CHARACTERIZATION AND SUITABILITY OF *DIOSCOREA ALATA* (WATER YAM) IN THE PRODUCTION OF COUSCOUS

BY

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DECLARATION

I hereby declare that this submission is my own work towards the MSc., and that to the best of my knowledge, it contains no material previously published by another nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

Consumer utilization of *Dioscorea alata* could be enhanced by processing them into a more stable, acceptable and convenient food product. The aim of this study was to evaluate the suitability of *Dioscorea alata* for couscous production. Fifteen varieties of *Dioscorea alata* were used for this study. Yam couscous was prepared using both the blanched-grated-tuber and the flour methods. The yam tubers were first characterized for the chemical composition (moisture, ash and protein) and physicochemical properties (amylose content, starch granule size and pasting properties). A shelf life study was conducted over 24 week period within which the moisture content, pH, microbial load and sensorial qualities of the yam couscous were determined. The *Dioscorea alata* flours had relatively high gelatinization temperatures and low peak viscosities. The gelatinization temperature is positively correlated with the gelatinization time. The *Dioscorea alata* starches had granule sizes, ranging from 20 µm to 60 µm and very low amylose content. The blanched-grated-tuber (BGT) method was easier in terms of labour and time and gave better couscous than couscous made by the flour method in terms of sensory qualities. In decreasing order of goodness, couscous from TDa 99/00528, TDa 291 and TDa 98/001168, Matches, TDa 99/00199 and TDa 99/00214 were judged as the most preferred. There was a general increase in bacteria count of yam couscous over storage period. However, no *E. coli* and Coliforms were present. The sensory quality of the yam couscous was acceptable over the storage period. It is possible to produce acceptable couscous from *Dioscorea alata* which will be safe for human consumption and keep for not less than 24 weeks in a cool dry place.

DEDICATION

This work is dedicated to my parents, Mr. & Mrs. Opata and My siblings Katherine, Adolphus and Edwin Opata for their love and support in all my endeavours.

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CHAPTER 1

1.0. INTRODUCTION

Roots and tubers are second to cereals in terms of consumption in most parts of Africa including West Africa. The principal root and tuber crops of the tropics are cassava (*Manihot esculenta* Crantz), yam (*Dioscorea* spp.), sweet potato (*Ipomoea batatas* L.), potato (*Solanum* spp.) and edible aroids (*Colocasia* spp. and *Xanthosoma sagittifolium*). They are widely grown and consumed as subsistence staples in many parts of Africa, Latin America, the Pacific Islands and Asia. The potential of these crops is particularly high in the humid tropics and those sub-humid tropics, which are not suitable for cereal production (Calverley, 1998). Root and tubers play important economic and diversified roles in the food systems of developing countries. Being an important food security crop, they contribute more than fifty percent (50 %) calories in the diet of most people in Africa (Kordylas, 1990).

The yam tuber is the second most important crop after cassava. It is widespread in the humid tropics throughout the world in a wide variety of species (Kordylas, 1990). Its importance in the diet and socio-economic life of the people in the growing regions cannot be overlooked. Research shows that yam alone plays an important role in the diet of about two hundred million people in West Africa (Calverley, 1998). Those of particular importance are White Guinea yam *(Dioscorea rotundata Poir)*, Water yam (*Dioscorea alata)*, Yellow yam *(Dioscorea cayenensis Lam.)*, Trifoliate yam (*Dioscorea dumetorum)*, Potato or Aerial yam *(Dioscorea bulbifera)* and Chinese Yam *(Dioscorea esculenta)*. Together, these six species account for ninety percent of all the food yams grown in the tropics (Hahn *et al*., 1995 and Orkwor, 1998).

Nigeria is said to be the leading producer of yam producing approximately 70% to 75% of the world's yam. Much of the remainder is produced in Côte d'Ivoire, Ghana, Benin, Togo, and Cameroon (Hahn *et al.*, 1995 and Vernier, 1998). It has been estimated that the world yam production would increase by 27 % between the years 2003 and 2020. In Ghana alone, yam production increased from 3,363,000 Mt to 3,892,000 Mt between the year 2000 and 2004 (Vernier, 1998; Kenyon *et al.*, 2006). However, there is competition with other crops like cassava, rice and maize in Nigeria and Ghana, and taro in the South Pacific (Opara, 1999).

As production of yam increases over the years, post - harvest losses also increase (Akoroda and Hahn, 1995). Like the other roots and tubers, yam is bulky very perishable due to high moisture content. These make them less convenient for transportation and storage compared to cereals, hence increasing their losses after harvest. It has been estimated that between 10 % and 60 % of yam harvested are lost (National Academy of Science, 1978). One sure means of post – harvest loss in yam has been weight loss due to physiological processes such as sprouting, dehydration and respiration (Vernier, 1998). Other factors such as damage, rodent attack, fungal and bacterial diseases have also contributed to the post – harvest losses of yams. Weight loss during storage in traditional or improved barns, or clamp storage have been estimated to reach between 10 % and 12 % in the first three months and between 30 % and 60 % after six months. In West Africa alone, this amounts to an annual loss of one million tonnes of tubers (Akoroda and Hahn, 1995). Due to these huge losses incurred during harvesting and storage, farmers tend to sell their produce immediately after harvest at very uneconomical prices. Processing of yam tubers into more stable and convenient forms will increase shelf life, availability and enhance its usage.

The main processed form in which yam is consumed in West Africa so far is flour (Iwuoha, 2003), which is made from dried yam chips, even though there are other products such as yam flakes and yam granules (couscous) which is locally referred to as '*wasawasa*.' These products are normally made from the White yam (*Dioscorea rotundata Poir*) whilst neglecting other yams species especially Water yam (*Dioscorea alata). Dioscorea alata* has been a lesser choice compared to white and yellow yams due to its generally loose watery texture (Opara, 1999). Consumer utilization of water yam could be enhanced if this species of yam can be processed into a more stable, acceptable and convenient product.

1.1 Objectives

The objective of this study was to evaluate the suitability of *Dioscorea alata* for couscous production. This would be achieved by:

- Determining the pasting characteristics of *Dioscorea alata* flour.
- Establishing the appropriate processing method for yam couscous and assessing the qualities of the product through sensory evaluation.
- Conducting shelf life studies on the product.

CHAPTER 2

2.0. LITERATURE REVIEW

2.1. Nature and Taxonomy

Yam is a tuber forming and liana type plant that is generally classified under the order Dioscoreales and the family of Dioscoreaceae. Being essentially a monocotyledonous plant, yam also shows some features of dicotyledonous plants (Brunnschweiler *et al.*, 2004). Presently, the term yam is confined to plants of the genus *Dioscorea* which have been reported as comprising of about 600 species. Approximately 200 species are distributed throughout the tropics and subtropics (Ayensu, 1972) and about 50 to 60 species are cultivated or gathered for food or pharmaceutical purposes (Hahn *et al.*, 1995).

The genus *Dioscorea* is subdivided into five sections: Enantiophyllum, Lasiophyton, Opsophyton, Combilium, and Macro-gynodium. The section Enantiophyllum comprises most of the economically important yam species (*Dioscorea alata, D. cayenensis, and D. rotundata)* as well as two species of minor importance *(D. opposite and D. japonica*). The other four sections which are made up of less important *Dioscorea sp* in terms of consumption, are as follows; Lasiophyton (*D. dumetorum*, *D. hispida*), Opsophyton (*D. bulbifera*), Combilium (*D. esculenta*) and Macro-gynodium (*D. trifida*) (Brunnschweiler *et al.,* 2004).

The organ of dormancy and the economically most important part of the plant is the starch rich storage tuber in the soil. The yam roots grow more or less horizontally within the soil and lie close to the soil surface (Onwueme and Charles, 1994). Tubers are necessarily bifunctional as they give rise to aerial shoots and function as storage organs. The number and shape of yam tubers vary largely among species (Huber, 1998). While *D. rotundata* (white yam) tubers are generally large and cylindrical in shape with white flesh, the tubers of *Dioscorea alata* are usually single and show a great deal of variation in size, shape and colour. They are generally cylindrical but may be long and serpentine to almost globular, and are often branched or lobed, or even flattened and fan-shaped. Their weight is usually between 5 to 10 Kg though special cultivation can produce giant tubers of 60 Kg or more. The flesh of some cultivars can be pink or even deep reddish-purple. Tubers of *D. cayenensis* (yellow yam) are in many respects similar to that of *D. rotundata* (Ayensu, 1972). *D. rotundata* and *D. cayenensis* are referred to as *D. rotundata – cayenensis* complex in some regions of West Africa (Nigeria, Ivory Coast, Benin and Ghana) because of their close similarity (Terauchi *et al*., 1992; Agbor-Egbe and Treche, 1995). Their weight varies between 2 Kg and 5 Kg. In rich, well- worked deep soil and on mounds, yams can reach weights of 15 Kg to 20 Kg and more.

2.2. Importance of yam and its production world wide

Yam has become an important crop in the growing regions. Not only is it an important staple crop, it also has a ritual and socio – cultural significance. Yams have also played a very important role in the socio – economic status of the people in the growing regions and have also served as a food security crop (Otegbayo *et al*., 2006). This reflects in its production over the years.

Yam forms about 10 % of the total roots and tubers produced in the world (FAO, 2006). Total world production of yam has increased from 33 to 39 million tonnes per annum between the years 1996 and 2002 (Figure 2.1) of which about 20 to 30 tonnes are produced in Africa (FAO, 2006). The respective production figures for the other roots and tubers are as follow; cassava 184.9 million tonnes (world) and 51.2 million tonnes (West Africa), sweetpotato 136.1 million tonnes (world) and 3.0 million tonnes (West Africa) and Irish potato 307.4 million tonnes (world) and 0.6 million tonnes (West Africa).

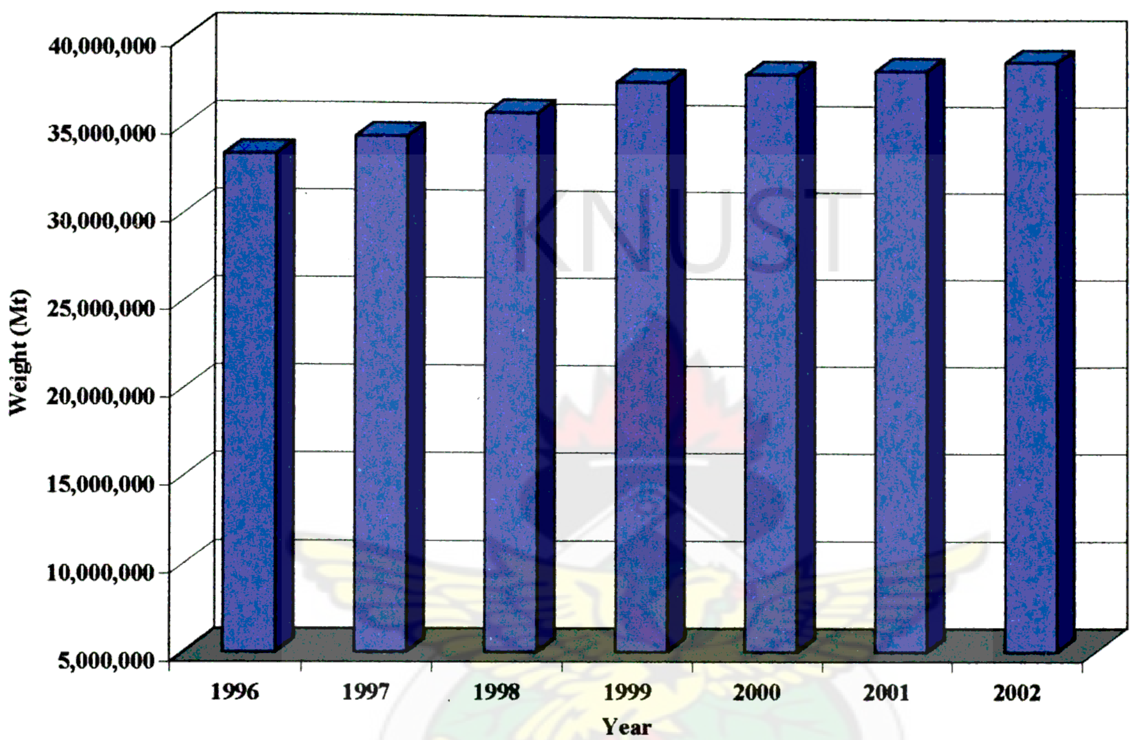


Figure 2.1: World production of yam between the years 1996 to 2002

Source: FAOSTAT, 2006

2.3. Nutritional, anti-nutritional composition and secondary metabolites of yam

2.3.1. Nutritional and anti-nutritional composition of yam

Staple foods in West Africa, which are mostly roots and tubers, often provide appropriate calories but lack adequate amount of protein. However, yam is greatly superior to cassava, sweetpotato and taro in terms of protein and vitamin C content (Wanasundera and Ravindran, 1994; Brunnschweiler *et al.*, 2004). The protein content and quality of yam is comparable to that of Irish potato, containing small amounts of the essential amino acids (such as aspartic acid, glutamic acid, alanine and phenylalanine) for human nutrition. Yam is also reported to have important quantities of dry matter, starch, minerals (calcium, phosphorus and magnesium) and vitamins (ascorbic acid, beta carotene, thiamin and riboflavin) (Craufurd *et al*., 2001). Amongst all the yam species, *D. dumetorum* is the most packed in nutrients; containing high protein and mineral values (Trèche and Delpeuch, 1982; Sealy *et al*., 1985; Afoakwa and Sefa-Dedeh, 2002 a and b). However, *Dioscorea alata* cultivars possess higher content of protein, vitamin C and low lipid content than *D. cayenensis, D. esculenta, D. rotundata* and *D. trifida* (Muzac-Tucker *et al*., 1993; Agbor-Egbe and Treche, 1995). Table 2.1 shows the nutritional profile of some root and tuber crops

The main anti-nutritional components found in yam are Phytic acid (Phytate) and Oxalic acid (Oxalate). They are found in very minute quantities. The Phytic acid content of the yam ranges from 58.6 to 198.0 mg/100 g, while the oxalate levels ranges from 486 to 781 mg/100 g on dry matter basis. The levels of oxalates in yams may not put a nutritional concern since 50 % to 75 % of the oxalates are in the water-soluble form (Wanasundera and Ravindran, 1994).

Table 2.1: Main components of some starch-rich tuber and root crops

Component (g/100g)	Yam		Cassava	Taro	Irish potato	Sweet potato
	Dioscorea alata	*Dioscorea rotundata*	*Manihot esculenta*	*Colocasia esculenta* L.	*Solanum tuberosum*	*Ipomoea batatas* Poir.
Moisture	65.0 – 78.6	60.0 - 71.2	63.1	72.0	77.8	69.2
Protein	1.1 -3.1	1.1 -2.3	1.0	2.0	2.0	1.6
Total carbohydrate			32.1	24.0	15.4	31.3
Starch	15.9 – 28.0	26.8 - 30.2		23.0	14.1	19.5
Free sugar	0.5 -1.4	0.3		0.9	0.7	11.9
Fat	< 0.1 - 0.6	0.1	0.2		0.1	0.6
Crude fibre	1.4 -3.8	1.0 -1.7	2.9	3.8	2.5	7.8
Minerals[mg/100g]	2.5 -6.6	3.2 -5.7			0.7	1.1
Vitamin C[mg/100g]	2.0 -8.2	6.0 - 12.0	30.0	6.0	17.0	30.0

Source: Souci et al., 1994 and Asiedu et al., 1997

2.3.2 Secondary metabolites in yams

Dioscorea species are not only known for their food value but also for their secondary metabolites. Compounds such as steroidal saponins, diterpenoids and alkaloids, have been exploited in one way or the other. Alkaloids (dioscorin: $C_{13}H_{19}O_2N$) appear to be dominant in the African *Dioscorea* species. *D. dumetorum* species contain dioscoretin which is responsible for the hypoglycaemic activity of the tubers (Iwu *et al.*, 1990). Some wild species of yam such as *D. composita* Hemsl., *D. floribunda* , *D. mexicana* and *D. trifida* L. are planted for pharmaceutical purposes (Chu and Figueiredo-Ribeiro, 1991). Sapogenic precursors of cortisone and steroidal hormones such as progesterone found in these wild species led to their improvement for higher production of these secondary plant metabolites (Martin and Ortiz, 1963; Haraguchi *et al.*, 1999). In *Dioscorea* species used for food purpose, toxicity is generally weak (Burkill, 1985). There are two yam species, which still contain toxicologically questionable components, these are; dioscorin in *D. hispida* (Asia) and dihydrodioscorin in *D. dumetorum* (Africa) (Trèche, 1998).

2.4. Browning in yam

There are two types of browning found in foods; enzymatic and non enzymatic browning. Both forms of browning contribute to the discolouration of foods (Mornar-Perl and Friedman, 1990).

2.4.1. Enzymatic browning in yam

The browning that occurs in freshly cut yam is basically enzymatic. They occur due to the action of polyphenoloxidase and peroxidase and the production of polyphenolic substances (Akissoe *et al.*, 2003). Various polyphenolic constituents have been reported to be responsible for the discolouration of edible yam. They include catecholamine, cyanidin-3-glucoside, catechol and procyanidin oligomers. The latter has been reported as contributing to the discolouration of water yam *(Dioscorea alata)* (Wanasundera and Ravindran, 1994 and Akissoe *et al*., 2003).

The concentration of polyphenols varies in the different varieties. This has led to variation in the susceptibility of yam to browning making some food products such as boiled yam and fried yam prepared from some yam species unattractive to consumers. Among the three most important yam species consumed in Africa, water yam is the most susceptible to browning followed by yellow yam, whiles white yam is the least susceptible (Izundu 1995). The variety of yams very susceptible to browning may however be suitable for the dark coloured foods, such as ''amala'' and 'kokonte' acceptable to consumers.

In a whole yam tuber, concentration of polyphenols is highest in the head region and exhibits great discolouration (browning). The middle section is lowest in polyphenol concentration which makes it suitable for light coloured yam products (Akissoe *et al*., 2003). According to a study conducted by Akissoe *et al*., 2002, polyphenol content in yam was positively correlated to the discoloration of yam and processed products like ''amala''. Polyphenol concentration in yams is affected by storage time, which consequently affects the colour of food processed from them. Onayemi and Idowu (1988) reports of an increase in the levels of polyphenolic and glycoalkaloid substances of yam which are concentrated at head region during storage. Asemota *et al*. (1992) also observed the increase in the peroxidase and o-dipolyphenolase activity during three weeks of storage. This was confirmed by Izundu (1995) in a separate study where he observed that yam flour prepared immediately after harvest did not display any significant browning due to negligible peroxidase activity. However, polyphenoloxidase activity decreases with starch content in long term storage (Wanasundera and Ravindran, 1994; Akissoe *et al.*, 2003). Reducing of peroxidase and polyphenoloxidase activities in edible yam tubers have been done through blanching and drying respectively (Akissoe *et al.*, 2003). Sodium metabisulfide is also used as an anti oxidant to prevent the enzymatic oxidation (Potter and Hotchkiss, 1995).

2.4.2. Non enzymatic browning in yam

Non enzymatic browning in yam is due to Milliard reactions and they are normally referred to as Milliard browning. Milliard browning occurs as a result of the combination of reducing sugars with free amino acids (Mornar-Perl and Friedman, 1990). Another level of browning in yams which is also non enzymatic is After-cooking darkening. This is as a result of ferrous iron present in the tuber oxidizing to ferric iron when the yam tubers are cooked especially in water or with steam (Mornar-Perl and Friedman, 1990).

2.5. Uses of yam

The uses of yam can be grouped into two, the food and the non food uses. Food yam tubers are either consumed as a freshly prepared dish or a dish from a processed tuber.

2.5.1. Utilization of fresh yam tubers for food

Food yam is mostly consumed as freshly prepared dish (Ravi *et al.*, 1996). Nigeria the highest consuming yam zone, normally consume yam as a pounded sticky elastic dough called 'fufu'. Tubers may also be consumed directly after boiling or cooked in pottage with protein sources and oils added. Furthermore, frying and roasting are important cooking methods of yam (Achi, 1999; Asiedu *et al.*, 1997). In Ghana and Nigeria, yam tubers are also used as fried mashed yam balls and soup thickener. A few yam species, i.e. *D. fandra* in Madagascar or *Dioscorea alata* in tropical Asia, are sometimes consumed in the raw state (Degras, 1986). Yam cultivars, which contain toxic substances such as dioscorene, are first sliced and soaked in salt water for several hours before further processing for consumption. Coloured cultivars of *Dioscorea alata* have been utilized as a colouring and flavouring agent for ice cream (Salda *et al.*, 1998)

2.5.2. Utilization of processed forms of yam tubers.

The only processed yam product traditionally made at village level is dried yam chips and subsequently into yam flour. Yam flour is favoured in the Yoruba area where the reconstituted food is known as ''amala'' (Ph Action news, 2002). To a limited extent, yam flour is manufactured in Ghana and it is known as 'kokonte'. The nutritional value of yam flour has been proven to be the same as that of pounded yam. The mixing of yam flour with low cost soy flour gained interest because the protein content of foods such as reconstituted yam pastes could be enhanced. The incorporation of proteins, lipids and minerals into traditionally yam products is substantial without diminishing the acceptability of the products. Baked products (bread and pastries), made from yam flour solely or mixed with cereal flour have been reported (Egesi *et al.*, 2003). The flour can be turned into granules or mixed into biscuits, baby foods, etc. Small companies are already developing new products based on yam chips. In Benin, for example, the production of 'wasawasa' or couscous from yam chip flour granules, prepared in the same way as semolina, is an emerging small-scale industry (Ph Action news, 2002).

2.6. Quality Characteristics of yam

Kramer (1965) defined quality of food as the composite of those characteristics that differentiate individual units of a product and have significance in determining the degree of acceptability of that unit to the user. Thus the overall quality of food product may be broken down into its component characteristics each of which may be measured and controlled independently. Quality factors of food have been grouped into different categories which includes; appearance, flavour and texture (Kinesthetic) factors. The quality criteria used by consumers to determine the choice of a yam variety are: appearance, texture and taste whereas odour and colour are of secondary importance. The choice of a yam variety is not only based on the sensorial and nutritional quality or on the dish one is willing to prepare but also on its availability on the market (Konan *et al*., 2003).

2.6.1 Textural properties of yam

The texture of yams has been an important quality attribute of yam for both farmers and consumers. A study conducted by Onayemi *et al*. (1987) on the textural properties of raw and cooked yam of *Dioscorea alata, D. cayenensis* and *D. rotundata* showed the compressive strength of cooked yam varies among species and different tuber parts. They also observed that the proximal tuber parts were hard and dry, the middle parts mealy and fracturable and the distal parts waxy, moist, soft and grainy and lacked disintegration. The textural properties of these yam tubers also differs based on the cooking time (i.e. whether at harvest or after storage). Research has also indicated that proximal tuber parts takes a longer cooking time than the middle or distal parts (Onayemi *et al.*, 1987). The texture of cooked yam of stored tubers was generally mealier and the amount of released starch was lower than that of cooked fresh yam. In *D. dumetorum* tuber, hardness and adhesiveness determined by Warner-Bratzler blade tests has been found to increase significantly during 72 hours of post-harvest storage. This correlated with an increase in cellulose, hemicellulose and lignin during storage of such tubers (Afoakwa and Sefa-Dedeh, 2002 a). Freshly harvested *D. dumetorum* tubers showed high levels of acid and neutral detergent fibre content, which increased rapidly by length of storage period at 28 °C. A hardening effect was observed after short storage times, which was attributed to lignification of the cell walls. Lignification of cell walls is considered to be responsible for increased rigidity and toughness in plant cell walls. Large differences in the textural changes exist among different yam species during storage. *D. dumetorum* tubers begin to harden a few days after harvest yet smaller changes are observed in *D. cayenensis, D. rotundata* and *Dioscorea alata* tubers up to six months of post-harvest conservation (Brunnschweiler *et al.*, 2004).

A sensory texture profile of pounded yam, 'fufu', prepared from *Dioscorea alata* (variety Bètè bètè) revealed lower firmness, adhesiveness, extensibility and gumminess compared to that of *D. cayenensis-rotundata* (variety Krenglè). This translated into the low consumer acceptability of 'fufu' from *Dioscorea alata* compared to 'fufu' from *D. cayenensis-rotundata* (Nindjin, 2002). These textural properties of the yam tuber can be attributed largely to the starch content of the yam since they form the greater proportion of the yam on dry matter basis.

2.6.1.1. Rheological properties of yam starch

The thermo-physical and rheological properties of yam are also important in designing handling and processing operations. They are also useful in predicting starch behaviour during cooking and cooling processes. Some of the relevant properties include specific heat capacity of tuber, size of starch granules, viscosity, and gelatinisation temperature (Hardenburg *et al.*, 1986). In industrial processing the range of starch granules and their gelatinization temperatures are economically important for good product formulation and equipment performance. The granules of yam starch from the different species may be classified into four groups based on size and form (Table 2.2). Other rheological properties of yams also vary among the species (Table 2.3).

Table 2.2: Starch granule size and shape of yams

Species	Starch characteristics
Dioscorea alata	Fairly large granules, oval or egg-shape, elongated round squares, or mussel-shell-shaped, sometimes with one side flattened
D. rotundata	
D. opposita	
D. bulbifera	Many fairly large granules, of round triangular form, sometimes elongated, rarely trapezoid form
D. cayenensis	
D. esculenta	All granules small, rounded or polyhedral, sometimes complex as though built up from many small granules
D. hispida	
D. dumetorum	

Source: Coursey, 1967; Emiola and Delarosa, 1981

Table 2.3: Categorization of yam species based on starch granule size and form

Species	Granule size (μ)	Gelatinization temperature (°C)
Dioscorea alata	5-50	69.0-78.5
D. rotundata	5-45	64.5-75.5
D. cayenensis	3-25	71.0-78.0
D. opposite	5-60	65.5-75.5
D. Bulbifera	5-45	72.0-80.0
D. esculenta	1-15	69.5-80.5
D. hispida	1-5	75.5-83.0
D. dumetorum	1-4	77.0-85.5
D. trifida	10-65	-

Source: Seidmann, 1964

Starch acts as storage reserve for the plant and is found to be compartmentalized in the plastids or vacuoles. In higher plants, starch granules are formed in plastids, called amyloplasts (Miranda *et al*., 2002). Yam starches of different *Dioscorea* species differ in form and size. According to Moorthy (2002) granule size was 20 μm - 140 μm for *Dioscorea alata* and 10 μm - 70 μm for *D. rotundata* and *D. cayenensis*. Starch size of *Dioscorea alata* (varieties Florido and Bètè bètè) and *D. cayenensis-rotundata* (Krenglè) granules varied between 13 μm and 52 μm and 19 μm and 50 μm, respectively (Brunnschweiler *et al*., 2004). The granule size of the starch determines its rate of water absorption, water binding capacity and peak viscosity (Scott, 1996).

Depending on the yam species, the amylose content of their starches ranges between 14 % and 30 %. *Dioscorea alata*, contains 21 % to 30 % amylose whilst *D. rotundata* contains 21.1 % - 24.6 % and *D. cayenensis* contains 21.1 % to 25.3 % (Moorthy, 2002). The amylose content has also been proven to affect the pasting viscosity of the starches and also the hardness of starchy foods (Tester and Morison, 1990). Food samples with high amylose content tends to be harder that those with relatively low amylose content.

Yam starches have higher gelatinization temperature than that of many other starches. Farhat *et al.* (1999) reported DSC peak gelatinization temperatures of 78.8 °C for *Dioscorea alata*, 74.8 °C for *D. rotundata* and 72.9 °C for *D. cayenensis* starches. Also, Moorthy, (2002) and Brunnschweiler *et al.* (2004) found Peak gelatinization temperatures measured with DSC to be between 74.4 °C and 77.0 °C for *Dioscorea alata* and 75.0 °C for *D. cayenensis-rotundata* starch. Hoover (2001) established that starches of *Dioscorea alata*, *D. rotundata*, *D. dumetorum*, *D. esculenta* and *D. abyssinia* exhibit high pasting temperatures and thermal stability, suggesting that strong bonding forces are present within the granules.

Rolland-Sabaté *et al.* (2003) classified yam starches in three groups according to their physico-chemical and functional properties. The first group includes *Dioscorea alata* and *D. cayenensis-rotundata* varieties, which were characterized by large starch granules, high amylose contents, high intrinsic and apparent viscosities and low gelatinization enthalpies. A second class includes *D. esculenta* varieties that contain small granules, have low intrinsic and apparent viscosities and high gelatinization enthalpies. A third group consisting of *D. dumetorum* varieties is close to the second group but characterised by 100 % A-type crystallinity patterns. Because of its high amylose content and thus favourable film forming capacity yam starch was found to be an appropriate source for the preparation of biodegradable and edible films (Mali *et al.*, 2002). The type and nature of starch present in yams would have an effect on their product texture (Scott, 1996). The attributes of starch from *Dioscorea alata* described may generally imply that couscous processed from these yam varieties may be hard and sticky. The stickiness and hardness of water yam couscous may be attributed to high apparent viscosity and high amylose content of the tuber respectively (Scott, 1996).

