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EFFECT OF DIFFERENT DRYING METHODS ON THE FUNCTIONAL AND PHYSICOCHEMICAL PROPERTIES OF THE FLOUR OF SELECTED YAM CULTIVARS IN GHANA

A THESIS SUBMITTED TO THE DEPT. OF FOOD SCIENCE AND TECH. IN PARTIAL FULFILLMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN FOOD SCIENCE AND TECHNOLOGY

By

AMMA ADUTWUMWAH SARPONG (BSC HONS.)

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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 person 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.

Amma Adutwumwaah Sarpong	……	……
Student Name	Signature	Date

Certified by Supervisors

Mr. E. A. Amankwah	……	……....
	Signature	Date
Mr. J. Barimah	……	……
	Signature	Date

Certified by Head of Department

Prof. (Mrs.) Ibok Oduro	……	……
	Signature	Date

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I dedicate this work to the Glory of God. To Christopher Appiah-Agyei and the Sarpongs' family.

ABSTRACT

Yams (tubers of the *Dioscorea spp*.) which are highly consumed in most parts of the world suffer great deal of postharvest losses after harvesting and during storage due to the high moisture content. Drying of yams is one of the most important methods of preservation so as to minimize postharvest losses and to extend products shelf life during storage. The effect of different drying methods (open sun, solar and solar adsorption drying) on the functional and physicochemical properties of the flour of selected yam cultivars in Ghana was investigated. Two yam varieties, *Dioscorea rotundata* (Pona, Dente and Lilii) and *Dioscorea alata* (Matches) were used. The properties studied included solubility, swelling power, water binding capacity, amylose and amylopectin ratio, granule size, pH, and colour. The drying process indicated that different yam cultivars are influenced differently during drying. The difference in drying behaviour may be due to structural differences. In view of this the functional and physicochemical properties of the yam samples were differently affected. With the exception of amylopectin content, solubility and pH values which were higher in the solar dried and open sun dried yam samples, the values for the amylose content, swelling power, water binding capacity and colour were lower than those of the solar adsorption dried yam samples. The drying methods showed significant effect ($P < 0.05$) on the properties of the yam flours. The results indicate that different drying methods have some profound effect on the granule size and other functional and physicochemical properties of yam flour. The interrelationships between the drying methods, cultivars, functional and physicochemical properties were evaluated with SPSS 20 by Pearson correlation.

Table of Contents

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to Study

Drying plays an important role in the preservation of agricultural products (Waeswak *et al.*, 2006). It enhances the resistance of high humid products against degradation by decreasing their water activity (Doymaz and Pala, 2003; Simal *et al.*, 2005).

In many agricultural countries crops such as cereals, grains, fruits, vegetables, roots and tubers are dried to improve shelf life, retain original flavour and reduce weight which facilitates transport and trade (Demir *et al.*, 2007). This aids in minimizing postharvest losses of agricultural produce. As a mass and heat transfer process drying ensures water/moisture evaporation from foodstuffs to the drying medium (air). Parameters such as product dimensions and weather conditions (temperature and relative humidity) are very important in drying. Drying rate is high when product thickness is small (Garg and Kumar, 2000).

Sun drying of crops is the most widespread method of food preservation especially in Africa due to solar irradiance being very high for the most of the year. It involves spreading of crop in thin layers on mats, trays or paved grounds exposing the product to direct sun and wind. This method has several drawbacks among these are adverse/hash environmental conditions such as weather uncertainties, infection by dust, insects, rodents

and fungi (Madhlopa *et al.,* 2002). This results in poorer quality of food caused by contamination, thereby reducing shelf life, food hygiene and safety. The solution to this traditional drying method involves the use of solar dryers which utilize free, renewable and non-polluting energy source provided by the sun. Moreover, solar drying is not a full proof since the sun comes and goes during certain periods of the day. Therefore a shorter drying time is preferable for drying products with high moisture content such as yam (50-80% wet basis) (Osunde, 2008). Based on this, there is therefore the need for solar adsorption drying system, a new and improved method to complement sun and solar drying methods. In Solar Adsorption Drying System (SADS) ambient air is blown through an adsorbent system (silica gel) which improves the drying capacity. This air is then channeled into a drying chamber for drying. Since adsorption drying does not need the sun for its operation, this method can be used as a complementary method. It can be utilized for continuous drying when the sun is not available.

The methods of drying can have significant impact on the physicochemical properties of food (yam) such as solubility, swelling power, water binding capacity, amylose and amylopectin ratio, granule size, pH and colour. It can cause structural disruption of yam (Prachayawarakom *et al.,* 2008). This can affect the solubility and swelling ability of the granules in the presence of water (Pimpaporn *et al.,* 2007). This interruption of the structure organization causes leaching of soluble polysaccharide, amylose molecules (Roberts and Waters, 2008). Different drying methods affect the compactness of food structure; while very low temperature may promote microbial growth, high temperature and low humidity may cause surface hardening of food (Dewi *et al*., 2011). Jayaraman *et al.* (1990) examined the tissue structure of air-dried cauliflower. The sample was reported to exhibit irreversible cellular rupture and dislocation, resulting in loss of integrity and

hence a dense structure of collapsed capillaries. High temperature and shear may also cause granule disruption (Yang and Gadi, 2008) which can influence the water binding capacity, since starch from the broken granules passes into solution (Park *et al*., 2004). Model based designed and construction of dryer system leads to dryer conditions that meet the requirement of temperature and air speed for drying agricultural products.

Yam belongs to the genus *Dioscorea* (family Dioscoreaceae) with over 600 species. Yam is highly perishable when fresh, primarily due to its high moisture content (50-80 % wet basis) (Osunde, 2008).

Most studies that have been carried out on the physicochemical properties of yam flour were done using drying methods such as freeze-drying, convectional hot air-drying and drum drying (Chin-Lin Hsu *et al.*, 2003), sun and oven drying (Jimoh *et al.*, 2007; Adedeji, 2004). However, there is no literature in the area of sun and solar drying methods compared with solar adsorption drying system on physicochemical properties of yam. This study is focused on investigating the effect of different drying methods (sun, solar and solar adsorption drying system) on the physicochemical properties of the flour of selected yam varieties *Dioscorea rotundata* (Pona, Dente and Lilii,) and *D. alata* (Matches).

1.2 Problem Statement

Research by Madhlopa *et al.* (2002) and Kingsly *et al.* (2010) indicated that sun drying exposes food product to direct sun, wind and microbes. This causes contamination leading to loss of food product and quality. The physicochemical properties of dried products of yam are also affected as a result of the transformations that take place during drying.

1.3 Justification

Apart from loss of quality during sun drying, the time of drying is also high. SADS utilizes solar collector and adsorption systems. The solar collector system (solar drying system) accumulates heat from the sun's energy during the day while the adsorption system uses adsorption energy to continue drying at low temperature (when the sun's energy is no more in the night). These combined methods reduce the drying time drastically while drying is done at relatively low temperature. Thus, the effect on physicochemical property may be reduced.

1.4 General/Main Objective

To determine the effect of different drying methods on the drying behaviour and physicochemical properties of the flour of selected yam varieties.

1.5 Specific Objective

1. To determine the effect of different drying methods and yam varieties on their drying behaviour.

2. To determine these effect on the physicochemical properties of the flour of the selected yam varieties.

3. To evaluate the effect of the different drying methods on the functional properties of the yam flours.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Yam Origin and Production

Yam is an economically useful plant belonging to the genus *Dioscorea* or the tubers/rhizomes of the plants (Coursey, 1983). Yams are cultivated for the consumption of their starchy tubers in Africa, Asia, Latin America and Oceania. Some species of yam originated from Africa before spreading to other parts of the world while some originated from Asia and spread to Africa (Hahn *et al.*, 1987). The global yam production was almost 48.7 million tonnes with 97% of this coming from sub-Saharan Africa. West and Central Africa accounted for 94%, Nigeria as the largest producer with 34% million tonnes, Cote d'voire 5 million tonnes and Ghana 3.9 million tonnes (FAO, 2005).

Production of yam in Africa is largely confined to the "yam zones" comprising Cameroon, Nigeria, Benin, Togo, Ghana and Cote d'voire where approximately 90% of the world production takes place (FAO, 2006; Jimoh 2009). Nigeria alone accounts for considerably more than half of the world total production (Ihekoranye and Ngoddy, 1995). Other countries where a significant production of yams occurs are Brazil, Venezuela, Papau New Guinea, China and Philippines. Yam production is a major source of employment to people both during planting and harvesting. However, its production is relatively expensive compared with other root and tuber crops; this is attributed to costly inputs, especially labour and planting materials. Yam is the second most important food crop after cassava in Africa (FAO, 1997). Yams are high in starch and contain the enzyme amylase which converts starch to sugars as the tuber matures in storage (Ravindran and

Wanasundera, 1992). It is the preferred stable crop that plays a predominant socio-cultural role in lives of the people of sub-Saharan Africa (Andreas, 2003).

2.2 Morphology of Yam

The yam plants are herbaceous or woody climbing plants with tuberous starch storage organs. Yams have a rough skin which is difficult to peel, but softens after heating. The skins vary in colour from dark brown to light pink. The leaves are shiny and heart-shaped and are borne on long petioles, usually simple and coordinate or acuminate. The flowers are small with male and female parts separated and usually sterile as a result of centuries of vegetative propagation (Coursey, 1983). The tubers can be propagated by planting sections containing the "eyes" or "buds".

Yams are perennial plants with strongly marked annual cycle of growth. Typical *dioscorea* species produce annual stems, which climb by twinning through the underground and trees. Persistent tubers are necessarily bi-functional as they give rise to aerial shoots and functions as storage organs. Yam tubers can be stored up to six months without refrigeration (Iwuoha, 2004) which makes them a valuable source during the period of food scarcity at the beginning of the wet season.

The structure of yam tuber is highly variable depending on the species. Differences in growing environment, maturity, method of storage and species may also affect variation in the tuber composition (Asiedu, 1986). Size of individual tubers may range from a few grammes to over 50 kilogrammes and tuber length of 2 m to about 3 m or more depending

on the species. Yam tubers are more or less cylindrical in shape and covered by a thick layer of cork.

