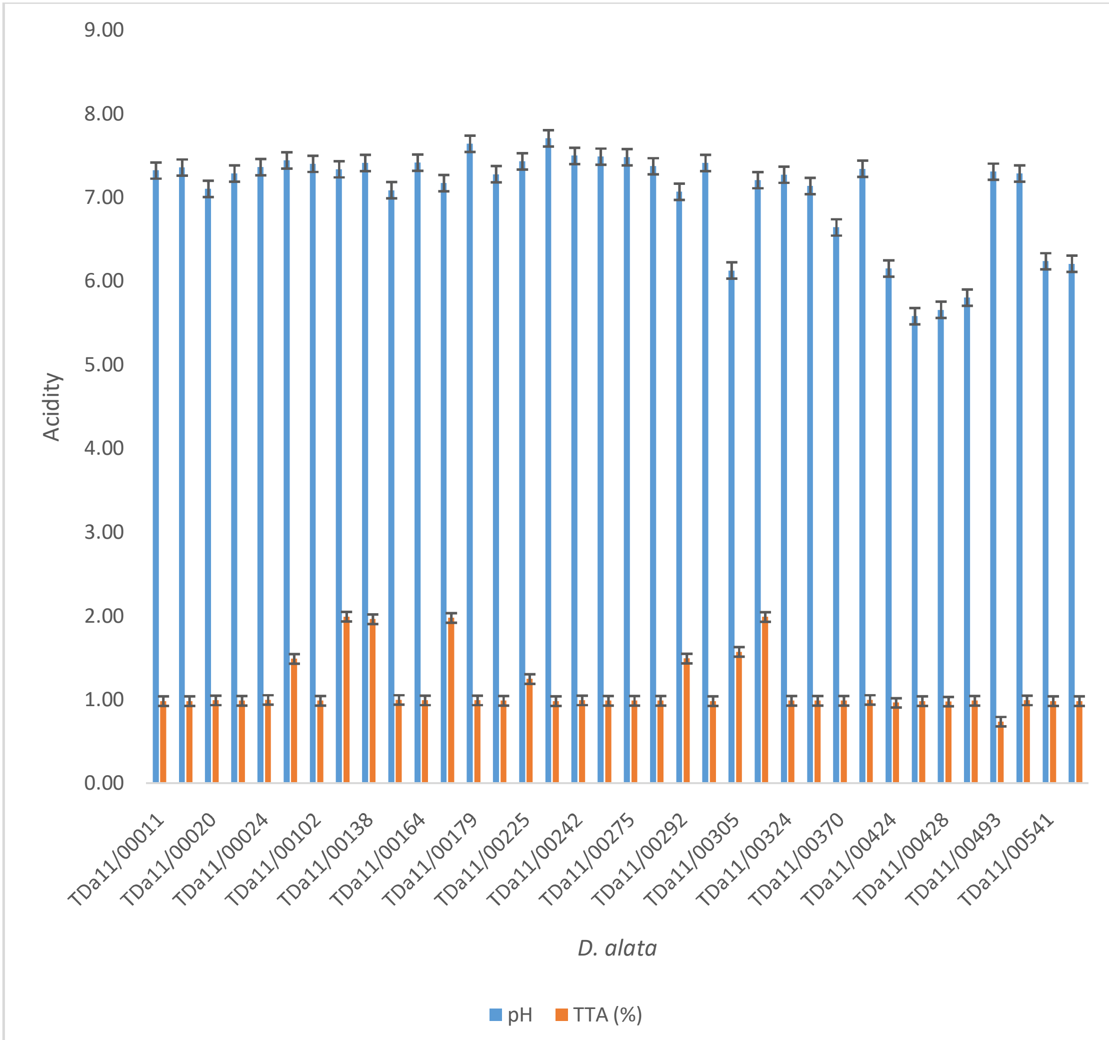


Figure 4.15: pH and Titratable Acidity of starch from *D. alata* varieties

similar to previous report by Tortoe*et al.* (2019) for *D. alata*(5.88 to 6.93). The acidity content of these yams indicates that they are nearly neutral or low acidic starches (Thomas and Atwell, 1999), which are important for food industries.

4.10 Pasting Properties of *Elubo* (Fermented yam flour)

The pasting properties of *elubo* (fermented yam flour) prepared from *D. rotundata* and *D. alata* are presented in Tables 4.16 and 4.17 respectively. *Elubo* is the intermediate product between yam tubers and *amala*; hence, it is essential to understand its rheological properties on exposure to heat. The properties of *elubo* during the heating and cooling process between 50 and 95 °C recorded were peak viscosity,breakdown viscosity, setback viscosity, holding strength also known as trough viscosity, final viscosity, pasting temperature and peak time. The peak viscosity of *elubo* from species of *D. rotundata* and *D. alata* varied from 103 to 293.33 RVU and 14.29 to 143.88 RVU respectively, with *D. alata* varieties having significantly lower peak viscosity than those of *D. rotundata* varieties. Peak viscosity reflected the ability of *elubo*from *D. alata* not being able to swell freely during heating, before it breaks down, which could be attributed to the lower swelling power of *D. alata* species. Otegbayo *et al.* (2014) also reported peak viscosity to be the ability with which the starch granules are dismembered, forming a paste on cooking, hence there is greater disintegration of starch granules of *D. rotundata* than for *D. alata* species. Moreover, lower peak viscosity values were observed in *elubo* when compared with those of their corresponding starch, resulting from starch annealing that occurred during blanching of the tubers for *elubo*processing.

The holding strength ranged from 100.67 to 274.25 RVU (Table 4.16) and 12.92 to 140.04 RVU (Table 4.17) for *D. rotundata* and *D. alata* varieties respectively, with significant difference within the varieties for each species. This result reflects the ease of the starch granules to remain uninterrupted when held at constant temperature and mechanical shear (Otegbayo *et al.*, 2014), and it has been reported to be accompanied by breakdown viscosity. The *D. alata* varieties (1.38 – 11.83 RVU) have significantly lower breakdown viscosity than *D. rotundata* (1.38 to 46.13 RVU). Sample *Agbanwobe* emerged as the variety with the highest holding strength and peak viscosity, while sample*Agboyo-abbi* variety held the lowest holding strength and peak viscosity for *D. rotundata* specie. For *D. alata*varieties, variety TDa11/00022 had the

Table 4.16: Pasting properties of *Elubo*from *D. rotundata* varieties

Sample	Peak viscosity (RVU)	Holding strength (RVU)	Breakdown Viscosity (RVU)	Final Viscosity (RVU)	Setback viscosity (RVU)	Peak Time (min)	Pasting Temp (^{o}C)

Agbanwobe	293.33^{l}	274.25^{l}	19.08^{f}	364.29^{k}	90.04^{ef}	6.53^{cd}	88.05^{h}
TDr95/18531	229.46^{h}	217.33^{h}	12.13^{def}	290.58^{g}	73.25^{d}	6.60^{cd}	81.53^{bc}
TDr89-02665	251.50^{j}	210.04^{h}	41.46^{hi}	310.00^{i}	99.96^{gh}	5.43^{a}	82.28^{cd}
TDrUfenyi	232.29^{h}	216.83^{h}	15.46^{ef}	299.79^{h}	82.96^{e}	7.00^{d}	83.58^{e}
TDr97-00917	126.83^{b}	115.67^{b}	11.17^{cdef}	154.21^{b}	38.54^{a}	7.00^{d}	84.75^{f}
TDr99-02607	184.50^{e}	179.00^{f}	5.50^{abcd}	231.58^{e}	52.58^{b}	6.27^{bc}	83.53^{e}
TDr89-21-3	271.33^{k}	268.63^{j}	2.71^{ab}	365.58^{k}	96.96^{fg}	7.00^{d}	89.33^{i}
Agba	232.75^{h}	196.13^{g}	36.63^{gh}	301.92^{h}	105.79^{h}	5.50^{a}	87.23^{h}
Agboyo-abbi	103.46^{a}	100.67^{a}	2.79^{ab}	139.00^{a}	38.33^{a}	7.00^{d}	81.48^{bc}
Ameh	152.21^{c}	146.75^{d}	5.46^{abcd}	186.75^{c}	40.00^{a}	7.00^{d}	83.98^{ef}
Fakinsa	268.33^{k}	255.67^{i}	12.67^{def}	376.04^{l}	120.37^{i}	6.87^{d}	79.05^{a}
Lagos	150.75^{c}	149.38^{d}	1.38^{a}	191.38^{cd}	42.00^{a}	6.40^{bc}	83.15^{de}
Nwopoko	246.33^{j}	200.21^{g}	46.13^{i}	325.42^{j}	125.21^{i}	5.43^{a}	86.10^{g}
PAA-IITA	155.58^{c}	139.42^{c}	16.17^{ef}	192.88^{cd}	53.46^{b}	6.33^{bc}	84.10^{ef}
Pampas	212.42^{g}	178.75^{f}	33.67^{g}	240.63^{f}	61.88^{c}	5.40^{a}	88.05^{h}
Ogoja	168.25^{d}	157.83^{e}	10.42^{bcde}	225.00^{e}	67.17^{cd}	6.63^{cd}	82.28^{cd}
Sandpaper	190.88^{f}	177.17^{f}	13.71^{ef}	246.38^{f}	69.21	6.03^{b}	83.13^{de}
Takalafia	238.79^{i}	201.25^{g}	37.54^{gh}	305.92^{hi}	104.67^{gh}	5.57^{a}	81.05^{b}
2665	154.79^{c}	151.17^{de}	3.63^{abc}	194.96^{d}	43.79^{a}	6.93^{d}	83.13^{de}
Mean	**203.36**	**186.11**	**17.25**	**260.12**	**74.01**	**6.36**	**83.99**
STD	**53.97**	**48.29**	**14.46**	**72.99**	**28.85**	**0.62**	**2.70**

*Values are average of replicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.

Table 4.17: Pasting properties of *Elubo*from *D. alata*varieties

Sample	**Peak viscosity (RVU)**	**Holding strength (RVU)**	**Breakdown viscosity (RVU)**	**Final Viscosity (RVU)**	**Setback viscosity (RVU)**	**Peak Time (min)**	**Pasting Temp (^{o}C)**