2.7. Post harvest quality changes in yam

Changes that occur in yam during storage and processing can have either a good or a bad effect on the quality of the tuber. Reduced tuber respiration and thus reduced physiological activity in the tuber before the onset of sprouting makes yam tubers dormant several weeks after biological maturation. The *D. dumetorum* tuber is however an exception since it becomes hard and inconsumable after a few days after harvest (Trèche and Delpeuch, 1982; Sealy *et al*., 1985; Afoakwa and Sefa-Dedeh, 2002 a and b). The changes in the chemical composition caused by metabolism during storage are basically a reduction of moisture, starch and protein content, resulting in a decrease in the salable weight of the tuber but also improves the eating quality. It is also accompanied by an increase of total sugars due to starch hydrolysis. The starch break down may be enhanced by enzymatic activities and temperature excesses.

2.7.1. Post harvest quality changes due to degradation of stored starch

According to Hariprakash and Nambisan (1996) there is an average decrease in starch content of 32 % and 26 % of tubers after 90 days of storage in *D. rotundata* and *Dioscorea alata*, respectively. In *D. rotundata* tubers there is a decrease in the starch content of the proximal, middle and distal tuber parts by 33 %, 29 % and 41 %, respectively. It has also been observed that sprouting reduces the starch content in the tuber especially at the proximal and middle parts after 60 days of storage. During the storage of yam tubers, there an increase in the contents of sucrose and maltose as a result of starch hydrolysis but this is reduced upon sprouting of the tuber (Kouassi *et* *al*., 1990; Hariprakash and Nambisan, 1996). Increases in reducing and non-reducing sugars have been reported in *D. rotundata* tubers during dormancy but only in proximal tuber parts. These have been attributed to an increase in the activity of enzymes involved in sugar metabolism during storage of yam (Ugochukwu *et al*., 1977). The increase in sugars during yam storage would lead to decrease in peak viscosity of the starch which will translate into a decrease in the stickiness of couscous (FAO, 1995).

2.7.2. *Post harvest quality changes due to temperature excesses*

The yam tuber contains living tissues that makes it undergo a number of physiological activities during storage. This includes respiration and transpiration. Temperature is the single most important factor affecting the rate of respiration (Booth, 1974).

It is known that low temperatures reduce the rate of metabolic activity of yam tubers but temperatures in the range 10 °C to 12 °C cause damage through chilling which, because of a breakdown of internal tissues, increases water loss and susceptibility to decay. The symptoms of chilling injury are not always obvious when the tubers are still in cold storage; they become noticeable as soon as the tubers are restored to ambient temperatures (Booth, 1974).

Lower storage temperatures are widely practiced as a technique for reducing the metabolic activity of roots and tubers and prolonging their dormancy. Temperatures of 16 °C to 17 °C have been used to prolong the storage period for *Dioscorea alata* tubers for up to four months, provided the tubers were properly cured prior to storage in order to control infection by wound pathogens. Socio-economic constraints in most developing countries will limit the use of refrigeration in the storage of roots and tubers at farmer level (Onayemi and Idowu, 1988).

2.8. Post – harvest processing of yam tubers

Apart from the fact that processing of yam tubers into more stable products reduces their post harvest losses, it also diversifies the forms in which the yam tubers are consumed. Yams have not been processed to any significant extent commercially. The main products form in which yam is stored have been dried yam chips and yam flour. The manufacture of fried products from *Dioscorea alata* has also been attempted in the form of chips and French fries. Pickling of peeled yam tubers have also been tried with little success (Onayemi and Potter, 1974).

Another product from yam is couscous. It is locally known as 'wasawasa' in Burkina-Faso and Benin is also stored in the dried form.

2.9. Couscous: Origin and Process

Couscous is a kind of pasta originating from the North African countries, such as Egypt, Libya, Tunisia, Algeria, and Morocco. Couscous was traditionally made from the hard part of the durum wheat (*Triticum turgidum*), the part of the grain that resisted the grinding of the relatively primitive millstone (Wright, 2006). In modern times, couscous production is largely mechanized, and the product sold in markets around the world.

The traditional method of preparing couscous is a steam-cook process in a special pot called "couscoussière". The semolina is sprinkled with water and rolled with the hands to form small pellets, sprinkled with dry flour to keep them separate, and then sieved. The pellets which are too small to be finished granules of couscous fall through the sieve to be again sprinkled with dry semolina and rolled into pellets. This process continues until all the semolina has been formed into tiny granules of couscous of uniform size. Granule size uniformity is very important for good cooking quality. Hydration rate during cooking will be slower with larger than with smaller couscous granules. The granules are precooked, dried in the sun, and stored. This process is very labour-intensive. In the traditional method of preparing couscous, groups of women would come together and make large batches over several days (www.en.wikipedia.org).

Commercial, couscous can be produced in a continuous batch process. The steps required to make commercial couscous are the same as traditional couscous. The steps include:

1. Blending: Semolina is mixed with water or salt water;
2. Agglomeration: Semolina particles are combined into a mixture;
3. Shaping: The particulate mixture is reduced and shaped;
4. Steaming: The resulting granulates are precooked;
5. Drying: The coarse agglomerates are dried;
6. Cooling: The products are cooled to ambient temperature;
7. Grading: The couscous is separated into fine (0.8 to 1.2 mm), medium, and coarse (1.5 to 2.5 mm) granules; and
8. Storage (www.ndsu.edu).

Commercially processed couscous is normally referred to as instant couscous. The package directions usually instruct to add a small amount of boiling water or stock to the couscous and to cover tightly for 5 minutes. The couscous swells and within a few minutes it is ready to fluff with a fork and serve. Pre-steamed couscous takes less time to prepare than regular couscous, most dried pasta, or dried grains such as rice (www.en.wikipedia.org).

Couscous is traditionally served under a meat or vegetable stew. It can also be eaten alone, flavoured or plain, warm or cold, as a dessert or a side dish. Couscous quality criteria include size uniformity, color, stickiness, and mouth-feel (Aboubacar and Hamaker, 1999). Properly cooked couscous should be light and fluffy, not gummy or gritty. Sticky cooked couscous is extremely undesirable. Stickiness has been positively correlated with starch damage and long rehydration time for weak gluten cultivars (Smith, 2006).

2.9.1. *Similar products of couscous*

The name couscous is also used for prepared dishes made from other grains, such as barley, pearl millet, sorghum, rice or maize and tubers such as cassava and yam (Wright, 2006). The following are some varieties of couscous

- **Berkoukesh**: Is a Moroccan speciality. They are pasta bullets made by the same process, but are larger than the grains of couscous.
- **Kouskousaki**: This is common in Greece and Turkey. It is boiled and served with cheese and walnuts.
- **Attiéké**: This is a variety of couscous made from grated cassava. It is a staple food in Côte d'Ivoire, some parts of Ghana and also known to surrounding areas of West Africa.
- **Wasawasa**: This is a variety o couscous prepared from yam. It is common to the people of Benin and Burkina-Faso.

2.9.1.1. Yam Couscous

Yam couscous is one of the rare forms of couscous. There are two forms of the yam couscous: enriched couscous which can be kept for up to eight months and ordinary couscous which can be kept for a year or even longer (Spore, 1998). Yam couscous takes the form of pre-cooked granules and can only be distinguished from wheat couscous by its taste and white colour.

Peeled yams are first of all cooked for 45 to 50 minutes and then crushed. The crushed couscous is then dried for 72 hours. Improper drying make the couscous turn couscous moldy and black. Drying produces grains of differing sizes which are prepared in the same way as normal couscous (Spore, 1998). Production of this product on a larger scale, it can make a significant contribution to development in rural areas and creation of employment as well as greater production of yams (Spore, 1998).

CHAPTER 3

3.0. METHODOLOGY

3.1. Sample source

Water yam (*Dioscorea alata*) samples used for the study were freshly harvested from the Savanna Agriculture Research Institute (SARI) Nyankpala in the Northern region. Samples were sorted out cleaned and whole samples selected for the study. Fifteen (15) varieties were used, which included two local types, 'Matches' and Red water yam. The others were TDa 99/00208, TDa 98/01166, TDa 99/00528, TDa 297, TDa 291, TDa 98/01176, TDa 98/ 001168, TDa 99/00240, TDa 99/000480, TDa 99/00199, TDa 98/01174, TDa 99/00214 and TDa 99/00049. Plate One (1) shows some pictures of the Dioscorea alata varieties. Semolina couscous (Graine de Couscous, Ferrero) was obtained from Shoprite supermarket, Accra.

3.2. Sample Preparation

3.2.1 Yam starch extraction

Starch extraction was done by the crude water extract method (www.cassavabiz.org). The yam tuber was peeled, washed and cut into pieces. For every 200 g of cut yam pieces, 250 ml of water was added for grinding with a Moulinex Blender (OPTIBLEND 2000, France). The blended pulp was mixed with enough water to allow for straining through a cheese cloth. This was repeated three times. The extract containing the starch was allowed to stand for 24 hours under ambient temperature. After sedimentation, the supernatant was decanted and the starch left at the bottom of the vessel was collected and dried in a solar dryer at a temperature range of 25 ° C and 50 ° C for 24 hours. The dried Starch was ground with a Moulinex Blender

(OPTIBLEND 2000, France) and sifted using Meinzer II sieve shaker with a standard sieve of aperture 250 μm.

3.2.2 Dried chips production

The hand cut chips (5 cm length x 1.5 cm thickness) were solar dried in a solar dryer at temperatures between 25 °C (morning) to 50 °C (sunny afternoons) for 4 days.

3.2.3. Flour preparation

The dried chips and dried semolina granules were milled in a hammer mill and sieved through a Meinzer II sieve shaker with a standard sieve of aperture 250 μm to obtain yam flour and semolina flour respectively. The flours were stored at ambient temperature (25 ° C to 30 ° C) in plastic bags and portions used for physico-chemical analysis.

Yam Selection and weighing
↓
Washing
↓
Hand Peeling
↓
Slicing [(into thin slices (0.5 cm thickness)]
↓
Solar drying (25 ° C to 50 ° C)
↓
Milling
↓
Sieving
↓
Packaging (into low density polyethylene)

Figure 3.1: Flow diagram of yam flour processed from dried yam chips

3.2.4. Couscous Preparation

Two methods of couscous preparations were employed; the blanched-grated-tuber and the flour methods. The dried yam couscous were divided into different portions, weighed and packaged in plastic (polystyrene) bags and stored in a cool dried cabinet prior to analysis.

3.2.4.1. Couscous processing by the blanched-grated-tuber method

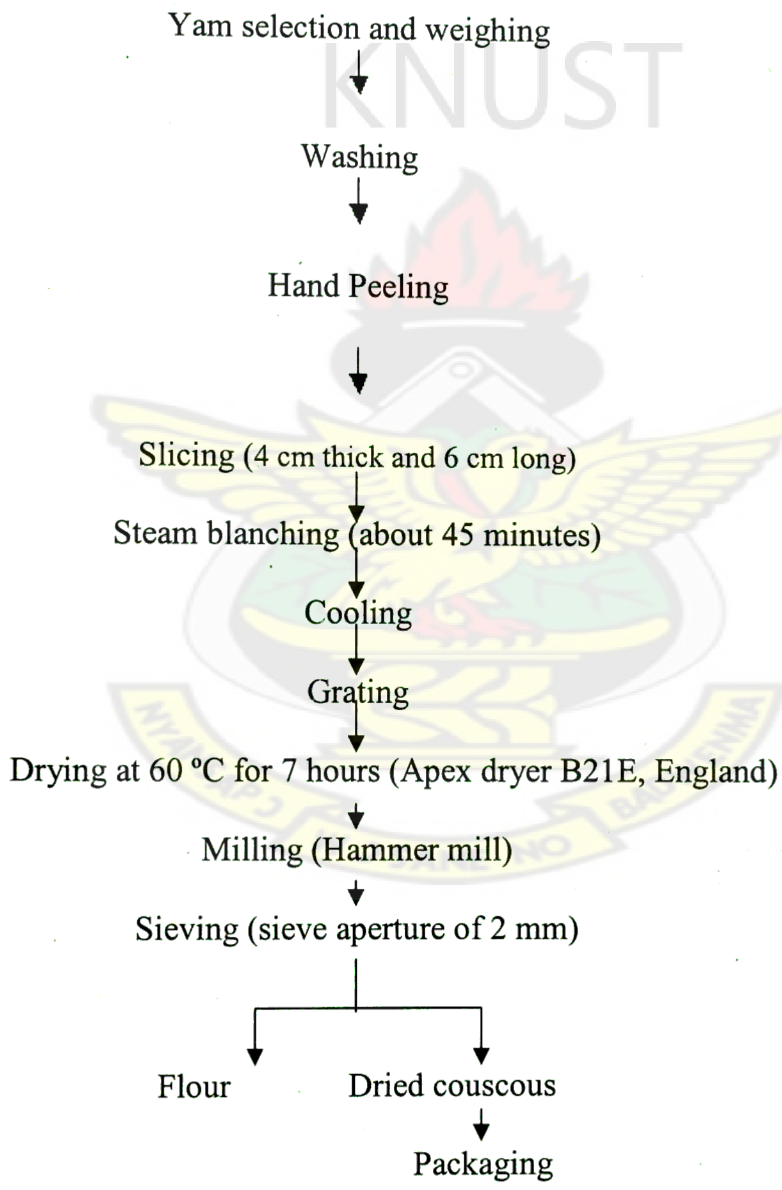


Figure 3.2: Flow diagram for *dried couscous* processed by the blanched-grated-tuber method

3.2.4.2. Couscous processing by the flour method

Flour + water

↓

Kneading (agglomerate formation)

↓

Shaping (using sieve to form grains)

↓

Steaming (30 minutes)

↓

Collection and maceration of grains

↓

Drying

↓

Packaging

Figure 3.3: Flow diagram of dried couscous processed by the flour method

3.2.5 Evaluation of the appropriate amount of water needed for the preparation of ready – to – eat couscous

Different volumes of water (200 ml, 180 ml, 150 ml, 100 ml, 90 ml, 80 ml, 70 ml, 60 ml, and 50 ml) were added to hundred grams (100 g) of couscous and steamed in a 1.8L Philips rice cooker for 20 minutes. The textural quality of the samples was assessed through physical observation. This was done determine the adequate amount of water needed for the preparation of water yam couscous.

3.3. Physico – chemical analysis

3.3.1. Weight measurement of fresh Dioscorea alata sample

Five whole freshly harvested tubers were randomly selected, weighed and the average weight of the tubers was determined.

3.3.2. Chemical Analysis

The moisture, crude protein (N x 6.25), ash and fat contents were determined using the official methods of the Association of Official Analytical Chemists (AOAC, 1990).

3.3.2.1 Determination of moisture

Two grams (2 g) of sample was weighed into a previously dried and weighed glass crucible. The samples were dried in a thermostatically controlled oven at 105 °C for 24 hours. The glass crucibles containing the dried sample were placed into a desiccator to cool and then weigh. The moisture content was then obtained by difference and expressed as percentage of the initial weight of the sample (Appendix 1A).

3.3.2.2. Crude Protein

The analysis was done in two stages: the digestion of the sample and the distillation of the sample.

3.3.2.2.1. Digestion

Two grams (2 g) of sample was digested with 25 ml of conc. H_2SO_4 in a Kjeldahl digestion flask in the presence of catalyst and anti bumping (1/2 tablet Se) agents in a fume chamber until the solution was clear. The clear solution was transferred into a

100 ml volumetric flask and filled to the mark with distilled water after cooling at room temperature.

3.3.2.2.2. Distillation

Distillation was done using the steam distillation apparatus. Twenty five millilitres (25 ml) of 2 % Boric acid was poured into a 250 ml conical flask adding 2 drops of mix indicator. The mixture was placed under the condenser outlet with the tip of the condenser completely immersed into the Boric acid solution. Ten millilitres 10 ml of the digested sample solution was added to about 20 ml of 40 % NaOH solution in a decomposition flask and closed tightly. The NH_3 librated during distillation was collected into the Boric acid solution. Distillation was continued for about 5 minutes after the colour of the solution in the conical flask had changed to bluish green. Distillate was titrated with 0.1 N HCl solution and the titer value recorded. Titer values obtained were used to calculate the total nitrogen and then converted into percentage crude protein by multiplying by an appropriate conversion factor (Appendix 2A). A blank titration was carried out with distilled water.

3.3.2.3. Total Ash

Two grams (2 g) of the sample was weighed into a previously washed, dried and weighed porcelain crucible. The crucible and its content were placed into a Muffle furnace preheated to 600 °C for 2 hours. The crucible and its content were then put into a desiccator to cool and weigh. The ash content was then obtained by difference and expressed as percentage of the initial weight of the sample (Appendix 3A).

3.3.3. Pasting properties of Dioscorea alata flour

Pasting properties of the water yam flour and semolina flour were determined using the Brabender Viscoamylograph E (IDENT. 802525, Duisburg – Germany). About 8.7 % slurry (on dry matter basis) of flour samples was analyzed. The samples were heated at a rate of 1.5 °C/min continuously from 30 °C to 95 °C, and held at this temperature for 15 minutes. The slurry was then cooled to 50 °C at the same rate. Duplicate determinations were done on all samples.

3.3.4. Granule shape and size determination

Granular shape and size distribution of the different starches was performed by using an image analyzer system 'IMAGE-PRÓ-PLUS' (Média Cybernetics) attached to a light microscope. A starch sample was sprinkled on a glass slide, 1–2 drops of 1:1 water– glycerin solution was added and mixed with the starch, and the slide was then covered with a glass cover slip. The slides were observed under an optical microscope with an objective lens of magnification, x10 and images obtained under normal light were analyzed. The parameters evaluated were shape and diameter of large and small granules. Pictures of the image of the starch granules obtained under the microscope were taken using a digital camera (Plate 2).

3.3.5. Amylose Determination in yam Starch

The amylose content of the starch samples were determined based on the iodine colorimetric method described by McCready and Hassid (1943).

3.3.5.1. Preparation of Starch Sample for Amylose Determination

The starch (20 mg) was weighed into a 50 ml beaker; 10 ml of 0.5 M potassium hydroxide solution was added and dispersed using a stirring rod until fully dispersed. The dispersed sample was transferred into a 100 ml volumetric flask and diluted to the mark with distilled water with careful rinsing of the beaker (AOAC, 1990). An aliquot of the test starch solution (10 ml) was transferred into a 50 ml volumetric flask and 5 ml of 0.1 M hydrochloric acid and 0.5 ml iodine reagent B was added. The mixture was diluted to 50 ml. The absorbance of the solution was measured after 5 minutes of standing in a Spectrophotometer (Spectronic 21D, Milton Roy UK) at a wavelength of 625 nm. The absorbances of the solution were read against a control solution which contained no starch in a spectrophotometer. The concentration of amylose was determined using equation derived from the standard curve.

Calibration was performed with pure amylose as described above. Amylose (20 mg) was dissolved in water, transferred to 100 ml volumetric flask and 10 ml of 0.5 M KOH was added and diluted to the mark. Aliquots were pipetted in 50 ml volumetric flasks covering the volume range from 0.5 ml to 5 ml. The absorbances of the solutions were read after 5 min of standing in a Spectronic 21D, (Milton Roy UK) at a wavelength of 625 nm (AOAC, 1990). Linear regression analysis was carried out to derive an equation for determination of percentage amylose (Appendix B). The standard curve for amylose is given in (Appendix B).

3.3.5.2. Preparation of iodine solution

3.3.5.2.1. Preparation of solution A

Twenty grams (20 g) Potassium iodide and 2 g resublimed iodine were weighed into 100 ml beaker, dissolved in a minimum amount of water, transferred into a 100 ml volumetric flask and made to the mark. This solution referred to as iodine solution A, was stored in a brown bottle in the dark.

3.3.5.2.2. Preparation of solution B

Ten mililitres (10 ml) of the stock solution (solution A) was pipetted into a volumetric flask and diluted to 100 ml with distilled water to form iodine solution B.

3.3.6. Percentage Yield of couscous

Five kilograms (5 Kg) of water yam tubers was used in the preparation of couscous using the blanched-grated-tuber method. The weight of the couscous obtained was measured. The yield of couscous was calculated as the percentage of weight of couscous divided by weight of water yam used (Appendix 4A).

3.3.7. Colour Measurement of couscous

Colour of yam couscous (dried), were measured using the CIE L, a, b system with a Minolta chromameter (CR310, Japan). The instrument was calibrated using a white ceramic (L= 97.51; a= 0.29; b= 1.88) standard plate. Measurements were done in triplicates and mean values were used.

3.3.8. pH

Ten grams (10 g) of ground couscous samples was mixed with 100ml of distilled water. The mixture was shaken to evenly suspend the particles and digested for 30 minutes with frequent shaking. The digested mixture was then allowed to stand for 10 minutes after which it was decanted and allowed to cool to 25 °C. The pH of the filtrate was determined using the Sper Scientific pH meter (840087, Taiwan) (AOAC, 2000).

3.4. Consumer evaluation of acceptability of water yam couscous

Processed couscous were moistened with water and steamed for thirty minutes prior to sensory evaluation. Panelists assessed the couscous samples in the hot state. Thirty healthy (Self claim) yam consumers in the Biochemistry Department (KNUST) assessed the 15 different couscous samples. The assessments were done in three days. Quality attributes such as colour, texture (hardness), flavour (taste and smell) and overall acceptability were assessed. The assessment of the overall acceptability was done with vegetable stew. The seven point hedonic scale was used for the evaluation (1 – like very much; 7 – Dislike very much) (Kramer and Twingg, 1980). Appendix C shows sample of the evaluation form used.

3.5. Shelf life studies

Two yam couscous samples from TDa 98/01166 and TDa 297 were used for the shelf life studies. This was conducted every 8 weeks, for 24 weeks. Sensory evaluation by trained panelists, microbiological evaluations, moisture and pH of the couscous samples were measured to evaluate the quality of the product over the 24 week period.

For each couscous samples, 5 portion sizes of about 200g each were weighed and packaged in polystyrene bags for sensory evaluations. Another twenty (20) portion sizes of about 20g each were also weighed, packaged polystyrene bags and stored for the microbiological analysis, pH and moisture determinations. The samples were stored in a cool dry wooden cabinet.

Semolina couscous (Graine de Couscous (Ferrero), was used as standard for comparison during the sensory evaluations.

3.5.1. Sensory evaluation by trained panelist.

Fifteen (15) trained panelists were used for this evaluation. Steam semolina couscous, TDa 98/01166 couscous and TDa 297 couscous were coded with three digit random numbers. Two table spoons of steamed couscous sample were put in a white disposable plate bearing a three digit code of a corresponding couscous sample. Each panelist was served in separate booths under white light. Samples were served hot (about 60 ºC) and the panelists were asked to rank attributes of each sample on a 10 cm line scale. Assessment of the overall acceptability of the couscous was done with vegetable stew. Appendix D shows sample of the sensory evaluation used.

3.5.2.1. Training of sensory panelists

Trained panelists selected from Food Research Institute were retrained on the couscous products. The training focused on the following attributes: flavour, colour, appearance, stickiness, hardness, dryness, taste, mouth feel, and overall acceptability. Descriptions of some of these parameters are in Appendix D3.

3.5.3. *Sensory evaluation by couscous consumers*

Ten (10) couscous consumers at Paloma Restaurant, Accra were made to assess one of the selected yam couscous samples for the shelf life studies using the semolina couscous as standard. This group of people used a scale of 0 (Dislike very much) to 10 (like very much) to assess the product (Appendix D2).

3.5.4. *Microbiological analysis*

The microbiological analysis was carried out on the first day of preparation, eighth, sixteenth, and twenty fourth week of storage. The analysis was done in duplicates

3.5.4.1. *Sample culture preparation*

One gram (1 g) of couscous sample was homogenized with 9 ml saline peptone water in stomacher bag for 30 s. A serial dilution of 10^{-1} to 10^{-4} was prepared. All plating was done by the pour plate method.

3.5.4.2. *Total Plate count*

Using a fresh pipette, 1ml aliquots of each serial dilution was transferred into sterile petri dishes having a label corresponding to the dilution. To each dilution in the sterile petri dish, 15 ml of molten PCA media was added to cover the base of the petri dishes. The petri dishes were swirled clockwise and anticlockwise to ensure uniform mixing and allowed to set. Plates were incubated at 37 °C for 24 hours.

3.5.4.3. *Yeast and Mould Count*

To each dilution in the sterile petri dish, 15 ml of molten Oxy – Tetracycline – Glucose Yeast Extract Agar (OGYE) was added to cover the base of the petri dishes.

The petri dishes were swirled clockwise and anticlockwise to ensure uniform mixing and allowed to set. All plates were incubated at 25 °C for 3 – 5 days.

3.5.4.4. Coliforms

To each dilution in the sterile petri dish, 15 ml of molten Triptone Soya Agar was added to cover the base of the petri dishes. The petri dishes were swirled clockwise and anticlockwise to ensure uniform mixing and allowed to set. This was followed by addition of Violet Red Bile Agar which was also allowed to set after clockwise and anti clockwise swelling. Plates were incubated at 37 °C for 24 hours. Colonies between 50 and 150 which look dark purple with a clear zone around them were counted.

3.5.4.4.1. Confirmatory test

Five (5) suspected colonies were picked randomly into a test tube containing already sterilized Brilliant Green Bile Broth. This was incubated for 37 °C for 24 hours. The tubes that shown gas production were positive for Coliforms.

3.5.4.5. Escherichia – Coli

About 0.1 ml of broth from tubes that have tested positive for Coliforms are picked into a Violet Red Bile broth (E – coli broth). Covas reagent was added and incubated at 44 °C for 24 hours. Tubes that showed red rings were positive for *E, Coli*

3.6. Data Analysis

Analysis of variance (ANOVA), Kruskal-Wallis test on non parametric data (Bower, 1998) and mean separations were conducted using Statgraphics statistical package (Centurion edition). Significant differences were determined at $p < 0.05$. Microsoft Excel was used in the graphical representations.

CHAPTER 4

4.0. RESULTS AND DISCUSSION

4.1. Weight of *Dioscorea alata* varieties

TDa 98/01176 recorded the lowest mean weight of 0.95 Kg, while TDa 99/00528 and TDa 297 had the highest mean weights of 2.7 Kg. TDa 99/00208, Red water yam, TDa 99/00049, TDa 98/01176, TDa 99/00199 and TDa 98/01174 had mean weights less than 2 Kg whilst the rest of the samples were 2 Kg and above but not up to 3 Kg (Figure 4.1). The variation in sample weights was significant ($p < 0.05$). The mean weight range of the *Dioscorea alata* samples obtained from the studies was lower than the 5 Kg to 10 Kg weight reported by Ayensu (1972) and Onwueme and Charles (1994) for *Dioscorea alata*. The weights of some of the varieties were similar to values reported for the *D. rotundata – cayenensis* complex. According to Brunnschweiler *et al.* (2004) the weight of *D. rotundata – cayenensis* ranges from 2Kg to 5 Kg.

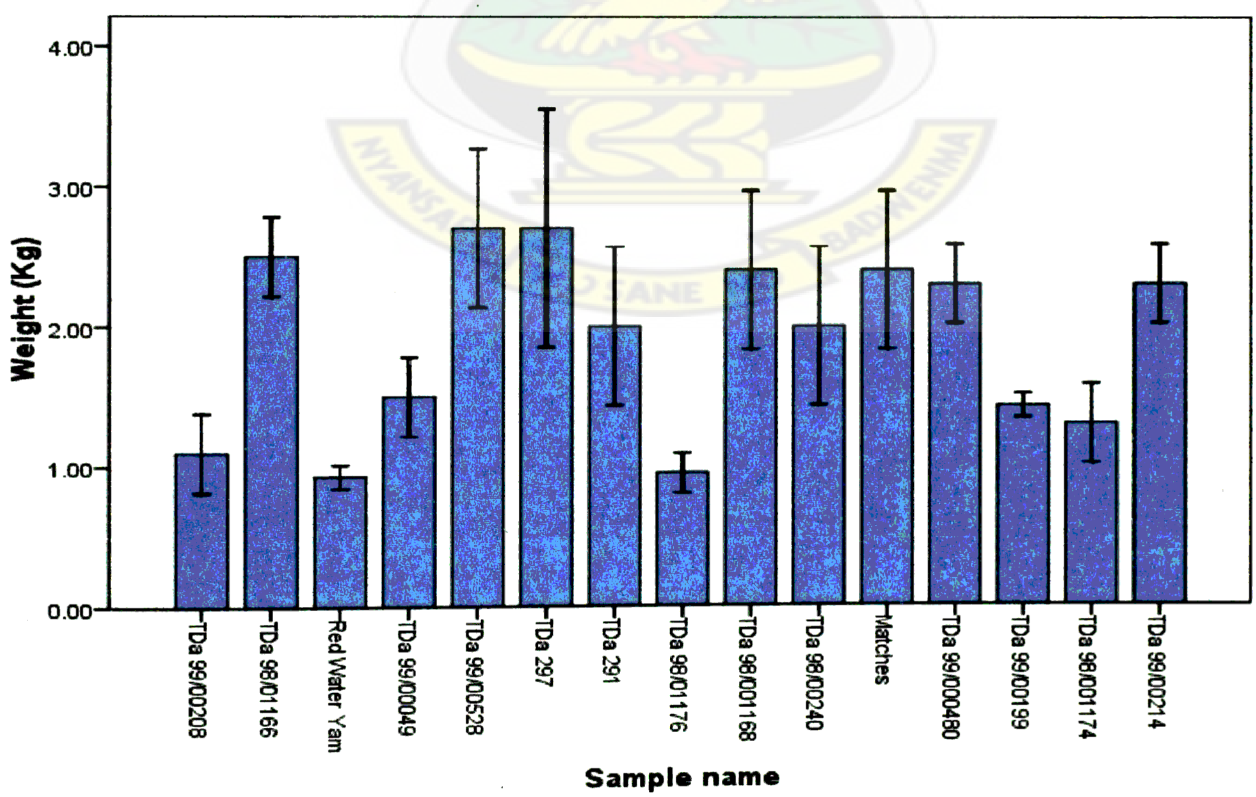


Figure 4.1: Weight distribution of the *Dioscorea alata* varieties

4.2. Chemical analysis and pasting properties of the *Dioscorea alata* varieties

4.2.1. Moisture content

TDa 99/00240 variety recorded the highest moisture value of 80.37 % whilst TDa 99/00199 recorded the lowest value of 61.00 % (Figure 4.2). The average moisture content of all the fresh tubers obtained was comparable to those reported by other researchers which ranged from 63 % to 76 % (Asiedu *et al.*, 1997 and Opara, 1999) for *Dioscorea alata*. Higher moisture content of water yam tubers makes lesser dry matter available for couscous processing and vise-versa. High dry matter has been shown to be associated with fine structure, dense mouthfeel and quality (Martin, 1974; Bourrieau, 2000). According to Lebot *et al.* (2005), most of the white flesh tubers with high dry matter are not susceptible to browning. The variability of the moisture content of the various varieties of *Dioscorea alata* studied was significant ($p < 0.05$).