The genus *Dioscorea* contains a wide range of yam species used as food and medicine (Hahn *et al.,* 1987). There are many widespread varieties of yam species, the most economic important species grown include *Dioscorea rotundata* (white yam), *D. cayenensis* (yellow yam), *D. alata* (water yam), *D. esculenta* (Chinese yam), *D. bulbifera* (aerial yam) and *D. dumentorum* (trifoliate yam) (Ike and Inoni, 2006).

2.2.1 White Yam (*Dioscorea rotundata*)

This originated in Africa and is the most widely grown and preferred yam species. The tuber is roughly cylindrical in shape. The skin is smooth and brown and has firm flesh. A large number of white yams exist with difference in the production and post-harvest characteristics. In Ghana, there are many cultivated species of *Dioscorea rotundata* of which Pona, Laribako and Dente are the main cultivars of importance. There are other important cultivars which are not as sweet as the aforementioned cultivars, yet occupy very important niche in the yam market ensuring that there is yam all year round. Among these cultivars are Lilii, Muchumudu, Serwa, Dorban, Afebetua, Mmowea and others (Otoo and Aseidu, 2009).

2.2.2 Water Yam (*Dioscorea alata*)

D. alata originated from South East Asia, and in Africa is second only to white yam in popularity. It is also known as "water yam", "winged yam" and "purple yam" and has the largest distribution world wide of any cultivated yam, being grown in Asia, the Pacific Islands, Africa and the West Indies (Mignouna, 2003). In the United States, it has become

an invasive species in some Southern states. The tuber shape is generally cylindrical but can be extremely variable. Tuber flesh is white and watery in texture.

Dioscorea alata is one of the yam species of economic importance but less attention is paid to it in Ghana, probably as a result of tradition which fails to recognize its unique characteristics (WirekoManu *et al.,* 2011). *Dioscorea alata* has an advantage for sustainable cultivation especially when yam production seems to be on the decline as a result of high cost of production, low yield and postharvest losses and others. *D. alata* has not been studied extensively especially in Ghana as compared to other root and tuber crops (Hoover, 2001) probably because of its perceived unimpressive food quality traits. The texture of the flesh is usually not as firm as that of *D. rotundata* and less suitable than other species for the preparation of most food products from yam such as fufu, pounded yam and boiled yam in West Africa.

2.3 Utilization and Processing of Yam

Yam is estimated to feed millions of people and is extremely important for at least 60 million people comprising rural producers, processors and consumers in West Africa (Babaleye, 2005).Yam can be processed by drying, boiling, frying, milling, pounding, roasting and steaming (Iwuoha, 2004). Yam tubers are consumed in the form of flour, chips, fufu and slices. The most processed traditional yam product is yam flour (Abioye *et al.,* 2008) which contains proteins, carbohydrates and trace amounts of minerals and vitamins. Processed yams are used for domestic and commercial purposes. Boiled yam is prepared by peeling, cutting yam into slices, washing and boiling of yam in source pan on fire. This can be eaten with sauce or soup of choice. Yam can also be mashed or pounded into dough after boiling (Ferede *et al.,* 2010; Ikenebomeh, 2000). Fried yam involves

frying cut yam chips in vegetable or palm oil and is usually consumed with pepper, fish and stew. Roasted yam involves roasting whole yam or sliced yam on fire. Roasted and fried yams have become a very popular street meal in West Africa. There are indication that yam has great prospect of contributing to closing the projected food deficit in Africa in the 21st century, if efforts are made to identify and overcome the constraints to its production (FAOSTAT, 2005).

Yam is commonly processed into flour by drying yam slices and milling. Yam flour can easily be stored for a long period (12-18 months), if the flour is free from moisture. This helps to reduce postharvest losses of fresh yams (Afoakwa and Sefa-Dedeh, 2001a). The storage environment must be dry to prevent the growth of moulds and must be well protected from weevils, which may infest the dried products (Ige and Akintunde, 1981). Yam flour is used to prepare a thick paste "amala", as binders in cakes to give it volume. Yam flour (composite flour) is incorporated with wheat flour in the production of bakery goods such as cookies, bread and cakes (pastries). Yam flour can also be added to soup to give it body.

2.4 Yam Storage

Yam is an annual crop and for it to be available throughout the year, harvested tubers must be stored for six to eight months before new yams are harvested. The possibility to store fresh yam tubers is influenced by their dormancy which occurs shortly after their physiological maturity. During dormancy, the metabolic function of the tuber is reduced. It allows the tuber as an organ of vegetative propagation to overcome an unfavourable

climatic period. The duration of natural dormancy fluctuates according to the variety of yam, between four and eighteen weeks (Knoth, 1993).

During the storage period, a substantial amount is lost. Some of these losses are endogenous, i.e. physiological and include transpiration, respiration and germination. Other losses are caused by exogenous factors like insects, pests, nematodes, rodents, rot bacteria and fungi on stored product (Wilson, 1980). Yam is stored in barn which is a principal traditional storage structure in major producing areas. Barns are usually located under the shade and constructed so as to facilitate adequate ventilation while protecting tubers from flooding, direct sunlight and insect attack. Yam is also stored underground in trench or clamp silos.

2.5 Postharvest Loses of Yam

Yam, like other root and tuber crops such as cassava and taro, suffers considerable postharvest losses which can be as high as 60% (Cousey and Booth 1997; Wheatley, 2000; Alabadan, 2002). These losses could be caused by external agents such as insects, rodents, fungi and bacteria or physiological processes such as sprouting, transpiration and respiration (Scott *et al.*, 2001b). The physiological processes which depend on the storage environment (temperature and relative humidity) affect the internal composition of the tuber and result in destruction of the edible materials. When sprouting begins, tubers cannot be stored effectively because it increases the susceptibility of the tubers to pathogens and causes a rapid loss of stored carbohydrate (Girardin *et al.*, 1998).

Other causes of postharvest losses include damage during harvesting and transportation of the crop. Biochemical changes such as changes in starch, sugars and protein take place during long-term storage (Afoakwa and Sefa-Dedeh, 2001a). A study of yam tuber (*D. dumetorium*) stored under ambient and cold room conditions showed a rapid drop in moisture and starch content and an increase in the total alcohol-soluble sugars and reducing sugars after 72 hours of storage (Afoakwa and Sefa-Dedeh, 2001a). The rate of decrease in moisture and starch content and the rate of increase in sugar level were higher in tubers stored at room temperature than those stored under cold room conditions. Generally, in stored tubers there is reduction in weight, crude protein, starch and mineral content while sugar and fibre content increase (Osunde and Orhevba 2009).

Yam suffers high degree of postharvest spoilage due to high moisture content ranging between 65-85% of the tuber (Kordylas, 1990). To overcome this problem, yam is processed using methods like peeling or slicing, blanching in hot water at 40-60°C, sun drying and milling into flour for preparing food such as amala or gbodo and fufu (Akissoe *et al.,* 2001). This is common to some West African countries such as Nigeria, Benin and Ghana. Postharvest losses of tubers can be minimized through desprouting and the application of chemical compounds such as gibberillic acid which prolong dormancy and retard sprouting (Ramannyam and Nair, 1982). Researchers (Girardin *et al.,* 1998; IITA, 2007) indicate that gibberillic acid when applied to tubers soon after harvest was able to extend dormancy by 9-11 weeks for *D. rotundata* and by 13 weeks for *D. alata* species of yam tuber. Other chemicals used in yam storage include commercial wax, lime, benlate and captan.

2.6 Nutritional Composition of Yam

Root and tuber crops are only second in importance to cereals as a global source of carbohydrates. They also provide some minerals and essential vitamins although some of these minerals and vitamins may be lost during processing (Eka, 1998). The lesser known yams have been reported by (Eka, 1998) to be rich in crude protein than other varieties and are relatively high in ash, which are concentrated in the peels. The peel contains more fibre, ash, protein, calcium and iron than the edible parts of tubers (Ketiku *et al.,* 1983). In some parts of Africa, the diet is supplemented with tender leaves of sweet potato, cassava and cocoyam which are rich sources of protein, minerals and vitamins (Hahn *et. al.*, 1987). Yams are excellent sources of carbohydrate, energy, vitamins (especially vitamin C), minerals and proteins. A yam meal could supply 100% of energy and protein, 13% of the calcium and 80% of the iron requirement of an adult meal (Knoth, 1993). Peroni *et al*. (2006) reported higher amounts of phosphorus in yam (0.022%) compared to other tropical and tuber crops such as cassava and sweet potato.

Table 2.1: Nutrient contents of yam species (Dioscorea spp.) per 100g of edible tuber portions

Nutrient (g/100g)	*D. alata*	*D. rotundata*	*D. cayenesis*	*D. esculenta*	*D. dumetorum*
[c] Moisture (%)	65-78.6	50-80	60-84	67-81	67-79
[a] Carbohydrate (%)	22-31	15-23	16	17-25	17-28
[c] Starch (%)	16.7-28	26.8-30.2	16	25	18-25
[d] Protein (%)	1.1-3.1	1.1-2.3	1.1-1.5	1.3-1.9	2.8
[a] Crude fat (%)	< 0.10.6	0.05-0.1	0.06-0.2	0.04-0.3	0.3
[b] Free sugar (%)	0.5-1.5	0.3-1	0.4	0.6	0.2
[c] Fibre (%)	1.4-3.8	1-1.7	0.4	0.2-1.5	0.3
[a] Ash (%)	0.7-2.1	0.7-2.6	0.5	0.5-1.5	0.7
[d] Phosphorus (mg)	28-52	17	17	35-53	45
[b] Calcium (mg)	28-38	36	36	12-62	52
[b] Vitamin C (mg/100g)	2-8.2	6-12	-	-	-
[d] Iron (mg)	5-11.6	5.2	5.2	0.8	-
[d] Food energy (kcal)	140	142	7.1	112	122
[c] Thiamine (mg)	0.03-0.04	-	-	0.01	-

Source: a Eka (1985); b Asiedu et al. (1997); c Osagie (1992) and d Opara (1999)

2.7 Functional and Physicochemical Properties

Physicochemical properties which comprise the physical, chemical and/or organoleptic properties of the product are important in determining product performance, characterization and useful for industrial application.