TDa11/00011	86.96^{p}	77.75^{p}	9.21^{opq}	128.79^{r}	51.04^{no}	7.00^{b}	83.93^{bcdef}
TDa11/00014	21.46^{b}	18.71^{b}	2.75^{b}	37.54^{b}	18.83^{b}	7.00^{b}	86.40^{ghij}
TDa11/00020	74.33^{n}	67.17^{n}	7.17^{jkl}	103.54^{no}	36.37^{hij}	7.00^{b}	83.15^{abcd}
TDa11/00022	143.88^{m}	140.04^{w}	3.83^{cd}	179.13^{x}	39.08^{jk}	7.00^{b}	85.55^{fghi}
TDa11/00024	14.29^{a}	12.92^{a}	1.38^{a}	25.00^{a}	12.08^{a}	6.97^{a}	84.73^{cdefgh}
TDa11/00063	63.42^{j}	56.08^{j}	7.33^{jklm}	93.50^{jk}	37.42^{hijk}	7.00^{b}	84.28^{bcdef}
TDa11/00102	44.17^{e}	37.75^{f}	6.42^{hij}	72.67^{f}	34.92^{gh}	7.00^{b}	85.45^{efghi}
TDa11/00110	96.83^{qr}	86.71^{r}	10.13^{qr}	141.08^{t}	54.38^{p}	7.00^{b}	84.75^{cdefgh}
TDa11/00138	136.38^{v}	129.21^{v}	7.17^{jkl}	175.54^{w}	46.33^{l}	7.00^{b}	86.38^{ghij}
TDa11/00162	39.25^{d}	33.96^{e}	5.29^{fg}	65.92^{e}	31.96^{ef}	7.00^{b}	83.55^{bcdef}
TDa11/00164	98.83^{rs}	88.54^{rs}	10.29^{r}	142.75^{t}	54.21^{p}	7.00^{b}	84.68^{cdefgh}
TDa11/00167	117.46^{u}	105.63^{u}	11.83^{s}	162.79^{v}	57.17^{q}	7.00^{b}	86.38^{ghij}
TDa11/00179	69.13^{lm}	61.33^{lm}	7.79^{lmn}	101.00^{mn}	39.67^{k}	7.00^{b}	$85.15^{cdefghi}$
TDa11/00189	70.75^{m}	62.04^{m}	8.71^{nop}	101.96^{mn}	39.92^{k}	7.00^{b}	83.15^{abcd}
TDa11/00225	100.08^{s}	90.08^{s}	10.00^{qr}	139.38^{t}	49.29^{mn}	7.00^{b}	$85.13^{cdefghi}$
TDa11/00232	64.13^{j}	57.67^{jk}	6.46^{ijk}	95.58^{k}	37.92^{ijk}	7.00^{b}	83.58^{bcdef}
TDa11/00242	79.92^{o}	71.21^{o}	8.71^{nop}	106.38^{o}	35.17^{ghi}	7.00^{b}	84.73^{cdefgh}
TDa11/00247	57.75^{hi}	50.38^{i}	7.38^{klm}	101.08^{mn}	50.71^{no}	7.00^{b}	87.10^{ij}
TDa11/00275	51.79^{g}	44.63^{gh}	7.17^{jkl}	80.67^{g}	36.04^{hi}	7.00^{b}	84.38^{cdefg}
TDa11/00287	69.00^{lm}	59.75^{klm}	9.25^{opq}	106.00^{o}	46.25^{l}	7.00^{b}	85.20^{defghi}
TDa11/00292	52.54^{g}	45.25^{h}	7.29^{jkl}	84.21^{h}	38.96^{jk}	7.00^{b}	85.60^{fghi}
TDa11/00299	94.71^{q}	82.88^{q}	11.83^{s}	142.33^{t}	59.46^{q}	7.00^{b}	83.45^{abcde}
TDa11/00305	32.79^{c}	29.67^{d}	3.13^{bc}	54.42^{d}	24.75^{c}	7.00^{b}	88.03^{j}
TDa11/00317	89.04^{p}	81.00^{q}	8.04^{lmn}	133.58^{s}	52.58^{op}	7.00^{b}	83.15^{abcd}
TDa11/00324	60.21^{i}	50.58^{i}	9.63^{pqr}	100.21^{mn}	49.62^{mn}	7.00^{b}	83.53^{bcdef}
TDa11/00368	65.50^{jk}	56.00^{j}	9.50^{pqr}	96.00^{kl}	40.00^{k}	7.00^{b}	86.48^{hij}
TDa11/00370	80.08^{o}	72.17^{o}	7.92^{lmn}	117.54^{p}	45.37^{l}	7.00^{b}	82.23^{ab}
TDa11/00374	48.50^{f}	42.50^{g}	6.00^{ghi}	72.92^{f}	30.42^{def}	7.00^{b}	83.95^{bcdef}
TDa11/00424	66.88^{kl}	58.79^{jkl}	8.08^{lmn}	91.63^{ij}	32.83^{fg}	7.00^{b}	83.98^{bcdef}
TDa11/00426	40.63^{d}	35.08^{e}	5.54^{fgh}	62.92^{e}	27.83^{d}	7.00^{b}	83.08^{abc}
TDa11/00428	108.63^{t}	100.38^{t}	8.25^{mn}	147.50^{u}	47.12^{lm}	7.00^{b}	84.68^{cdefgh}
TDa11/00434	80.25^{o}	71.79^{o}	8.46^{no}	125.63^{q}	53.83^{p}	7.00^{b}	81.50^{a}
TDa11/00493	65.50^{jk}	59.83^{klm}	5.67^{fghi}	98.96^{lm}	39.13^{jk}	7.00^{b}	83.83^{bcdef}
TDa11/00495	56.63^{h}	52.21^{i}	4.42^{de}	89.29^{i}	37.08^{hijk}	7.00^{b}	84.73^{cdefgh}
TDa11/00541	23.83^{b}	20.83^{b}	3.00^{bc}	41.88^{c}	21.04^{b}	7.00^{b}	84.73^{cdefgh}
TDa11/00555	30.71^{c}	25.92^{c}	4.79^{ef}	55.25^{d}	29.33^{de}	7.00^{b}	83.10^{abc}
Mean	69.34	62.12	7.22	102.07	39.95	7.00^{b}	84.54
STD	30.37	28.93	2.52	37.71	11.21	0.01	1.39

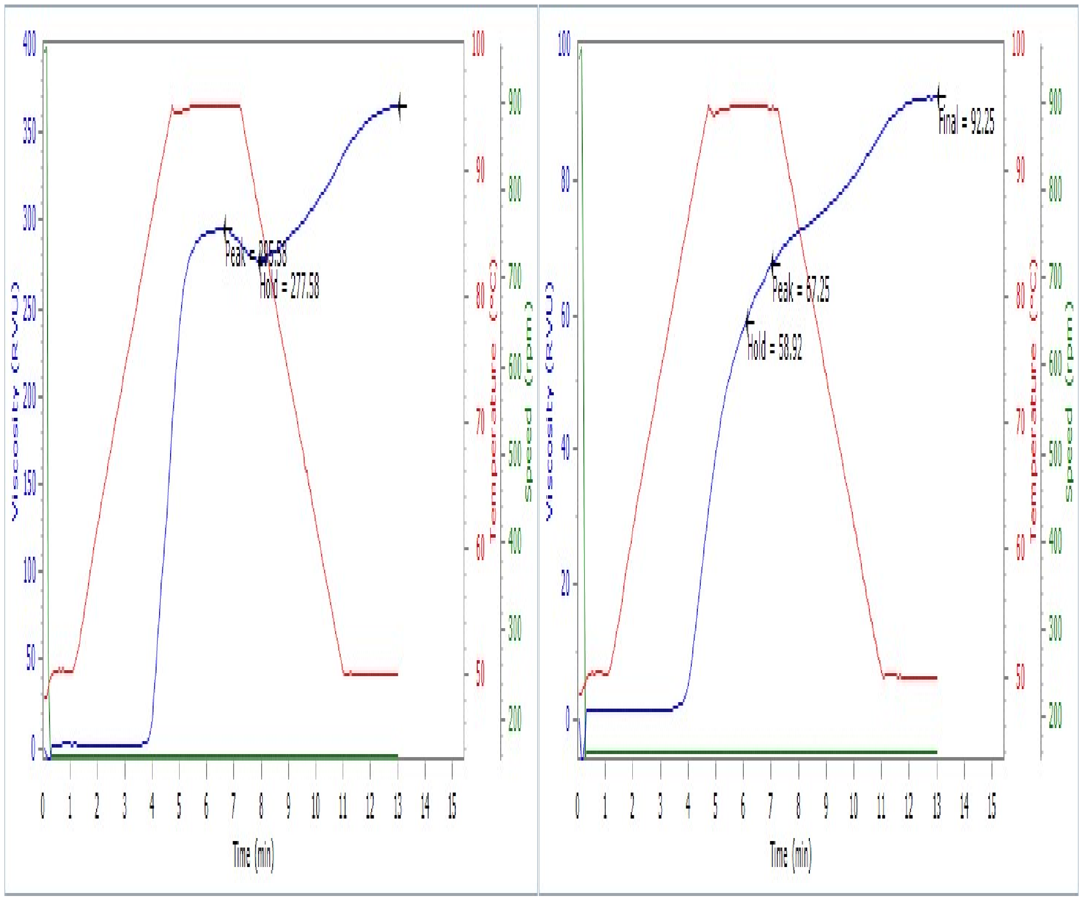
*Values are average of replicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.

highest peak viscosity and holding strength, while variety TDa11/00024 had the minimum values for all the pasting viscosities and the peak time.

The species had final viscosities ranging from 139.00 to 376.04 RVU (Table 4.16) for *D. rotundata* varieties and 25.00 to 179.13 RVU (Table 4.17) for *D. alata*varieties. Final viscosity is the ability to gel after heating and cooling, or form a thick paste (Wireko-Manu *et al.*, 2011; Otegbayo *et al.*, 2014). The significantly higher final viscosity of *elubo* for species of *D. rotundata* showed that the resulting *amala* will be more rigid and viscous on cooling, compared with those of *D. alata* that resulted in a less rigid gel on cooling, as observed during the sensory evaluation. *Elubo* from *D. rotundata* varieties have significantly higher setback viscosity than those of *D. alata* varieties, ranging from 38.33 to 125.21 RVU and 12.08 and 59.46 RVU respectively. This is in contrast to the setback viscosity of starch, which showed higher values for *D. alata* species than those of *D. rotundata* (Tables 4.12 and 4.13).

The differences between the peak times of *D. alata* varieties were insignificantly different ($p \geq 0.05$) except for variety TDa11/00024, while *D. rotundata* varieties showed insignificant difference among some varieties and significant differences among others (Table 4.16 and 4.17). The pasting temperature which signifies the gelatinisation temperature ranged from 79.05 to 89.33 °C for *D. rotundata* and 81.50 to 88.03 °C for *D. alata* varieties. The result showed that there was no significant difference between the cooking times for almost all the varieties, as shown by insignificant difference ($p \geq 0.05$) between pasting temperatures of both species. The strength of force of association within granules of starch is shown by the pasting temperature (Afoakwa and Sefa-Dedeh, 2002), pointing to stability of the resulting *amala*. Figure 4.16a and b give typical pasting graph for*elubo*of *D. rotundata* and *D. alata*.

The pasting properties of fermented flour involved in the making of *amala* were generally lower than those of the isolated starch. The pasting properties of *elubo*showed significantly higher pasting characteristics of peak viscosity, breakdown viscosity, holding strength, final viscosity and setback viscosity for *D. rotundata* than those of *D. alata* species. Hence *elubo* from *D. rotundata* specie have higher ability to swell freely before breaking down, remaining intact and undisrupted over a hold period and greater capacity to gel after heating. Moreover, the pasting result of the



(a) Agbanwobe (b) TDa11/00424

Figure 4.16: Typical pasting graphs for *elubo* from (a) *D. rotundata* and (b) *D. alata*

extracted starch showed that *D. alata* specie have higher final viscosity and set back viscosity than those of *D. rotundata* species, among other pasting viscosities. The process of blanching, and steeping for 24 hours during *elubo*processing would have annealed the starch, as well as increased the exudation of the amylose constituent into the steeping water,hence the variation and disparity in the pasting attributes of *elubo and* the extracted starch of the *Dioscorea species*.

The dendogram of the pasting properties of *elubo*for both species revealed three clusters (Figure 4.17). Cluster A contain exclusively nine *D. rotundata* varieties, which varied from others in terms of their high peak viscosity, breakdown viscosity, holding strength and final viscosity. Cluster B is sub-divided into two sub-groups, I and II, composed of both *D. rotundata* and *D. alata* species, with lower viscosities than cluster A. Cluster B, sub-group I is composed of 8 *D. alata* varieties and 2 *D. rotundata* varieties, with distinctly lesser peak viscosity, holding strength and final viscosity than cluster B, subgroup II- made up of 8 *D. rotundata* and 2 *D. alata* varieties. Cluster C is made up of exclusively *D. alata* (26 varieties) which exhibit lowest peak viscosity, holding strength, break down viscosity, and final viscosity, with slightly higher pasting temperature.