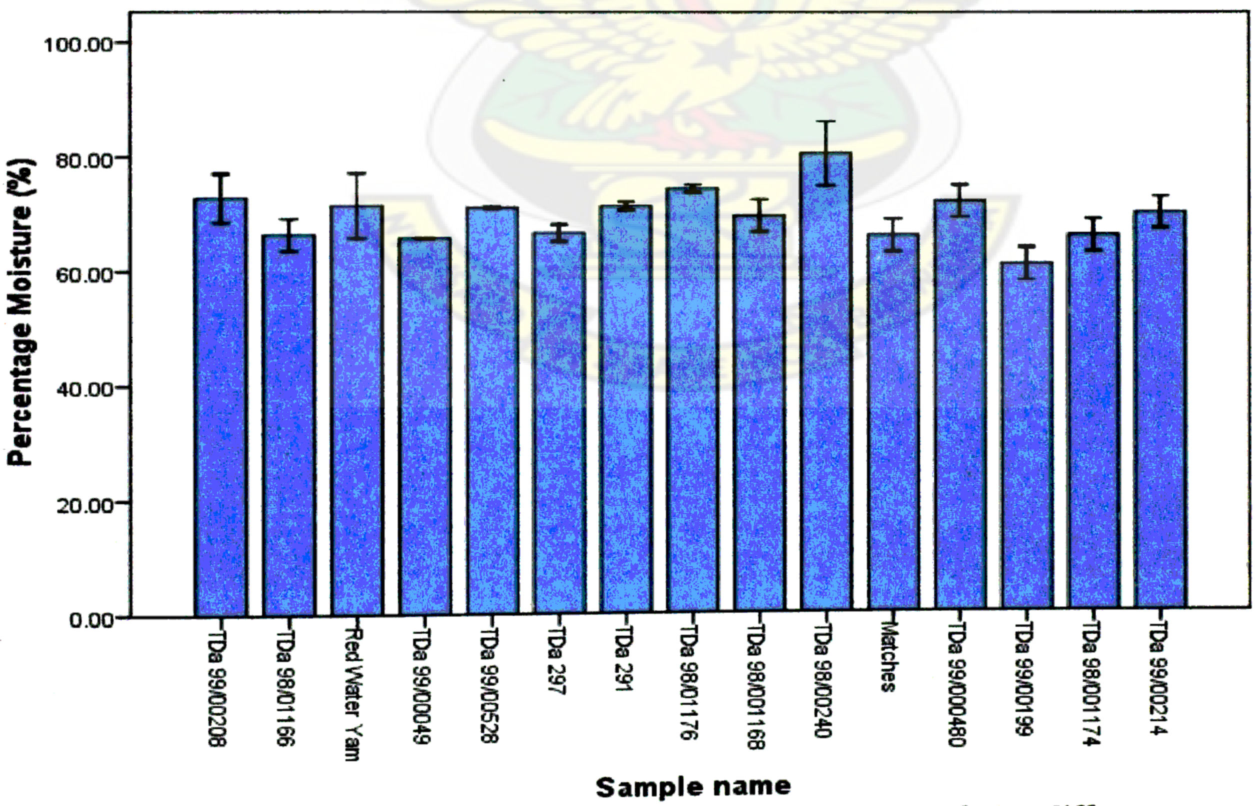


Figure 4.2: Comparison of the percentage moisture content of the different *Dioscorea alata* varieties.

4.2.2. *Crude Protein*

The protein content of the *Dioscorea alata* samples used for the study varied significantly ($p < 0.05$). The samples had relatively high crude protein content which ranged from 6.20 % for TDa 291 to 9.6 % for TDa 98/01176 varieties and TDa 98/01166 on dry matter basis (Figure 4.3). Wanasundera and Ravindran (1994) reported an average crude protein content of 7.4 g /100 g when they assessed the nutritional composition of seven cultivars of *Dioscorea alata*. A study conducted by Agbor – Egbe and Treche (1995) reported, the crude protein content of *Dioscorea alata* from 4.7 g /100 g to 15.6 g /100 g. These values were comparable to values reported for sweetpotato (5.6 g /100 g; Bradbury and Holloway, 1988) but higher than that of cassava (1.7 g /100 g; Gomez and Valdiviesom, 1983). These relatively high values recorded imply that couscous process from these *Dioscorea alata* varieties could meet some of the protein needs of its consumers.

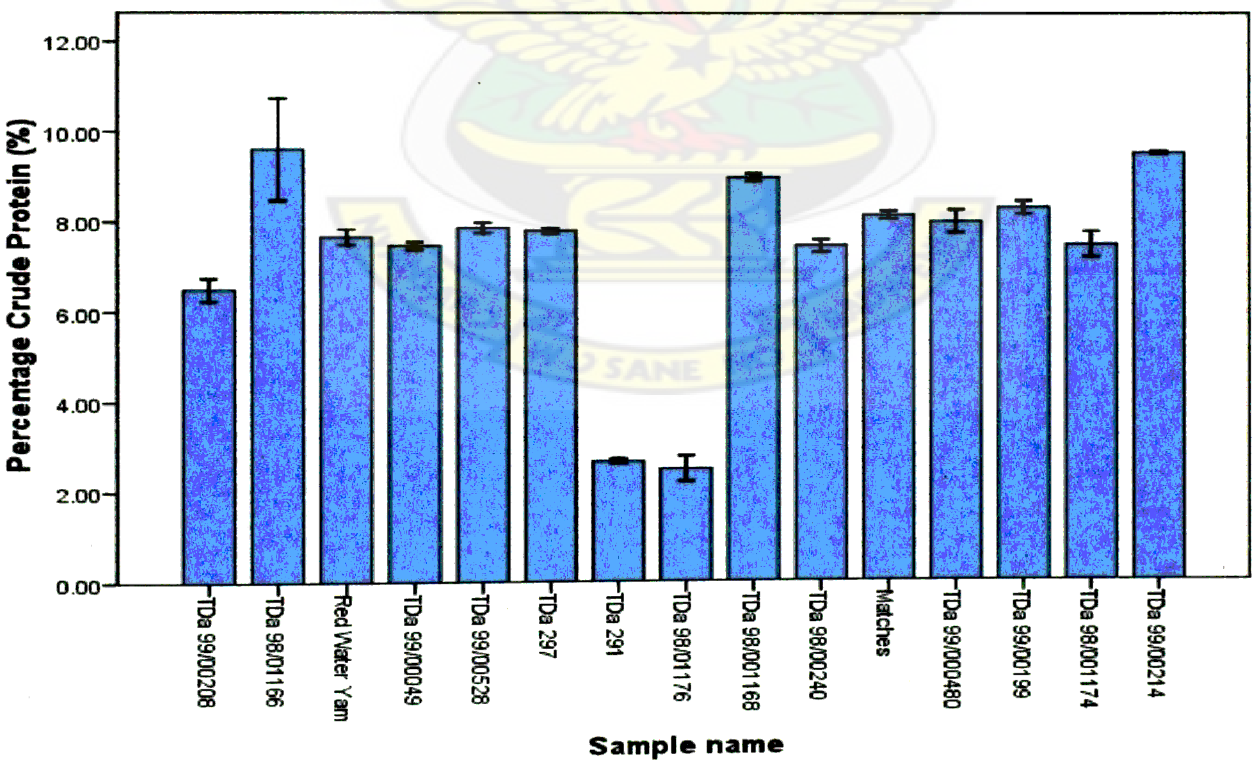


Figure 4.3: Comparison of the Protein content of the different *Dioscorea alata* varieties

4.2.3. Total Ash

The total ash content of the samples were between 2.17 g /100 g and 3.81 g/100 g on dry matter basis for TDa 99/00208 and TDa 98/00528 varieties respectively (Figure 4.4). The results obtained deviates from the ranges of 2.5 mg /100 g to 6.6 mg/100 g reported by Souci *et al.* (1994), 21 mg /100 g to 44 mg/100 g reported by Agbor – Egbe and Treche (1995) and 0.67 g /100 g to 2.06 g/100 g reported by Asiedu *et al.* (1997) and Opara (1999) on dry matter basis. The variations in the results obtained from that of literature may be attributed to environmental factors and the nature of soil used in planting the different cultivars (Muller, 1988). The variability of ash content of the samples under study was significant ($p < 0.05$).

The Codex limit for percentage ash content for semolina couscous is 1.1% maximum (Codex Stan 202 – 1995). The ash content semolina couscous and couscous from other grains like sorghum has been reported to be an indication of the level of decortication to remove substantial amount of the bran, for the purpose of improving couscous colour and yield (Aboubacar and Hamaker, 1999).

With the ash limits for semolina couscous, it implies that couscous from the *Diosorea alata* varieties under study would be richer in minerals compared to semolina couscous.

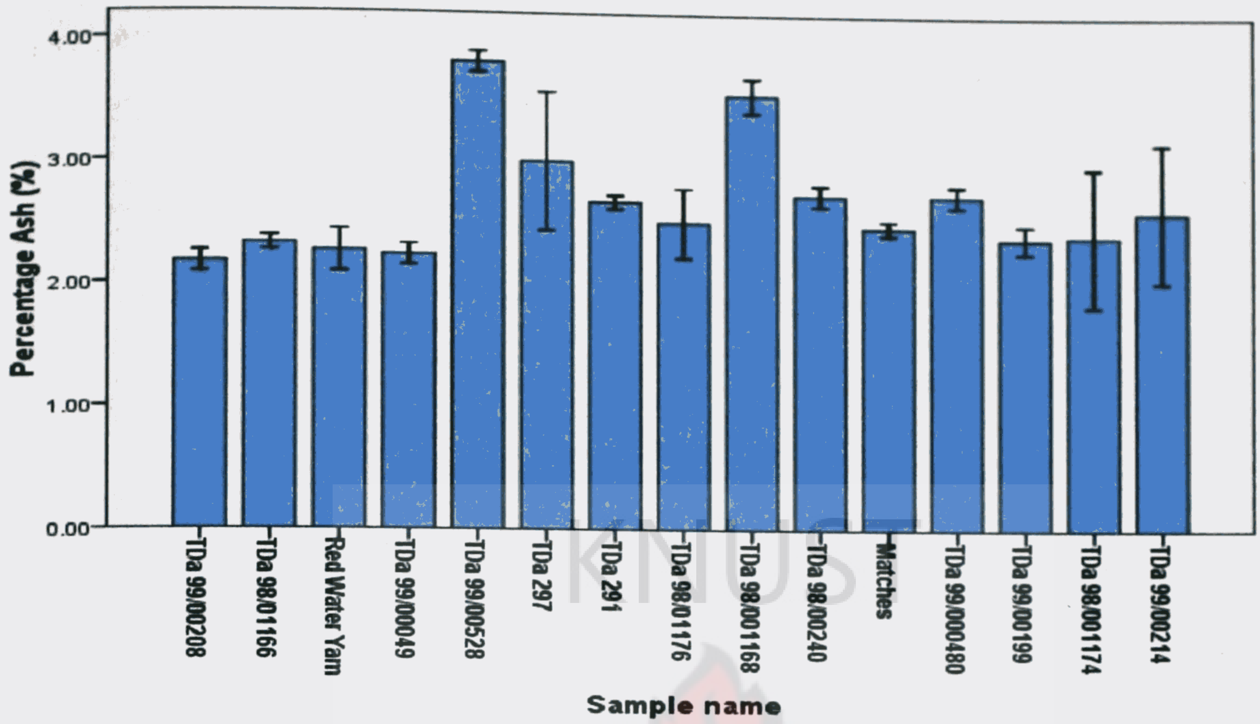


Figure 4.4: Comparison of the Total Ash content of different *Dioscorea alata* varieties

4.3. Comparative study of the pasting characteristics of *Dioscorea alata* flour with semolina flour

The Brabender Viscoamylograph gives useful information of the gelatinization characteristics of flour (or starch). This includes the hot paste viscosity, cold paste viscosity, set back viscosity, breakdown viscosity, gelatinization time and onset gelatinization temperatures. The variability of all pasting parameters evaluated except the break down viscosity was significant ($p < 0.05$). Figure 4.5 shows a sample amylograph of the *Dioscorea alata* varieties under study.

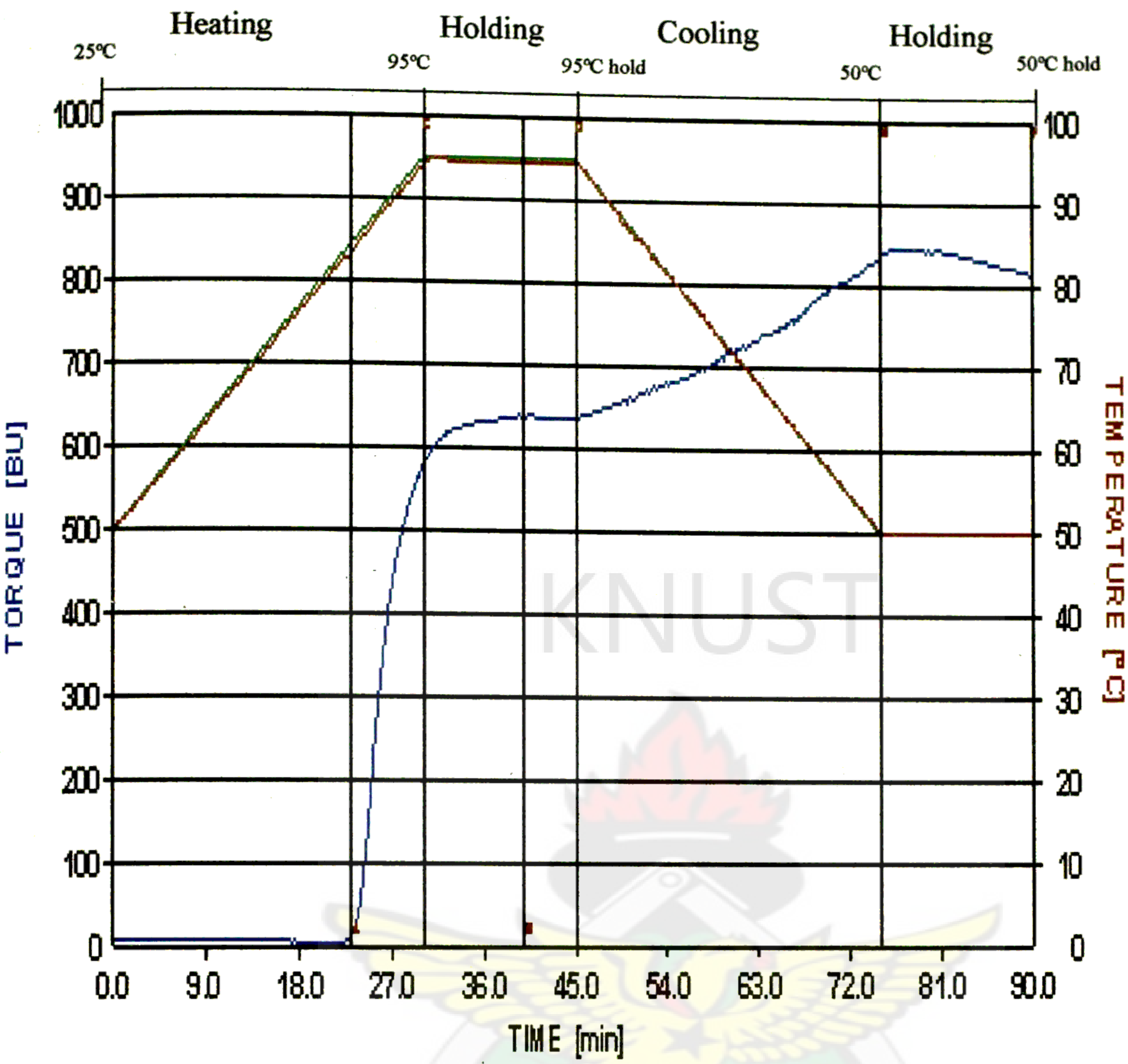


Figure 4.5: A representative sample amylograph of the *Dioscorea alata* varieties

4.3.1. Gelatinization time

The gelatinization time, is the shortest time for the onset of gelatinization. It ranged from 21.25 minutes to 30.05 minutes for 'Matches' and TDa 99/00214 respectively (Figure 4.6). The gelatinization time of 26.05 recorded for the semolina flour was comparable to the gelatinization time of TDa 99/00528. The variations in the gelatinization times were significant ($p < 0.05$) and this could be due to the differences in size of the starch granules. Large starch granules swell faster especially on heating (Lindeboom *et al.*, 2004). According to Daramola and Osanyinlusi (2006), the gelatinization (cooking) time has cost implications. The shorter the gelatinization time, the less energy will be needed to cook, hence the lesser the cost of cooking. There was a positive correlation (r = 0.99, p < 0.01) between the gelatinization temperature and gelatinization time of flour samples. Implying that, the higher the gelatinization temperature of a sample, the longer it takes to gelatinize. The 'Matches' variety which recorded the least gelatinization time among all the varieties assessed would therefore require the least energy to cook and TDa 99/00214 with the highest gelatinization time would require more energy to cook. For industrial purposes the 'Matches' variety would be useful if energy is the main factor in consideration.

Couscous made from the *Dioscorea alata* samples with shorter gelatinization time may require less time to cook compared to couscous made from tubers with longer gelatinization time. During couscous preparation using any of the yam varieties under study, a minimum cooking time of approximately 22 minutes will be required to gelatinize the starch present. Inadequate cooking time of yam couscous, may lead to improper gelatinization of the starch and unpleasant hard texture of the food product.

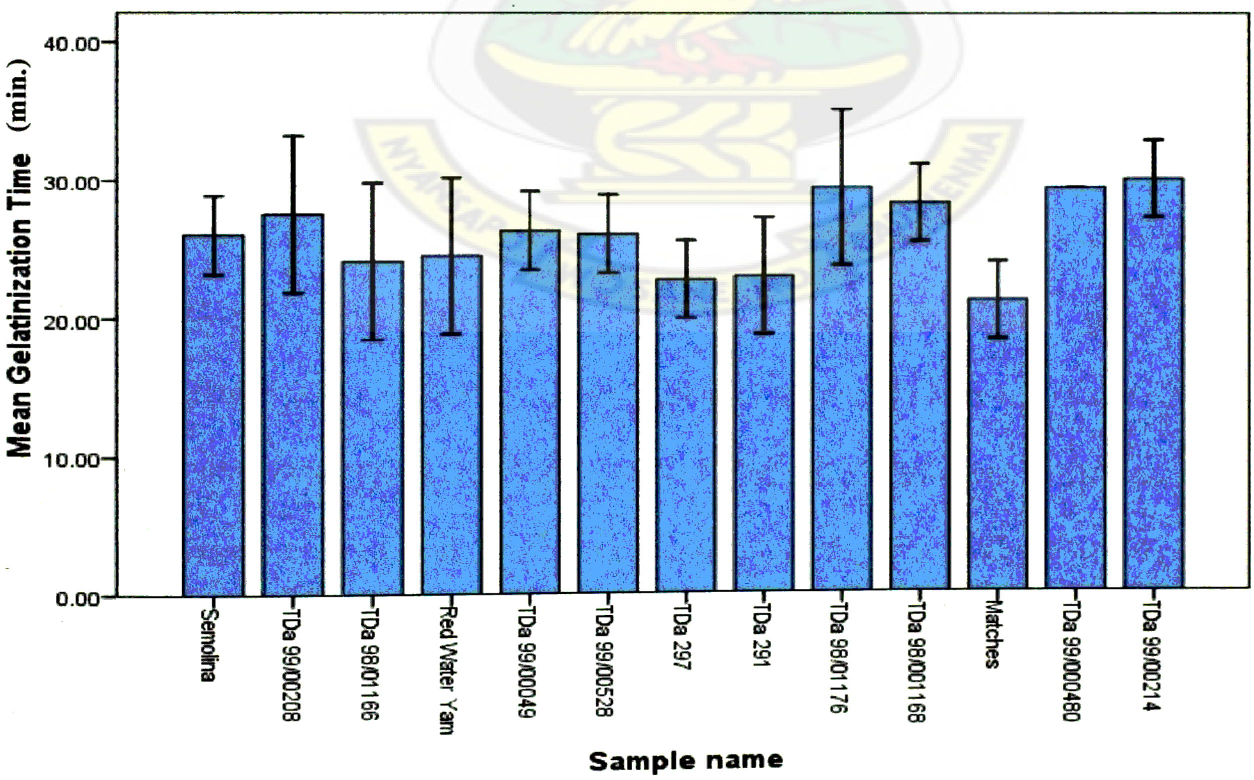


Figure 4.6: Comparison of the Gelatinization time of the different varieties of *Dioscorea alata* and Semolina flours

4.3.2. Onset gelatinization temperature

The onset gelatinization temperature for flour ranged from 81.20 °C to 94.20 °C for 'Matches' and TDa 99/00214 respectively (Figure 4.7) and 88.10 °C for semolina flour. The values recorded for the semolina flour was comparable to that of the TDa 99/00528 flour (88.40 °C). The onset gelatinization temperature is an indication of the minimum temperature required to cook a given sample and it also has cost implications similar to gelatinization time (Daramola and Osanyinlusi, 2006). The gelatinization temperatures recorded in this study were comparable to that reported by Otegbayo *et al.* (2006) which ranged between 80.27 °C and 84.07 °C. Gelatinization temperatures of 69 ºC to 88 ºC and 74.4 ºC have also been reported by NRI (1978) and Alves *et al.* (2002) respectively. The temperatures obtained in the study were slightly higher than the 76–79 ºC reported for various *D. rotundata* and *D. esculenta* yam starches (Amani *et al.*, 2005). This implies that *Dioscorea alata* starch will take a longer time to gelatinize during processing than *D. rotundata* and *D. esculenta*.

The amylose, lipid and phosphorous content, starch concentration and starch granule size all affect the thermal properties of flour and starches (Akpapunam and Sefa – Dedeh, 1995; Peroni *et al.*, 2006). Starches that contain amylopectin molecules with a large proportion of long branch chains are also reported to display higher gelatinization temperatures (Jane *et al.*, 1999; Kasemsuwan *et al.*, 1995; Franco *et al.*, 2002). Cooke and Gidley (1992) reported that, the higher temperature and larger total energy reflect stronger crystalline structures or more molecular orders. The relatively high onset gelatinization temperatures recorded will make the varieties under study suitable ingredients for processed foods that require high cooking temperatures such as yam couscous. The steaming step in yam couscous preparation employs temperatures of about 100 °C, higher than the onset gelatinization temperatures of the tubers under study. This is important to provide adequate temperature to gelatinize the starch present and cook the product.

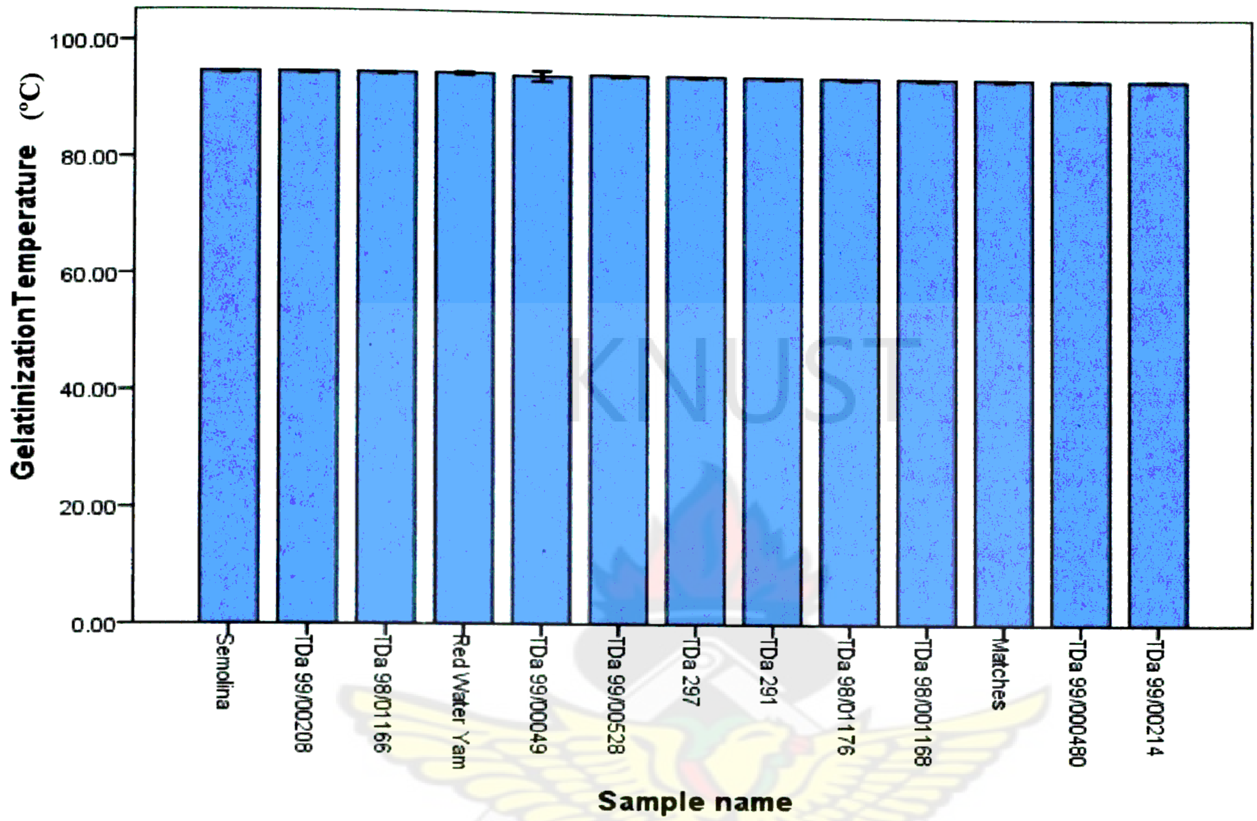


Figure 4.7: Comparison of the Pasting temperatures of the different varieties *Dioscorea alata* and the Semolina flours

4.3.3. Peak viscosity

The peak viscosity of the varieties under study varied significantly ($p < 0.05$), ranging from 37.00 BU for TDa 98/001168 and 185.00 BU for TDa 297 (Figure 4.8). Peak viscosity is linked to the ease of cooking of sample analyzed. Thus Peak viscosity is indicative of the strength of pastes, which are formed from gelatinization during processing in food applications (Afoakwa and Sefa – Dedeh, 2002a). The rather low values recorded could probably be due to the presence of interfering non-starch components in flour, which are not present in an isolated starch paste (Niba *et al.*, 2002). These non-starch components reduce the total starch content resulting in decrease in starch granule swelling.

There was a slight negative correlation between the peak viscosity of the flour and the average starch granule sizes of the *Dioscorea alata* samples ($r = -0.32$, $p > 0.05$). This implies that the peak viscosity was not strongly dependent on the starch granule size.