2.7.1. Solubility and Swelling Power

Solubility fundamentally depends on the solvent used as well as on temperature. As a solid dissolves in a liquid, heat is required to break the bonds holding the molecules in the solid together. The addition of more heat facilitates the dissolution reaction by providing energy to break bonds in the solid. Therefore, an increase in temperature produces an increase on the solubility for solids. For many solids dissolved in liquid water, the solubility increases with temperature up to 100 °C (Hill and Petrucci, 1999). Swelling power gives an idea of how much water is able to enter into the amyloplast of starch granules. When heated in water, starch becomes soluble. The granules swell by absorbing water, losing their crystalline structure. The smaller amylose molecules of starch then leach out of the granule, forming a network that holds water and increasing viscosity (starch gelatinization). The amylose acts both as diluents and inhibitor of swelling. Kordylas (1990) reported that, starch granules/units begin to absorb water and swell even when temperature reaches about 20 °C to 30 °C.

Solubility has been shown to positively correlate with swelling power suggesting that solubilization occurred along with granular swelling (Srichuwong *et al*., 2005). The starch molecules are held together by hydrogen bonding in the form of crystalline bundles called micelles (Rincon *et al.,* 1999). Thus swelling power and solubility patterns of starches have been used to provide evidence for associative binding force within the granules (Srichuwong *et al.*, 2005).

Furthermore, solubility and swelling power provide the magnitude of interaction between starch chains within amorphous and crystalline domains and also evidence of association bonding within the granules of the product such as yam flour/starches. Soni *et al.* (1993)

attributed high solubility in starches to the easy solubility of the linear fraction (amylose) which is linked loosely with the rest of the macromolecular structure and released /leached out during the swelling process. Kittahara *et al.* (1996) also explained that the linear relationship is because the swelling starch granules above the gelatinization temperature is often accompanied by leaching of soluble polysaccharides, hence as the starch is swelling, soluble polysaccharides are being leached out. Adebowale *et al*. (2002) also confirmed that maximum swelling power and solubility occurred at 90 °C when Bambara groundnut starch (slurry) was heated at temperatures of 60 °C, 70 °C, 80 °C and 90 °C.

Yam species exhibit lower and single stage swelling properties (example curves) unlike cassava which displays two. This is attributed to the more highly ordered internal arrangement in the granules of yam (Swinkels, 1985). Differences in swelling power and solubility between species and among cultivars could be due to differences in starch composition and granule organization (Singh *et al.*, 2003). Table 2.2 represents solubility and swelling power of cultivars of *Dioscorea alata* (Tda 98/01166 and Tda 92-2) obtained from the International Institute of Tropical Agriculture, Ibadan (IITA) and cultivars of *Dioscorea rotundata* (Omolokun and Abuja) from Bodija market Ibadan, Nigeria. Yam varieties dried using open sun drying.

Table 2.2: Solubility and Swelling power of yam flour from *D. rotundata* and *D. alata*

Sample	Solubility index (%)	Swelling power (g/g)%
Omolokun	12.19	4.40
Abuja	12.70	3.89
Td 98/01166	11.66	4.45
Td 92-2	12.03	4.05

Source: Jimoh et al. (2007)

2.7.2 Water Binding Capacity (WBC)

Water binding capacity is an important functional property required in food formulations especially those involving dough handling such as yam fufu. Water binding capacity is the ability of starch granules to bind water molecules physically and chemically (Potter *et al.*, 1995). The ability of starch to absorb water is an indication of its moisture stability especially in food industry (Adebowale *et al.*, 2006). WBC of starches also provides evidence of the degree of intermolecular association between starch polymers due to its associative forces such as hydrogen and covalent bonding (Rincon *et al.*, 1999). Faridi (1994) observed that when a product is milled, much of the starch is damaged. This is because during the milling a sizeable amount of shear stress is placed on the starch granules. The percentage of the starch granules that are subjected to shear stress of damage loses their order and crystallinity. When such granules are placed in water, they absorb much higher levels of water than undamaged granules.

Solubility correlates with water binding capacity, the higher the solubility the higher the water binding capacity. Work by Darkwa *et al.* (2003) on cassava varieties indicated that Gblemoduade, which had the least solubility had the least WBC. This went to confirm

Soni *et al.* (1987), that other factors that contribute to WBC are not only ultra-structure (molecular arrangement, amorphous and crystallinity areas) but also compositional (mainly amylose, amylopectin) characteristics of the starch and other factors. They reported that a loose association of amylose and amylopectin molecules in the native granules contributed to high WBC. Hoover and Sosulki (1986) reported that the engagement of hydroxyl groups to form hydrogen and covalent bonds between starch chains might lower WBC. Wooton and Bamunurachi (1987) also reported that difference in WBC of starches is as a result of the different degrees of availability of water binding sites considered to be hydroxyl and interglucose oxygen atoms. During gelatinization of starch, the water binding sites are increased due to interruption of the granular bonds by heat.

Table 2.3: Water Binding Capacity of yam flour from *D. rotundata* and *D. alata*

Sample	Water Binding Capacity (%)
Omolokun	134.13
Abuja	122.20
Td 98/01166	152.07
Td 92-2	146.07

Source: Jimoh et al. (2007)

2.7.3 Amylose and Amylopectin

Amylose is a smaller polymer with linear structure. It is one of the molecules/components of starch and consists of (1-4) linked alpha D-glucose units (Karim *et al.,* 2000). However, some amylose molecules have about 0.3-0.5% alpha-1-6 branches (Takeda *et al.,* 1999). Amylose chains can exist in a disordered amorphous conformation or two different helical

forms. It can bind with itself in a double helix (A or B) or with another hydrophobic molecule such as iodine, fatty acids or an aromatic compound. This is known as V form and is how amylopectin binds to amylose to form starch. A mixture of A and B unit cells gives the C structure, resulting in an intermediate packing density between the two forms (Sarko and Wu, 1987). Amylose is easily leached from the swollen granules just above the gelatinization temperature. It is important energy storage, a thickner, water binder, emulsion stabilizer and gelling agent in both food based and industrial systems. In the laboratory setting it acts as marker. Iodine can exist inside the helical structure of amylose, binding with the starch polymer that absorbs certain known wavelengths of light (Balagopalan *et al*., 1988). Hence a common test is the iodine test for starch which gives a blue-black colour. The amylose content of yam starches is between 14 and 30% depending on yam species, with 21-30 % amylose for *D. alata*, 21-25% for *D. rotundata* and 21-25 for *D. cayenensis* (Moorthy, 2002). Higher values have been reported in literature for *D. alata* (Peroni *et al.*, 2006). Other starches such as sweet potato has 18%, wheat 26%, corn 28% and the amylose content of cassava starches reported by various workers: 13.6-23.8% (Richard *et al.*, 1991), 22.6-26.2 (Moorthy *et al.*, 1992) and 22.3-24.6 (Barimah *et al.*, 1999).

Table 2.4: Amylose and Amylopectin ratio of yam flour from *D. rotundata* and *D. alata*

Sample	Amylose content (%)	Amylopectin content (%)
Omolokun	23.09	76.91
Abuja	22.49	77.51
Td 98/01166	23.01	76.99
Td 92-2	23.49	76.51

Source: Jimoh et al. (2007)

Amylopectin as a component of starch has a larger molecular weight than amylose. It is formed by non-random alpha, (1-6) branching of the amylose-type alpha (1-4) –D-glucose units (Karim *et al.,* 2000). Amylopectin like amylose has type A, B and C chain structure/form. A chains binds in clusters only to B chains, B chains bind to other B chains or to a C chain which has a reducing end R of which there is one per of molecule (Manners, 1989) .Type A chains (crystallites) is denser with unbroken chain lengths of about 23-29 glucose units and are found in most cereals. Type B with slightly longer unbroken chain lengths of about 30-40 glucose units are found in banana, tubers and stems. Type C structure which is a combination of types A and B is found in the seeds of grain legumes such as peas and beans (Imberty and Perez, 1988). Different starches therefore contain either A, B or both polymorph forms and they are called A-, B, or C type starches respectively. Amylopectin interferes with the interaction between amylose chains (and retrogradation) and its solution can lead to an initial loss in viscosity, followed by a more slimy consistency. The crystallinity of amylopectin is reduced in the presence of amylose, and this influences the ease of water penetration into the granules (syneresis).

Starches with high amylose/low amylopectin contents tends to be of the type B structure while those with low amylose/high amylopectin content are of either the type A or the intermediate type C form (Richard *et al.,* 1991). Previous reports (Riley *et al*., 2004) have shown that type C and type A starches are more digestible than type B starches. Amylose content plays a key role in the digestion of starches as starches with low amylose contents are more digestible than starches with high amylose content. Table 2.5 gives a summary of some of the differences between amylose and amylopectin characteristics.

Table 2.5: Differences between amylose and amylopectin characteristics

Property	Amylose	Amylopectin
[a] Molecular structure	Linear (α 1-4)	Branching (α1-4, α1-6)
[b] Molecular weight	~ 106	~108
[b] Helical complex	Strong	Weak
[a] Ioding colour	Blue	Red-purple
[b] Retrogradation	Rapidly	Slowly
[a] Gel property	Stiff, irreversible	Soft, reversible
[b] Film property	Strong	Weak and brittle

Source: a Jane (2000); b Zobel (1988)

Fig. 2.1: Starch chains with types A, B and C

Source: Wang et al. (1998)

2.7.4 Granule size

Yam flour granules consist of starch molecules which are arranged radially and form a series of concentric layers that alternate as amorphous and semi-crystalline regions. Each starch molecule is a larger polymer made up of glucose units linked together by glycosidic bonds into larger strands/polymers. There are two polymer types, amylose and amylopectin. Their relative amount can influence physicochemical properties such as solubility, swelling power, water binding capacity, viscosity, gelatinization and retrogadation (Lindoboom *et al*., 2004). When flour suspension is heated the granules swell by absorbing water, the crystalline structure of the molecules are lost. This is followed by leaching of smaller amylose molecules, forming a network that holds water and increasing viscosity. Yam flour granules are microscopic and vary in size and shape depending on the variety/species. The size distribution of granules determines its swelling functionality with granules being generally either larger or lenticular (lens-like, A-starch) or smaller and spherical (B-starch) with less swelling powers (Fortuna et al., 2000).