4.11 Instrumental Colour Parameters of *Elubo*and *Amala*

The CIE tristimulus parameters as shown by the L*, a* and b* attributes, as well as the brown index, gave an objective evaluation of the colour properties of *elubo*and *amala* from *D. rotundata* and *D. alata* (Tables 4.18 and 4.19). L* represents the lightness or luminance component, where 0 stands for black, and 100 stands for white; *a** (red-green) coordinate – values in the positive region are red and values in the negative region are green and 0 stands for neutral; *b** (yellow-blue) coordinate – values in the positive axis are yellow, and values in the negative axis are blue and 0 stands for neutral. The chromatic entities ranging from -120 to +120 are the a* and b* parameters (Leon *et al.*, 2006).

The L* parameter of *elubo* and its resulting *amala* from *D. rotundata* species were greater than those of *D. alata* species significantly. L* range from 68.26 to 91.77 and 44.57 to 75.16 for *elubo*of *D. rotundata* and *D. alata* respectively; while the resulting *amala* ranged from 33.13 to 46.79 and 24.38 to 32.58 for *D. rotundata* and *D. alata*

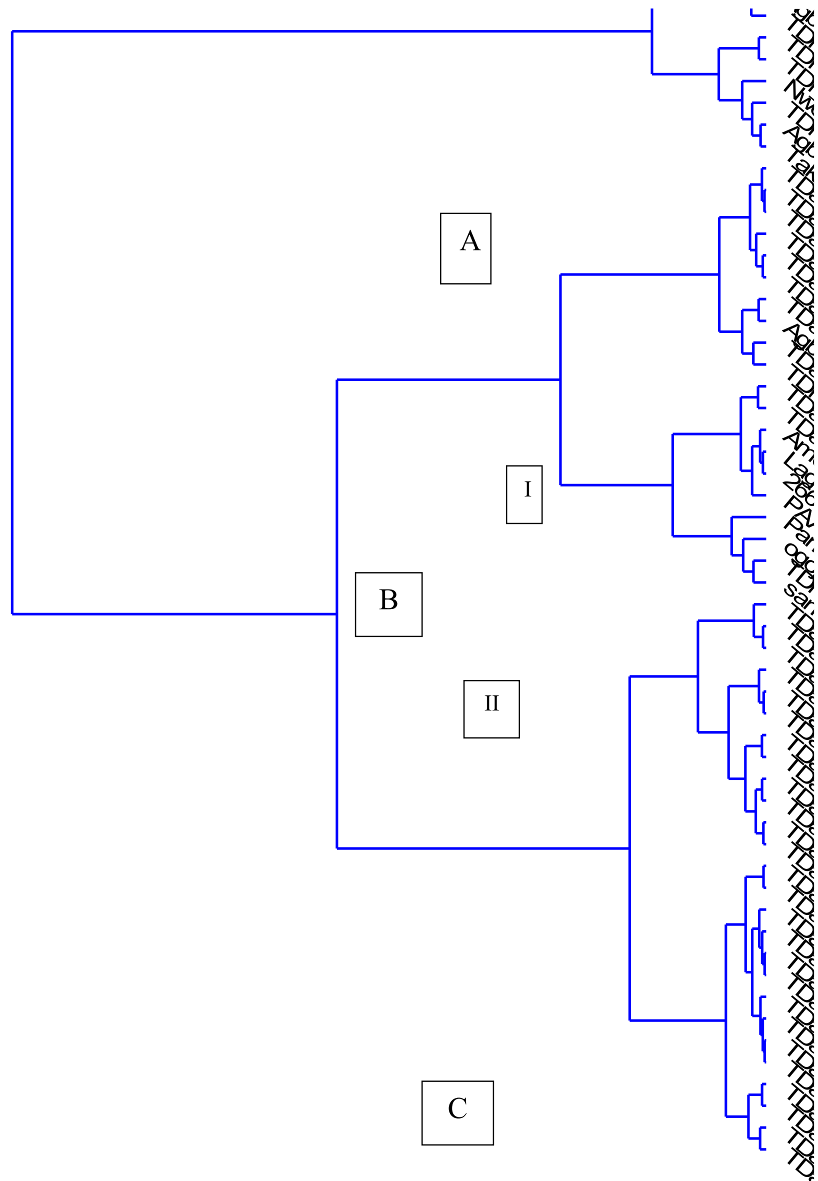


Figure 4.17: Cluster analysis of pasting properties of *elubo* from *Dioscoreaspp*

Table 4.18: Colour parameters of *elubo*and *amala* from *D. rotundata* varieties

Sample	L* elubo	a* elubo	b* elubo	L* amala	a* amala	b* amala	Brown index (amala)
Agbanwobe	83.68^{f}	3.45^{d}	12.95^{ef}	41.34^{i}	2.88^{bc}	6.39^{cd}	58.66
TDr95/18531	86.03^{gh}	3.15^{cd}	13.35^{fg}	41.25^{i}	3.08^{bc}	6.49^{cd}	58.75
TDr89-02665	88.41^{ijk}	4.17^{f}	13.08^{ef}	43.38^{k}	3.72^{de}	6.96^{d}	56.62

TDrUfenyi	87.35^{hi}	2.71^{ab}	12.90^{ef}	44.62^{l}	3.12^{bcd}	8.46^{e}	55.38
TDr97-00917	68.26^{a}	4.87g	11.94^{b}	35.68^{d}	4.35^{f}	5.94^{bcd}	64.32
TDr99-02607	73.64^{c}	4.86^{g}	12.67^{de}	30.18^{a}	2.57^{ab}	3.76^{a}	69.82
TDr89-21-3	85.32^{g}	2.77^{ab}	12.56^{cde}	40.72^{hi}	2.83^{bc}	6.83^{cd}	59.28
Agba	89.80^{k}	3.11^{cd}	11.67^{b}	46.79^{m}	2.88^{bc}	7.03^{d}	53.21
Agboyo-abbi	85.26^{g}	2.48^{a}	13.74^{gh}	40.14^{gh}	2.17^{a}	5.90^{bcd}	59.86
Ameh	77.96^{e}	4.99^{g}	14.23^{hi}	35.57^{d}	4.21^{ef}	6.75^{cd}	64.43
Fakinsa	77.84^{e}	2.72^{ab}	14.17^{hi}	33.13^{b}	3.37^{cd}	6.69^{cd}	66.87
Lagos	76.01^{d}	3.86^{e}	12.91^{ef}	34.48^{c}	3.28^{cd}	6.13^{cd}	65.52
Nwopoko	88.02^{ij}	3.80^{e}	13.07^{ef}	40.90^{i}	2.20^{a}	4.77^{ab}	59.10
PAA-IITA	89.14^{jk}	2.97^{bc}	12.16^{bcd}	39.77^{g}	2.88^{bc}	6.17^{cd}	60.23
Pampas	83.14^{f}	3.26^{cd}	12.55^{cde}	38.61^{f}	2.99^{bc}	6.14^{cd}	61.39
Ogoja	71.97^{b}	7.61^{h}	15.64^{j}	36.31^{e}	6.43^{g}	5.93^{bcd}	63.69
Sandpaper	88.36^{ijk}	2.78^{ab}	12.14^{bc}	42.72^{j}	2.56^{ab}	6.53^{cd}	57.28
Takalafia	78.84^{e}	3.26^{cd}	11.00^{a}	41.34^{i}	3.10^{bc}	5.63^{bc}	58.66
2665	91.77^{l}	3.22^{cd}	14.33^{i}	45.12^{l}	3.44^{cd}	8.32^{e}	54.88
Mean	82.67	3.69	13.00	39.58	3.27	6.36	60.42
STD	6.59	1.19	1.06	4.25	0.93	1.03	4.25

*Values are average of replicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.

Table 4.19: Colour parameters of *elubo*and *amala* from *D. alata*varieties

Sample	L* elubo	a* elubo	b* elubo	L* amala	a* amala	b* amala	Brown index (amala)
TDa11/00011	56.05^{fg}	7.82^{cdefg}	14.83^{cdefghi}	28.39^{ef}	5.73^{efgh}	5.89^{fgh}	71.61
TDa11/00014	70.61^{p}	8.93^{ijklm}	17.24^{jk}	29.51^{ghijk}	4.93^{abc}	5.23^{bcde}	70.49
TDa11/00020	64.18^{kl}	8.32^{efghijkl}	15.79^{fghijk}	28.57^{efg}	4.79^{ab}	5.05^{bc}	71.43
TDa11/00022	68.97^{no}	7.88^{defgh}	15.85^{fghijk}	31.90^{op}	6.51^{j}	6.87^{jk}	68.10
TDa11/00024	58.88^{hi}	8.67^{ghijklm}	14.56^{bcdefgh}	31.18^{mno}	6.54^{j}	7.00^{kl}	68.82
TDa11/00063	60.82^{j}	8.14^{efghij}	15.40^{efghijk}	29.55^{hijk}	5.55^{def}	6.20^{hi}	70.45

TDa11/00102	58.66^{hi}	7.57^{bcdef}	14.64^{cdefgh}	24.38^{a}	4.78^{ab}	4.04^{a}	75.62
TDa11/00110	61.03^{j}	$8.36^{efghijkl}$	15.70^{fghijk}	28.26^{def}	6.64^{jk}	5.87^{fgh}	71.74
TDa11/00138	75.16^{q}	$8.19^{efghijk}$	16.21^{ghijk}	31.28^{mno}	6.35^{ij}	7.06^{kl}	68.72
TDa11/00162	55.70^{fg}	8.08^{efghi}	$14.87^{cdefghi}$	30.72^{lmn}	5.80^{fgh}	6.03^{ghi}	69.28
TDa11/00164	63.04^{k}	$8.24^{efghijk}$	15.47^{fghijk}	24.58^{a}	5.61^{defg}	5.68^{efg}	75.42
TDa11/00167	74.30^{q}	6.92^{ab}	14.43^{bcdefg}	32.58^{p}	6.69^{jk}	7.07^{kl}	67.42
TDa11/00179	71.05^{p}	$8.42^{efghijkl}$	17.35^{k}	31.58^{no}	4.68^{a}	5.42^{bcdef}	68.42
TDa11/00189	63.80^{kl}	9.39^{mn}	16.69^{hijk}	30.42^{klm}	6.02^{ghi}	6.25^{hi}	69.58
TDa11/00225	54.09^{de}	7.55^{bcde}	13.05^{abcd}	27.35^{bcd}	5.42^{def}	5.04^{bc}	72.65
TDa11/00232	57.28^{gh}	8.72^{hijklm}	$15.41^{efghijk}$	29.88^{jkl}	6.44^{ij}	6.27^{hi}	70.12
TDa11/00242	50.05^{c}	7.11^{abcd}	12.48^{ab}	28.94^{efghij}	5.17^{bcd}	5.01^{b}	71.06
TDa11/00247	64.78^{l}	8.79^{ijklm}	15.93^{fghijk}	30.79^{lmn}	6.99^{k}	7.43^{l}	69.21
TDa11/00275	53.52^{de}	8.08^{efghi}	$15.08^{defghij}$	25.24^{a}	5.54^{def}	5.08^{bc}	74.76
TDa11/00287	60.15^{ij}	9.90^{no}	16.15^{ghijk}	29.80^{ijk}	7.06^{k}	5.84^{fgh}	70.20
TDa11/00292	48.18^{b}	7.11^{abcd}	12.78^{abc}	24.52^{a}	5.75^{fgh}	5.68^{efg}	75.48
TDa11/00299	55.09^{ef}	9.08^{klm}	15.05^{defghi}	27.12^{b}	6.07^{hi}	5.14^{bcd}	72.88
TDa11/00305	68.24^{mn}	6.39^{a}	$14.54^{bcdefgh}$	29.36^{ghij}	7.52^{l}	7.98^{m}	70.64
TDa11/00317	59.85^{ij}	9.18^{lmn}	16.86^{ijk}	28.63^{efgh}	5.36^{def}	5.07^{bc}	71.37
TDa11/00324	51.49^{c}	8.80^{ijklm}	15.61^{fghijk}	28.55^{efg}	5.38^{def}	5.53^{cdefg}	71.45
TDa11/00368	67.78^{mn}	$8.45^{fghijkl}$	16.02^{fghijk}	28.89^{efghi}	5.78^{fgh}	6.00^{ghi}	71.11
TDa11/00370	64.20^{kl}	8.73^{hijklm}	12.87^{abc}	28.09^{cde}	5.27^{cde}	5.13^{bc}	71.91
TDa11/00374	57.90^{h}	6.32^{a}	13.32^{abcde}	30.99^{mn}	4.67^{a}	5.22^{bcde}	69.01
TDa11/00424	70.10^{op}	$8.66^{ghijklm}$	16.05^{fghijk}	28.97^{efghij}	4.65^{a}	5.12^{bc}	71.03
TDa11/00426	63.38^{kl}	7.02^{abc}	14.33^{bcdefg}	30.42^{klm}	5.79^{fgh}	6.91^{jk}	69.58
TDa11/00428	66.78^{m}	$8.61^{ghijklm}$	16.44^{ghijk}	27.29^{bc}	5.62^{defgh}	5.80^{fgh}	72.71
TDa11/00434	56.29^{fg}	10.59^{o}	17.00^{ijk}	29.16^{fghij}	7.75^{l}	6.48^{ij}	70.84
TDa11/00493	53.02^{d}	$8.52^{ghijklm}$	13.87^{abcdef}	28.25^{def}	5.58^{defg}	5.13^{bc}	71.75
TDa11/00495	60.88^{j}	9.03^{jklm}	15.94^{fghijk}	30.40^{klm}	6.57^{j}	6.91^{jk}	69.60
TDa11/00541	44.57^{a}	6.50^{a}	12.10^{a}	27.47^{bcd}	5.46^{def}	5.63^{defg}	72.53
TDa11/00555	53.50^{de}	10.17^{o}	16.50^{ghijk}	28.64^{efgh}	6.43^{ij}	6.03^{ghi}	71.36
Mean	60.65	8.28	15.18	28.93	5.86	5.89	71.07
STD	7.39	1.00	1.38	2.04	0.80	0.85	2.04