The stickiness of cooked flour is a function of starch gelatinization (FAO, 1995). The peak viscosity of the flour could also be an indicator of the stickiness of the couscous products. In a study conducted by Otegbayo *et al*. (2006) there was a significant association found between the peak viscosity, final viscosity, and set back viscosity of starch and stickiness, springiness, cohesiveness and hardness of pounded yam (*Dioscorea alata*) samples made from them. Samples which were very viscous may have a higher swelling power of their starches and hence their high peak viscosities. This increase in viscosity may translate into the increase in the stickiness of the yam couscous. Unlike pounded yam that needs high peak viscosities for a good texture, a low peak viscosity may contribute to a less sticky couscous which is an important textural parameter of couscous (Aboubacar and Hamaker, 1999). There was no significant difference ($p > 0.05$) in the peak viscosity of TDa 98/001168 flour (37 BU) and the semolina flour (38 BU). The peak viscosities of TDa 99/00214 (28 BU), TDa 99/000480 (31 BU) and TDa 98/01176 (34 BU) were lower than the peak viscosity of semolina couscous flour. Therefore the tubers of samples TDa 98/001168, TDa 99/00214, TDa 99/000480 and TDa 98/01176 could probably make couscous with stickiness comparable to the semolina couscous.

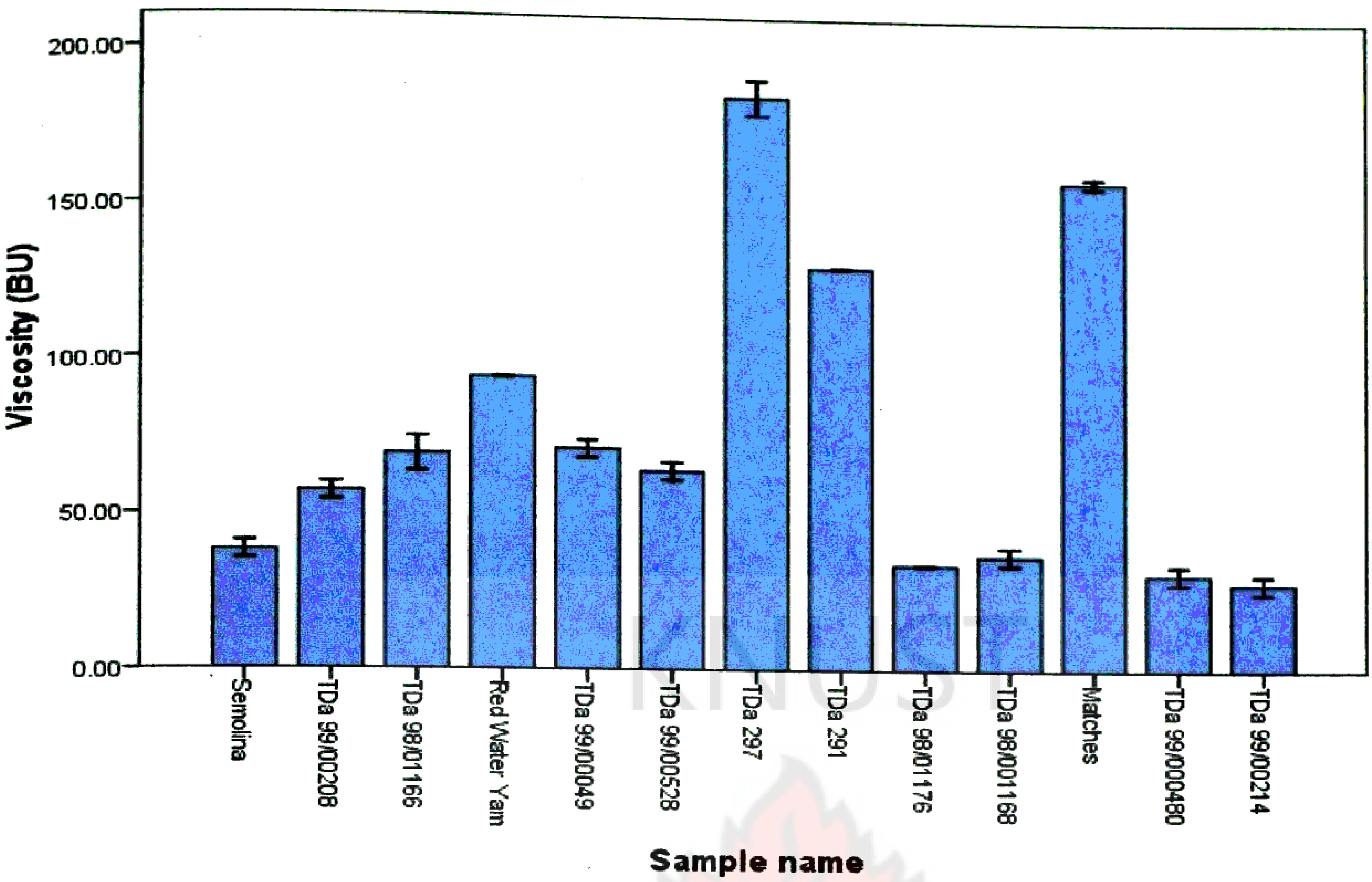
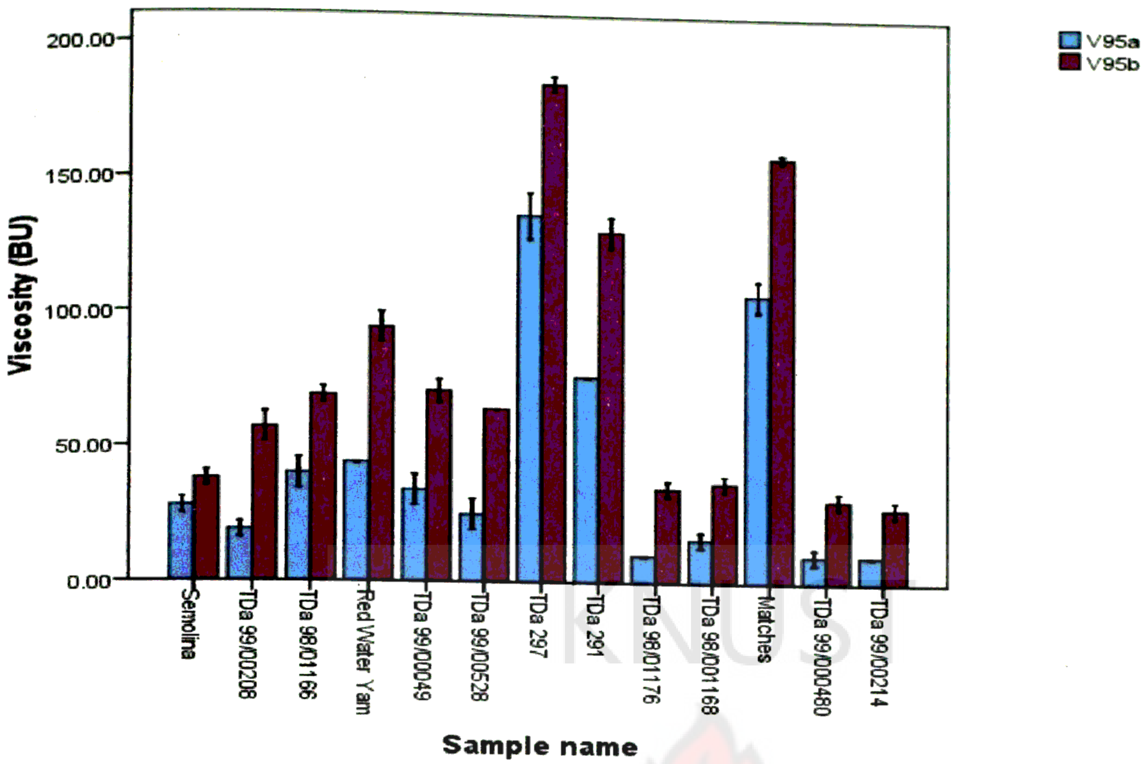


Figure 4.8: Comparison of the Peak viscosities of the different varieties *Dioscorea alata* and the Semolina flours

4.3.4. Hot paste viscosities (Viscosity at 95 °C and at 95 °C hold)

Viscosity at 95 °C, which is the viscosity of the hot paste, ranged from 10 BU to 136 BU for TDa 98/01174 and TDa 297 respectively. There was a remarkable increase in viscosity after holding at 95 °C for 15 minutes, thus the viscosity of TDa 98/01174 increased to 35 BU after holding for 15 minutes and that of TDa 297 increased to 170 BU after holding for 15 minutes (Figure 4.9). The viscosity at 95 °C of the semolina couscous (28.00 BU) was comparable to what was recorded for TDa 99/00528. There was also an increase in viscosity after holding at 95 °C for 15 minutes to 38.00BU.



Key: V95a - Viscosity at 95 °C

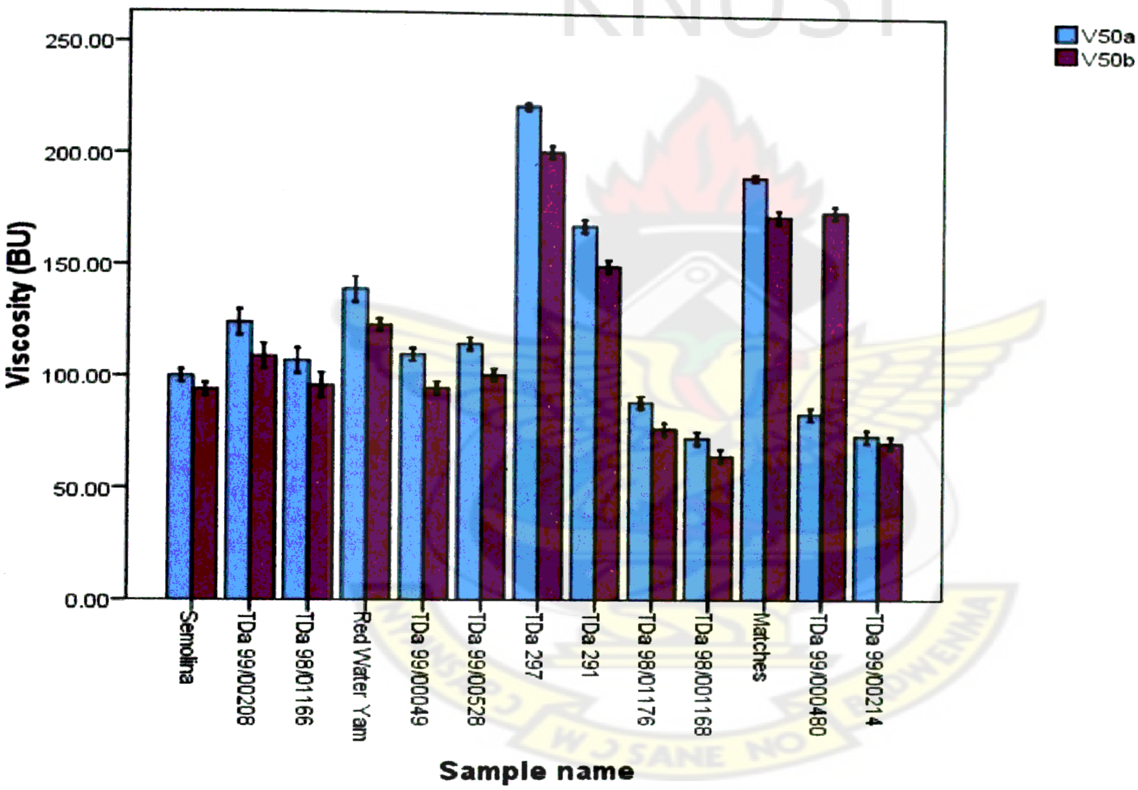
V95b – Viscosity at 95 °C after holding for 15munites

Figure 4.9: Comparison of the hot paste viscosity of the different varieties of *Dioscorea alata* and Semolina flours

4.3.5 Cold paste viscosities (viscosity at 50 °C and viscosity at 50 °C hold)

The viscosity at 50 °C ranged between 73 BU to 221 BU for TDa 98/001168 and TDa 297 respectively (Figure 4.10). However the viscosity at 50 °C after holding for 15 minutes was lower than the viscosity at 50 °C, and it ranged from 65 BU to 201 BU for TDa 98/001168 and TDa 297 respectively (Figure 4.10). This implied that the cold paste viscosities were higher than the hot paste viscosities similar to what have been observed by Afoakwa and Sefa – Dedeh (2002a). The cold paste viscosity of the semolina flour also recorded a similar trend, decreasing from 100 BU to 94 BU after holding for 15 minutes.

The increase in the viscosities during cooling of the paste might be due to the high degree of association between the starch–water systems and their high ability to re-crystallize; resulting in progressively higher viscosities during cooling of yam starches (Kaur *et al.*, 2006). Cooling of cooked yam couscous resulted in hardening of the product, which may be attributed to the recrystallization of the starch-water system. According to Ayernor (1985), the rate at which rigidity occur in yam starches is dependent on the degree of starch – water binding which can be affected through processes that influence the interaction between the starch particles and water.



Key: V50a - Viscosity at 50 °C

V50b – Viscosity at 50 °C after holding for 15munites

Figure 4.10: Comparison of the Cold paste viscosity of the different varieties of *Dioscorea alata* and Semolina flours

4.3.6. Setback viscosity

The setback viscosities of flour samples ranged from of 31 BU to 67 BU for 'Matches' and TDa 99/00208 respectively (Figure 4.11). The viscosity after cooling the paste to 50 ºC is a reflection of the retrogradation tendency and setback viscosity of the paste. It is an indication of gel stability and potential for retrogradation in foods (Sackey, 1998). The lower the setback viscosity, the more stable the paste is to shearing and retrogradation. This implies that in general, *D. alata* samples under study have a stable paste since they recorded relatively low setback viscosities. Yams with high setback values have also been reported to have good textural properties (cohesiveness) when pounded (Otegbayo *et al.*, 2006).

Cohesiveness of a sample is defined as the amount of deformation before rapture after compressing that sample between the molar teeth. It can also be defined as the denseness and cohesion of a sample throughout mastication (Civille and Szczesniak, 1973). The setback value recorded for the semolina couscous was 62 BU (Table 4.1), comparable to the setback viscosities of TDa 98/01176 (55 BU) and TDa 99/00208 (67 BU). From the study, TDa 99/00208 which had the highest setback viscosity may produce a better cohesive fufu when pounded than the other varieties of low setback viscosity. The cohesiveness of the grain mass of couscous produced from TDa 99/00208 may be comparable to the cohesiveness of the grain mass of semolina couscous.

4.3.7. Breakdown viscosity

The breakdown viscosity of all the yam flour samples and the semolina flour were 0 BU. Viscosities attained at 95 ºC after holding for 15 minutes is an indication of the breakdown viscosity of the paste and it is an indication of the paste stability during cooking. The zero breakdown viscosity recorded is an indication of very low paste stability of the flour samples, which might be due to very weak cross-linkage between the starch granules (Farhat *et al.*, 1999, Oduro *et al.*, 2000)

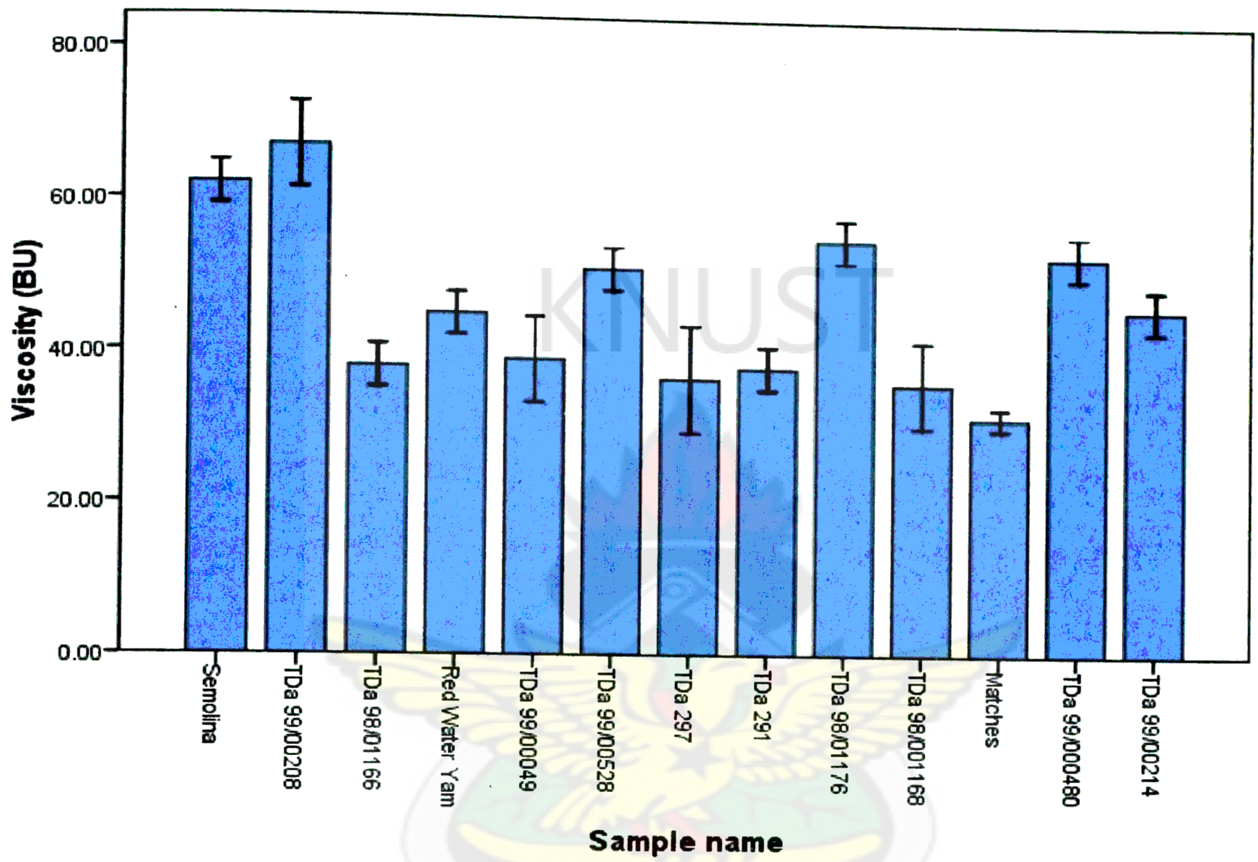


Figure 4.11: Comparison of the Setback Viscosities of the different varieties of *Dioscorea alata* and Semolina flour

4.4. Granule sizes and shape

The starch of all the samples under study had a high proportion of fairly large granule size, ranging from 20 μm to 60μm (Table 4.1). Values ranging from 5 μm to 50 μm have been reported by NRI (1978). The granule shapes of the samples were variable. The starch granules of 'Matches', TDa 291, TDa 98/001168, TDa 99/000480, TDa 99/00199 and TDa 99/00280 varieties were elliptical. Red water yam, TDa 297, TDa

98/01176 and TDa 99/00049 had their small size granules being round and the large size ones being oval in shape. The rest of the tubers had polygonal shapes (Table 4.1).

According to Scott (1996) and Lindeboom *et al.* (2004), starch composition, gelatinization and pasting properties, enzyme susceptibility, crystallinity, swelling and solubility are all affected by granule size. The larger the granule, the less molecular bonding, so they swell faster. Large starch granules tend to build higher viscosity, but the viscosity is unstable because the physical size of the granule makes it more sensitive to shear. Granule shape and size are very important characteristics also for starch extraction industry since they define mesh size for extraction and purification sieves (Leonel *et al.*, 2003). Granule shapes are also indicators of the plant origin of the starch and could therefore be utilized as a quality parameter to identify adulterated starch (Niba *et al.*, 2002). Pictures of the starch granules are shown in plate 2. The variability of the granule sizes were not significant ($p > 0.05$).

Table 4.1: Granule sizes and shape of *Dioscorea alata* varieties

Sample	overall size (µm)	Average (µm)	Shape
TDa 99/00208	30 – 60	45	Elliptical
TDa 98/01166	30 – 50	40	Polygonal
Red water yam	20 – 30	25	Round, oval
TDa 99/00049	30 – 50	40	Round, oval
TDa 99/00528	30 – 50	40	Polygonal
TDa 297	20 – 40	30	Round, oval
TDa 291	30 – 50	40	Elliptical
TDa 98/01176	30 – 50	40	Round, oval
TDa 98/001168	30 – 50	40	Elliptical
TDa 99/00240	30 – 50	40	Polygonal
'Matches'	20 – 40	30	Elliptical
TDa 99/000480	30 – 50	40	Elliptical
TDa 99/00199	30 – 50	40	Elliptical
TDa 98/01174	20 – 40	30	Polygonal
TDa 99/00214	20 – 40	30	Polygonal

4.5. Amylose

The variability of the amylose content of the starches was significant ($p < 0.05$). The amylose content of the starch analyzed ranged from 25.00 g/Kg to 39.36 g/Kg (Figure 4.12). These values deviated from values reported by other researchers for yams which includes; 290 g/Kg (McPherson and Jane, 1999), 270 g/Kg (Hoover and Vasanthan, 1994), 285 g/Kg (Gunaratne and Hoover, 2001), and 300 g/Kg (Mali *et al.*, 2002 and Alves *et al.*, 1999). However Riley *et al.* (2006) recorded values of between 20 g/Kg – 23 g/Kg for some *Dioscorea alata* samples assessed. These latter results seem to be closer to what was recorded in this study. These differences might be explained by the different growing conditions, lipid content and amylose determination technique. (Mali *et al.*, 2002). The genetic make up of the samples could also have contributed to the low values obtained.

The zero breakdown viscosities recorded which, is an indication of paste stability could be attributed to low amylose content of the yam starches. It could also be responsible for the hardening of the cooked yam couscous especially when it is cold. Whiles amylose and lipids inhibit starch granule swelling, amylopectin enhances swelling of starch granules and pasting (Tester and Morrison, 1990).

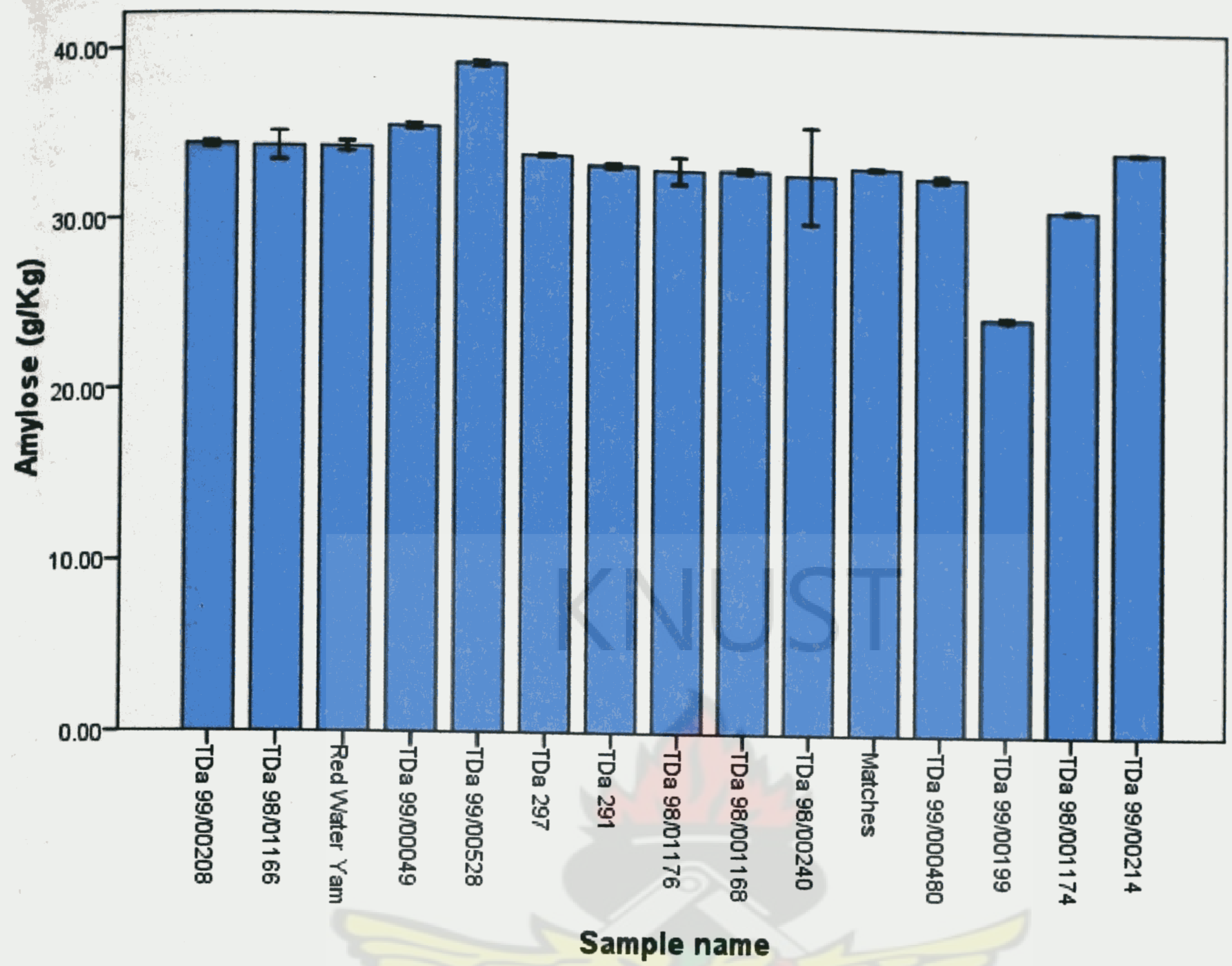


Figure 4.12: Comparison of the Amylose content of the different varieties of *Dioscorea alata* starches

4.7. Pre-evaluation of couscous processing methods

Two methods were adopted for the processing of couscous; that is, the blanched-grated tuber and the yam flour methods. Table 4.2 shows the quality of couscous from the two processing methods. Couscous prepared by the blanched-grated-tuber (BGT) method was less time consuming, similar to semolina couscous and can be distinguished only by its taste and colour. Whiles it took approximately 8 hours to finish the preparation of couscous by the blanched-grated-tuber method, it took between 20 hours to 110 hours to prepare couscous from yam flour depending on the flour preparation method. The flour obtained from oven dried chips gave a better couscous compared to the flour obtained from solar dried chips. This might be due to the discolouration of the chips through enzymatic browning. The temperatures (60 °C) used during the oven drying of the chips could have deactivated the enzymes responsible for browning (Akissoe *et al.*, 2003). From the results of this study, couscous processed by the blanched-grated tuber method was adapted for further studies.

Table 4.2: Quality of couscous from blanched-grated tuber and yam flour

Variety	Processing method	Estimated time for preparation (hours)	Colour/ appearance	Texture	Comments
'Matches'	BGT	8	Creamy white	Hard and coarse	sizes were even after milling
	FSD	110	Dark brown	Hard and brittle	Off flavour development
	FOD	20	Creamy white	Hard and brittle	
Akaba	BGT	8	Creamy white	Hard and coarse	Colour was lighter than that of 'Matches'
	FSD	80	Dark brown	Hard and brittle	Off flavour development
	FOD	20	Creamy white	Hard and brittle	

BGT= Blanched-grated tuber; FSD=Flour from Solar dried chips; and FOD=Flour from oven dried chips

4.8. Evaluation of Couscous processed by the blanch- grated- tuber method.

4. 8.1. Couscous yield

The yield of the processed couscous ranged from 16 % to 24.2 % (Figure 4.13). The yield of the couscous correlated positively to the mean weight of the tubers ($r = 0.77$; $P < 0.05$). This implies that the large size tubers yielded more than the small tubers. This could be attributed to more peel loss in the smaller size samples compared to the large samples. There was also a slight negative correlation between the moisture content of the tubers and the yield ($r = -0.40$; $P < 0.05$). Implying that the yield of couscous is likely to increase with decreasing moisture content of the yam tuber it is processed from. The lower the moisture content, the higher the dry matter hence, the higher the yield of couscous to be obtained. The variability in the yields of couscous from the different varieties was significant ($p < 0.05$).

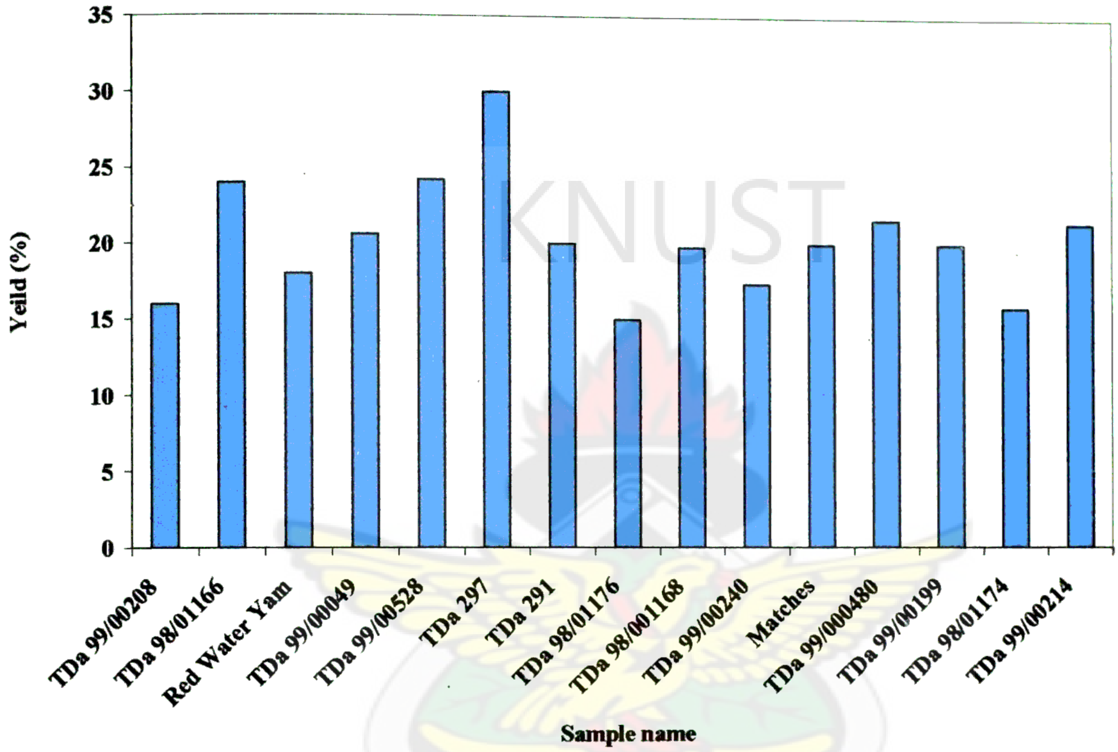


Figure 4.13: Percentage yield distribution of couscous processed from the different Dioscorea alata varieties by the blanch-grated-method.