Granule size influences many properties of particulate materials including the macroscopic behaviour of products and is a valuable indicator of quality and performance (French, 1984). This governs the manufacture and industrial application of products and is true for powders (flour), suspensions and aerosols. The size and shape of powders influences flow and compaction properties. Larger more spherical granules will typically flow more easily than smaller/high granules. Smaller granules dissolve more quickly and lead to higher suspension viscosities than larger ones (French, 1984).

In general granule size may vary from less than 1 µm to 100 µm. Moorthy (1994), reported that large variability in shape exists among yam flour granules/starches: round, triangular,

oval and elliptical. Granule size was reported to range from 20-140 µm and from 10-70 µm for *D. alata* and *D. rotundata/cayenesis* respectively (Moorthy, 2002).

Moorthy and Nair (1989) also reported bigger starch granules for *D. alata* (35 µm) and *D. rotundata* (33 µm) with smaller granule size for *D. esculenta* (2-15 µm). Table 2.6 also represents some species of yam and their starch granule characteristics.

Table 2.6: Starch granules characterization from different yam species

Species	Granule size (µm)	Starch characteristics
D. alata	5-50	Fairly large granules, oval
D. rotundata	5-45	or egg-shaped, elongated rounded, square or mussel-shell shaped, sometimes with side flattened
D. cayenesis	5-60	Many fairly large granules,
D. bulbifera	5-45	of rounded triangular form, sometimes elongated, rarely trapezoidal form
D. esculenta	1-15	All granules small, rounded
D. dumetorum	1-4	polyhedral, sometimes complex as though built from many smaller granules

Source: Emiola and Delarosa (1981)

2.7.5 pH

pH is the amount of hydrogen ions in a particular solution. A solution that contains more hydrogen ions tends to be more acidic. The less the ions present in a solution the more alkaline (basic) the solution (Jeromy, 2002). pH is measured on a scale of 0 to 14 with 7 being neutral. Temperature plays a significant role in pH measurement. All solutions will change their pH value with temperature. This is as a result of the shifting of the equilibrium of the components, mainly of dissociation. Solution temperature compensation, converts the pH at the measurement temperature to the pH at the reference temperature. The reference temperature is almost always 25 °C. pH is an important parameter in determining the quality of products such as flour. It gives an indication of the hydrogen ions (proton) in solution. The standard pH specification for starch solution of 2 % $^{w}/_{v}$ is 4.5-7.0 (Sigma, 1999).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Source of raw materials

Fresh yam varieties *D. rotundata* (Pona, Lilii, and Dente) and *D. alata* (Matches*)* were obtained from Ejura in collaboration with the Crop Research Institute at Fumesua Kumasi Ghana.

3.2 Drying methods/procedures

3.2.1 Preparation of yam samples for drying

The yam tubers were selected randomly and weighed with analytical balance, OHAUS, Pioneer ™ (Model PA 2102 balance Washington USA) and sliced using a stainless steel knife and 3x3 cm cutter. The yam samples were cut into slab of size 1 cm (length, breath and thickness). The thickness was determined with the aid of vernier caliper.

3.2.2 Drying of yam samples

Approximately one hundred and twenty grammes (120g) of yam samples (slaps) of each variety were placed on trays and dried in the open sun (OSD), solar dryer (SD) (consisting of a fan, a collector and drying chamber) and a combination of SD and adsorption system (SADS) during the night. Relative humidity readings (ambient, cabinet dryer, collectors and chimney) were recorded with a thermo hygrometer (Hanna, Model H191610C, Segni, Italy) and temperature with thermocouple connected to a data logger (Agilent data acquisition logger 3470A Santa Clara USA). Yam samples were weighed at 30 minutes intervals for the first 2 hours and 1 hour till the end of drying. The samples were stored

after each drying day at room temperature in a transparent zipped plastic bag. The dried yam samples (slaps) were milled and frozen in a refrigerator for further analysis.

3.3 Determination of Moisture content

Moisture content was determined according to the method of AOAC (1997). Five grammes (5 g) of peeled and chopped fresh yam tuber were weighed into a dried and pre-weighed (petri-dish). The petri-dish and its content was dried in an oven (Beveiling, Model LA01805 Munich Germany) at 105 °C for 24 hours. The moisture content was calculated as weight loss.

3.4 Determination of functional and physicochemical properties of yam flour

3.4.1 Solubility and Swelling power

Solubility and Swelling power were determined as described by Oladele and Aina (2007). One gramme of sample flour was mixed with 40 ml of distilled water in a centrifuge tube and heated at 80°C for 30 min while stirring continuously. The tube was removed from the bath, wiped dry, cooled to room temperature and centrifuged for 15 min at 2200 rpm (Centrifuge 74-9. FY134, the Netherlands BEUN-DE RONDE B.V. AMSTERDAN, Model 11904). The supernatant was evaporated to dryness and the residue weighed to determine the solubility. The swollen sediment obtained after decanting the supernatant was weighed and swelling power was determined.

3.4.2 Water Binding Capacity

Water binding capacity (WBC) of starch was determined in triplicate according to the methods of Yamazaki (1965). Two grammes of flour were dissolved in 40 ml of distilled

water in a centrifuge tube. The suspension formed was agitated for 2 hr on Gallenhamp Orbital Shaker (Model 01377049, Hanwell London England. It was centrifuged for 10 min at 2200 rpm. The free water was decanted from the wet flour and drained for 10 min. The wet flour was weighed and the water binding capacity calculated.

3.4.3 Amylose/Amylopectin ratio

The method of Martin *et al.* (1994) for Amylose Analysis of Rice was used. It is a colourimetric method in which amylose forms starch iodine complex (dark blue colour) due to its high affinity for iodine. Flour sample was sieved through 150 µm mesh for better reproducibility. About 0.1g of the flour sample was weighed into a 100 ml volumetric flask. One milliliter of 95 % ethanol and 9 ml 1N sodium hydroxide were added and heated in a boiling water bath for 5 min. The solution was removed from the water bath and made up to 100 ml mark with deionized water. One milliliter of this solution was pipetted into test tubes (in duplicates). To each content of the test tube, 2 ml of 0.1N acetic acid, 1 ml iodine solution and 16 ml deionized water were added to develop a dark blue colour. The solution was vortexed with a Rotamixer (Model 12035699 Hooks and Tucker Instruments Ltd, Vulcanway Croydon, England) and allowed to stand for 20 min. It was revortexed and the absorbance read on a Spectrophotometer (Milton Roy Spectronic CE 1021, Theale Court England) at 620 nm. Absorbance of standard rice with known amylose concentration was used to estimate the amylose content of the sample.

3.4.4 Granule size

3.4.4.1 Microscopic studies of yam flour granules

Granule size was studied using a compound light microscope. Measurement of microscopic objects depends on the availability of the following accessories: measuring eyepiece, eyepiece micrometer and stage micrometer. The accessories aid in the measurement of objects and calibration of the factor (for objective magnification). In the calibration, the micrometer disk (round glass disk with scale) of the eyepiece micrometer was inserted in the measuring eye piece with the focusing lens adjusted until a sharp image of the scale was observed. The stage micrometer (Graticules, Tonbridge, Kent Model 02A00400, Kent, England) was placed on the stage with the microscope focused on the scale. The micrometer disk (round glass disk with scale) of the eyepiece micrometer was inserted in the measuring eyepiece with the focusing lens adjusted until a sharp image of the scale was observed. The stage micrometer (Graticules, Tonbridge, Kent Model 02A00400, England; sensitivity 0.01 mm) was placed on the stage with the microscope focused on the scale. By turning the eyepiece both scales appear sharply defined and laid parallel to each other. The number of divisions of the eyepiece that corresponded to the distance on the stage micrometer gave a factor of 2.7 µm.

3.4.4.2 Determination of size and shapes of yam flour granules

A small amount of the flour was placed on a microscope slide (Olympus, Model WF10XMicro, Tokyo Japan) using a spatula. The flour was mixed with a drop of distilled water which distributed thinly on the slide; a slide cover was placed on it. The shapes of the yam flour granules were observed under the compound light microscope (Leica

Buffalo, N.Y. 14240 Model: 1349522X, New York USA) using eyepiece (magnification X20) and objective (magnification X40) while the sizes were determined by measuring the granule area with the eyepiece micrometer fixed to the lens of the microscope. The actual sizes of the granules were calculated by multiplying their mean area by the factor 2.7 µm. A minimum of 9 granules (3 large, 3 medium and 3 small) were selected randomly and measured for each variety.

3.4.5 pH

One gramme of flour samples of the yam varieties was weighed into a beaker containing 10 ml of distilled water. It was allowed to stand for 15 minutes with constant stirring. The pH was determined using a pH meter (Hanna, Model 8521 Washington USA).

3.4.6 Colour

The colour of the yam flour was determined by the Hunter Lab colour scale (1976) with Minolta Chromameter CR 10 SN, RS-232C, Tokyo Japan. The colour space was pressed until L, a, b were displayed on both the chromameter and the calibration tile. The flour sample was poured into a petri- dish and covered. The measuring head of the chromameter was placed firmly on the petri-dish and the side trigger pressed. The petri-dish was turned to ensure that the sub sample (sample at the bottom) returned to the main sample (sample came to the top) and remixed thoroughly. The procedure was repeated in duplicate for the flour of each yam sample. The sample identification (name/code) and Lab values were recorded on a paper feed of the chromameter.

L runs from 100 to 0; the maximum L = 100 indicates lightness/white

L = 0 indicates black

The a and b have no specific numerical limits. Positive a (+ values) indicates red while Negative a (- values) is green. Positive b indicates (+ values) yellow while Negative b (- values) is blue.