*Values are average of replicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.

amala respectively (Table 4.18 and 4.19). These L* values of *D. rotundata* varieties for both *elubo* and *amala* that were higher signifies lighter colours than those of *D. alata* which reflected in the brown index, as well as the colour attribute evaluation of the descriptive sensory properties.

The brown index signified the extent of discoloration, which has been attributed to the total phenol contents of materials (Babajide*et al.*, 2006). *D. alata*varieties have significantly higher brown index content of 71.07 for *amala* than those of *D. rotundata* varieties- 60.42, signifying larger amount of polyphenol content, as well as higher rate of thermal degradation to coloured phenols (Akissoe*et al.*, 2003). The study observed brown index that is comparable to the report given by Jimoh *et al.* (2009): 56.67 and Babajide*et al.* (2006): 57.45 for *amala* from *D. rotundata*. However, some authors attributed the dark colour of *amala* to some other factors like the drying parameters, drying process, infestation by insects, contamination with dirts, dust and other undesired materials (Ojokoh and Gabriel, 2010; Adejumo*et al.*, 2013). The *elubo* used for this study were processed using the same drying parameters and process, with no insect infestation and contamination with extraneous materials, hence the variation in the brown index is as a result of varietal differences as well as the polyphenol contents of each variety.

The a* coordinate, indicating the red-green (positive and negative values respectively) axis, are presented in Table 4.18 and 4.19. The a* parameter of *elubo* ranged from 2.48 to 7.61 and 6.32 to 10.59 for species of *D. rotundata* and *D. alata* respectively. The resulting *amala* gave a* parameter ranging from 2.17 to 6.43 and 4.65 to 7.75 for species of *D. rotundata* and *D. alata* respectively. The positive values are indication of the samples tending more towards the red axis than green. Although, *D. alata* varieties had higher positive values than those of *D. rotundata,* which is nearer to red axis indicating darker or duller appearance in relation to the green axis, which correlates with the L* value, as well as colour attribute of the descriptive sensory evaluation results of *amala*.

The b* coordinate of *elubo*for *D. rotundata* and *D. alata*varieties varied from 11.00 to 15.64 and 12.10 to 17.35 respectively; while the *amala* gave 3.76 to 8.46 and 4.04 to 7.98 for *D. rotundata* and *D. alata*varieties respectively (Table 4.18 and 4.19). The b* coordinate of *elubo*and *amala* also gave positive values, which tends towards yellow axis than blue axis. *D. alata* varieties (15.18) had significantly higher positive b* coordinate of *elubo*than *D. rotundata* varieties (13.00), whereas, *D. rotundata* varieties gave insignificantly higher b* coordinate of *amala* than *D. alata*varieties. This objective colour analysis method points to *elubo* from *D. rotundata* to be creamier in colour, than those of *D. alata*, while the resulting *amala* from *D. rotundata* species tend more to yellow axis than blue, meaning lighter (light brown or grey), than *D. alata,* as shown by the b* axis. These results point to the CIE tristimulus evaluation method as an objective means of colour evaluation which does not consider a single line of colour, but multiple strains of colour.

The cluster analysis of the colour parameters for both species revealed four clusters (Figure 4.18). Cluster I consist of exclusively *D. rotundata* species that are distinct from others relative to their L* axis, having the lightest colours. Cluster II comprises both *D. alata* and *D. rotundata* varieties having similar colours in terms of lightness as well, while clusters III and IV are made up of exclusively *D. alata* specie which are darker in colour in terms of lower L* values and higher a* values.

4.12 Descriptive Sensory Properties of *Amala*

Tables 4.20 and 4.21 present the result of the descriptive sensory evaluation of *amala* produced from species of *D. rotundata* and *D. alata* respectively. *Amala* from *D. rotundata* varieties were significantly ($p < 0.05$) more stretchable, slightly sticky, smoother, soft, lighter in colour with bland aroma when compared with those of *D. alata* species.Stretchability is the extent to which a sample can be extended or stretched. Most *amala* from *D. rotundata* varieties were slightly stretchable, while few of *D. alata*varieties were slightly stretchable. No significant difference was observed between stretchability of *amala* for some varieties for each of the *Dioscorea species*. In *D. rotundata, amala* from *Nwopoko* was the most stretchable, and 2665 was the least stretchable; while TDa11/00287 and TDa11/00225 gave the most and least stretchable *amala* for *D. alata*respectively. However, varieties TDa11/00179, TDa11/00232, TDa11/00247 and TDa11/00287 of *D. alata* were similar to a majority of those of *D. rotundata* varieties in terms of stretchability.

The stickiness attributes of *amala* from *D. rotundata* and *D. alata* species were from 2.54 – 2.97 and 2.24 – 3.61 respectively (Table 4.20 and 4.21). Most *D. rotundata*

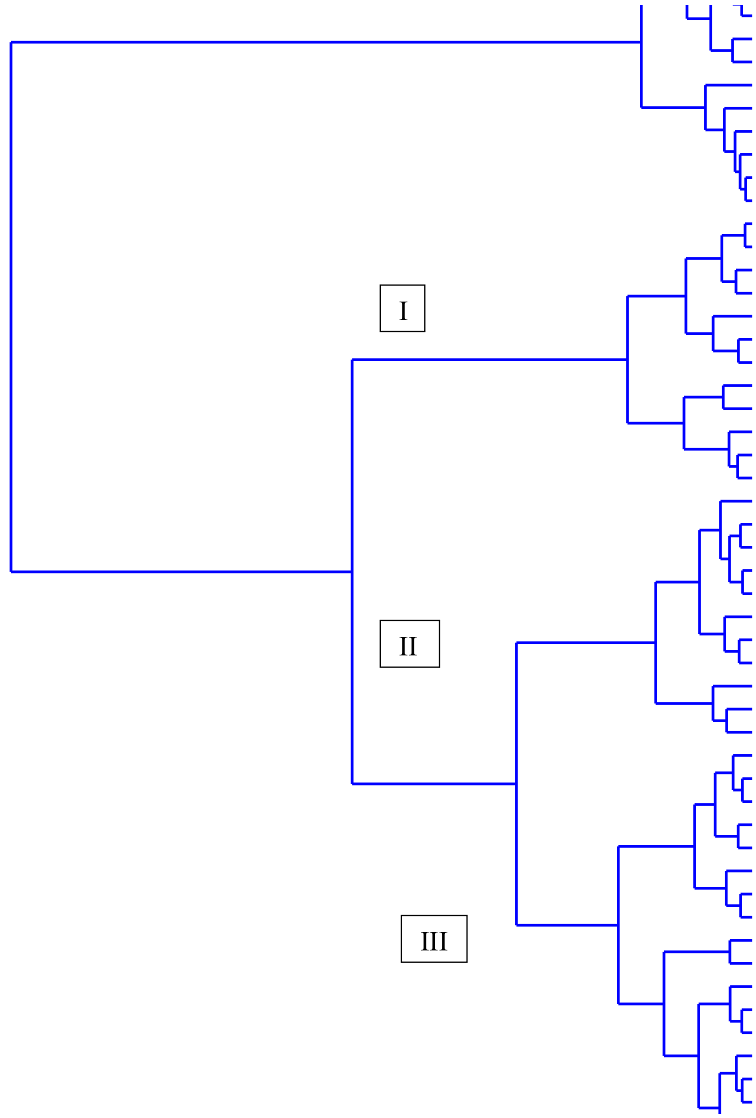


Figure 4.18: Cluster analysis of colour parameters from *Dioscoreaspp*

Table 4.20: Descriptive sensory properties of *amala* from *D. rotundata* varieties

Sample	Stretchability	Stickiness	Smoothness	Hardness	Taste	Aroma	Colour
Agbanwobe	2.00^{abc}	2.46^{abcd}	2.86^{bcd}	3.29^{def}	2.00^{a}	1.75^{ab}	4.32^{bcd}
TDr95/18531	2.38^{bcde}	2.34^{abcd}	2.88^{bcd}	3.16^{cd}	2.03^{a}	1.72^{ab}	4.63^{cdefg}
TDr89-02665	2.41^{cde}	2.75^{cd}	2.84^{bcd}	2.81^{abc}	1.97^{a}	1.59^{ab}	4.81^{cdefg}
TDrUfenyi	1.96^{ab}	2.21^{abc}	2.96^{d}	3.29^{def}	1.93^{a}	1.43^{ab}	4.25^{bc}
TDr97-00917	2.58^{de}	2.65^{cd}	2.92^{cd}	2.65^{ab}	1.88^{a}	1.54^{ab}	2.58^{a}
TDr99-02607	2.46^{cde}	2.57^{bcd}	2.93^{cd}	2.96^{bcd}	2.00^{a}	1.61^{ab}	3.07^{a}

TDr89-21-3	2.66^{ef}	2.81^{d}	2.75^{abcd}	3.09^{cd}	1.88^{a}	1.56^{ab}	5.00^{efg}
Agba	2.22^{bcde}	2.06^{ab}	2.88^{bcd}	3.31^{def}	2.03^{a}	1.69^{ab}	4.53^{cdef}
Agboyo-abbi	3.13^{g}	2.44^{abcd}	2.84^{bcd}	3.13^{cd}	2.00^{a}	1.53^{ab}	4.78^{cdefg}
Ameh	3.13^{g}	2.63^{cd}	2.97^{d}	3.00^{cd}	1.88^{a}	1.47^{ab}	3.88^{b}
Fakinsa	3.38^{gh}	2.54^{abcd}	2.54^{a}	3.17^{de}	2.00^{a}	1.83^{b}	5.33^{g}
Lagos	3.46^{gh}	2.04^{a}	2.75^{abcd}	3.50^{ef}	1.89^{a}	1.43^{ab}	4.43^{bcdef}
Nwopoko	1.75^{a}	2.32^{abcd}	2.93^{cd}	3.54^{f}	1.79^{a}	1.36^{a}	4.29^{bc}
PAA-IITA	2.14^{abcd}	2.68^{cd}	2.79^{abcd}	2.61^{a}	1.93^{a}	1.57^{ab}	4.43^{bcde}
Pampas	3.06^{fg}	2.47^{abcd}	2.63^{ab}	3.25^{def}	1.94^{a}	1.72^{ab}	5.09^{fg}
Ogoja	3.39^{gh}	2.42^{abcd}	2.64^{abc}	3.17^{de}	1.86^{a}	1.56^{ab}	2.50^{a}
Sandpaper	2.56^{de}	2.69^{cd}	2.97^{d}	2.97^{cd}	1.78^{a}	1.53^{ab}	4.97^{defg}
Takalafia	2.44^{cde}	2.50^{abcd}	2.97^{d}	3.28^{def}	2.06^{a}	1.66^{ab}	4.56^{cdefg}
2665	3.65^{h}	2.65^{cd}	2.82^{bcd}	2.94^{abcd}	1.85^{a}	1.53^{ab}	4.88^{cdefg}
Mean	2.67	2.49	2.83	3.11	1.93	1.58	4.33
SD	0.98	0.91	0.48	0.64	0.44	0.68	1.33

* Values are average of replicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.