4. 8.2. Colour (Luminosity) of couscous

The luminosity (L) of the couscous samples were significantly different ($p < 0.05$). TDa 291 had the lightest colour with L values of 79.46. This was followed by TDa 99/00199, TDa 98/01174, Red water yam, TDa 297, recording L values of 75.17, 75.00, 73.84 and 72.04 respectively. TDa 99/00214 was the darkest with L value of 58.67 (Table 4.3). The tubers that gave the darkest couscous colour might have accumulated high levels of polyphenols and anthocyanins over their storage period than those used for the lighter coloured couscous (Onayemi and Idowu, 1988). This implies that in making couscous with light colours (high L values), tubers with low polyphenols and anthocyanin levels may be considered. The head portion of the yam tuber that accumulates the highest levels of polyphenols during storage may not be suitable for couscous since it may also affect the colour (Onayemi and Idowu, 1988).

Table 4.3: ***Luminosity (colour)*** **of couscous samples**

Sample	Mean (L value)
TDa 291	79.46[j]
TDa 98/ 01176	60.02[c]
'Matches'	63.49[d]
TDa 98/001168	65.88[d]
TDa 99/00528	69.88[e]
TDa 297	72.04[g]
TDa 98/01166	71.72[f]
TDa 99/00199	75.17[i]
TDa 98/01174	75.00[i]
TDa 99/00049	58.82[a]
TDa 99/000480	62.35[c]
TDa 99/00214	58.67[a]
TDa 99/00240	59.13[c]
Red water yam	73.84[h]
TDa 99/00208	60.24[c]

Values not statistically different at ($p > 0.05$) share the same letters.

4. 9. Effect of water on the texture of ready-to-eat couscous

Steaming 100g of dried Couscous mixed with 100 ml of water yielded the best texture (soft but not mashy) after steaming. Volumes of water more or less than a 100 ml gave couscous of poor texture (either a mashy or hard product) (Table 4.4). The amount of water absorbed by the couscous samples may be dependent on the water absorption capacity and swelling capacity of the starches present in the samples.

Table 4.4: Effect of the volume of water added to texture of steamed yam couscous

Volume of water added To 100g of couscous	texture of couscous after steaming TDa 98/01166	TDa 297
200ml	Mashy	Mashy
180ml	Mashy	Mashy
150ml	Slightly mashy	Slightly mashy
100ml	Tender but not mashy	Tender but not mashy
90ml	Slightly hard	Tender but not mashy
80ml	Slightly hard	Slightly hard
70ml	Hard	Hard
60ml	Hard	Hard
50ml	Hard	Hard

4.10. Quality assessment of couscous by untrained (consumer) panellists

The variation in the median of all the attributes assessed (colour, flavour, hardness, stickiness and overall acceptability) were statistically significant ($p < 0.05$).

The colour of TDa 291, TDa 98/01176, 'Matches', TDa 98/001168, TDa 99/00528 couscous were the most preferred (Table 4.5) whiles the colour of TDa 99/00208 couscous was the least preferred choice of the panellists. The darkness of the colour could have made TDa 99/00208 unattractive to the panellists. Colour preference of Red water yam, TDa 99/00049, TDa 99/00240, TDa 99/00199 and TDa 98/00199 couscous were statistically insignificant ($p > 0.05$). There was a slight negative correlation between the consumer colour preference and the couscous and instrumental colour measurement ($r = -0.26$). This implies that some of the panellists liked the dark coloured yam couscous and others prefer the light coloured ones. This was expected since the variability in preference of foods is normally wide when consumer panellists (untrained) are used. Theses variations could be reduced drastically by the training of panellists (Stone and Sidel, 1993).

Hardness TDa 99/00528 couscous was the most preferred (Table 4.5). However, the variability in hardness of TDa 99/00528, TDa 99/00208, TDa 98/01166 and Red water yam were not statistically significant ($p > 0.05$). The variations in the hardness preferences of the yam couscous samples could be attributed to variations in consumer texture preferences of foods. It may also be due to the difference in the pasting profile of the samples resulting in their textural differences (Scott, 1996).

The sample with the least preference for stickiness was TDa 297 couscous which was the stickiest of all the samples and Red water yam couscous was the most preferred for stickiness (Table 4.5). Most of the yam couscous samples were quite sticker than the semolina couscous. The difference in stickiness of the yam and semolina couscous samples may be due to the differences in the sizes of their starch granules which have an influence on their peak viscosities. The average starch granule sizes recorded for the *Dioscorea alata* varieties were larger than the average value of 19.5μm reported for the granule sizes wheat starch (www.fao.org/starch). The stickiness of couscous has also been found to be correlated to the amount of damaged starch present. Addition of small amount of oil may be used to separate the couscous grains hence reduce its stickiness. This decrease in stickiness is likely to be due to a lipid-starch interaction (Aboubacar and Hamaker, 1999).

The panelists assessed the flavour of the samples by both their taste and smell senses. The sample with the most preferred flavour was TDa 99/00528 couscous, followed by TDa 98/001168, 'Matches', TDa 297 and, TDa 98/01176. These samples were not statistically different from TDa 99/000480 and TDa 99/00199. The flavour of TDa

99/00049 couscous was the least preferred (Table 4.5). The difference in the flavour acceptability may be due to genetic variations in the water yam varieties.

The overall acceptability of the couscous samples positively correlated with the colour ($r = 0.244$, $p < 0.01$), flavour ($r = 0.507$, $p < 0.01$) hardness ($r = 0.371$, $p < 0.01$) and had a slight negative correlation with stickiness ($r = -0.174$). The first five samples that were most preferred by the panellists when samples were assessed in combination with vegetable stew were; TDa 297, TDa 99/00528, TDa 98/01176 and TDa 98/001168. 'Matches' and TDa 99/00480 couscous were ranked the same as TDa 98/001168 couscous.

Table 4.5: Mean rank scores of sensory attributes of couscous assessed by consumer panellist

Sample	Colour	Flavour	Hardness	Stickiness	Overall Acceptability
TDa 99/00208	407.15	231.43	233.93	299.67	241.83
TDa 98/01166	233.83	270.38	227.67	228.70	228.15
Red water yam	285.62	247.73	225.00	119.80	232.22
TDa 99/00049	273.65	289.15	243.23	239.13	279.35
TDa 99/00528	125.18	110.38	150.67	299.35	148.50
TDa 297	208.42	184.50	198.25	405.52	109.17
TDa 291	93.00	218.70	282.82	161.10	163.25
TDa 98/01176	115.50	210.20	224.13	137.80	148.50
TDa 98/001168	120.00	170.30	202.40	151.97	227.17
TDa 99/00240	305.00	258.12	276.27	158.23	246.83
'Matches'	120.00	170.30	202.40	151.97	227.17
TDa 99/000480	305.00	246.03	267.33	304.33	227.17
TDa 99/00199	269.42	224.40	204.70	229.80	249.25
TDa 98/01174	274.50	269.73	213.33	282.67	377.57
TDa 99/00214	310.08	281.13	240.37	212.47	276.33
P-Value	0.0000	0.0000	0.0031	0.0000	0.0000

4.11. Shelf life studies of couscous

The shelf life of food could be defined as the time it takes a product to decline to unacceptable level. It is taken as the time a product remains salable (Potter and Hotchkiss, 1996). The microbial load, pH, and moisture content of the products were evaluated over a storage time of 24 weeks. Sensory evaluations by trained panellists were also conducted.

4.11.1. Sample selection for shelf life studies

Samples selected for the shelf life studies were to be dependent on the pasting results, consumer sensory evaluation results and availability of the yam tuber. The peak viscosity which is a determinant of the stickiness of the samples could be a good index for selection of yam tubers for couscous production. The samples with low peak viscosity comparable to semolina couscous were TDa 98/001168, TDa 99/00214, TDa 99/000480 and TDa 98/01176 out of which the colour and flavour of TDa 98/01176 and TDa 98/001168 were the most preferred. TDa 297 flour had the highest peak viscosity and its couscous most sticky. However, it was judged the overall best followed by 98/01176 and TDa 98/001168 couscous. The overall acceptability of the couscous was more dependent on the flavour of the samples than the other sensory attributes. TDa 99/00528 couscous which had a hot paste viscosity comparable to the semolina couscous was also the most preferred for hardness and its hardness preference was similar to TDa 99/00208, TDa 98/01166 and Red water yam couscous.

Based on peak viscosity and general sensory performance, TDa 98/01176, TDa 98/001168, TDa 297, TDa 99/00528 and TDa 99/0048 could have been the best varieties for yam couscous. However due to unavailability of samples, elections were based on the overall acceptability results. TDa 297 couscous the overall best sample and TDa 98/01166 which had no significant difference with the second best samples, TDa 99/00528 and 98/01176 were selected for further analysis.

4.11.2. Microbiological evaluation of couscous

According to Codex Standards, couscous should be clean, safe and fit for human consumption (Codex Stan 202 – 1995). The safety of the couscous also includes microbiological safety. According to the US Durum specifications for couscous, Aerobic Plate Count, Total Coliforms, *E. coli*, Yeast and Mould Count are microbial quality index of couscous.

4.11.2.1. Aerobic Plate Count

Aerobic Plate Count is used in bacteria enumeration of food samples (Talaro and Talaro, 1993). TDa 98/01166 couscous recorded higher Aerobic Plate Count than TDa 297 couscous. The difference in the Aerobic Plate Count of the sample was significant ($p < 0.05$). TDa 98/01166 had an increase in the Aerobic Plate Count up to the 16th week and then decline sharply (Table 4.7). The increases recorded with the first 16 weeks could be that, there were enough nutrients for the growth of the bacteria. TDa 297 also observed an increase in the Aerobic Plate Count within the first eight weeks and then a subsequent decline. The variations that occurred over the storage period were also significant ($p > 0.05$). On the first day of preparation, the Aerobic Plate Count of TDa 98/01166 averaged 5.1×10^3 CFU/g whilst TDa 297 recorded 570 CFU/g (Table 4.7). These variations could have been due to differences in levels of exposure of the samples during processing. The bacteria present at this time could be thermophilic organisms since the couscous samples have been dried at 60 °C for 7 hours. At this temperature all the mesophilic and possibly the psychrotrophic organisms which are mostly the food spoilage organisms would have been destroyed (Adams and Moss, 1995). The values recorded for Aerobic Plate

Count over the 24 week storage period are all within the Ghana Standards Board acceptable limit of 1 x 10^6 for couscous (Ghana Standards, GS 730/2003).

Table 4.6: Mean Aerobic Plate Count of dry water yam couscous samples over the 24 weeks storage period

Sample	Period/ Aerobic Plate Count (CFU/g)			
	Week 0	Week 8	Week 16	Week 24
TDa 98/01166	5.1 x10^3 ± 1.4 x10^2	2.7 x 10^4 ± 3.2x10^2	1.3 x 10^5 ± 2.8 x10^3	5 .0x 10^3 ± 1.4 x10^2
TDa 297	5.7 x 10^2 ± 1 x 10^1	5.2 x 10^3 ± 1.4 10^2	7 .0x 10^2 ± 0.0	2.0 x 10^2 ± 0.0

4.11.2.2. Yeast and Mould Count

The yeast and mould growth of the samples were however not significant ($p > 0.05$), even though there were significant differences ($p < 0.05$) in their counts over the storage period. There was no mould and yeast growth in the couscous sample on the first day of preparation (week 0), 16th week and 24th week of storage. Oven drying of the yam couscous samples at 60 °C for 7 hours could have destroyed all the vegetative cells and spores of the yeast and mould that would have been present. According to Adams and Moss (1995), the vegetative cells and spores of yeast and mould are liked at below 100 °C in the baking of bread. Yeast and mould growth was observed on the eighth week of storage, which were 10CFU/g and 20CFU/g for TDa 98/01166 and TDa 297 respectively (Table 4.8). This growth observed may be due to contamination of the samples at the time of analysis. The acceptable limits for yeast and mould levels in couscous are 500 CFU/g according to the US durum couscous specifications

(Couscous specifications, 2007) and 1 x 10^4 CFU/g according to Ghana Standards Board specifications for couscous (Ghana Standards, GS 730/2003).

Table 4.7: Mean Yeast and Mould Count of dry water yam couscous samples over the 24 weeks storage period

Sample	Period/ Yeast and Mould Count (CFU/g)			
	Week 0	**Week 8**	**Week 16**	**Week 24**
TDa 98/01166	0^a	20^b	0^a	0^a
TDa 297	0^a	10^b	0^a	0^a

Values statistically different at ($p < 0.05$) shares different letters

4.11.2.3. Coliforms and E. coli count

There were no Coliforms and *E. coli* growth over the storage period. The Coliforms and *E. coli* which may be present would have been killed during the oven drying of the yam couscous. From the public health stand point, the couscous samples could be recognized as safe due to the absence of Coliforms and *E. coli* (Adams and Moss, 1995).

4.11.3. Effect of pH on the microbial growth over storage time

The variability of the pH of the samples and its change over the storage period were statistically significant ($p < 0.05$). There was a slight decrease in pH of TDa 98/01166 couscous sample from 5.58 on the first day of preparation to 5.32 by the 16th week (Figure 4.14), which was followed by a slight increase in pH by the 24th week to 5.4. A similar trend was followed by TDa 297 couscous, which had a pH of 5.54 on the first day of preparation, reduced to a pH of 5 after 16 weeks of storage and slightly increased to a pH of 5.1 after 24 weeks of storage. The decrease in pH could have been as a result of fermentation (Adams and Moss, 1995). However, the subsequent increase in pH could be due to the protein mass of the microbes over time. The normal pH range for bacteria growth has been reported to be between 6 and 8 (Adams and Moss, 1995). The pH ranges could have suppressed bacteria growth and could have accounted for the relatively lower Aerobic Plate Count especially in the TDa 297.

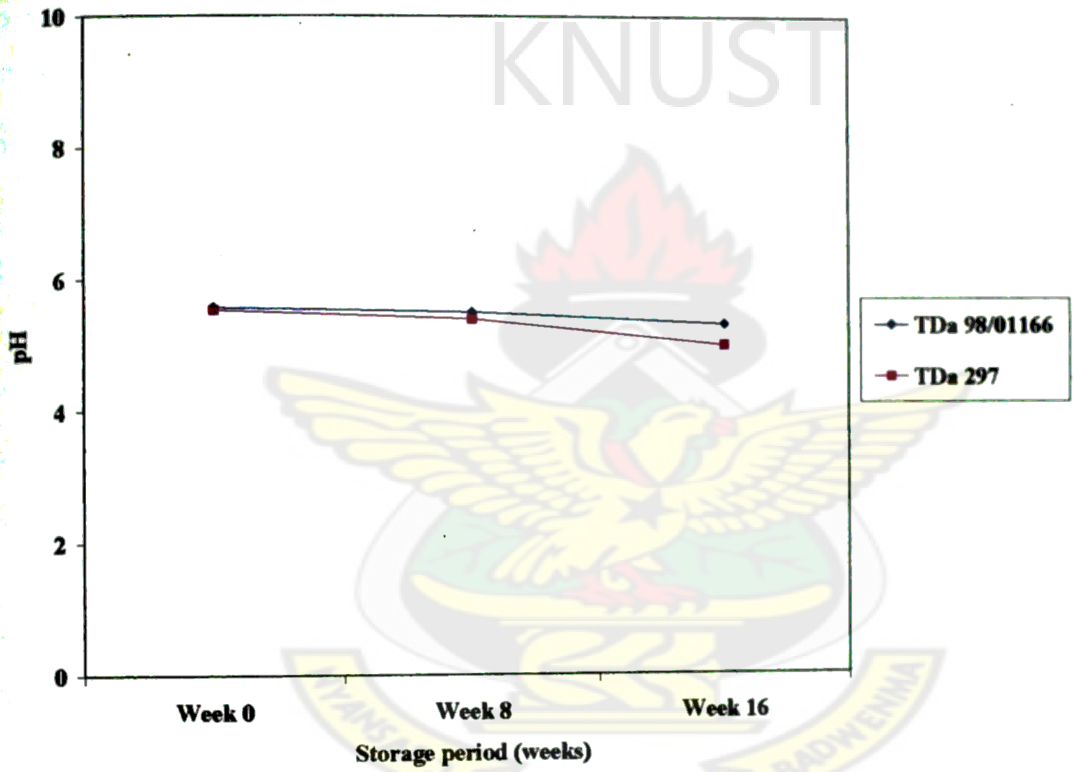


Figure 4.14: pH of water yam couscous samples over the 24 weeks storage period

4.11.4. Effect of moisture on the microbial growth over storage time

There was a gradual increase in the moisture content of the yam couscous samples over storage time and the variability in the moisture content of the samples were also significant ($p < 0.05$) over the storage time. The moisture content of TDa 98/01166 couscous was 8.1 % when it was freshly prepared. By the 24th week of storage, the moisture had increased to 10 %. The moisture content of TDa 297 couscous also increased from 6.6 % on the first day of preparation to 9 % by the 24th week of storage (Figure 4.15). The gradual increase of moisture in the water yam couscous samples may be due to the hydroscopic of nature of the inherent starch present. Despite the gradual increase in moisture content of the yam couscous samples over storage time, the values recorded were below the 13.5 % moisture limit specified by Codex standard (Codex, Stan 202-1995). The low moisture content recorded is an indication of the shelf life stability of the product.

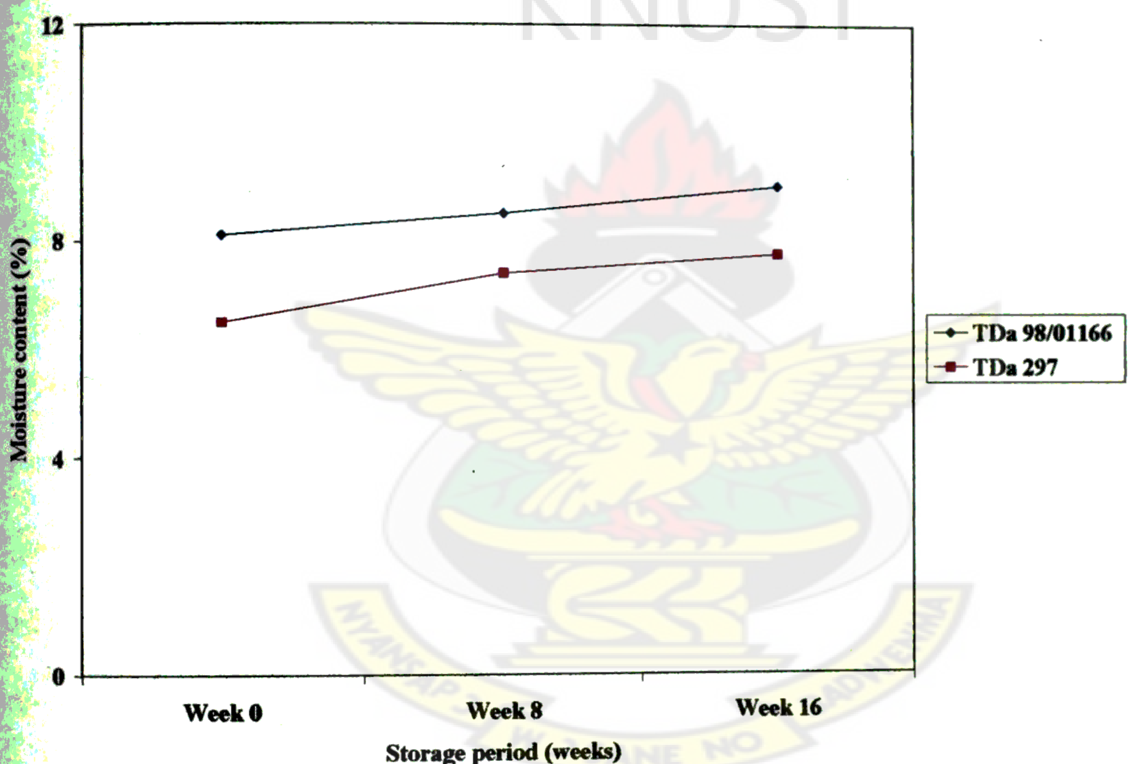


Figure 4.15: Moisture content of dry water yam couscous samples over storage period

4.11.5. Sensory evaluation by trained panellists

Sensory evaluation by trained panellists is an effective tool in new product development. The descriptors used included colour appearance, flavour, taste, texture and overall acceptability. The uniformity of grains was also an additional attribute assessed.

4.11.5.1 Colour (whiteness of colour)

The whiteness of the couscous samples were assessed on a line scale of 0 (not white) to 10 (white). There was a gradual decrease in the whiteness score of the storage period. TDa 297 couscous scored 3.71 on first assessment day. By the 24th week of storage, the whiteness score of the panellists have been reduced to 2.4. TDa 98/01166 which was the darker of the two yam couscous also scored whiteness values ranging from 0.97 to 0.93 on the first day and after 24 weeks of storage respectively (Figure 4.16). The standard couscous which was actually yellow scored an average of 0.83 for whiteness. The relatively low values of whiteness for the yam couscous recorded may be due to the amount of polyphenols that were present prior to processing. The levels of polyphenols have been reported to affect the colour of some processed foods such as 'amala' (Akissoe *et al.*, 2003). After cooking darkening in yams, which is as a result of ferrous iron present in the tuber oxidizing to ferric iron when the yam tubers are cooked especially in water or with steam could also result in the darkening of the yam couscous (Mornar-Perl and Friedman, 1990). The decrease in the whiteness of the yam couscous as assessed by the panellists was an indication of the darkening of the product over the storage time. The yellow colour of the semolina couscous was relatively stable during the storage period. The yellow colour of the semolina couscous may be due to high carotenoids level in durum wheat used. According to Graham and Rosser (2000), durum wheat used in the processing of semolina couscous is generally high in carotenoids content, because of the high market demand of strong pigment in pasta and noodle products.

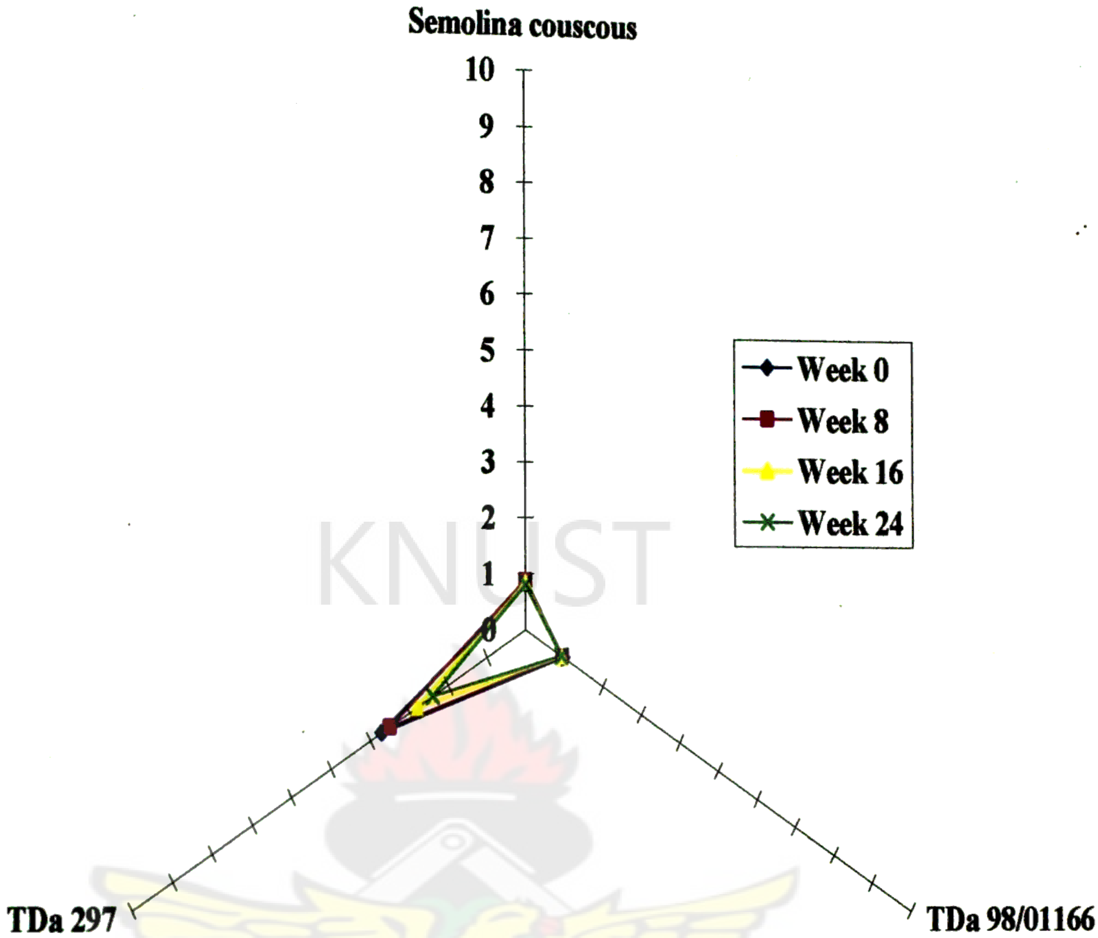


Figure 4.16: Comparison of the whiteness of steamed water yam and semolina couscous sample the 24 weeks over storage period

4. 11.5.2. Appearance

Two parameters were assessed under appearance: the presence of black specks and the uniformity of the couscous grains.

4.11.5.2.1. Presence of black specks

The presence of black speck in the product was assessed on the scale of 0 (no black specks) to 10 (all black specks). From the graph (Figure 4.17) very minimal black specks were recorded. However, TDa 98/01166 had the most of black specks and recorded the highest value of 1.5 on the 16th week of storage and the lowest value of 0.8 on the 8th week of storage (Figure 4.17). TDa 297 recorded black speck scores in the range of 0.9 to 0.95 while semolina couscous recorded the lowest black specks values which ranged between 0.2 and 0.24.

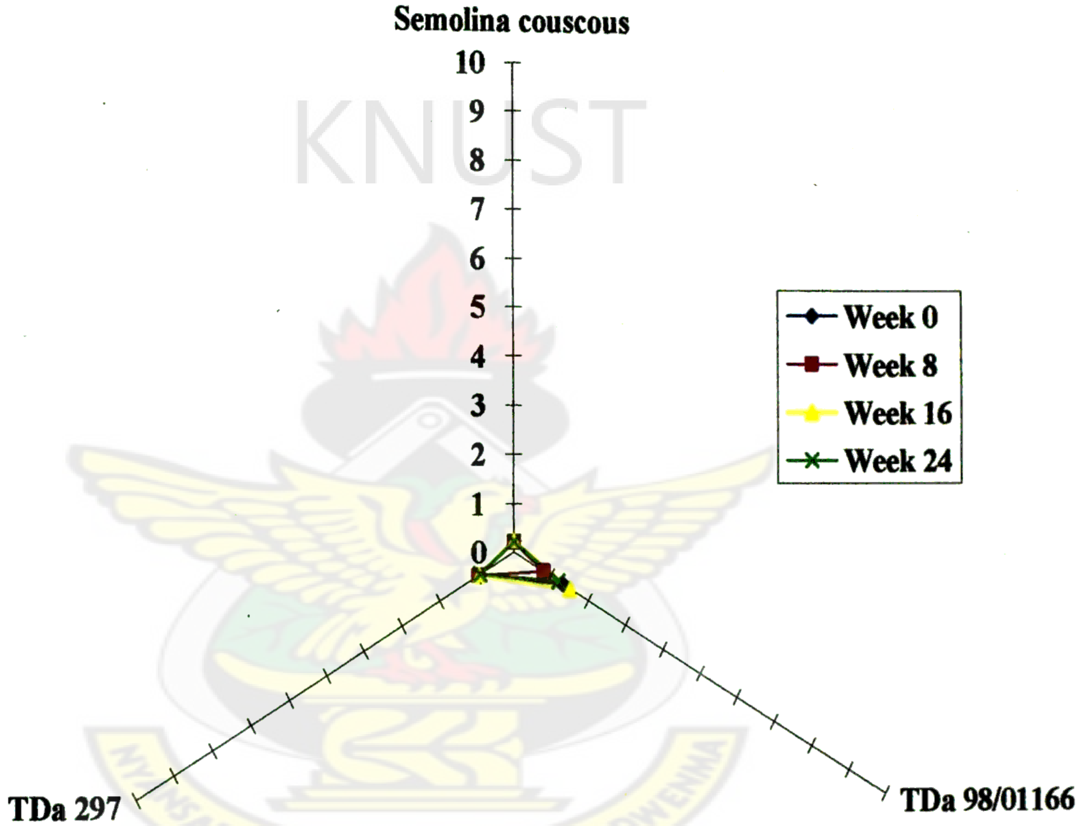


Figure 4.17: Comparison of black specks presence in steamed water yam and semolina couscous samples over the 24 weeks storage period

4.11.5.2.2. Uniformity of couscous grains

The variation in the uniformity of the samples over the storage period was significant ($p < 0.05$) even though yam couscous under the shelf life studies were processed using the same processing procedure. The sieving step during yam couscous processing allowed for grain uniformity by the removal of smaller grains with particles sizes lesser than 2 mm to allow for even grain sizes. Average values of 9.44, 8.06 and 7.08 were scored for semolina, TDa 98/0166 and TDa respectively (Figure 4.18). The semolina couscous grains were the most uniform.