3.5 Statistical Analysis

Data obtained were analyzed using SPSS version 20. Two-way Analysis of Variance was used to establish the effect of drying methods and cultivars on the functional and physicochemical properties. One-way Analysis of Variance with Fisher's least significant differences (LSD) was used to confirm the significant differences between the drying methods with the means of the cultivars at 95.0% Confidence level. The functional and physicochemical properties of the cultivars (4 cultivars with two replicates each) under the different drying methods were correlated with SPSS 20 using Pearson Correlation.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Conditions of drying of yam varieties and drying medium

The moisture content (wb) for the fresh *Dioscorea rotundata* cultivars ranged from 57.01% to 67.34% while that of *Dioscorea alata* cultivar was 71.01%. The moisture content of the fresh yam varieties obtained from the study falls within the range of 50-80% (wb) reported by Osunde, (2008). The results confirm that yam indeed has higher moisture content (wet basis). The range of dry matter content in the order SAD, SD and OSD were 32.66 - 39.23%, 28.99 – 42.99% and 28.99 – 42.99% respectively (Table 4.1). *D. rotundata* cultivars recorded higher dry matter content compared to *D. alata* cultivar. Among the *D. rotundata* cultivars Pona had the highest dry matter content followed by Lilii while Dente had the lowest. Martin (1994) associated high dry matter content to good eating quality while Otegbayo, (2004) mentioned that it is an important chemical index of food quality in root and tuber crops. In Ghana, Pona is preferred to the other *D. rotundata* cultivars because of its good eating quality (IITA, 2009). The dry matter content of 28.99% recorded in the study for *D. alata* variety falls within the range of 13.68 – 37.4% reported by Mazinya-Dixon and Asiedu (2003) and Lebot *et al*. (2005).

Table 4.1: Moisture content and drying time of *Dioscorea rotundata* and *D. alata* cultivars

Drying method	Cultivars	Fresh tuber Moisture content (wb)	Dry matter (%)	Moisture content (db)	Drying time (min)
	D. rotundata				
SAD	Pona	60.77	39.23	0.07	1680
	Dente	67.34	32.66	0.12	3600
	Lilii	65.18	34.82	0.09	2040
SD	Pona	60.77	39.23	0.08	2280
	Dente	67.34	32.66	0.18	2880
	Lilii	65.18	34.82	0.02	1800
OSD	Pona	60.77	39.23	0.05	3120
	Dente	67.34	32.66	0.23	3000
	Lilii	65.18	34.82	0.09	2640
	D. alata				
SD	Matches	71.01	28.99	0.03	1800
OSD	Matches	71.01	28.99	0.03	2280

Different drying methods influence differently the drying behaviour of a food product due to various factors such as temperature gradient, relative humidity, air velocity, etc. It is also strongly influenced by the bond formation and interaction between water and other molecules in the food. Figures. 4a-c presents the drying behaviour of various yam cultivars (Pona, Lilii and Dente) under drying methods SAD, SD and OSD. It is observed that the SAD dried sample dried faster followed by SD and OSD in that order. The SAD dried

sample was faster due to the fact that adsorption drying employing silica gel as adsorbent took place at night for the first and second day. For instance by the close of the 2nd day (2nd night not inclusive) percentage moisture loss (kg/kg db) for SAD, SD and OSD were between 77-89%, 69-83% and 60-76% respectively with the 1st night drying significantly contributing to the high moisture loss. In solar drying, the combination of solar collector and fan (forced convection) coupled with heat accumulation enhances evaporation of water from the food. However, because the sun comes and goes during certain periods of the day higher drying rates could not materialize. Moreover, in the open sun drying, the drying process occurred at low temperature (ambient) where the yam varieties were exposed to the environment with low rate of air movement causing low drying rates.

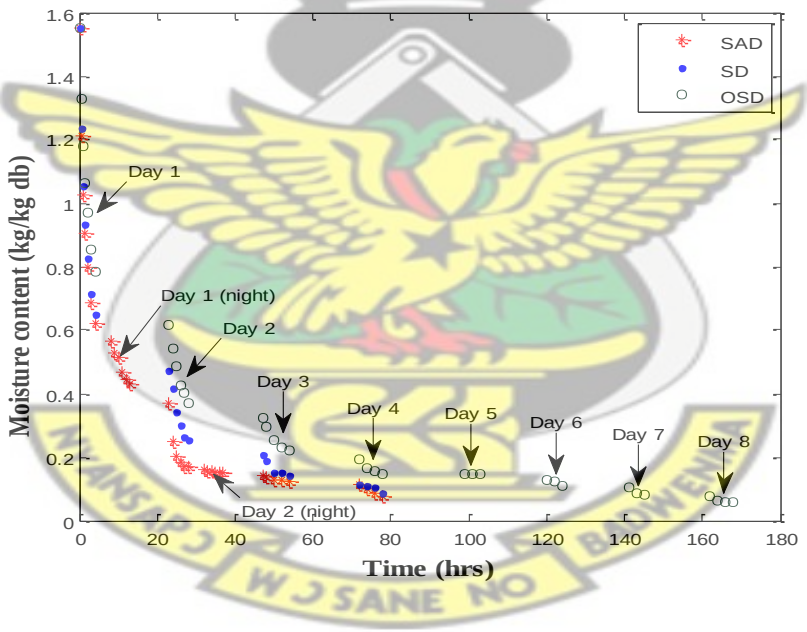

Fig. 4 a. *Drying of Pona under different drying methods*

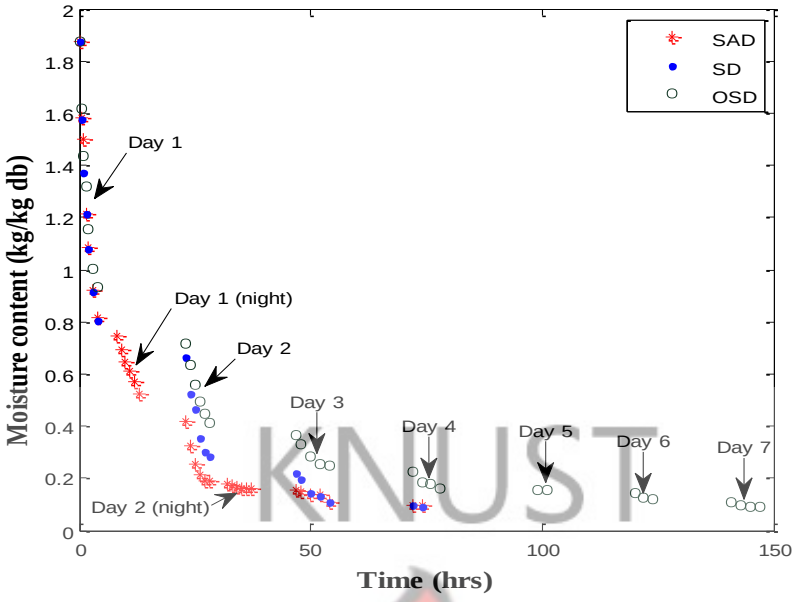

Fig. 4 b. *Drying of Lilii under different drying methods*

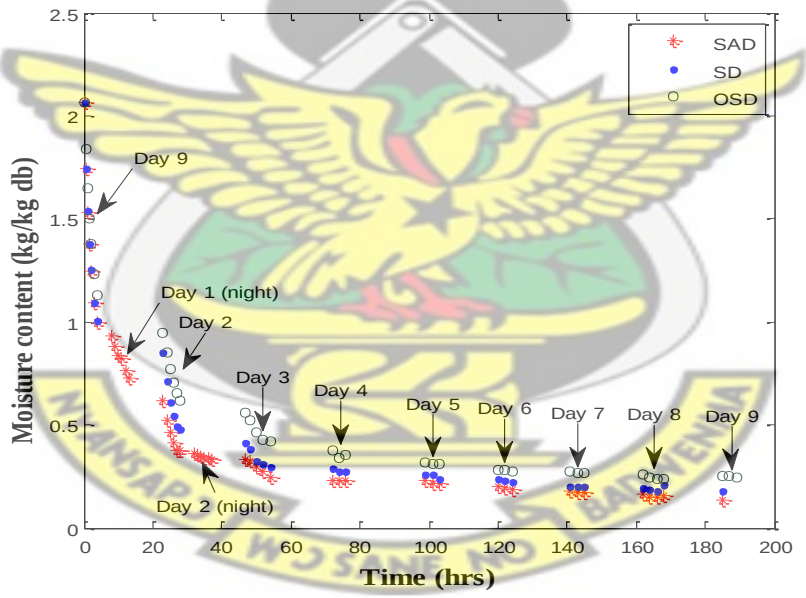

Fig. 4 c. *Drying of Dente under different drying methods*

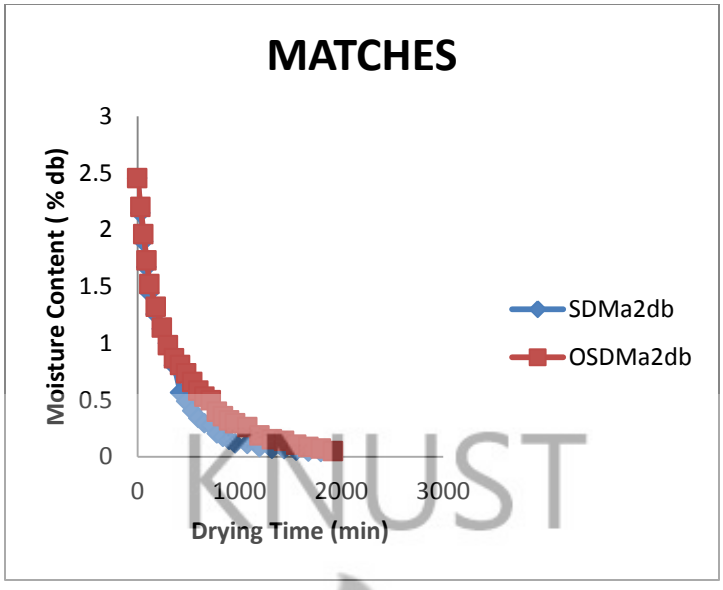

Fig. 4 d. *Drying of Matches under different drying methods*

With regards to the effect of drying methods on the yam cultivars it was observed that the rate of drying of Dente was slower than both Lilii and Pona (Fig 4 e). While it took four days to dry the Pona and Lilii to moisture content of between 0.05-0.09 kg/kg db for all drying methods it took nine days to dry Dente to between 0.07-0.12 kg/kg db (Table 4.1). In relation to Matches it was observed that Matches dried at a lower rate. In all cases the SAD was most effective. The differences in drying behaviour of various yam samples indicate that there exist structural differences. These lead to differences in physicochemical properties of the yam varieties. Investigation into the water binding capacity (WBC), swelling power (SP), solubility (S), amylose and amylopectin content of the dried samples as well as the granule size analysis were thus imperative.