Stectchability: very stretchable-1, stretchable-2, sligthly stretchable-3, not stretchable-4: Stickiness: Very sticky-1, sticky-2, sligthly sticky-3, not-sticky- 4: Smoothness: Lumpy-1, coarse-2, smooth-3: Hardness: very hard-1, hard-2, soft-3, very soft-4: Taste: sweet-1, bland-2, bitter-3: Aroma: Pleasant-1, bland-2, unpleasant-3: Colour: Dark brown-1, brown-2, light brown- 3, Grey-4, light grey-5, very light brown-6

Table 4.21: Descriptive sensory properties of *amala* from *D. alata*varieties

Sample	Stretchability	Stickiness	Smoothness	Hardness	Taste	Aroma	Colour
TDa11/00011	3.70^{kl}	2.80^{bcdefghi}	2.73^{abcd}	2.60^{fghi}	2.00^{defg}	1.87^{bcdef}	1.33^{ab}
TDa11/00014	3.29^{cdefghijkl}	3.21^{ijkl}	2.93^{cd}	2.68^{fghi}	1.86^{bcdefg}	1.96^{cdef}	1.64^{bcdef}
TDa11/00020	3.18^{bcdefghi}	3.32^{jkl}	2.71^{abcd}	2.36^{abcdef}	1.57^{a}	1.61^{abcde}	2.07^{ghijk}
TDa11/00022	2.92^{abcd}	2.47^{abc}	2.72^{abcd}	2.58^{efghi}	1.92^{cdefg}	1.75^{bcdef}	2.47^{lmn}
TDa11/00024	3.74^{kl}	2.79^{bcdefghi}	2.85^{cd}	3.12^{j}	1.94^{cdefg}	1.71^{abcdef}	2.53^{lmn}
TDa11/00063	3.07^{bcdefg}	2.64^{abcdef}	2.75^{abcd}	2.61^{fghi}	1.82^{abcdef}	1.86^{bcdef}	1.79^{defgh}
TDa11/00102	3.71^{kl}	3.50^{kl}	2.83^{cd}	2.08^{abc}	2.04^{efg}	1.75^{bcdef}	2.79^{n}
TDa11/00110	2.97^{abcde}	2.62^{abcdef}	2.68^{abcd}	2.53^{defgh}	1.85^{bcdefg}	1.76^{bcdef}	2.03^{fghij}
TDa11/00138	3.33^{defghijkl}	3.03^{defghijk}	2.57^{abc}	2.03^{ab}	1.87^{bcdefg}	1.87^{bcdef}	2.53^{lmn}
TDa11/00162	3.50^{fghijkl}	2.82^{bcdefghi}	2.64^{abcd}	2.64^{fghi}	1.82^{abcdef}	1.54^{abc}	1.93^{efghix}

TDa11/00164	3.63^{jkl}	3.29^{ijkl}	2.92^{cd}	2.54^{defgh}	2.00^{defg}	1.67^{abcdef}	1.38^{abc}
TDa11/00167	3.13^{bcdefghij}	2.80^{bcdefghi}	2.73^{abcd}	2.93^{hij}	1.80^{abcde}	1.70^{abcdef}	2.43^{klmn}
TDa11/00179	2.75^{ab}	2.50^{abc}	2.64^{abcd}	2.44^{bcdef}	1.81^{abcdef}	1.61^{abcde}	1.53^{abcde}
TDa11/00189	3.71^{kl}	3.43^{kl}	2.61^{abcd}	2.11^{abc}	1.86^{bcdefg}	1.57^{abcd}	2.25^{ijklm}
TDa11/00225	3.80^{l}	3.10^{efghijk}	2.70^{abcd}	1.93^{a}	2.00^{defg}	1.90^{bcdef}	1.50^{abcd}
TDa11/00232	2.86^{abc}	2.61^{abcde}	2.71^{abcd}	2.61^{fghi}	1.75^{abcd}	1.86^{bcdef}	1.64^{bcdef}
TDa11/00242	3.29^{cdefghijkl}	3.61^{l}	2.43^{ab}	2.14^{abcd}	1.68^{abc}	1.50^{ab}	2.14^{hijkl}
TDa11/00247	2.86^{abcd}	2.36^{ab}	2.67^{abcd}	2.92^{ij}	1.89^{bcdefg}	1.61^{abcde}	2.36^{jklmn}
TDa11/00275	3.06^{bcdefgh}	2.71^{abcdefg}	2.82^{cd}	2.35^{abcdef}	1.94^{cdefg}	1.82^{bcdef}	1.85^{defgh}
TDa11/00287	2.50^{a}	2.88^{cdefghij}	2.79^{bcd}	2.29^{abcdef}	1.91^{bcdefg}	2.06^{f}	1.68^{bcdefg}
TDa11/00292	3.46^{efghijkl}	2.85^{cdefghij}	2.58^{abcd}	2.58^{efghi}	2.08^{fg}	2.04^{ef}	1.23^{a}
TDa11/00299	3.04^{bcdefg}	3.14^{fghijkl}	2.89^{cd}	2.68^{fghi}	1.79^{abcde}	1.61^{abcde}	1.75^{cdefgh}
TDa11/00305	3.30^{cdefghijkl}	2.50^{abc}	2.77^{abcd}	3.27^{j}	1.93^{cdefg}	1.73^{bcdef}	3.37^{o}
TDa11/00317	3.25^{bcdefghijk}	2.86^{bcdefghij}	2.64^{abcd}	2.54^{defgh}	1.82^{abcdef}	1.68^{abcdef}	1.75^{cdefgh}
TDa11/00324	3.57^{hijkl}	3.21^{ghijkl}	2.43^{ab}	2.39^{bcdef}	1.86^{bcdefg}	2.00^{def}	1.57^{abcde}
TDa11/00368	3.57^{hijkl}	3.23^{hijkl}	2.67^{abcd}	2.40^{bcdef}	1.83^{bcdefg}	1.57^{abcd}	2.77^{n}
TDa11/00370	3.41^{defghijkl}	2.85^{bcdefghij}	2.65^{abcd}	2.29^{abcdef}	1.85^{bcdefg}	1.56^{abcd}	1.62^{abcde}
TDa11/00374	3.25^{bcdefghijk}	2.79^{bcdefghi}	2.71^{abcd}	2.61^{fghi}	1.64^{ab}	1.29^{a}	2.71^{mn}
TDa11/00424	3.44^{efghijkl}	2.83^{bcdefghi}	2.64^{abcd}	2.17^{abcde}	1.83^{bcdefg}	1.53^{abc}	1.86^{defgh}
TDa11/00426	3.35^{defghijkl}	2.24^{a}	2.62^{abcd}	2.71^{fghi}	1.88^{bcdefg}	1.82^{bcdef}	1.74^{bcdefg}
TDa11/00428	3.60^{ijkl}	2.70^{bcdefgh}	2.73^{abcd}	2.93^{hij}	1.90^{cdefg}	1.77^{bcdef}	1.70^{bcdefg}
TDa11/00434	2.88^{abc}	2.50^{abcd}	2.82^{cd}	2.71^{fghi}	1.88^{bcdefg}	1.65^{abcdef}	1.82^{defgh}
TDa11/00493	3.00^{bcdef}	3.17^{ghijkl}	2.97^{d}	2.63^{fghi}	2.10^{g}	1.70^{abcdef}	1.83^{defgh}
TDa11/00495	3.47^{efghijkl}	2.50^{abc}	2.71^{abcd}	3.00^{ij}	1.94^{cdefg}	1.74^{bcdef}	2.24^{hijkl}
TDa11/00541	3.53^{ghijkl}	3.10^{efghijk}	2.80^{bcd}	2.47^{cdefg}	1.93^{cdefg}	1.50^{ab}	1.63^{bcdef}
TDa11/00555	3.63^{jkl}	3.03^{defghijk}	2.40^{a}	2.70^{fghi}	2.03^{efg}	1.60^{abcde}	1.53^{abcde}
Mean	3.30	2.89	2.71	2.54	1.88	1.71	1.97
Std	0.87	0.87	0.61	0.74	0.43	0.70	0.80

Values are average of replicates results. Significant difference ($p < 0.05$) is shown by values having different superscripts in a column.Stectchability: very stretchable-1, stretchable-2, sligthly stretchable-3, not stretchable-4: Stickiness: Very sticky-1, sticky-2, sligthly sticky-3, not-sticky- 4: Smoothness: Lumpy-1, coarse-2, smooth-3: Hardness: very hard-1, hard-2, soft-3, very soft-4: Taste: sweet-1, bland-2, bitter-3: Aroma: Pleasant-1, bland-2, unpleasant-3: Colour: Dark brown-1, brown-2, light brown- 3, Grey-4, light grey-5, very light brown-6

varieties were within the range of sticky and slightly sticky, while most *D. alata* varieties fell within the range of slightly sticky and non-sticky. Hence, it was described that *D. rotundata* varieties were slightly stickier in nature than *D. alata*. Stickiness or adhesiveness is another important quality attribute of 'dough' or 'swallow', that result during cooking, leading to alterations occurring in cell separation (Rosenthal, 1999). Stickiness results from the liberation of gelatinized starch or amylose from ruptured cells (Otegbayo *et al.*, 2007).

The preparation of *amala* from tubers of yam involves series of heating processes: blanching of yam tuber to produce *elubo* and reconstitution of *elubo* to prepare *amala*.

Hence a number of reactions would have occurred along the line including solubilisation of yam tuber components and exudation of amylose from the starch which greatly contribute to the adhesive nature of the resulting *amala*. The slightly sticky attributes of *amala* of *D. rotundata* and *D. alata*varieties could have resultedfrom exudation of amylose from theirruptured cells during reconstitution. The slightly stickier nature of amala of those of *D. rotundata* could be linked to the higher setback viscosities of their *elubo* (Table 4.16 and 4.17), which is a pointer to the rate of retrogradation. Moreover, harder gel, i.e. amala were observed for *D. alata* varieties, breaking upon pressing hence, not sticking to the hand, compared with those of *D. rotundata* that were closely bound giving a more stretchable product, slightly sticking to the hand upon application of slight pressure.