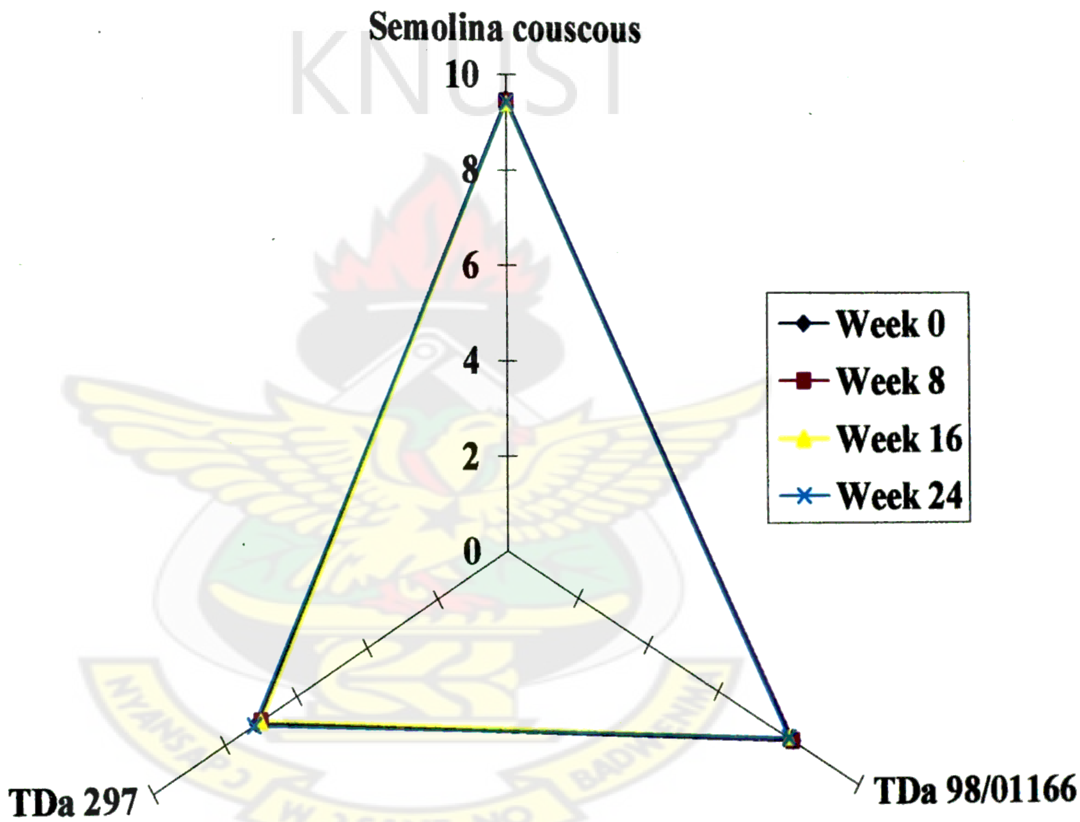


Figure 4.18: Comparison of the uniformity grains of water yam and semolina couscous samples over the 24 weeks storage period storage time

4.11.5.3. Flavour

The variability of the flavour acceptability of the couscous samples was not significant ($p > 0.05$). TDa 297 scored the highest flavour value of 7.9 followed by semolina couscous with a value of 7.57 whilst TDa 98/0116 recorded the lowest value of 7.1 on the first day of preparation. There were slight differences in the flavour of the samples on the 8th and 16th weeks of storage. However, there was a drastic reduction in the flavour of the samples after 24th weeks of storage. Semolina couscous, TDa 98/0116 couscous and TDa 297 couscous scored 5.08, 5.55 and 5.26 respectively (Figure 4.19). The reduction in the flavour score may be attributed to off flavour development in the samples due to absorption of unpleasant flavour components during the storage period. It could also be due to breakdown of flavour components and fermentation of the samples.

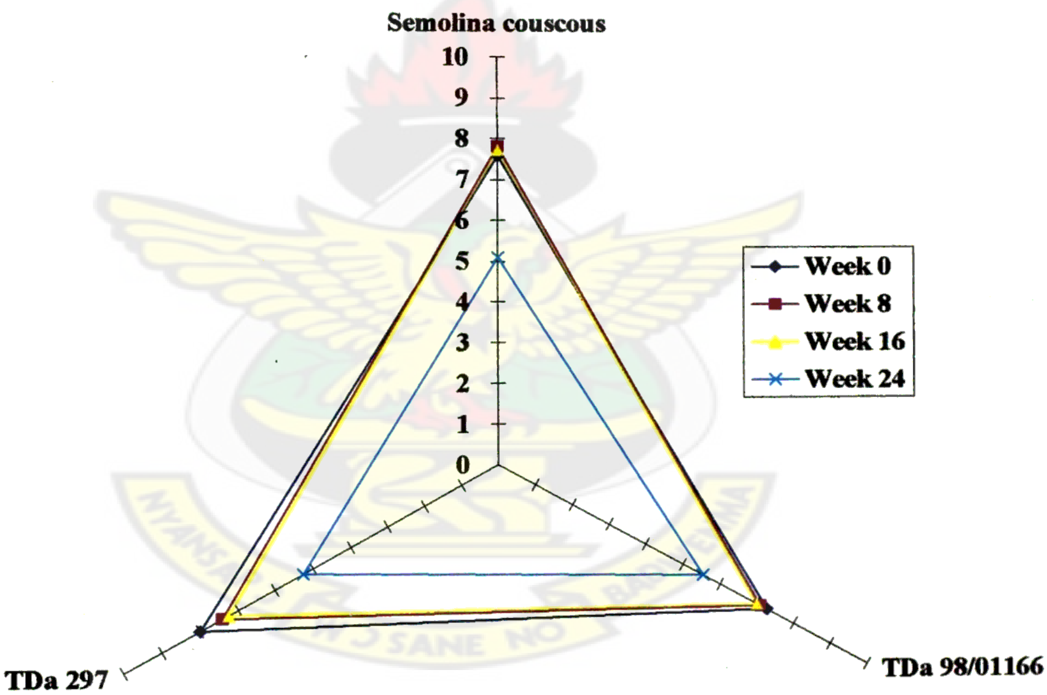


Figure 4.19: Comparison of the flavour acceptability of water yam and semolina couscous samples over the 24 weeks storage period

4.11.5.4. Taste

Panellists assessed the presence of sour taste and the taste acceptability of the couscous over the storage time. The sour taste of all the couscous samples were virtually negligible on the first day of preparation and were as follows; TDa 297 (0.38), TDa 98/0166 (0.69) and semolina (0.16). According to the judgment of the panellists, there was an increase of the sour taste after 8 weeks of storage to 1.7, 2.2 and 1 for TDa 297, TDa 98/0166 and semolina couscous respectively. By the 24th week of storage, the sour taste had increased to 2, 2.5 and 1.05 for TDa 297, TDa 98/0166 and semolina couscous respectively (Figure 4.20).

Although the taste acceptability score of all the couscous samples were above average, generally TDa 297 couscous was better than semolina couscous. The taste acceptability score of TDa 98/01166 couscous was the least of the three samples assessed (Figure 4.21). The variability of the taste acceptability of the sample over the storage period was significant ($p < 0.05$).

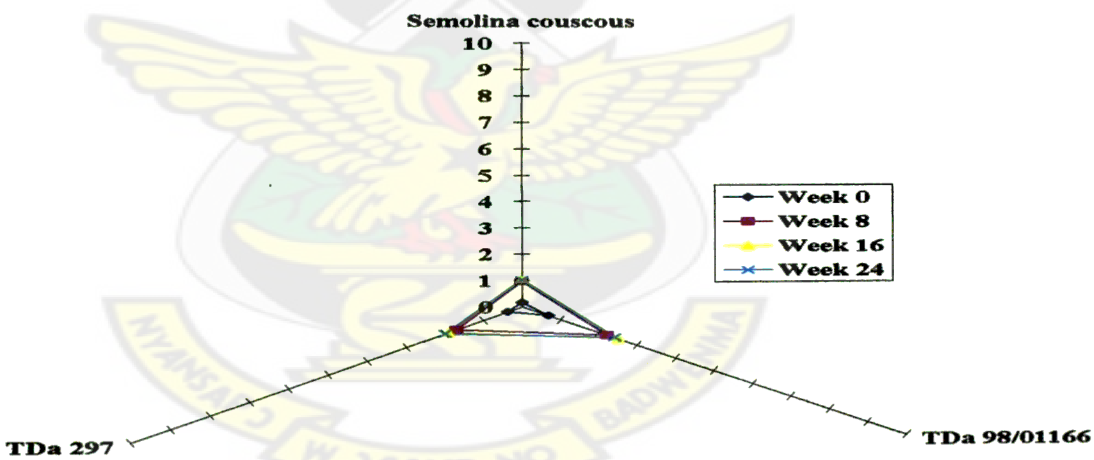


Figure 4.20: Comparison of the sour taste of water yam and semolina couscous samples over the 24 weeks storage period

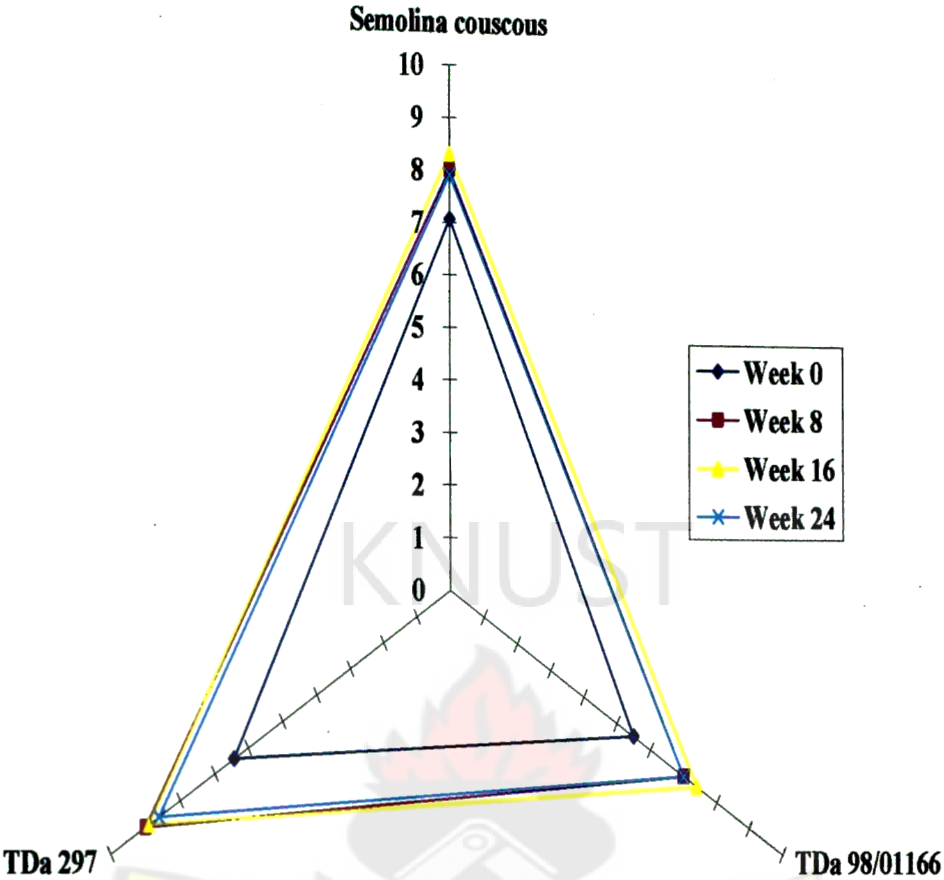


Figure 4.21: Comparison of the taste acceptability of water yam and semolina couscous sample over the 24 weeks storage period

4.11.5.5. Texture

The textural attributes of the products evaluated included stickiness, dryness, hardness and mouth feel. On the line scale of 0 (not sticky) to 10 (sticky), the stickiness of the samples on the first day was 3.3 and 2.97 for TDa 297, TDa 98/0166 couscous respectively. These values were comparable to what was recorded for the semolina couscous (3.36). There was no consistent trend in the stickiness of the products. The 8th week recorded the lowest values of stickiness of 3, 2.8, and 3.11 for TDa 297, TDa 98/0166 and semolina couscous respectively (Figure 4.22). The stickiness of the samples could be attributed to the amount of free starch particles present in the couscous samples. It could also be dependent on the amount of the very small floury particles which may be present in the couscous samples. Theses free starch particles and smaller floury particles have been reported to contribute to the stickiness of moistened steamed couscous (Aboubacar and Hamaker, 1999). Even though the peak viscosity was expected to contribute to the stickiness of the couscous, there was very slight correlation between the peak viscosity and stickiness ($r = 0.25$, $p > 0.05$). This could be due to the controlled volumes of water used in steaming of the couscous.

The variability of the hardness score of the couscous samples was not significant ($p > 0.05$). The average score for hardness were 3.46 for semolina couscous, 3.79 for TDa 98/0166 couscous and 3.77, for TDa 297 couscous (Figure 4.23).

There was a slight decrease in dryness of the samples with time. The dryness score averaged 3.15, 3.72 and 3.59 for semolina, TDa 98/0166 and TDa 297 couscous respectively (Figure 4.24). The results imply that the products were relatively moist since the line scale was from 0 (not dry) to 10 (very dry). The variability of dryness of samples over the period was not also significant ($p > 0.05$).

The mouth feel of the products were described on a line scale of 0 (rough mouth feel) to 10 (smooth mouth feel). The average score on mouth feel of the samples over the 24 week period were, 7.03, 5.2 and 5.33 for semolina, TDa 98/0166 and TDa respectively (Figure 4.25). This implies that the mouth feel of semolina couscous is smoother than the yam couscous.

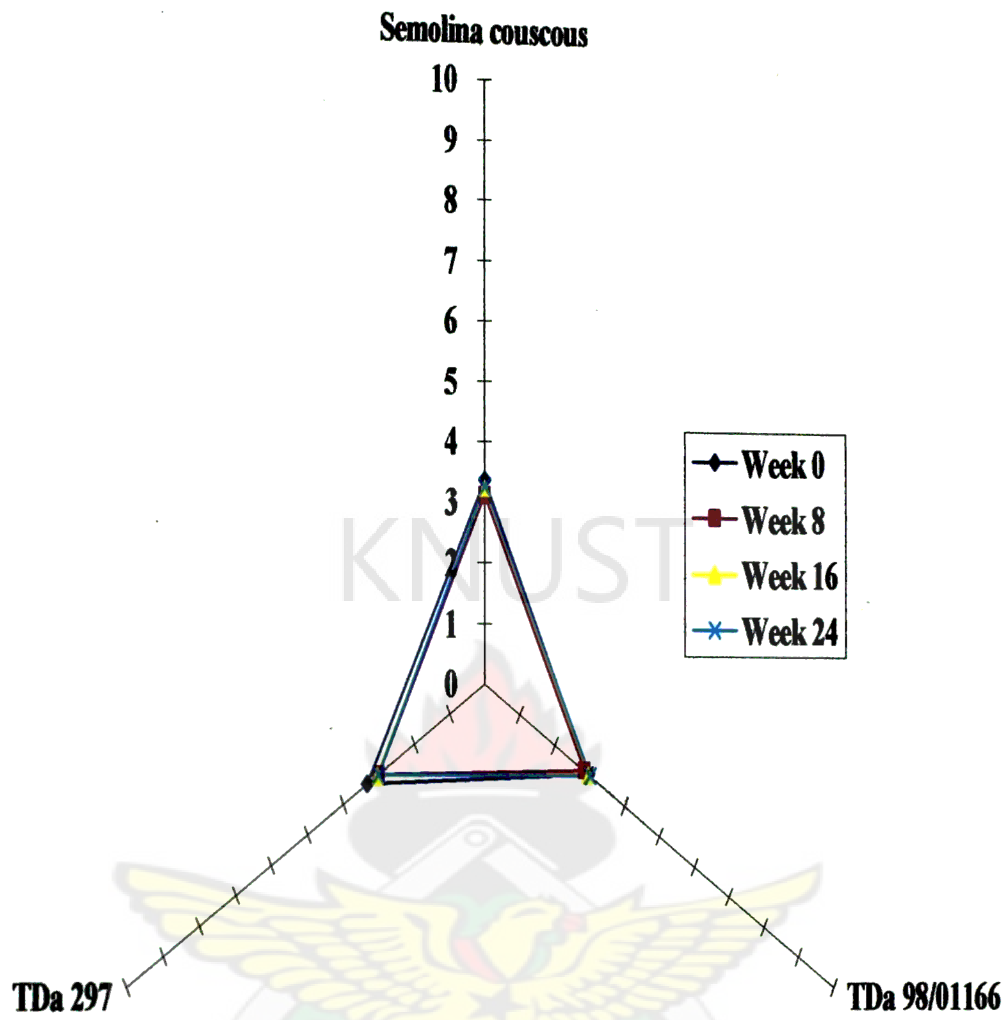


Figure 4.22: Comparison of the stickiness of water yam and semolina couscous samples over the 24 weeks storage period

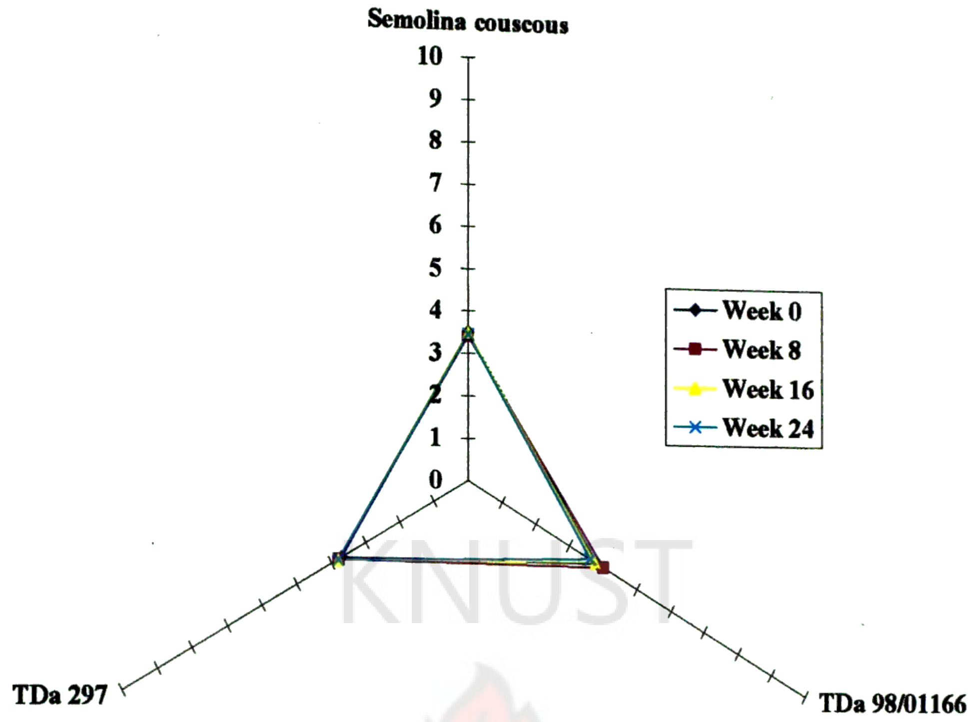


Figure 4.23: Comparison of the hardness of water yam and semolina couscous samples over the 24 weeks storage period

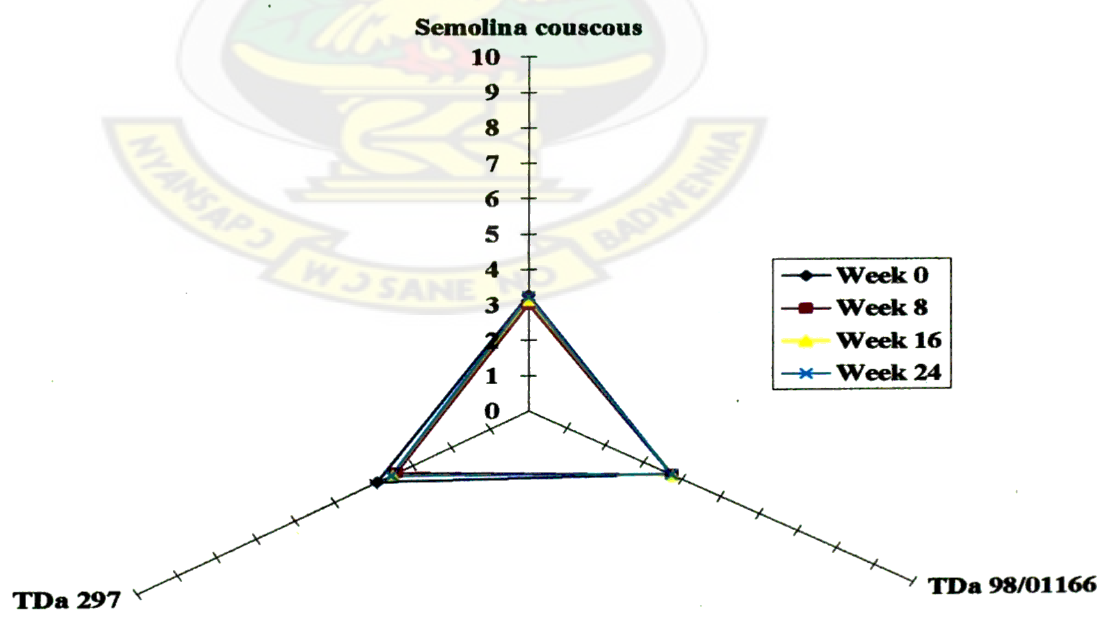


Figure 4.24: Comparison of the dryness of water yam and semolina couscous samples over the 24 weeks storage period

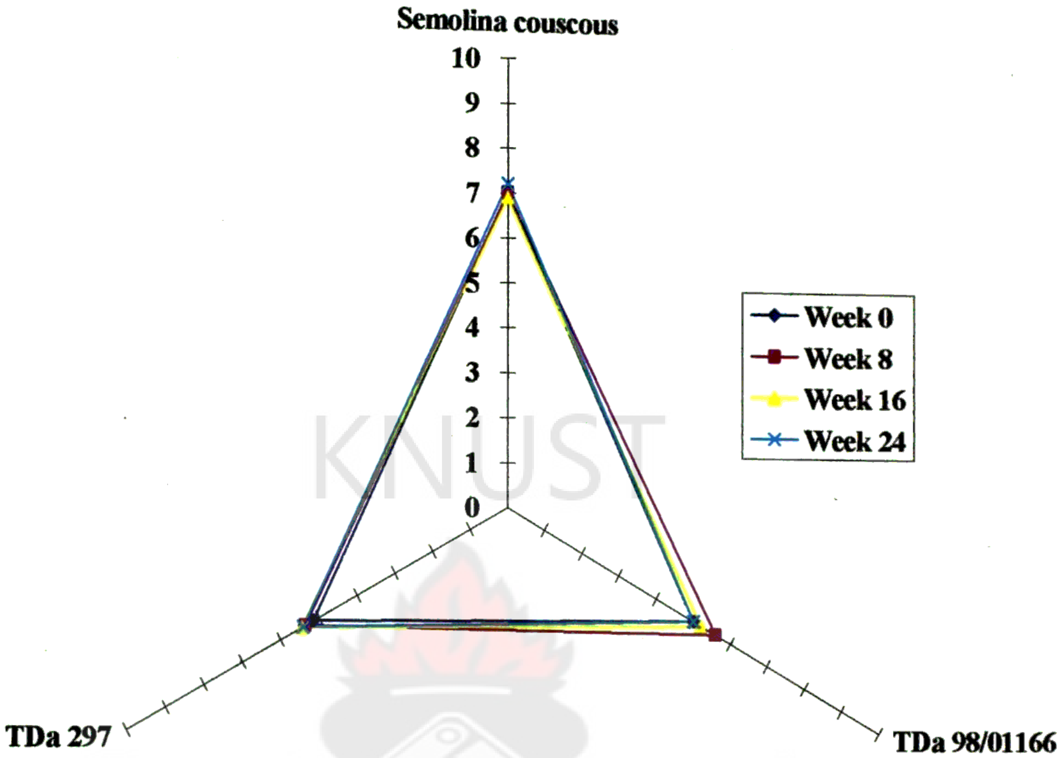


Figure 4.25: Comparison of the mouthfeel of water yam and semolina couscous samples over the 24 weeks storage period

4.11.5.6. Overall acceptability

There was no significant difference in the overall acceptability score of the couscous, which were semolina (7.05), TDa 98/0166 (7.01) and TDa 297 (7). The overall acceptability of the yam couscous products was comparable to that of the wheat couscous (Figure 4.26). The slight increase in sourness and the slight darkening of the yam couscous did not affect the overall sensory attribute of the product during the 24 weeks of storage.

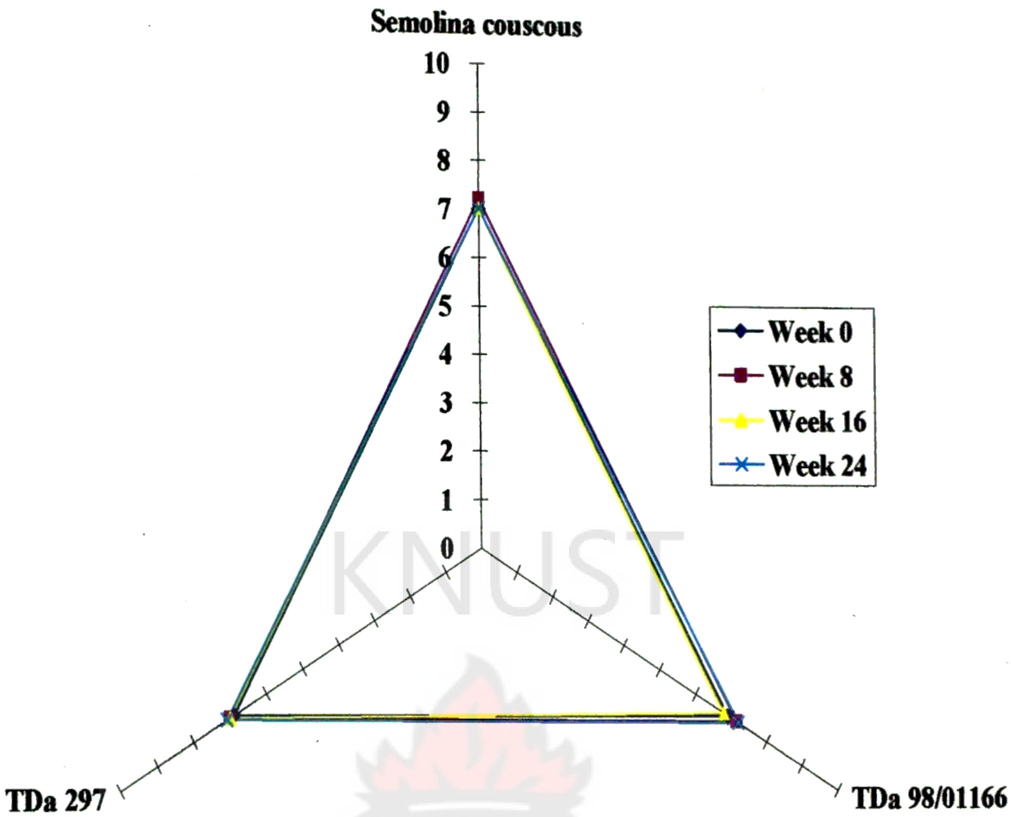


Figure 4.26: Comparison of the overall acceptability of water yam and semolina couscous samples over the 24 weeks storage period

4.12 Sensory evaluation by couscous consumers at Paloma restaurant

TDa 297 couscous used for the shelf life studies was used for this category of sensory analysis. Panellists were asked to score from 0 (dislike) to 10 (like). The results obtained for the yam couscous was quiet comparable to semolina couscous even though the semolina couscous was the most preferred choice of the panellists. The average score of colour of the yam couscous was 8 and 5 respectively (Table 4.9 and 4.10). This implies that the yellow colour of the semolina couscous was more appealing to the panellists than the off white colour of the yam couscous. The flavour score of 5 recorded by the yam couscous was lower compared to that of semolina couscous which recorded a value of 7. The scores of taste, stickiness, and overall acceptability were all 7 for semolina couscous and 6 for yam couscous. Stickiness scored 7 for semolina couscous and 5.1 for yam couscous. This was an indication that stickiness of the semolina couscous was preferred to the yam couscous. On the whole, the semolina couscous was preferred to the yam couscous by these set of panellist.