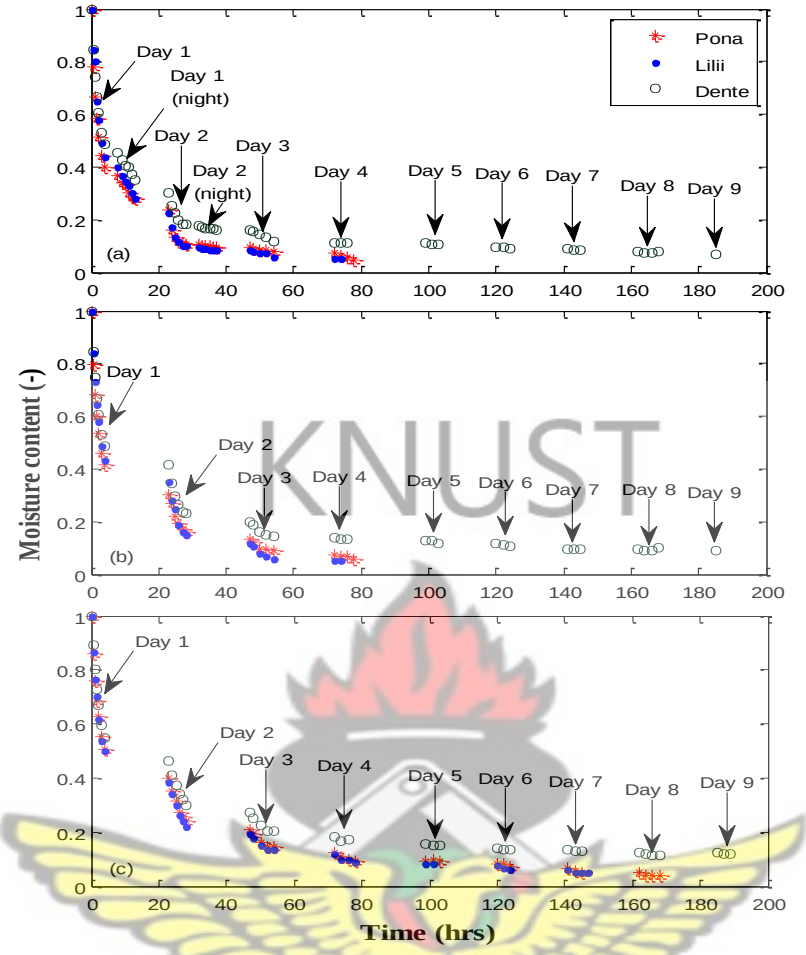

Fig. 4 e. Effect of drying methods SAD (a), SD (b) and OSD (c) on yam cultivars (Pona, Lilii and Dente).

4.2 Functional and Physicochemical properties of yam flour

4.2.1 Amylose and Amylopectin content of Yam flour

Studies on the physicochemical properties of flour are important for food processing because they influence the characterization (quality and texture) and industrial application of food products (Moorthy, 1994; Gerarld *et al*., 2001; You and Izidorazyk, 2002). Tables 4.2 - 4.7 show the physicochemical properties of flour samples from *D. rotundata* and *D. alata* varieties using OSD, SD and SAD respectively. The drying methods had different

effect on the amylose and amylopectin content. While the SAD had the least effect on the amylose content, the OSD had the highest effect. In view of this the yam samples dried under SAD had the highest amylose content followed by the SD dried samples and OSD dried samples in that order. On the other hand, the opposite was observed with the amylopectin content. The range of amylose content in the order SD, OSD and SAD were 41.96 – 45.54%, 42.86 – 45.54% and 44.64 - 46.63% respectively.

Yam flours generally have higher amylose contents than those from other root and tuber crops (Baah *et al*., 2009). Amylose values of between 27.6 and 39.4% for *D. alata* have been reported by other researchers (Hoover, 2001; Peroni *et al.*, 2006). Sahorè *et al.* (2005) obtained amylose content of 2.32 and more than 25% for wild yam species. Amylopectin content ranged from 54.46 to 58.04% for the SD dried yam flour samples, 54.46 to 60.71% OSD and 53.57 to 55.36% SAD dried yam flour samples. Among the cultivars dried under SD, Lilii had the highest amylose content (45.54%) while Pona had the lowest (41.96%). With regards to OSD dried cultivars Dente had the highest amylose content (45.54%) while Matches had the least (39.29%). For the cultivars dried under the SAD, Dente had the highest amylose content followed by Matches while Lilii and Pona had the same amylose content. Among the cultivars dried under SD, Pona had the highest amylopectin content while Lilii had the lowest. With regards to OSD, Matches had the highest amylopectin content while Dente had the lowest. For the cultivars dried under SAD, Pona and Lilii had the highest amylopectin content while Dente had the lowest amylopectin content. *D. rotundata* cultivars recorded high amylose content and low

amylopectin content while *D. alata* cultivar recorded high amylopectin and low amylose contents (Table 4.2).

The drying methods have effect on the physical and chemical standards of the dried product as a result of the transformation that takes place. The disruption of the cellular/granular structure within the amorphous and crystalline domain by the different drying methods might have caused the differences in amylose and amylopectin content of the yam samples. This effect might have enhanced (strong) bond formation and increased the interaction between the water molecules. Thus facilitating the release of amylose. The high intensity of bonding and interaction might have resulted in the yam samples dried under the SD to have a higher amylose content compared to the OSD and SAD yam samples. Moreover, the interference of the interaction between amylose chains by amylopectin might have resulted in the OSD yam samples to have a higher amylopectin content compared to SD and SAD yam samples. These findings from the study agree with the report of Tester and Morrison (1990). Lorenz and Collins (1990) reported that the higher the amylose content the lower the swelling power because amylose reinforces the internal network within the granules and therefore restricts swelling while Tester and Morrison (1990), mentioned that the swelling power of starch granules is the result of the presence of amylopectin with amylose acting as a dilutant. This is confirm by a correlation result of ($r = -0.534$, $r = +0.151$ and $r = +0.887^{**}$) for OSD, SD and SAD cultivars (Table 4.7). The research study has shown that yam samples such as SAD and OSD dried Dente and SD dried Lilii which recorded higher amylose contents had low swelling power. These results from the study confirm the report by Lorenz and Collins, (1990). The drying methods had significant effect ($P < 0.05$) on amylose content and amylopectin contents under the cultivars Pona and Matches. However, there was no significant differences ($P >$

0.05) amylose content and amylopectin contents of the cultivars Dente and Lilii under SAD, SD and OSD. Krossman and Lloyd (2000) reported that enzymatic activity in the biosynthesis of various starch may cause differences in amylose and amylopectin content. Moreover, amylose/amylopectin ratio is useful in determining the characteristics/nature of starches and their products. Juliano and Hicks (1996) mentioned that the amylose content in rice has been used as a vital indicator in the selection and development of improved rice varieties for parboling-caning application.

Table 4.2: Effect of drying methods on the Amylose and Amylopectin content of Yam flour

Cultivar	Amylose content (%)			Amylopectin content (%)		
	SAD	SD	OSD	SAD	SD	OSD
D. rotundata						
Pona	44.64±1.27[a]	41.96±0.01[b]	42.86±0.07[ab]	55.36±0.08[a]	58.04±0.01[b]	57.14±0.01[c]
Dente	46.43±0.01[a]	43.75±2.53[a]	45.54±1.27[a]	53.57±0.13[a]	56.25±2.53[a]	54.46±1.25[a]
Lilii	44.64±1.27[a]	45.54±1.26[a]	42.86±0.01[a]	55.36±0.01[a]	54.46±1.25[a]	57.14±0.01[a]
D. alata						
Matches	45.50 ±0.01[a]	42.86±2.52[a]	39.29±0.01[ab]	53.64±0.01[a]	57.14±2.52[a]	60.71±0.[01ab]

Values are presented as mean ± standard deviation of two replicates. Values followed by different letters (superscripts) in a row for each yam cultivar are significantly different ($p < 0.05$) under each property.

4.2.2 Interrelation of Microstructure, Swelling power, Solubility and Water Binding Capacity of yam flour granules

Microstructure of food is an essential component in determining its functionality. Microstructure changes of a product are key determinant of the changes in the macroscopic properties of materials. While a product/structure with large granule sizes would facilitate rapid water diffusion or promote a rapid water uptake during drying, a compact structure or small granule sizes at the surface of the product can cause slower moisture migration during drying. Different drying methods can affect the microstructure (cell/tissue structure) of products and of varying degrees on different species and varieties of samples. The heat content and the extent of drying can result in varying degrees of breakdown of cell walls, decreased intercellular contact and the collapse or sustenance of cell structure of the dried products.

The present research shows that the yam flour granules of Pona were generally triangular, rounded, oval and irregular. Those of Lilii were oval, elliptical and rounded while Dente had predominantly cylindrical, oval, and elliptical or triangular granule shapes. Matches also recorded oval, elliptical, few rounded and irregular shapes. Dente having many cylindrical, oval and elliptical granule shapes dried very slowly. Therefore, many cylindrical oval and elliptical granule shapes in yam flour samples are attributed to slow drying. Similar shapes of yam flour granules; oval, rounded, elliptical or triangular with a few being irregular have been reported in literature (Moorthy, 1994; 2002; Brunnschweiler *et al.*, 2004; Otegbayo, 2004). A minimum of nine (9) randomly selected granules with triangular, oval, cylindrical and rounded shapes within each sample were used for average granule size determination. There were thirteen (13) flour samples in all of *D. rotundata* and *D. alata* cultivars. Photographs of the yam flour granule shapes are presented below.