Amala samples prepared from *D. rotundata* species were portrayed to be smoother in texture than the ones prepared from *D. alata*varieties. Ameh, Sandpaper and Takalafia gave the smoothest *amala* for *D. rotundata*, with TDa11/00493 giving similar result. Also, in terms of hardness, *D. rotundata* species were softer when compared with those of *D. alata* species, which showed significantly hard *amala*. The aroma of *amala* from *D. rotundata* was described to be more pleasant than those of *D. alata* species.

In terms of colour, *amala* from *D. rotundata* varieties were described to be lighter in colour than *amala* from *D. alata* varieties falling in the region of light grey and brown respectively (Table 4.22). Sample Fakinsa and Ogoja recorded the lightest and darkest colours for *D. rotundata*, while TDa11/00305 and TDa11/00292 had the lightest and darkest colours for *D. alata*respectively (Table 4.20 and 4.21). The colour of fermented yam flour changes during preparation of *amala* as a result of heat

Table 4.22: Summary of Sensory Evaluation of *Amala* from *Dioscoreaspp*

Sample	*D. rotundata*	*D. alata*
Stretchability	2.67 ± 0.56^{a}	3.30 ± 0.32^{b}
Stickiness	2.49 ± 0.22^{a}	2.89 ± 0.33^{b}
Smoothness	2.83 ± 0.13^{b}	2.71 ± 0.13^{a}
Hardness	3.11 ± 0.25^{b}	2.54 ± 0.30^{a}
Taste	1.93 ± 0.08^{b}	1.88 ± 0.11^{a}
Aroma	1.58 ± 0.12^{a}	1.71 ± 0.17^{b}
Colour	4.33 ± 0.80^{b}	1.97 ± 0.48^{a}

Stectchability: very stretchable-1, stretchable-2, sligthly stretchable-3, not stretchable-4: Stickiness: Very sticky-1, sticky-2, sligthly sticky-3, not-sticky- 4: Smoothness: Lumpy-1, coarse-2, smooth-3: Hardness: very hard-1, hard-2, soft-3, very soft-4: Taste: sweet-1, bland-2, bitter-3: Aroma: Pleasant-1, bland-2, unpleasant-3: Colour: Dark brown-1, brown-2, light brown- 3, Grey-4, light grey-5, very light brown-6

degradation of the initially colourless complex polyphenols (proanthocyanidins and lignins) to coloured phenols during preparation' (Akissoe*et al*., 2003). Hence, darker colour of *D. alata*varieties could have resulted from larger amount of this complex polyphenols and higher rate of thermal degradation than *D. rotundata* varieties. Non-enzymatic browning caused by Mailard reaction between amino acids and free sugars is another factor that could be responsible for the darkening of *amala* (Achi and Akubor, 2000). Colour of food products influences decision of consumers in terms of quality as well as appreciation; hence colour is an important quality parameter of foods. According to Mahony (2011) and Mestres*et al.* (2004) colour influences the quality of food, as well as the biochemical characteristics of food materials. Plates 4.1

and 4.2 give typical representations of *amala* and *elubo* from *D. rotundata* and *D. alata*respectively.

The principal component analysis (PCA) of sensory evaluation properties of *amala* is presented in Table 4.23 for *D. rotundata* and *D. alata*. This pointed out that stretchability, stickiness, hardness, taste, aroma and colour are significant sensory attributes for *amala*. The positive and negative loadings of *D. rotundata* showed that as the *amala* became more stretchable, it became less sticky, softer and increased pleasant aroma. While for *D. alata*, it showed that as it became less stretchable, it became stickier to the hand, softer in nature, bitter, that is, more astringent to taste, and darker in colour.

The descriptive sensory evaluation properties (stretchability, stickiness, smoothness, hardness, taste, aroma and colour) were characterised by cluster analysis. The dendogram emerged two major clusters with two sub-groups under each cluster, as shown in Figure 4.19. Cluster A is composed of a group of only *D. alata*varieties, while cluster B combines both species, with cluster B-sub-group II, consisting exclusively of *D. rotundata* species. The distinct properties of *amala* in B cluster are the stretchability, stickiness, smoothness, taste and colour. Cluster B, sub-group I represent both *D. rotundata* and *D. alata* varieties. Cluster B, sub-group II is composed of distinctly *D. rotundata* varieties, which are more stretchable, smoother and lighter in colour than those of sub-group I. This implies that these varieties of *D. alata* (TDa11/00305, TDa11/00024, TDa11/00495, TDa11/00374, TDa11/00167, TDa11/00022 and TDa11/00247) under cluster B, sub-group I, are similar in sensory

a) *Elubo*

b) *Amala*

Plate 4.1: Typical representation of *elubo* and *amala* from *D. rotundata*

a) *Elubo*

b) *Amala*

Plate 4.2: Typical representation of *elubo* and *amala* from *D. alata*

Table 4.23: Principal component analysis for descriptive sensory evaluation of *amala*

	D. rotundata			***D. alata***		
Attributes	**PC1 (28.25%)**	**PC2 (24.89%)**	**PC3 (19.60%)**	**PC1 (26.14%)**	**PC2 (22.36%)**	**PC3 (16.60%)**
Stretchability	0.1931	0.3485	-0.6042	-0.4463	0.1120	0.5626
Stickiness	-0.2590	0.6100	0.1696	-0.6235	-0.0332	0.1439
Smoothness	-0.4678	-0.2934	0.3932	0.2491	0.0569	0.3687
Hardness	0.2874	-0.5806	-0.2680	0.5695	-0.0388	0.3655
Taste	0.4591	-0.0731	0.4929	0.0499	0.5993	0.4426
Aroma	0.509	0.2767	0.3693	0.1044	0.6061	-0.2265
Colour	0.3526	0.0370	0.0206	0.1108	-0.5051	0.3821

*Percentage contribution of each principal component (PC) is in parenthesis. Red print shows the important attribute in each PC (≥ ~0.50)

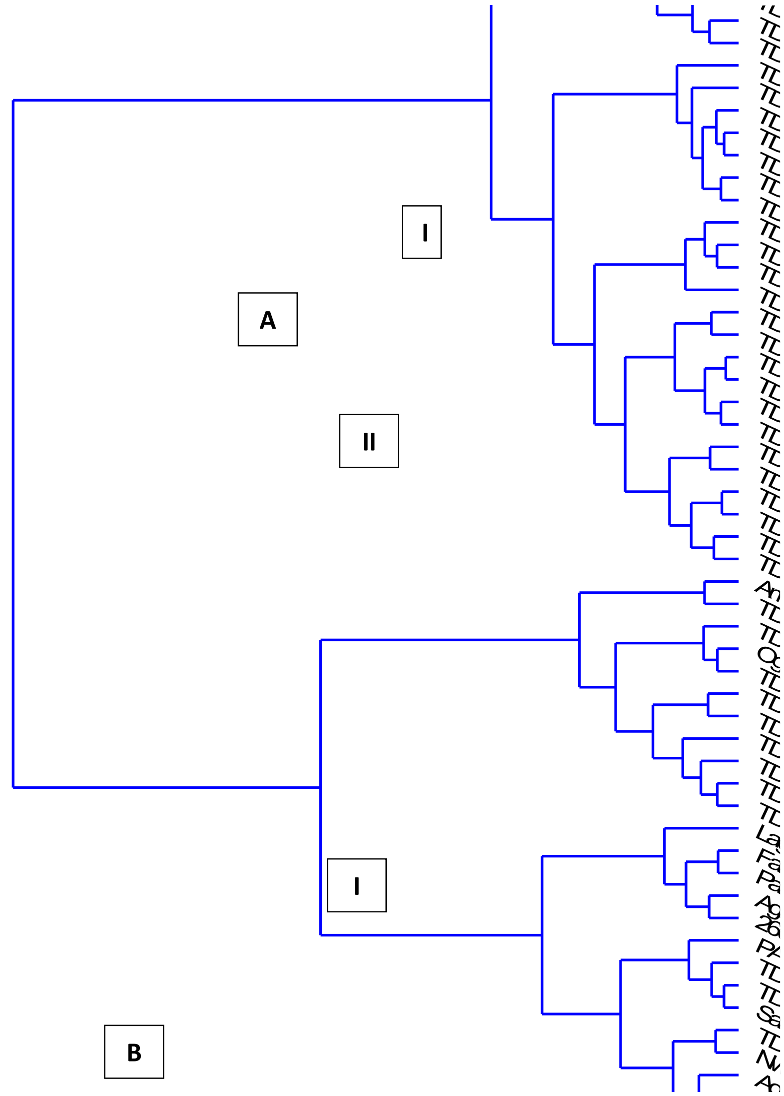


Figure 4.19: Cluster analysis of sensory properties of *amala* from *Dioscoreaspp*

attributes to those of *D. rotundata* varieties. These *D. alata* varieties could be said to have similar properties with those of *D. rotundata* in terms of the swelling power of their starch for TDa11/00024, TDa11/00495, TDa11/00374 (Table 4.15); pasting properties of starch for TDa11/00305, TDa11/00495, TDa11/00374 (Table 4.13) and pasting properties of *elubo* for TDa11/00167, TDa11/00022 and TDa11/00247 (Table 4.17). Hence, the sensory attributes of the resulting attribute of *amala* could be combination effects of various properties.

4.13 Correlations between Yam Tuber Properties and *Amala*

Table 4.24 presents the canonical correlation between the quality of the resulting *amala* and properties of the yam tubers, as identified by Wilks' Lambda level of significance (F < 0.05). The identified quality indicators from the properties of the yam tubers for both species are presented in Table 4.25.

In both species, the chemical and functional properties of yam tubers had significant (P < 0.05) relationships on the sensory attributes of *amala*. Anti-nutritional properties were significantly correlated to the sensory properties of *amala* from *D. alata*, while pasting properties were further correlated to sensory properties of *amala* for both species.

4.13.1 Canonical correlation between the chemical properties, functional properties of yam and sensory properties of *amala*

Functional properties show complex associations among the structure, compositions and molecular conformation of food components, combined with the environmental nature (Chandra *et al*., 2013). Stretchability of *amala* (which is a slightly stretchable food item) was found to be significantly correlated to swelling power (p = 0.001) of yam starch for *D. rotundata*, with stretchability increasing with increasing swelling power. The swelling power is majorly monitored by the character and strength of the micellar networks (amylose molecules) that exists within the starch granules. This association may be a viscosity factor, as viscosity increases with swelling power.