Table 4.8: Sensory score of semolina couscous by panellist at Paloma Restaurant

Attribute	Frequency	Score					Mean Score
		9	8	7	6	5	
Colour		4	2	4	0	0	**8**
Appearance		0	3	4	3	0	**7**
Flavour		0	3	4	3	0	**7**
Taste		0	1	8	1	0	**7**
Texture							
Hardness		4	2	3	1	0	**7.9**
Stickiness		0	1	8	1	0	**7**
Overall acceptability		0	1	8	1	0	**7**

Table 4.9: Sensory score of yam couscous by panellist at Paloma Restaurant

Attribute	Frequency	Score					Mean score
		7	6	5	4	3	
Colour		3	3	4	0	0	**5**
Appearance		3	3	4	0	0	**5**
Flavour		2	0	7	1	0	**5**
Taste		3	4	3	0		**6**
Texture							
Hardness		1	8	1	0	0	**6**
Stickiness		2	0	7	1	0	**5.1**
Overall acceptability		4	2	4	0	0	**6**

4.13. Conclusion and recommendation

4.13.1. Conclusion

Dioscorea alata is suitable for couscous production. The *Dioscorea alata* varieties studied had relatively high pasting temperatures and low peak viscosities. The tubers also have zero breakdown viscosities. Couscous processed using the blanched-grated-tuber method was better in sensorial qualities in terms of colour, flavour and texture. It was also easier to prepare in terms of labour and time. Couscous from TDa 99/00528, TDa 297, TDa 291 and TDa 98/01176 varieties were the most preferred by consumer panellists. On the whole, Yam couscous was quite comparable to semolina couscous in terms of texture with the difference being in colour and taste. The sensory and microbial qualities of the yam couscous were acceptable over the period of storage. Yam couscous is considered safe for human consumption and can keep for not less the 24 weeks in a cool dry place.

4.13.2. Recommendations

Further studies need to be conducted on theses findings:

1. Breeding for improved tubers flesh colour for couscous production.
2. The reduction of stickiness of yam couscous to make it comparable to semolina couscous.
3. The promotion of couscous in restaurants and eateries to increase the knowledge of it and its use

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PLATES

Plate 1: Pictures of various varieties of *Dioscorea alata*

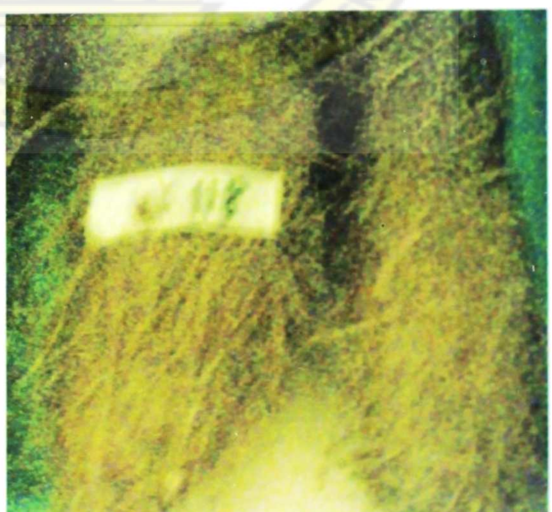
A: TDa 297

B: TDa 99/00240

C: Red water yam

D: TDa 291

E: TDa 99/00199



F: TDa 99/00214

G: TDa 99/00049

H: TDa 99/00528

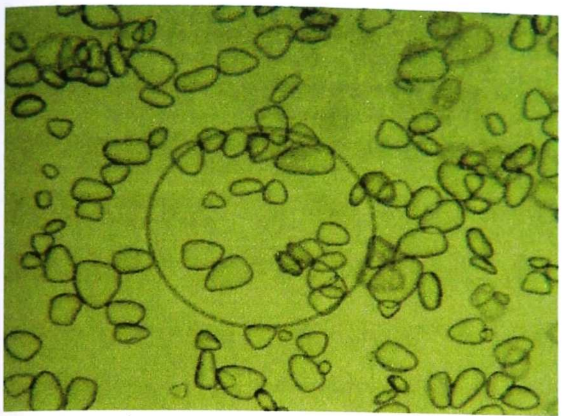
I: TDa 98/01166

J: 'Matches'

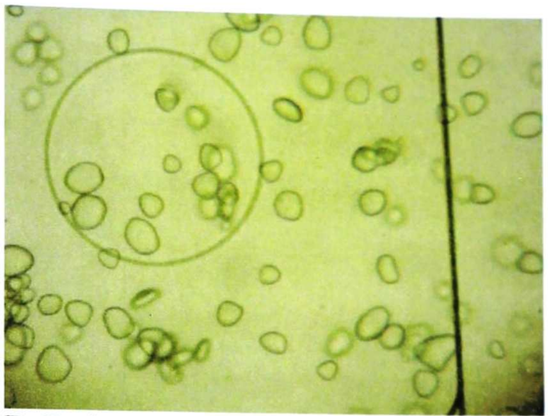
K: TDa 99/00208

L: TDa 98/01174

Plate 2: Micrograph of *Dioscorea alata* starch granules

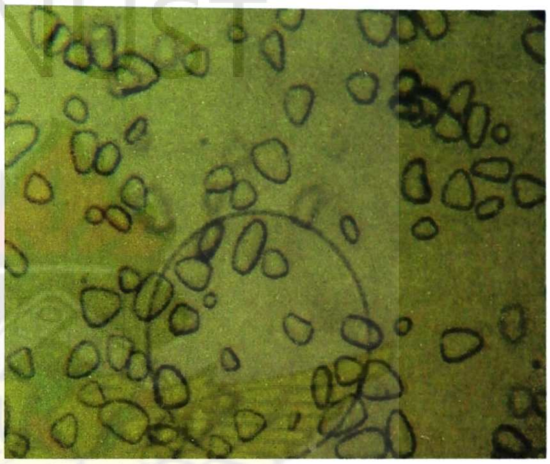


A: 'Matches'



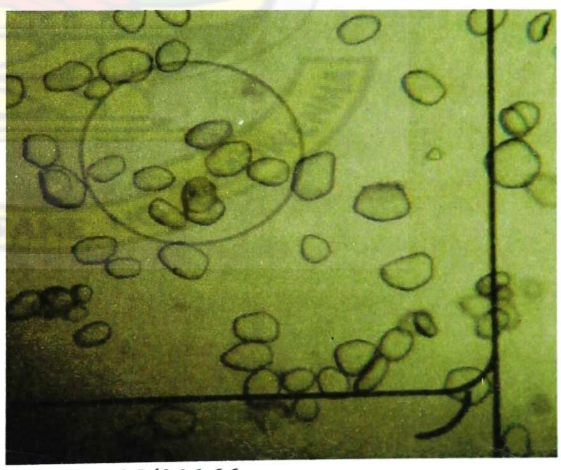
B: Red water yam

C: TDa 291

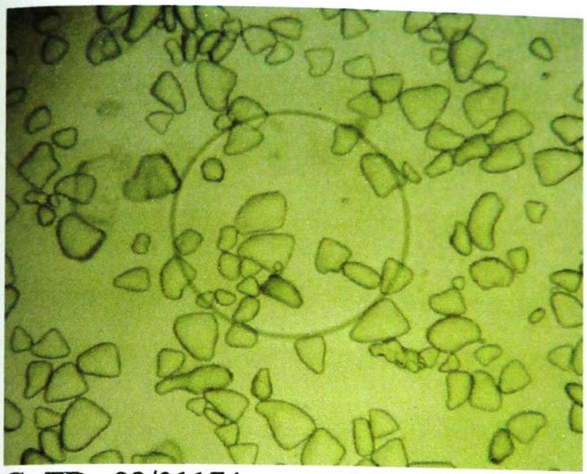


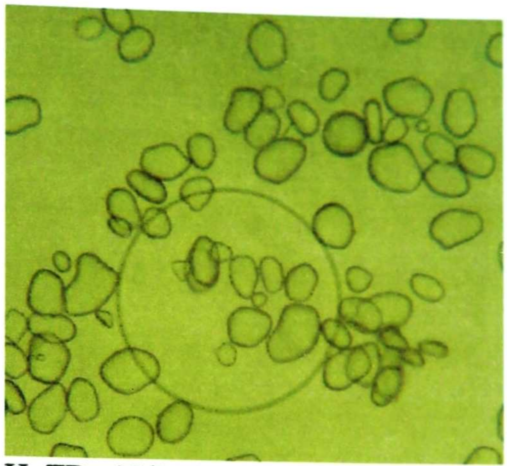
D: TDa 297

E: TDa 98/001168

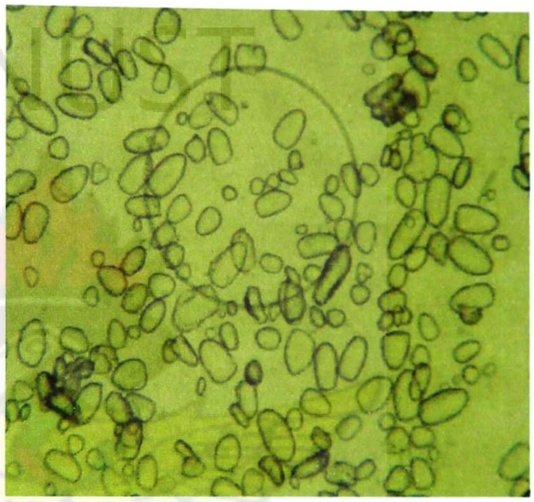


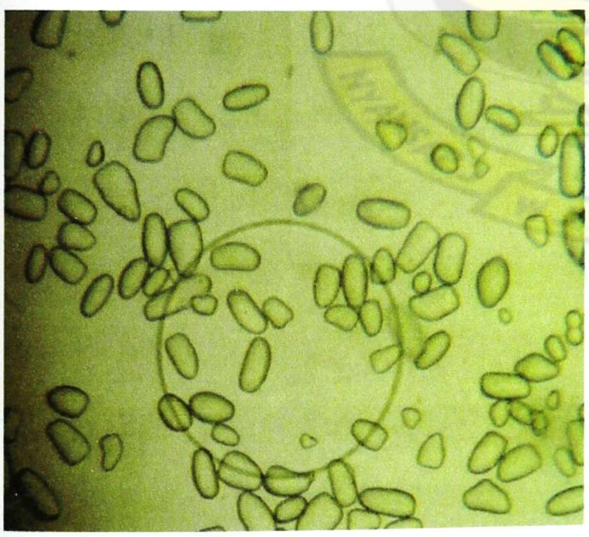
F: TDa 98/01166

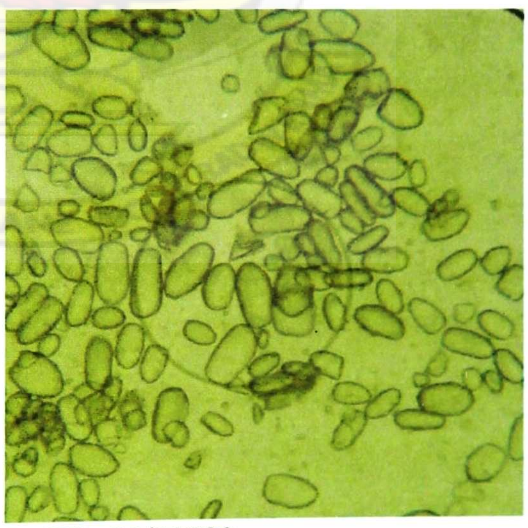

G: TDa 98/01174


H: TDa 98/01176

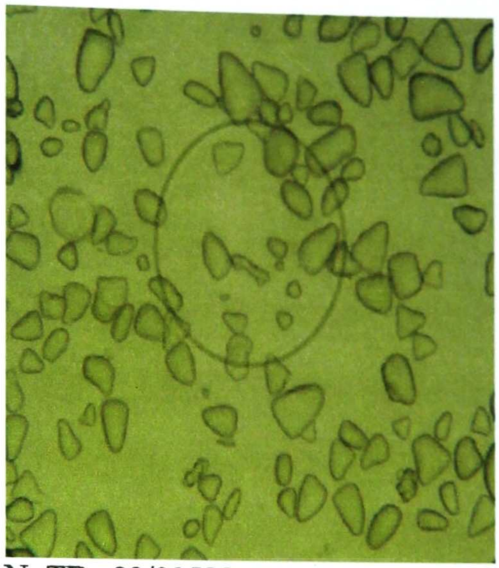

I: TDa 99/000480


J: TDa 99/0049

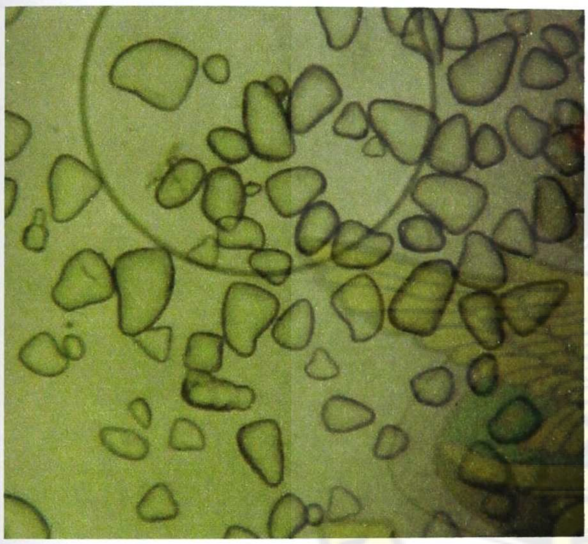

K: TDa 99/00199


L: TDa 99/00280

M: TDa 99/00214



N: TDa 99/00528

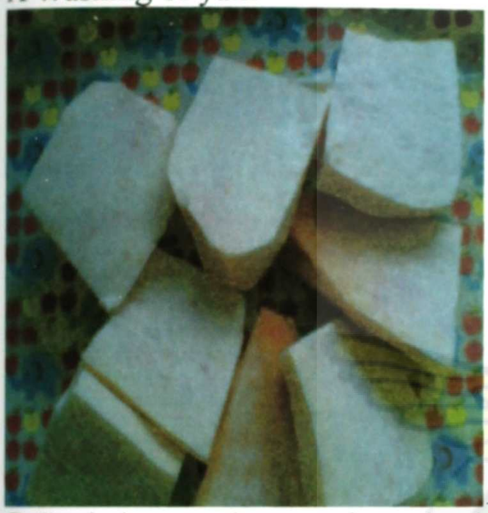


O: TDa 99/00240

Plate 3: Unit processes in couscous production

A Washing of yam

B: Peeling of yam

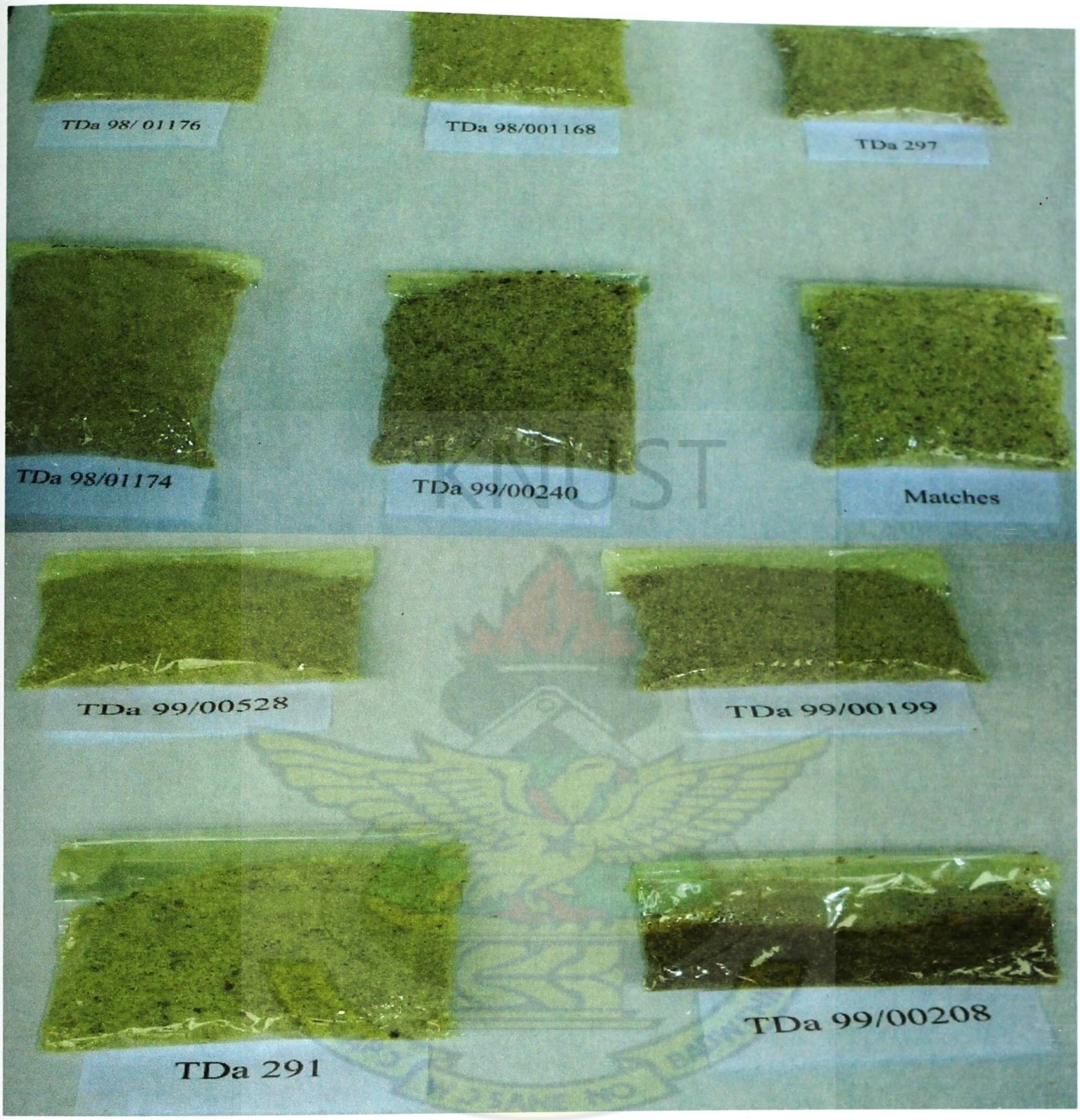


C: Peeled yam tubers cut into chunks

D: Steaming of yam tubers

E: Grated steamed yam tubers

Plate 4: Dried couscous sample of some of the varieties of *Dioscorea alata*



APPENDICES

Appendix A

Formulae used in calculations

1A. Percentage Moisture content

$$\% \text{ moisture} = \frac{\text{loss in weight of sample}}{\text{Original weight of sample}} * 100$$

2A. Percentage total nitrogen (%N)

$$\%N = \frac{100\,(\text{Sample titre} - \text{Blank titre})}{(\text{Weight of sample in g}) * 10} * (\text{Normality of HCl} * 0.01401) * 100$$

$$\%N = \frac{100\,(\text{Sample titre} - \text{Blank titre})}{(2\text{ g}) * 10} * (0.1N * 0.01401) * 100$$

Percentage protein (%P)

$$\%P = \%N * \text{conversion factor}$$

$$\%P = \%N * 6.25$$

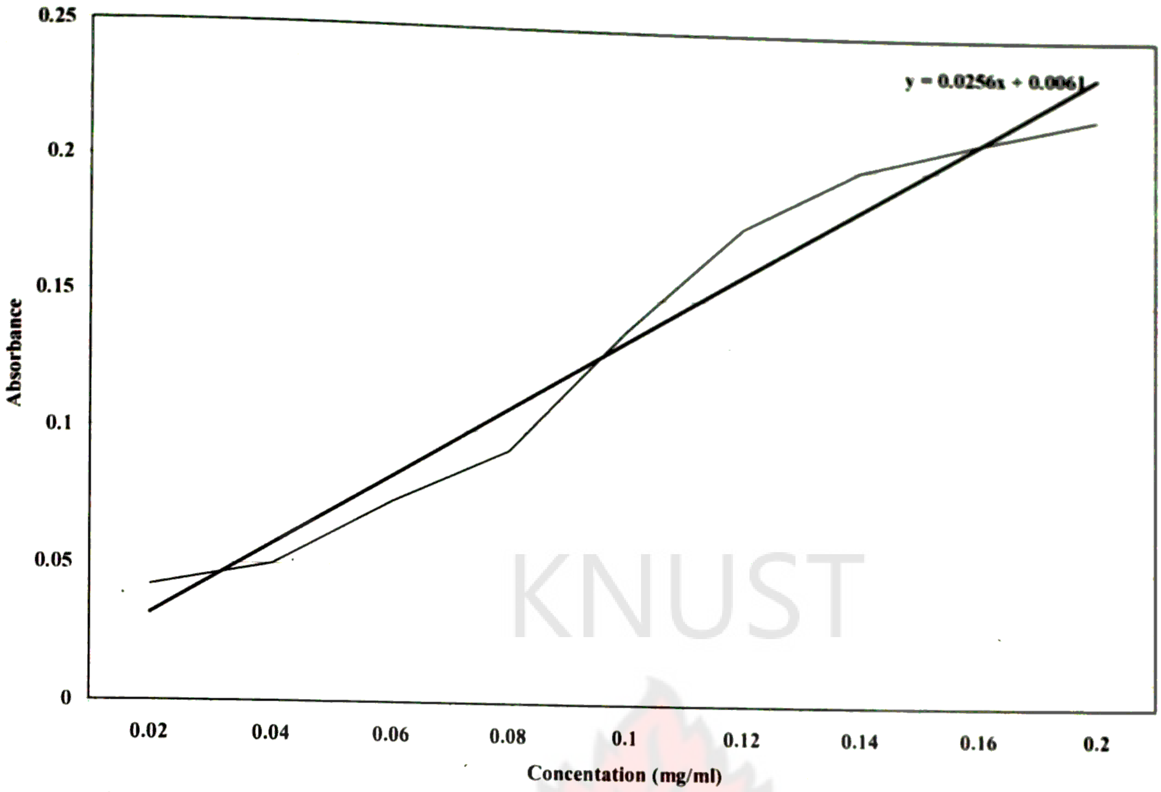
3A. Percentage ash content

$$\% \text{ ash} = \frac{\text{weight of ash}}{\text{Dry weight of sample used}} * 100$$

4A. Percentage yield (%Y) of couscous

$$\%Y = \frac{\text{Weight of couscous obtained}}{\text{Weight of fresh tubers used}} * 100$$

Appendix B



Standard curve of pure amylose showing the linear regression equation

Appendix C: Sensory evaluation ballot sheet used by untrained panelists

Name.................................. Age..

Date....................................

Instructions: You have been provided with ***couscous*** from different varieties of yam. Please access them based on the quality attributes listed below in order in which the samples have been presented.

Colour: please observe the colour of the samples tick in box that describes how best you like or dislike the colour and appearance of the samples

Sample...........	Sample...........	Sample.............
1. Like very much [ ]	Like very much [ ]	Like very much [ ]
2. Like [ ]	Like [ ]	Like [ ]
3. Like slightly [ ]	Like slightly [ ]	Like slightly [ ]
4. Neither like nor dislike [ ]	Neither like nor dislike [ ]	Neither like nor dislikes [ ]
5. Dislike slightly [ ]	Dislike slightly [ ]	Dislike slightly [ ]
6. Dislike [ ]	Dislike [ ]	Dislike [ ]
7. Dislike very much [ ]	Dislike very much [ ]	Dislike very much [ ]

Texture (Hardness and Adhesiveness)

Hardness: Please place sample between molar teeth and bite down evenly, evaluating the force required compressing the sample

Sample…………	Sample…………	Sample…………..
1. Like very much [ ]	Like very much [ ]	Like very much [ ]
2. Like [ ]	Like [ ]	Like [ ]
3. Like slightly [ ]	Like slightly [ ]	Like slightly [ ]
4. Neither like nor dislike [ ]	Neither like nor dislike [ ]	Neither like nor dislikes [ ]
5. Dislike slightly [ ]	Dislike slightly [ ]	Dislike slightly [ ]
6. Dislike [ ]	Dislike [ ]	Dislike [ ]
7. Dislike very much [ ]	Dislike very much [ ]	Dislike very much [ ]

Adhesiveness (sticky): Please place sample on tongue, press it against the palate, and evaluate the force required to remove it from the tongue.

Sample…………..	Sample…………….	Sample…………
1. Like very much [ ]	Like very much [ ]	Like very much [ ]
2. Like [ ]	Like [ ]	Like [ ]
3. Like slightly [ ]	Like slightly [ ]	Like slightly [ ]
4. Neither like nor dislike [ ]	Neither like nor dislike [ ]	Neither like nor dislikes [ ]
5. Dislike slightly [ ]	Dislike slightly [ ]	Dislike slightly [ ]
6. Dislike [ ]	Dislike [ ]	Dislike [ ]
7. Dislike very much [ ]	Dislike very much [ ]	Dislike very much [ ]

Flavour (Smell+ Taste): Please and taste the sample provided and access its flavour

Sample…………	Sample…………	Sample…………..
1. Like very much [ ]	Like very much [ ]	Like very much [ ]
2. Like [ ]	Like [ ]	Like [ ]
3. Like slightly [ ]	Like slightly [ ]	Like slightly [ ]
4. Neither like nor dislike [ ]	Neither like nor dislike [ ]	Neither like nor dislikes [ ]
5. Dislike slightly [ ]	Dislike slightly [ ]	Dislike slightly [ ]
6. Dislike [ ]	Dislike [ ]	Dislike [ ]
7. Dislike very much [ ]	Dislike very much [ ]	Dislike very much [ ]

Overall acceptability: Please take a quarter table spoon of sauce to half table spoon of sample to assess its overall acceptability.

Sample…………	Sample…………	Sample…………..
1. Like very much [ ]	Like very much [ ]	Like very much [ ]
2. Like [ ]	Like [ ]	Like [ ]
3. Like slightly [ ]	Like slightly [ ]	Like slightly [ ]
4. Neither like nor dislike [ ]	Neither like nor dislike [ ]	Neither like nor dislikes [ ]
5. Dislike slightly [ ]	Dislike slightly [ ]	Dislike slightly [ ]
6. Dislike [ ]	Dislike [ ]	Dislike [ ]
7. Dislike very much [ ]	Dislike very much [ ]	Dislike very much [ ]

Appendix D1: Sensory evaluation ballot sheet used by the trained panelist

Name: _ Date: _ _ _ _ _ _ _ _ _ _ _ _ _ _

Sample code: _

Please assess the ***couscous*** samples in front of you. Rinse your mouth water before tasting each sample.

Make a firm vertical line on the horizontal line to indicate your rating for the attributes.

Not white Very

white

Whitish Colour

None all

Appearance (Black Specks)

Not uniform Very uniform

Appearance (Uniformity)

Flavour acceptability Weak Strong

Taste (sour) Not sour Very sour

Weak Strong

Taste (Acceptability)

Not sticky Very sticky

Sticky texture

Soft Hard

Hard texture

Dry texture	Not dry	Very dry
Mouth feel	Rough	Smooth
Overall acceptability	Dislike very	like very much

Comments:

Appendix D2: Sensory ballot sheet used by panellist at Paloma restaurant

Please assess the samples place before you and score between 0 (dislike very much) to 10 (Like very much)

Attribute	Semolina couscous	Yam couscous
Colour acceptability		
Appearance (uniformity)		
Flavour acceptability		
Taste acceptability		
Texture acceptability		
Hardness		
Stickiness		
Overall acceptability		

Appendix D3: Panel technique and definition of terms

Pick a spoonful of sample and evaluate the following.

Uniformity of grains: visually inspect the uniformity of the size and shape of individual grains

Place a spoonful of sample in the mouth, manipulate gently and evaluate the following.

Dryness: degree of moisture on the surface of the grains

Place a spoonful of sample in the mouth, chew with molar teeth and evaluate the following.

Hardness (at first bite): Force required penetrating kernel with molar teeth

Stickiness: the degree to which grains adhere to and pack on teeth during mastication

Flavour: Pick a spoon full of the sample and smell, then put the sample in your mouth and masticate to assess the combination of the taste and smell of the sample

Appendix E: ANOVA tables

1E. ANOVA table of the Weight of *Dioscorea alata* tubers

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	11.438	14	0.817	113.995	0.0000
Within groups	0.107	15	0.007		
Total	11.545	29			

2E. Mean Weights of *Dioscorea alata* samples

Sample	Weight (Kg)
TDa 99/00208	1.10^{a}
TDa 98/01166	2.50^{e}
Red water yam	0.93^{a}
TDa 99/00049	1.50^{c}
TDa 99/00528	2.70^{f}
TDa 297	2.70^{f}
TDa 291	2.00^{d}
TDa 98/01176	0.95^{a}
TDa 98/001168	2.40^{ef}
TDa 99/00240	2.00^{d}
'Matches'	2.40^{ef}
TDa 99/000480	2.30^{e}
TDa 99/00199	1.43^{bc}
TDa 98/01174	1.30^{b}
TDa 99/00214	2.30^{e}

Values not statistically different at ($p > 0.05$) shares the same letters.