The pictures show the different shapes and size distribution of granules of yam cultivars after drying under SAD, SD and OSD. Granules sizes (µm) are also presented in (Table 4.3). The granule sizes (µm) of *D. rotundata* cultivars under SAD, SD and OSD ranged from 20 – 32, 11 – 21 and 21 – 24 respectively while those of *D. alata* cultivar under SD and OSD were 16 and 14 respectively. In general, the Dente yam cultivar recorded the least granule size thus it had the most effect from the three drying methods. On the other hand, the Pona cultivar recorded the highest granule size with the least effect from the drying methods.

According to Moorthy (1994), granule size of *D. esculenta* are very small (2-15 µm) and *D. alata* granules are very large (6-100 µm) while Brunnschweiler *et al.* (2004), observed yam granules sizes ranging between 19 and 52 µm for *D. alata* and from 19 to 50 µm for *D. cayenensis-rotundata* complex. The granule sizes for the *D. rotundata* and *D. alata* yam samples from this research fall within the range as reported by Moorthy (1994) and Brunnschweiler *et al.* (2004). The study has shown that the larger the granule size the higher the rate of water migration while the converse is true. Structural differences lead to the differences in the drying behaviour of the yam samples.

4.2.2.1 Swelling power of Yam flour

Drying method had varying effect on swelling power. Whereas the SAD had the least effect on swelling power, the OSD had the highest effect. Thus the yam samples dried under SAD had the highest swelling power followed by SD dried samples and OSD dried samples in that order. The range of swelling power in the order SAD, SD and OSD were 5.70 – 12.02%, 4.62 – 10.53% and 3.62 – 10.43% respectively. Among the varieties dried

under the SAD, Lilii had the highest swelling power (12.02%) with Matchs recording the lowest (5.70%).

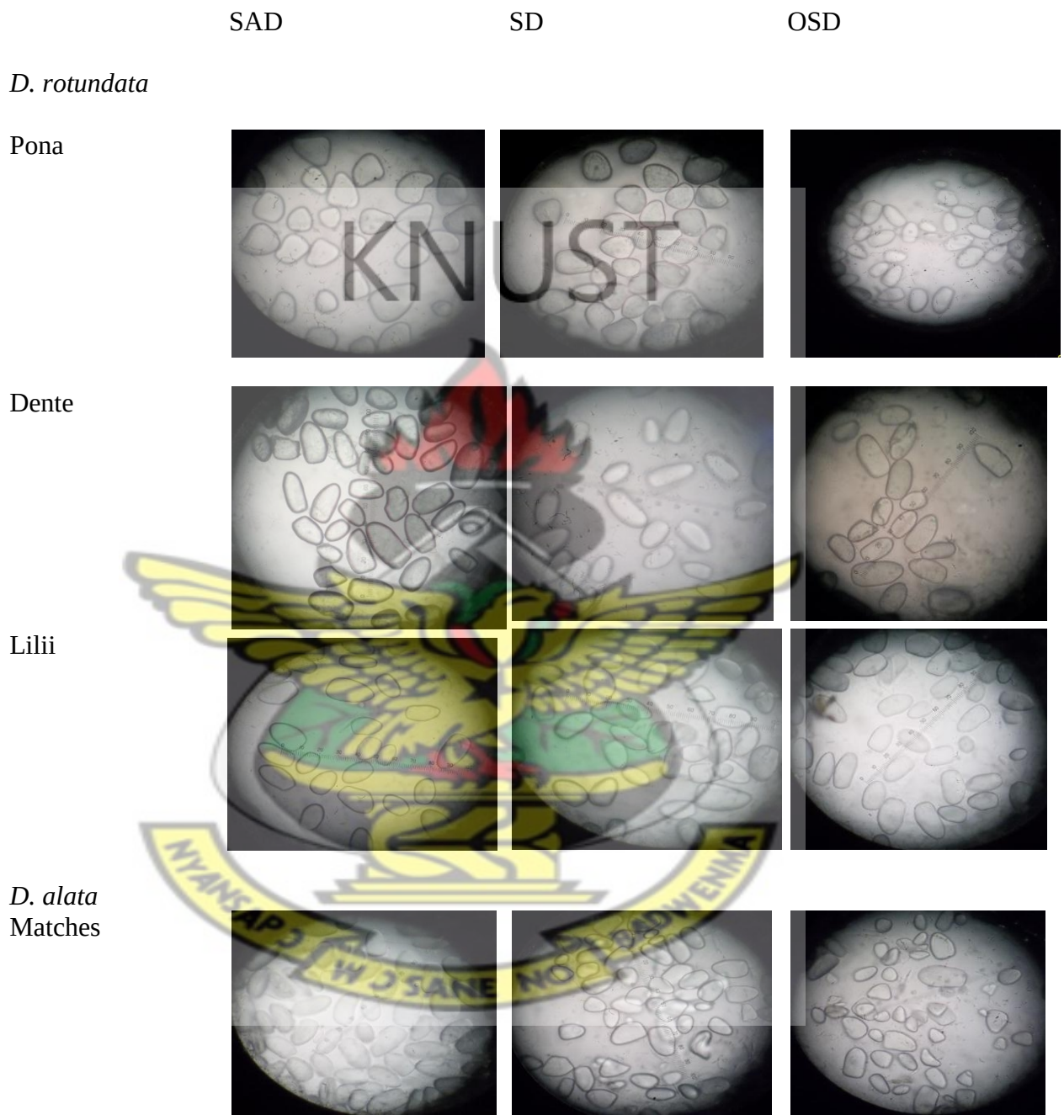

Plate of Granule shapes of Yam flour under different drying methods

For the cultivars dried under SD, Pona recorded the highest swelling power while Matches had the least. With regards to OSD, Lilii had the highest swelling power (10.43%) while Matches had the lowest (3.62%). *Dioscorea rotundata* varieties are known to have higher swelling power than other yam varieties/species (Walter *et al.,* 2000). Singh *et al.* (2003) reported that granule size contribute to swelling power while Fortuna *et al*. (2000), reported that large granules increase swelling. This is confirm by a correlation results of (r = +0.856**, r = +0.501 and r = +0.893**) for the OSD, SD and SAD cultivars. According to Lindeboom *et al.* (2004), starch composition, crystalline structure, swelling and solubility are all affected by granule size.

The study has shown that the *D. rotundata* cultivars (Pona and Lilii) which had larger granule size recorded higher swelling power while *D. alata* cultivar (Matches) which recorded low swelling power had small granule size. These results from the study are in agreement with the report of Walter *et al*. (2000), Singh *et al*. (2003), Fortuna *et al*. (2000) and Lindeboom *et al*. (2004). The intensity of structural changes caused by the different drying methods might have influenced the associative bonding within the granules. This might have brought about the differences in granular swelling of the yam varieties. The drying methods had significant effect ($P < 0.05$) on swelling power under the cultivars Pona, Lilii and Matches. High amylose content has been linked to low swelling power due to greater reinforcement of their internal network by amylose molecules (Lorenz and Collins 1990; Richardson *et al.,* 2000; Hoover, 2001). The research indicated that Dente which recorded high amylose content had low swelling power. This result confirms the report of Lorenz and Collins (1990), Richardson *et al*. (2000) and Hoover (2001). Granule shape and size are also important for the starch extraction industry since they define the mesh size for application and purification sieves (Leonel *et al.,* 2003). Iwuoha and

Nwakanma (1998) mentioned that flours with high swelling capacity will contribute better thickening as well as bulking agents.

Table 4.3: Granule size and shape of Yam flour from *D. rotundata* and *D. alata* cultivars

Drying method	Cultivar	Average granule size (µm)	Granule shape
	D. rotundata		
SAD	Pona	32	Triangular with different sizes
	Dente	24	Many cylindrical, elliptical and oval
	Lilii	29	Oval, elliptical and rounded
	Matches	20	Oval, elliptical and few irregular
SD	Pona	21	Triangular and oval
	Dente	11	Oval, many cylindrical and triangular
	Lilii	20	Elliptical and oval
OSD	Pona	24	Oval and triangular
	Dente	20	Cylindrical and elliptical with different sizes
	Lilii	21	Triangular, few rounded and oval
	D. alata		
SD	Matches	16	Oval, elliptical, few rounded and irregular
OSD	Matches	14	Elliptical, few rounded and irregular

4.2.2.2 Solubility of Yam flour

Here the OSD had the least effect on solubility while SAD had the highest effect. The range of solubility in the order OSD, SD and SAD were 9.53 – 16.85% and 7.86 – 15.88%, and 7.52 – 14.91%. Among the cultivars dried under OSD, Matches had the highest solubility (16.85%) while Lilii had the lowest solubility (9.53%). For the cultivars dried under SD Matches had the highest solubility while Pona had the lowest solubility. For the cultivars dried under SAD Matches had the highest solubility while Lilii had the lowest. *Dioscorea alata* cultivar had a higher solubility compared to *D. rotundata* cultivars (Table 4.4). High solubility has been associated with high amylose content which is believed to leach out easily during the swelling process (Soni *et al*., 1993). This is in agreement with the findings in this study as most of the varieties that had high solubility also recorded high amylose content. However, it was observed that OSD dried Matches yam sample which had the highest solubility had the lowest amylose content. This result agrees to what Riley *et al*. (2006) reported. They emphasized that increasing solubility decreased the amylose content in *Dioscorea alata* cultivars. This is confirm by a correlation result of (r = -0.786*) (Table 4.7). The drying methods had significant effect ($P < 0.05$) on solubility under the cultivars Pona and Matches. According to Asiedu (1986), differences in the growing environment, maturity stage and species may influence yam tuber composition.

4.2.2.3 Water binding capacity (WBC) of Yam flour

In relation to the water binding capacity, SAD had the least effect while OSD had the highest effect. For that matter, the yam samples dried under SAD had the highest WBC followed by SD dried samples and OSD dried samples.