Amala is a paste food item that is eaten with soup, and not alone, hence taste could be regarded as an unimportant quality attribute. However, when it was evaluated by sensory panelists and subjected to principal component analysis (Table 4.23), it was

Table 4.24: Summary of Canonical correlations between *amala* and properties of yam tubers

Yam Species	Parameter	% Contribution	Wilki'sLamda (Sig of F)	Significant level
Dioscorea rotundata	Chemical composition on fresh weight basis	77.97	0.000	Significant
	Pasting characteristics of starch	85.64	0.000	Significant

	Pasting characteristics of *elubo*	84.05	0.004	Significant
	Functional properties of starch	54.19	0.002	Significant
	Mineral composition of yam flour	-	0.553	Not-significant
	Anti-nutrient composition of yam flour	-	0.073	Not-significant
Dioscoreaalata	Chemical composition on fresh weight basis	41.57	0.001	Significant
	Pasting characteristics of starch	-	0.129	Not-significant
	Pasting properties of *elubo*	64.51	0.000	Significant
	Functional properties of starch	73.88	0.000	Significant
	Mineral composition of yam flour	-	0.519	Not-significant
	Anti-nutrient composition of yam flour	62.12	0.016	Significant

Table 4.25: Significant associations between the Sensory properties of amala and properties of yam tubers

Food	Parameter	Sensory attributes	Indicator

product			
Amala (*D. rotundata*)	Chemical composition on fresh weight basis	Taste (0.000)	Amylose (+ve, P= 0.022) Sugar (-ve, P= 0.011)
	Functional properties of starch	Stretchability (0.002)	Swelling power (-ve, P= 0.001)
	Pasting characteristics of starch	Smoothness (0.023)	Final viscosity (+ve, P= 0.027)
	Pasting characteristics of *elubo*	Stretchability (0.004)	Holding strength (+ve, P = 0.038)
Amala (*D. alata*)	Functional properties of starch	Stickiness (0.011)	Water absorption capacity (+ve, P= 0.036)
		Taste (0.000)	Water absorption capacity (+ve, P= 0.003)
	Pasting characteristics of *elubo*	Stickiness (0.010)	Peak viscosity (+ve, P = 0.000)
	Anti-nutrient of flour	Taste (0.013)	Tannin (+ve, P= 0.005)

❖ Correlation and level of significance are indicated in parenthesis

found to be an important attribute of *amala*, which could have been influenced by a number of other yam tuber components. Canonical correlation (Table 4.25) showed that some chemical properties of yam tubers were significantly associated to the taste (p = 0.000) of *amala*, including amylose content and sugar for *D. rotundata* species and tannin content for *D. alata* species. The results showed that the bland taste of the *amala* reduced, giving a more slightly sweet taste as the sugar content increased (Table 4.25), and hence increased sugar content in yam tubers decreases the bland taste of *amala*. The amylose content association with the taste showed that as the amylose content decreased, the amala taste gets more slightly sweet, as it moves farther away from astringent taste. It has been reported that amylose has definite impact on the basic texture and nature of product (Mishra and Rai, 2006), and not on taste. However, report has revealed that amylose content could affect other sensory qualities like taste (Chen *et al.,* 2017), as either too high or too low could alter the taste, hence amylose content should be moderate. Furthermore, discriminating between amylose and amylopectin in terms of taste, Ramirez (1991) observed preference for corn amylopectin than corn amylose by rats, as a result of an off- taste component in corn amylose. Hence, amylose content could be an indicator of taste in *amala*.

For *D. alata,* water absorption capacity was also identified as a functional property that associated with the taste of *amala.* The relationship showed that the taste of *amala* was slightly sweeter (decreasing astringency or slight bitterness) as the water absorption capacity decreased (Table 4.25); it showed that as the capacity of the starch content to retain water increased, the more dilute the components are and hence reduced sugar component, thereby leading to a decrease in the pleasing taste. Tannin was associated to the taste of *amala* for *D. alata*, with increasing tannin content, increasing the non-sweet taste of *amala.* Tannin has been stated to be significant in influencing the taste of food products it contains, characterised by their astringent properties (Laaksonen, 2011; Ashok *et al.*, 2012; Lamy *et al.,* 2016). This may be responsible for the non-sweet or slightly bitter taste characterised for *amala* of *D. alata*varieties by the sensory panelists; as higher tannin content was reported for *D. alata* than those of *D. rotundata* (Tables 4.6 and 4.7). Therefore, increase in the tannin content decreases the capacity of the starch to take up water, and hence increased astringent taste of the resulting *amala*.

Stickiness was found to be a significant attribute of *amala* ($p < 0.05$) from *D. alata* varieties, associated to the water absorption capacity ($p = 0.036$) of the yam tuber starch. The result showed that as the water absorption capacity increased, stickiness of *amala* reduced. Water absorption capacity affect the pasting capacity of flour (Ezeocha*et al.*, 2015), hence the increased capacity of the *D. alata*varieties to absorb water helped in the formation of paste that were firm, and hence not adhering to the hand. Moreover, some varieties that had lower water absorption capacity had increased sticky nature. The results of the sensory evaluation corroborate this, as samples that were harder were less sticky, compared to samples that were softer, adhering to the hand.

4.13.2 Canonical correlation between pasting characteristics of yam starch and *elubo* and sensory attributes of *amala*

There were significant associations between the properties of *amala* and the pasting properties of *elubo* for both species at $p < 0.05$ significant levels (Table 4.20). The stretchability of *amala* from *D. rotundata* varieties were correlated to the holding strength ($p = 0.04$) of the *elubo*as shown in Table 4.25; the stretchability of the *amala* reduces as the holding strength increased. The holding strength reflects the ability to withstand stress or mechanical fragmentation during a hold period. *Amala* is a food item that exhibit slight stretchability, hence the more strength the gelled component has to withstand stress over a hold period, the more compact it is, and the less stretchable it behaves.

Stickiness of a*mala* from *D. alata* was significantly correlated ($p < 0.05$) to peak viscosity of its *elubo*.For *D. alata* varieties, as their ability to swell freely before breaking down (that is, peak viscosity) decreased, the stickier the resulting *amala* was to the hand. Report has shown that peak viscosity is the capacity of granules of starch to form paste; the higher the peak viscosities of pastes, the thicker the pastes on cooking as a result of increase in viscosity from granule rupture and alignment (Otegbayo *et al.,* 2005). This may be an amylose content factor, as this has influence on both stickiness and extent of starch granules swelling- that is peak viscosity. Similar observation of association between peak viscosity and amylose content of starch has been stated to be negatively correlated (Collado*et al.*, 1999), as amylose content is responsible for reduced swelling and sticky nature of resulting food product. Hence, amylose with the presence of lipid (minor component of starch) tends to entwine with amylopectin, thereby restricting the increase in viscosity of starch granules (Yongfeng and Jay-Lin, 2015).

Correlation analysis between the pasting characteristics of starch and sensory attributes of *amala* showed that final viscosity is a significant characteristic of starch-based product for *D. rotundata*, as the textural attribute of smoothness was affected by its resulting viscosity after cooling the cooked paste. The capacity of gel formation following cooking and cooling starch suspension is known as final viscosity (Wireko-Manu *et al.*, 2011). Higher resulting viscosity after cooling cooked paste of starch will yield smoother texture of the *amala* from such a variety. This implies that varieties with higher final viscosity forms a firm viscous material after cooking and cooling, resulting in a product with better smoothness.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The research presents the characterisation of *D. alata*and *D. rotundata* varieties in terms of the granule sizes, functional properties, pasting properties, anti-nutritional composition, colour parameters as well as sensory properties and colour parameters of their resulting food product; *amala*.Granule morphology of *D. rotundata* varieties had larger starch granules than those of *D. alata*, which influenced the viscosity and swelling properties of their starches. The fresh tubers of *D. rotundata* varieties were lighter in colour as shown by the higher L* and b*; and lower a* values. Starch and sugar of *D. rotundata* species were higher than those of *D. alata* species, with lower crude fibre, ash and protein content. The high starch components of both*Dioscorea species* showed the potentials of these starches for exploitation and utilization in industries.

The anti-nutrient contents (tannin, phytate and oxalate) of *D. alata* were significantly higher than those of *D. rotundata*, which could be said to contribute to the increased astringent taste perception of food product from *D. alata* varieties. Swelling power and solubility index showed that *D. rotundata* have lower associative forces, which results in loose link between amylose and the rest of the macro molecules, resulting in greater solubility and swelling power.These could have influenced the differences in their textural quality.The pasting properties of *D. rotundata* varieties had higher peak viscosities, holding strength and breakdown viscosities; and lower setback viscosities than those of *D. alata* varieties, which influenced the textural properties of the resulting food product. Starches of *D. rotundata* could be used as thickeners, binders and fillers. *D. alata* starches could find application in dessert creams, as well as in products where high retrogradation is desired, such as noodles. The high pasting temperatures of *D. alata*and *D. rotundata* make them suitable for use in canned and sterilized foods.

Stretchability, stickiness, hardness, taste, aroma and colour were identified as the significant quality attributes in *amala*. *Amala* from *D. rotundata* varieties were described to be significantly slightly more stretchable, slightly sticky, smoother in texture, soft and firm, lighter in colour with bland aroma than those of *D. alata*. These varieties of *D. alata*; TDa11/00305, TDa11/00024, TDa11/00495, TDa11/00374, TDa11/00167, TDa11/00022 and TDa11/00247 behaved similarly with some of *D. rotundata* in stickiness, smoothness, taste and aroma. In terms ofstretchabilitythere were some varieties of *D. alata*which were similar to those of *D. rotundata* varieties; TDa11/00179, TDa11/00232, TDa11/00247 and TDa11/00287

The study established that functional, chemical and pasting properties of yam tubers are important in indicating the sensory properties of *amala*. Swelling power of starch was an indicator of stretchability in *amala*, water absorption capacity of starch as indicator of stickiness, sugar and tannin content of yam tuber as indicators of taste, final viscosity of starch as indicator of smoothness, holding strength of *elubo* as indicator of stretchability, peak viscosity of *elubo* as indicator of stickiness. Moreover, different species possessed varying indicators.

For *D. rotundata* species, stretchability of the*amala* increased as the swelling power increased;the astringent taste of the amala reduced, giving a more slightly sweet taste as the sugar content increased. Moreover, for *D. alata*species, tannin content was associated to the taste of *amala*, with increasing tannin content, increasing the astringent taste of *amala.*The stickiness of *amala* decreased as the water absorption capacity increased. Correlation analysis between starch pasting properties and the sensory attributes of *amala* showed that final viscosity of *D. rotundata* was associated with smoothness. The results obtained showed that the stretchability of *amala* from *D. rotundata* varieties was correlated to the holding strength of the *elubo*; the stretchability of the *amala* reduced as the holding strength increased. Stickiness of a*mala* from *D. alata* was significantly correlated to the peak viscosity of its *elubo*. The results showed that for *D. alata* varieties, as their ability to swell freely before breaking down decreased, the stickier the resulting *amala* was to the hand.

5.2 Recommendations

- Based on the functional properties, *D. rotundata* and *D. alata*flours are recommended for use in food industries. *D. alata*can be used in complementary food production, as well as noodles production, while *D. rotundata*can be used as binders and thickeners. Those with high pasting temperatures can be used in canned and sterilized foods. However, for optimum results from the use of the starches, modification of the native starch is recommended.
- The identified quality indicators are recommended as screening tools for breeders and food processors.
- There were varieties of *D. alata* that had similar sensory properties with those of *D. rotundata*; these could be further explored for *amala* and other food products at commercial and household level.
- Further research on other components of carbohydrates such as dietary fibres, which are non-starchy polysaccharides (cellulose, hemicellulose, lignin, neutral detergent fibre and acid detergent fibre) can be characterised for potential as indicator of quality in yam food products.

5.3 Contributions to Knowledge

This study has made the following contributions to knowledge:

- The study identified the chemical, pastingand functional characteristics of yam that determine the quality of *amala*, including sugar, amylose, tannin contents, swelling power, water absorption capacity, holding strength and peak viscosity.
- The research provided information on differences in properties, within varieties of yam in a species (intra-variations) and between species (inter-species variations), which affected the quality of food products from the yam species.
- Pasting properties of *elubo* and also the effect of processing on it were established; as blanching and fermentation operations resulted in reduced pasting viscosities.
- The research work revealed that some varieties of *D. alata* could as well give desired sensory properties, as those of *D. rotundata*, including TDa11/00305, TDa11/00024, TDa11/00495, TDa11/00374, TDa11/00167, TDa11/00022 TDa11/00247 TDa11/00179, TDa11/00232, and TDa11/00287.

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Appendix I

SENSORY PROFILE EVALUATION FORM

Sensory evaluation of *amala*.