3E. ANOVA table of the Moisture of *Dioscorea alata* tubers

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	582.140	14	41.581	15.341	0.0000
Within groups	40.657	15	2.710		
Total	622.797	29			

4E. ANOVA table of the Crude Protein content of *Dioscorea alata* tubers

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	232.649	14	16.618	1.569	0.1980
Within groups	158.871	15	10.591		
Total	391.520	29			

5E. ANOVA table of the Ash content of *Dioscorea alata* tubers

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	26.235	14	1.874	1.220	0.3530
Within groups	23.045	15	1.536		
Total	49.280	29			

6E. Mean Moisture, Protein and Ash of fresh Dioscorea alata tuber

Sample	Moisture (%)	Protein (%)	Ash (%)
TDa 99/00208	73.23^{ef}	6.49^{a}	2.17^{a}
TDa 98/01166	66.30^{bc}	9.60^{f}	2.32^{a}
Red water yam	71.41^{def}	7.66^{bc}	2.26^{a}
TDa 99/00049	67.71^{bc}	7.46^{b}	2.23^{a}
TDa 99/00528	70.98^{def}	7.86^{bcd}	3.18^{ab}
TDa 297	66.08^{b}	7.79^{bcd}	3.00^{ab}
TDa 291	71.25^{def}	6.20^{a}	2.67^{ab}
TDa 98/01176	74.25^{f}	6.20^{a}	2.50^{ab}
TDa 98/001168	69.43^{bcde}	8.97^{e}	3.50^{ab}
TDa 99/00240	80.37^{g}	7.45^{b}	2.73^{ab}
'Matches'	66.00^{b}	8.13^{cd}	2.47^{ab}
TDa 99/000480	72.00^{ef}	7.99^{bcd}	2.73^{ab}
TDa 99/00199	61.00^{a}	8.29^{d}	2.38^{ab}
TDa 98/01174	66.00^{b}	7.47^{b}	2.40^{ab}
TDa 99/00214	70.00^{cde}	9.51^{f}	2.60^{ab}

Values not statistically different at ($p > 0.05$) shares the same letters.

7E. ANOVA table of the Gelatinization time of flour

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	184.928	12	15.4107	1541.07	0.0000
Within groups	0.13	13	0.01		
Total	185.058	25			

8E. ANOVA table for Onset Gelatinization temperature of flour

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	419.698	12	34.9749	11366.83	0.0000
Within groups	0.04	13	0.0031		
Total	419.738	25			

9E. Mean Pasting Times of flours

Sample	Pasting time (minute)
TDa 99/00208	27.55 ± 0.00^{h}
TDa 98/01166	24.15 ± 0.14^{d}
Red water yam	24.55 ± 0.00^{e}
TDa 99/00049	26.36 ± 0.00^{g}
TDa 99/00528	26.10 ± 0.00^{f}
TDa 297	22.75 ± 0.00^{b}
TDa 291	23.55 ± 0.00^{c}
TDa 98/01176	29.46 ± 0.00^{j}
TDa 98/001168	28.35 ± 0.00^{i}
'Matches'	21.25 ± 0.00^{a}
TDa 99/000480	29.40 ± 0.00^{j}
TDa 99/00214	30.05 ± 4.00^{k}
Semolina	26.05 ± 0.00^{f}

Values not statistically different at ($p > 0.05$) shares the same letters.

10E: Mean Pasting Temperatures of flours

Sample	Onset Temperature (T °C)
TDa 99/00208	90.90 ± 0.00^{i}
TDa 98/01166	85.40 ± 0.00^{d}
Red water yam	86.3 ± 0.00^{e}
TDa 99/00049	88.80 ± 0.00^{h}
TDa 99/00528	88.40 ± 0.00^{g}
TDa 297	83.30 ± 0.00^{b}
TDa 291	84.90 ± 0.00^{c}
TDa 98/01176	93.7± 0.00^{l}
TDa 98/001168	91.90 ± 0.14^{j}
'Matches'	81.20 ± 0.00^{a}
TDa 99/000480	93.5 ± 0.00^{k}
TDa 99/00214	94.20 ± 4.00^{m}
Semolina	88.10 ± 0.00^{f}

Values not statistically different at ($p > 0.05$) shares the same letters.

11E. ANOVA table of Peak viscosity of flour

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	63117.40	12	5259.78	3038.99	0.0000
Within groups	22.50	13	1.73077		
Total	63139.90	25			

12E. Mean Peak Viscosities of flours

Sample	Peak Viscosity (BU)
TDa 99/00208	57.00 ± 0.00^{e}
TDa 98/01166	69.00 ± 0.00^{g}
Red water yam	94.00 ± 0.00^{h}
TDa 99/00049	71.00 ± 0.00^{g}
TDa 99/00528	64.00 ± 0.00^{f}
TDa 297	185.00 ± 1.41^{k}
TDa 291	130.00 ± 1.01^{i}
TDa 98/01176	34.00 ± 0.00^{c}
TDa 98/001168	37.00 ± 0.00^{d}
'Matches'	158.50 ± 3.40^{j}
TDa 99/000480	31.00 ± 0.00^{b}
TDa 99/00214	28.00 ± 0.00^{a}
Semolina	38.00 ± 0.00^{d}

Values not statistically different at ($p > 0.05$) shares the same letters.

13E. ANOVA table of Viscosity at 95 °C of flour

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	38089.50	12	3174.13	937.81	0.0000
Within groups	44.0	13	3.38462		
Total	38133.50	25			

14E. ANOVA table of Viscosity at 95 °C hold of flour

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	56867.80	12	4738.99	115.69	0.0000
Within groups	532.50	13	40.9615		
Total	57400.3	25			

15E. Mean Viscosities at 95 °C and 95 °C hold of flours

Sample (BU)	Viscosity at 95 °C (BU)	Viscosity at 95 °C hold
TDa 99/00208	19.00 ± 0.00^{b}	57.00 ± 0.00^{b}
TDa 98/01166	40.00 ± 0.00^{e}	69.00 ± 0.00^{b}
Red water yam	44.00± 0.00^{f}	94.00± 0.00c
TDa 99/00049	34.00 ± 0.00^{d}	71.00 ± 0.00^{b}
TDa 99/00528	25.00 ± 0.00^{c}	64.00 ± 0.00^{b}
TDa 297	136.00 ± 0.00^{i}	170.00 ± 0.00^{f}
TDa 291	76.00± 0.00^{g}	130.00± 0.00^{d}
TDa 98/01176	10.00± 0.00^{a}	35.00± 0.00^{a}
TDa 98/001168	16.00 ± 0.00^{b}	37.00 ± 0.00^{a}
'Matches'	107.00 ± 4.26^{h}	158.00 ± 4.26^{e}
TDa 99/000480	10.00± 0.00^{a}	31.00 ± 0.00^{a}
TDa 99/00214	10.00 ± 0.00^{a}	28.00 ± 0.00^{a}
Semolina	28.00 ± 0.00^{c}	38.00 ± 0.00^{a}

Values not statistically different at ($p > 0.05$) shares the same letters.

16E. ANOVA table of Viscosity at 50 °C of flour

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	50270.50	12	4189.21	3203.51	0.0000
Within groups	17.00	13	1.30769		
Total	50287.50	25			

17E. ANOVA table of Viscosity at 50 °C hold of flours

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	43665.8	12	3638.82	23652.33	0.0000
Within groups	2.00	13	0.153846		
Total	43667.8	25			

18E. Mean Viscosities at 50 °C and 50 °C hold of flours

Sample	Viscosity at 50 °C	Viscosity at 50 °C hold
TDa 99/00208	124.00 ± 0.00^{i}	109.00 ± 0.0^{h}
TDa 98/01166	107.00 ± 0.00^{f}	96.00 ± 0.0^{f}
Red water yam	139.00 ± 0.00^{j}	123.00 ± 0.0^{i}
TDa 99/00049	110.00 ± 0.00^{g}	95.00 ± 0.0^{d}
TDa 99/00528	115.00 ± 0.00^{h}	101.00 ± 0.0^{g}
TDa 297	221.50 ± 0.00^{m}	201.50 ± 0.0^{l}
TDa 291	168.00 ± 0.00^{k}	150.00 ± 0.0^{j}
TDa 98/01176	89.00 ± 0.00^{c}	77.00 ± 0.0^{d}
TDa 98/001168	73.00 ± 0.00^{a}	65.00 ± 0.0^{b}
'Matches'	190.50 ± 3.53^{l}	174.50 ± 4.26^{k}
TDa 99/000480	84.00 ± 0.00^{b}	71.00 ± 0.0^{c}
TDa 99/00214	74.00 ± 0.00^{a}	62.00 ± 0.0^{a}
Semolina	100.00 ± 0.00^{e}	94.00 ± 0.00^{e}

Values not statistically different at ($p > 0.05$) shares the same letters.

19E. ANOVA table of Setback viscosity of flours

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	2861.0	12	238.417	238.42	0.0000
Within groups	13.00	13	1.0		
Total	2874.0	25			

20E. Mean Setback viscosities of flours

Sample	Setback Viscosity (BU)
TDa 99/00208	67.00 ± 0.00^{h}
TDa 98/01166	38.00 ± 0.00^{bc}
Red water yam	45.00 ± 0.00^{d}
TDa 99/00049	39.00 ± 0.00^{c}
TDa 99/00528	51.00 ± 0.00^{e}
TDa 297	36.50 ± 0.00^{b}
TDa 291	38.00 ± 0.00^{bc}
TDa 98/01176	55.00 ± 0.00^{f}
TDa 98/001168	36.00 ± 0.00^{b}
'Matches'	31.50 ± 0.70^{a}
TDa 99/000480	53.00 ± 0.00^{ef}
TDa 99/00214	46.00 ± 0.00^{d}
Semolina	62.00 ± 0.00^{g}

Values not statistically different at ($p > 0.05$) shares the same letters.

21E. ANOVA table of Granule size of *Dioscorea alata* starch

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	966.667	14	69.048	0.334	0.9760
Within groups	31000	15	206.667		
Total	4066.67	29			

22E. ANOVA table of Amylose content of *Dioscorea alata* starch

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	247.733	14	17.6952	996.91	0.0000
Within groups	0.26625	15	0.01775		
Total	247.999	29			

23E. Mean amylose content of *Dioscorea alata* starches

Sample	Amylose content
TDa 99/00208	34.48^{h}
TDa 98/01166	34.30^{fgh}
Red water yam	34.40^{gh}
TDa 99/00049	35.56^{j}
TDa 99/00528	39.36^{k}
TDa 297	34.04^{f}
TDa 291	33.48d^{e}
TDa 98/01176	33.28^{cd}
TDa 98/001168	33.35^{cd}
TDa 99/00240	34.17^{fg}
'Matches'	33.66^{e}
TDa 99/000480	33.16^{c}
TDa 99/00199	24.81^{a}
TDa 98/01174	31.32^{b}
TDa 99/00214	34.86^{i}

Values not statistically different at ($p > 0.05$) shares the same letters.

24E. ANOVA of Yield of Yam Couscous

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	141.64	14	10.1171	882.57	0.0000
Within groups	0.17195	15	0.0114633		
Total	141.812	29			

25E. Mean Yield of Yam Couscous

Sample	Mean Yield
TDa 99/00208	16.00^{c}
TDa 98/01166	24.00^{j}
Red water yam	18.00^{e}
TDa 99/00049	20.60^{g}
TDa 99/00528	24.20^{k}
TDa 297	30.00^{l}
TDa 291	20.00^{f}
TDa 98/01176	15.00a
TDa 98/001168	19.80^{f}
TDa 99/00240	17.40^{d}
'Matches'	20.00^{f}
TDa 99/000480	21.60^{i}
TDa 99/00199	20.00^{f}
TDa 98/01174	15.80^{b}
TDa 99/00214	21.40^{h}

Values not statistically different at ($p > 0.05$) shares the same letters.

26E. ANOVA table of Couscous luminosity

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	2134.0	14	152.429	301.28	0.0000
Within groups	15.178	15	0.505933		
Total	141.812	29			

27E. ANOVA table of Aerobic Plate Count of couscous

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Period	1.06295E9	3	3.5431E9	6.55	0.0265
Sample	6.43445E9	1	6.43445E9	3.61	0.0493
Residual	1.08029E10	11	9.82079E8		
Total	2.78668E10	15			

28E. ANOVA table of Yeast and mold count of couscous

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Period	675.00	3	225.00	3.67	0.0000
Sample	25.00	1	25.00	33.00	0.0819
Residual	75.00	11	6.81818		
Total	775.00	15			

29E. ANOVA table of moisture content of couscous

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Period	2.345	2	1.1725	43.29	0.0001
Sample	5.20083	1	5.20083	192.03	0.0000
Residual	0.021667	8	0.0270833		
Total	7.7625	11			

28E. ANOVA table of pH of couscous

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Period	0.392275	3	0.130758	24.09	0.0000
Sample	0.1444	1	0.1444	26.61	0.0003
Residual	0.0597	11	0.005427		
Total	0.596375	15			

29E. ANOVA table of whiteness of couscous

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Sample	26.1445	2	13.0723	165.49	0.0000
Period	0.816046	3	0.272015	3.44	0.0388
Residual	1.42184	18	0.0789912		
Total	28.3824	23			

30E. ANOVA table of uniformity of couscous grains

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Sample	22.4472	2	11.2236	3461.31	0.0000
Period	0.035933	3	0.0119778	3.69	0.0312
Residual	0.058367	18	0.0032426		
Total	22.5415	23			

31E. ANOVA table of flavour of couscous grains

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Sample	0.437733	2	0.218867	2.86	0.0837
Period	21.1806	3	7.06019	92.13	0.0000
Residual	1.37947	18	0.076637		
Total	22.9978	23			

32E. ANOVA table of sour taste of couscous

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Sample	5.3947	2	2.69735	70.82	0.0000
Period	8.17778	3	2.72593	71.57	0.0000
Residual	0.685567	18	0.038087		
Total	14.258	23			

33E. ANOVA table of taste acceptability of couscous grains

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Sample	9.6676	2	4.8338	50.40	0.0000
Period	13.1725	3	4.39084	45.78	0.0000
Residual	1.72627	18	0.0959037		
Total	24.5664	23			

34E. ANOVA table of hardness of couscous grains

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Sample	0.534633	2	0.267317	24.69	0.0000
Period	0.0372	3	0.0124	1.15	0.3577
Residual	0.1949	18	0.0108278		
Total	0.7666733	23			

35E. ANOVA table of stickiness of couscous grains

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Sample	0.354233	2	0.177117	41.21	0.0000
Period	0.17098	3	0.0056994	13.26	0.0001
Residual	0.0773667	18	0.00429815		
Total	0.602583	23			

36E. ANOVA table of dryness of couscous grains

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Sample	1.4371	2	0.71855	62.05	0.0000
Period	0.197117	3	0.0657056	5.67	0.0065
Residual	0.2084333	18	0.0115796		
Total	1.84265	23			

37E. ANOVA table of mouthfeel of couscous grains

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Sample	16.609	2	8.30452	275.81	0.0000
Period	0.215383	3	0.0717944	2.38	0.1031
Residual	0.541967	18	0.0301093		
Total	17.3664	23			

38E. ANOVA table of overall acceptability of couscous grains

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Sample	0.0058333	2	0.00291667	0.15	0.8639
Period	0.166667	3	0.0555556	2.81	0.0689
Residual	0.355833	18	0.0197685		
Total	0.52833	23			

Appendix F: Mean sensory scores of couscous by trained panellists

1F: Scores of the whiteness of couscous samples over storage period

Sample	Period/ whiteness of colour			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	0.81	0.88	0.85	0.80
TDa 98/01166 couscous	0.97	0.95	0.94	0.93
TDa 297 couscous	3.71	3.50	2.80	2.40

2F: Scores of the presence of black specks of couscous samples over storage period

Sample	Period/ black specks			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	0.22	0.20	0.24	0.21
TDa 98/01166 couscous	1.30	0.80	1.50	1.20
TDa 297 couscous	0.92	0.95	0.93	0.90

3F: Scores of the uniformity of couscous grains over storage period

Sample	Period/ uniformity of grains			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	9.48	9.45	9.40	9.42
TDa 98/01166 couscous	8.12	8.11	8.00	8.00
TDa 297 couscous	7.12	7.00	7.00	7.20

4F: Scores of the flavour acceptability of couscous samples over storage period

Sample	Period/ Flavour acceptability			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	7.57	7.80	7.72	5.08
TDa 98/01166 couscous	7.26	7.10	7.00	5.55
TDa 297 couscous	7.99	7.40	7.24	5.26

Appendix F: Mean sensory scores of couscous by trained panellists

1F: Scores of the whiteness of couscous samples over storage period

Sample	Period/ whiteness of colour			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	0.81	0.88	0.85	0.80
TDa 98/01166 couscous	0.97	0.95	0.94	0.93
TDa 297 couscous	3.71	3.50	2.80	2.40

2F: Scores of the presence of black specks of couscous samples over storage period

Sample	Period/ black specks			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	0.22	0.20	0.24	0.21
TDa 98/01166 couscous	1.30	0.80	1.50	1.20
TDa 297 couscous	0.92	0.95	0.93	0.90

3F: Scores of the uniformity of couscous grains over storage period

Sample	Period/ uniformity of grains			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	9.48	9.45	9.40	9.42
TDa 98/01166 couscous	8.12	8.11	8.00	8.00
TDa 297 couscous	7.12	7.00	7.00	7.20

4F: Scores of the flavour acceptability of couscous samples over storage period

Sample	Period/ Flavour acceptability			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	7.57	7.80	7.72	5.08
TDa 98/01166 couscous	7.26	7.10	7.00	5.55
TDa 297 couscous	7.99	7.40	7.24	5.26

5F: Scores of the sour taste presence of couscous samples over storage period

Sample	Period/ Sour taste presence			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	0.16	0.96	1.05	1.00
TDa 98/01166 couscous	0.69	2.20	2.50	2.40
TDa 297 couscous	0.38	1.70	1.90	2.00

6F: Scores of the taste acceptability of couscous samples over storage period

Sample	Period/ taste acceptability			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	7.06	8.00	8.30	7.90
TDa 98/01166 couscous	5.50	7.00	7.40	7.00
TDa 297 couscous	6.42	9.00	8.90	8.60

7F: Scores of the stickiness of couscous samples over storage period

Sample	Period/ Stickiness			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	3.36	3.11	3.23	3.25
TDa 98/01166 couscous	2.97	2.84	2.95	3.00
TDa 297 couscous	3.33	3.00	3.05	3.00

8F: Scores of the hardness of couscous samples over storage period

Sample	Period/ Hardness			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	3.50	3.40	3.50	3.45
TDa 98/01166 couscous	3.80	4.00	3.75	3.60
TDa 297 couscous	3.70	3.78	3.80	3.80

9F: Scores of the dryness of couscous samples over storage period

Sample	Period/ Dryness			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	3.26	3.00	3.11	3.23
TDa 98/01166 couscous	3.71	3.73	3.75	3.70
TDa 297 couscous	3.91	3.40	3.50	3.55

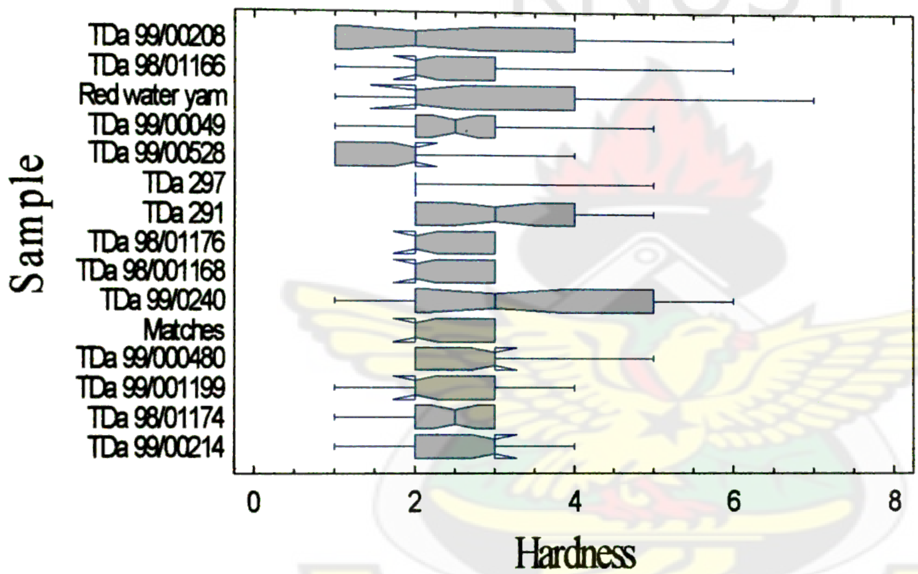
10F: Scores of the mouthfeel of couscous samples over storage period

Sample	Period/ Mouthfeel			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	7.00	7.00	6.90	7.20
TDa 98/01166 couscous	5.00	5.60	5.20	5.00
TDa 297 couscous	5.14	5.34	5.43	5.40

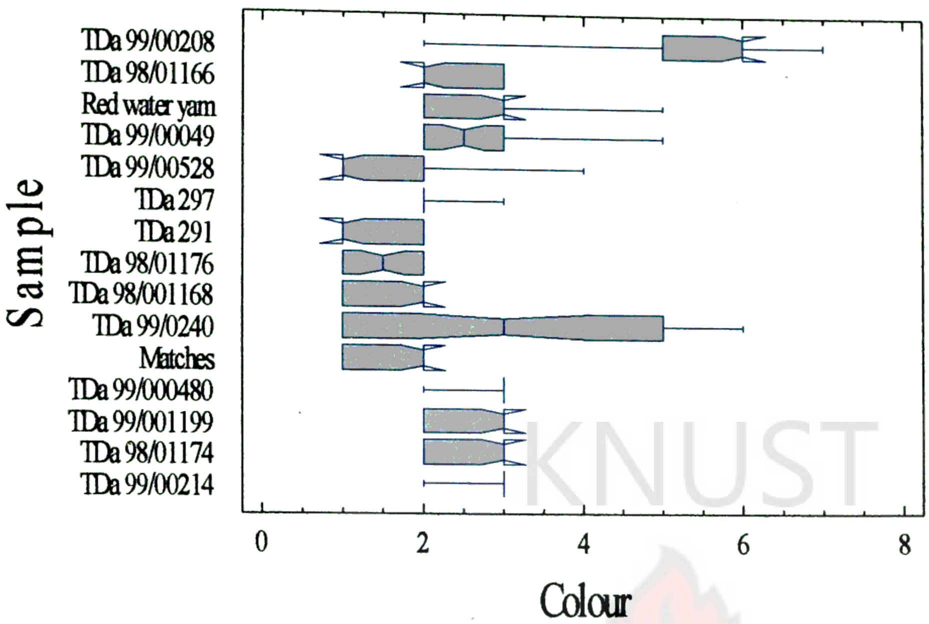
11F: Scores of the overall acceptability of couscous samples over storage period

Sample	Period/ Overall acceptability			
	Week 0	Week 8	Week 16	Week 24
Semolina couscous	7.00	7.20	7.00	7.00
TDa 98/01166 couscous	6.90	7.15	6.80	7.20
TDa 297 couscous	6.90	7.00	7.00	7.10

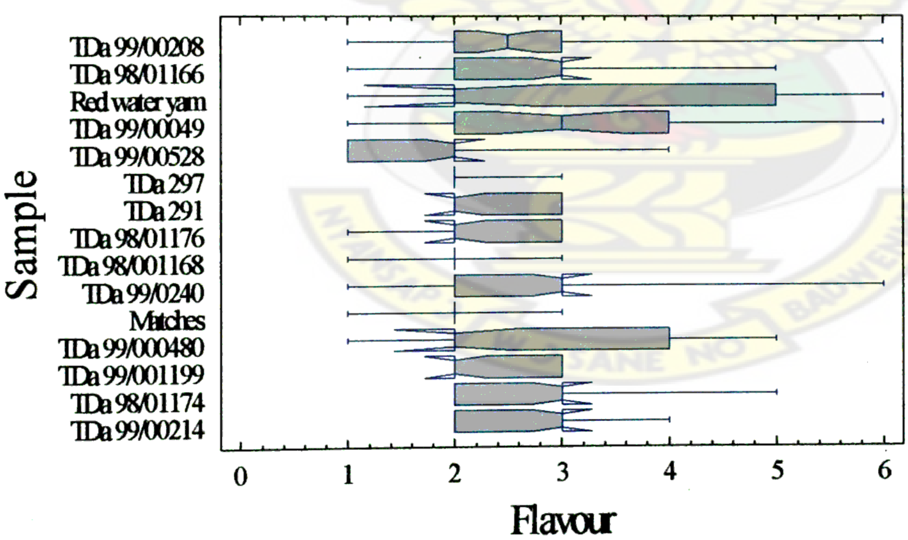
Appendix G: Box and Whisker plots for scores of consumer (untrained panellists) sensory evaluation



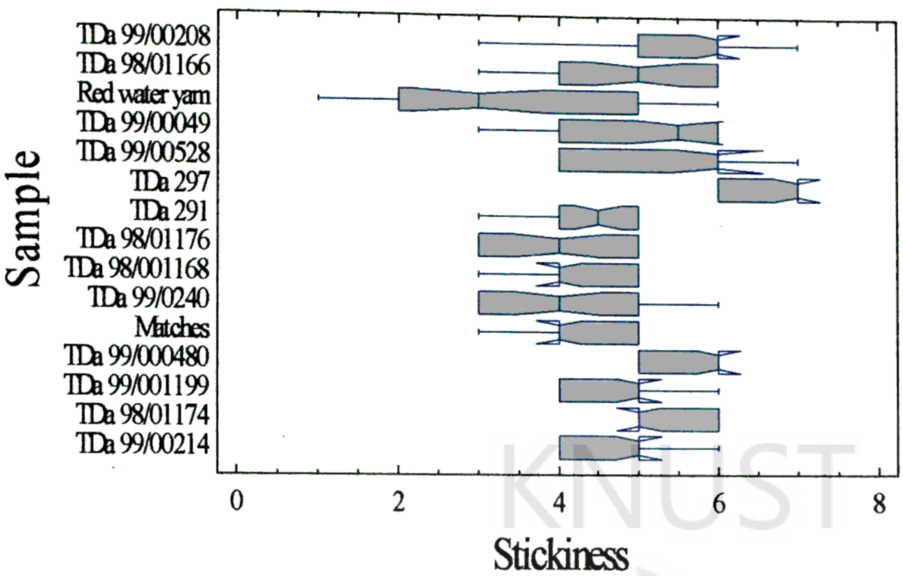
1G: Box and Whisker Plot for Hardness scores of couscous by consumer panelists



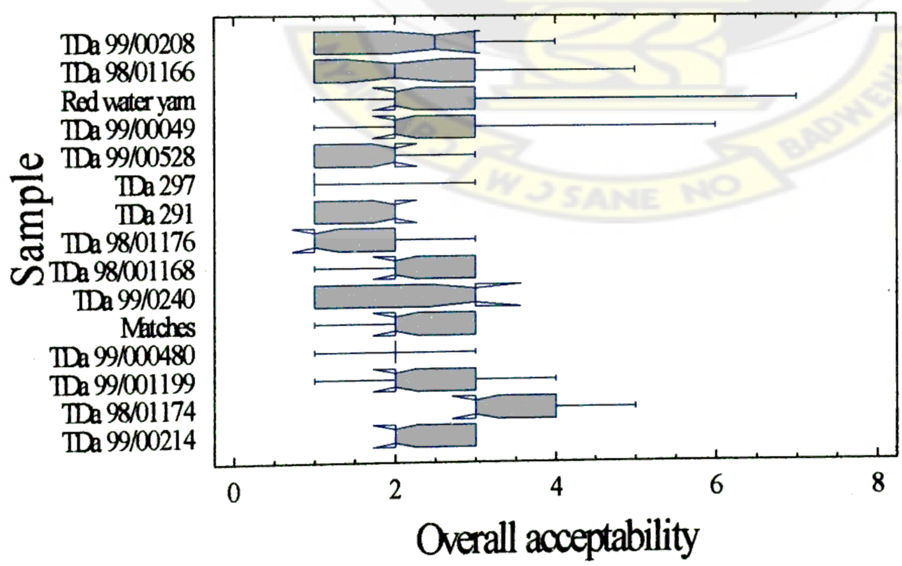
2G: Box and Whisker Plot for Colour scores of couscous by consumer panelists



3G: Box and Whisker Plot for Flavour scores of couscous by consumer panelists



4G: Box and Whisker Plot for Stickiness scores of couscous by consumer panelists



5G: Box and Whisker Plot for Overall acceptability scores of couscous by consumer panelists