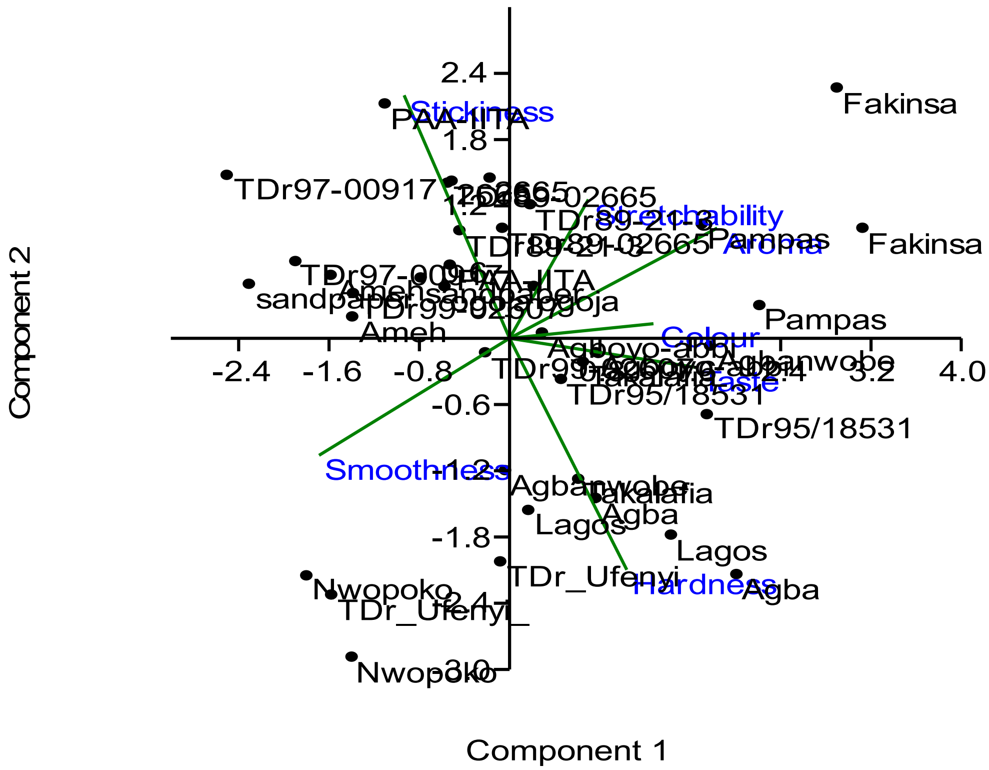
Name: .... Date: ....

Please examine these samples of***amala*** and assess them as indicated below. Tick your response for the attribute / characteristic of the product as you have been trained to do.

		Sample code:										
Attributes												
Stretchability	Very stretchable	1										
	Stretchable	2										
	Slightlystretchable	3										
	Non-stretchable	4										
Stickiness	Very sticky	1										
	Sticky	2										
	Slightly sticky	3										
	Non-sticky	4										

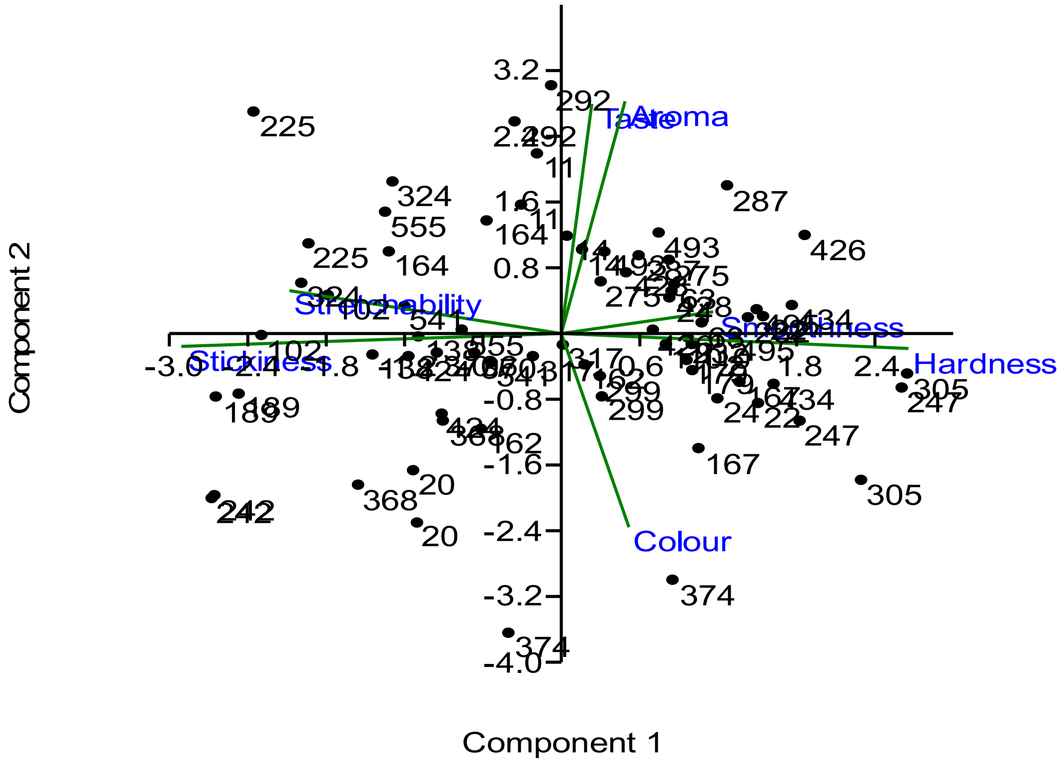
Smoothness	Lumpy	1
	Coarse	2
	Smooth	3
Hardness	Very Hard	1
	Hard	2
	Soft	3
	Very soft	4
Taste	Sweet	1
	Bland	2
	Bitter	3
Aroma	Pleasant	1
	Bland	2
	Unpleasant	3
Colour	Dark brown	1
	Brown	2
	Light Brown	3
	Grey	4
	Light grey	5
	Very light brown	6

Appendix II



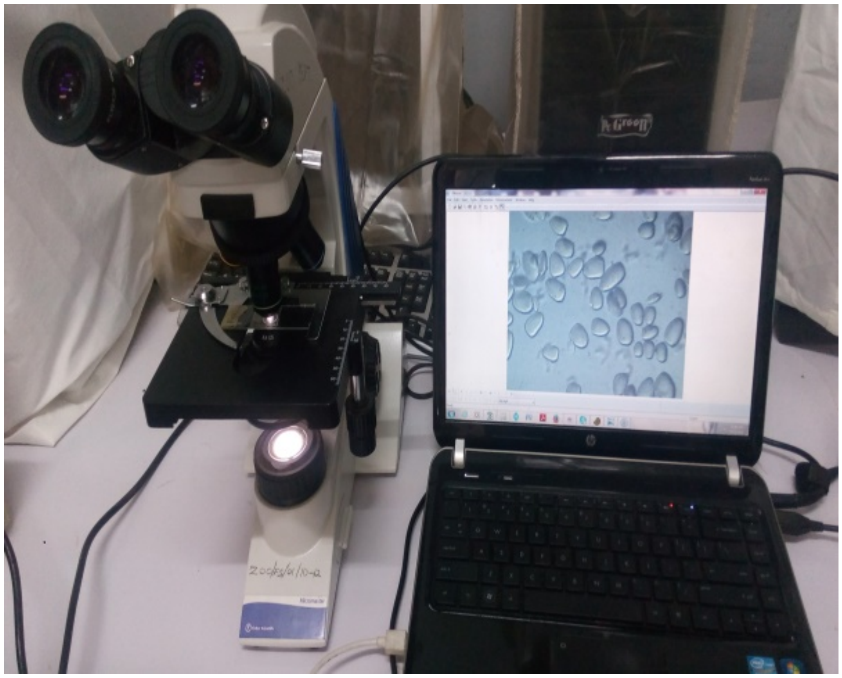
Principal Component Analysis (PCA) scatter plot for *amala* of *D. rotundata*

Appendix III



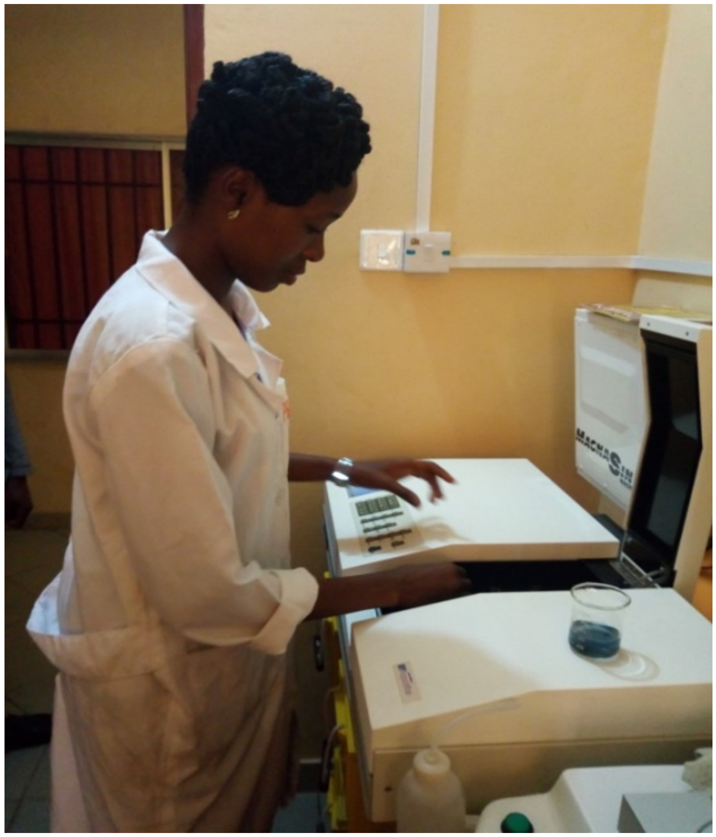
Principal Component Analysis (PCA) scatter plot for *amala* of *D. alata*

Appendix IV

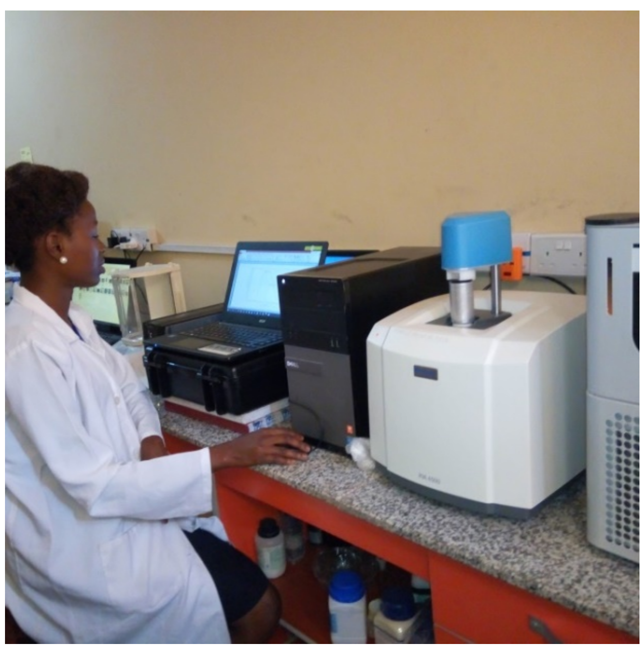


(a) Light microscope

(b) Atomic Absorption Spectrophotometer



(b) Spectrophotometer



(d) Rapid Visco Analyzer

(e) Near Infrared Reflectance Spectrometer

(f) High Performance Liquid Chromatography

(g) Sensory evaluation training in session

(h) Sensory evaluation in session

(i) *Amala* making machine

(j) *Amala* in the making

(k) Starch extraction in process

(l) starch extraction

(m) Yam barn