Table 4.4: Effect of drying methods on the Solubility and Swelling Power of Yam flour

Cultivar	Solubility (%)			Swelling Power (%)		
	SAD	SD	OSD	SAD	SD	OSD
D. rotundata						
Pona	8.64±0.01[a]	7.86±0.01[b]	9.57±0.08[c]	10.70±0.01[a]	10.53±0.01[b]	10.27±0.01[c]
Dente	10.14±0.86[a]	10.05±0.63[a]	10.31±0.45[a]	8.00±0.14[a]	7.26±0.01[b]	7.22±0.01[b]
Lilii	7.52±0.46[a]	8.4±0.21[ab]	9.53±0.44[b]	12.02±1.56[a]	7.69±0.04[b]	10.43±0.05[ab]
D. alata						
Matches	14.91±0.01[a]	15.88±0.20[b]	16.85±0.50[c]	5.70± 0.01[a]	4.62±0.02[b]	3.62±0.20[c]

Row- Drying methods, Column-Cultivar. Values are presented as mean ± standard deviation of two replicates. Values followed by different letters (superscripts) in a row for each yam cultivar are significantly different ($p < 0.05$) under each property.

The range of WBC in the order SAD, SD and OSD were 140 - 178.61%, 142.23 - 152.80% and 132 to 148.48%. Among the cultivars dried under SAD, Dente had highest WBC while Matches had the lowest WBC. For the cultivars dried under SD, Matches had the highest WBC while Pona had the lowest. With regards to the cultivars dried under OSD, Matches had the highest WBC while Lilii had the lowest WBC. The effect of the drying methods on the granular structure might have caused the yam samples to have different binding capacity to water molecules. Soni *et al*. (1993) reported that high WBC is attributed to loose association of amylose and amylopectin molecules in the native granule while a low WBC is attributed to a close association of amylose and amylopectin molecules in the native granule. This can be inferred from the research study that cultivars which recorded low WBC exhibited a closer association among the amylose and amylopectin molecules compared to those with high WBC. The correlation result of (r =

+0.607, r = -0.424 and r = -0.98) for OSD, SD and SAD cultivars confirms this. Engagement of hydroxyl groups to form hydrogen and covalent bonds between starch chains might lower the WBC (Hoover and Sosulki, 1986). This probably explains the reason for a lower WBC in some of the cultivars such as OSD dried Lilii and Pona. WBC varied significantly ($P < 0.05$) among the cultivars Pona, Dente, Lilii and Matches for the different drying methods. Water binding capacity is an important parameter to be considered in the preparation of food products such as snacks, mash and baked foods. It is an important functional characteristic in the development of ready-to-eat foods since high water binding capacity may assure product cohesiveness (Kulkani *et al.,* 1996). The higher water binding capacity of some of the samples such as SAD and SD dried Dente and OSD dried Matches implies the flours can be use in bakery products. This is because higher values increase the unit yield of products. Pomeranz (1991) reported that the higher the WBC, the greater the amount of water needed to make dough of desired quality. This serves as a guide in baking.

4.2.3 pH of Yam flour

From the pH determined, SD had the least effect while OSD had the highest effect. In view of this the yam samples dried under SD had the highest pH followed by SAD dried samples and OSD dried samples. The range of pH in the order SD, SAD and OSD were 6.22 – 7.27, 6.25 – 7.31 and 5.55 – 6.36 respectively. Among the cultivars dried under SD, Matches had the highest pH while Lilii and Dente had the lowest pH. For the cultivars dried under SAD Matches had the highest pH while Dente had the lowest. With the cultivars dried under OSD, Pona had the highest pH while Matches had the least. Different drying methods have different effect on the sensitivity component of the food.

The high pH values obtained indicate a low level of acidity in the yam flour samples. This implies fermentation was reduced since the pH of the flour ranged from 5.55 to 7.27. This indicates that the flour samples are of good quality. The drying methods had significant effect ($P < 0.05$) on pH under all the cultivars. pH of roots and tubers such as cassava and yam of 4 or less indicates appreciable level of fermentation and hence starch breakdown (Jeromy, 2002). Fermentation also gives characteristic aroma, flavour and sour taste to the flour and this make it less preferred for use in baking.

Table 4.5: Effect of drying methods on the WBC and pH of Yam flour

Cultivar	WBC (%)			pH		
	SAD	SD	OSD	SAD	SD	OSD
D. rotundata						
Pona	171.31±0.45^{a}	142.23±1.16^{b}	132±0.05^{c}	6.55±0.01^{a}	6.48±0.01^{b}	6.36±0.01^{c}
Dente	178.61±1.35^{a}	152.80±0.88^{b}	137.75±0.03^{c}	6.25±0.01^{a}	6.22±0.01^{b}	6.01±0.01^{c}
Lilii	142.23±0.19^{a}	148.12±0.01^{b}	130.61±1.01^{c}	6.29±0.01^{a}	6.22±0.01^{b}	6.36±0.01^{c}
D. alata						
Matches	140.00±0.01^{a}	141.48±0.52^{a}	148.48±0.39^{b}	7.31±0.01^{a}	7.27±0.01^{b}	5.55±0.01^{c}

WBC- Water Binding Capacity. Values are presented as mean ± standard deviation of two replicates. Values followed by different letters (superscripts) in a row for each yam cultivar are significantly different ($p < 0.05$) under each property.

4.2.4 Colour of Yam flour

The drying methods had different effect on the colour attribute. While SAD had the least effect on the colour that is maintaining a more whitish colour of the yam flour, OSD had the highest effect. With regards to this, SAD yam flour samples had a lighter colour indicated by higher L value followed by SD flour samples and OSD flour samples

respectively. The range of colour (L) in the order of SAD, SD and OSD were 83-90.38, 75.65-85.22 and 67.39-81.68. The OSD dried flour samples had the highest redness (indicated by "a" value) and yellowness (indicated by "b" value) followed by SD flour samples while SAD had the lowest. Among the cultivars dried by SAD Pona had the highest L value (appeared lighter/whiter) while Matches had the lowest. In the SD flour samples, Pona had the highest L value while Matches had the lowest. (Table 4.6). With OSD flour samples Lilii had the highest L value while Matches had the least. The methods of drying had significant effect ($P < 0.05$) on the L values under the cultivars Pona, Dente, Lilii and Matches. The a and b values varied significantly ($P < 0.05$) among the cultivars under the different drying methods. The light/white colour or appearance of the flour samples may be due to the effect of the drying methods on enzymatic/microbial activity.

The different drying methods might have inhibited the activities of enzymes (phenol oxidase or polyphenol oxidase) that could have caused browning of the products. The colour effect was higher in SAD than in SD and OSD in that order. The reduced light colour of the OSD flour samples is attributed to the activities of enzymatic reaction as a result of the prolonged drying time and exposure to the environment. Ozo and Caygill (1986) attributed the reduced light colour of sun-dried flours of *D. alata* varieties to enzymatic reaction while Jimoh *et al*. (2007), attributed the high redness (reduced light colour) observed in sun-dried flours of *D. rotundata* and *D. alata* cultivars to enzymatic activities as a result of the prolonged drying time. The results of the research study agree to the findings of Ozo and Caygill (1986) and Jimoh *et al.* (2007). In the case of white yam flours, higher white colour means better consumer acceptability in Taiwan. Although

browned yam flour is popular in some African countries (Ferombi *et al*., 2000), dark-brown colour flour is not acceptable in Taiwan.

Table 4.6: Effect of drying methods on the Colour (L, a and b values) of Yam flour

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	L			a			b		
Cultivar	SAD	SD	OSD	SAD	SD	OSD	SAD	SD	OSD
D. rotundata									
Pona	90.38±0.37^{a}	84.98±0.15^{b}	76.78±0.76^{c}	-1.17±0.04^{a}	0.69±0.01^{b}	0.24±0.05^{c}	6.67±0.01^{a}	7.35±0.01^{b}	7.00± 0.12^{c}
Dente	86.85±0.54^{a}	77.52±0.31^{b}	77.05±0.10^{bc}	-0.46±0.01^{a}	0.39±0.04^{b}	0.87±0.04^{c}	6.11±0.13^{a}	7.85±0.18^{b}	9.16±0.04^{c}
Lilii	84.18±0.59^{a}	78.16±0.31^{b}	81.78±0.43^{c}	-0.35±0.14^{a}	0.38±0.05^{b}	0.15±0.04^{b}	5.52±0.04^{a}	7.78±0.27^{b}	7.14±0.11^{c}
D. alata									
Matches	83.00±0.01^{a}	76.34±0.76^{b}	67.61±0.10^{c}	-1.23±0.01^{a}	0.64±0.08^{b}	1.42±0.42^{c}	7.88±0.01^{a}	9.03±0.18^{b}	10.18±0.06^{c}

Values are presented as mean ± standard deviation of two replicates. Values followed by different letters (superscripts) in a row for each yam cultivar are significantly different ($p < 0.05$) under each property

4.3 Correlation of functional and physicochemical properties

For the cultivars dried under OSD a positive correlation was observed between amylose and swelling power (r = +0.535), amylose and colour (L value) (r = +0.698), granule size and colour (r = +0.48), amylopectin and WBC (r = +0.607) which was not significant. However, a strong positive correlation was observed between granule size and swelling power (r = +0.856), solubility and WBC (r = +0.956), amylopectin and solubility (r = +0.786) which was significant (Table 4.7). Moreover, a negative correlation but not significant was observed between amylose and WBC (r = -0.608), amylose and swelling power (r = -0.534) while a strong negative correlation was observed between amylose and solubility (r = -0.786), granule size and solubility (r = -0.875), granule size and WBC (r = -0.862), solubility and swelling power (r = -0.925), swelling power and WBC (r = 0.992), amylopectin and amylose (r = -1.000) which were all significant . With the cultivars dried under SD there was a positive correlation between amylose and WBC (r = +294), amylose and colour (r = +0.367), granule size and swelling power (r = + 0.501), granule size and colour (r = + 0.605) amylopectin and solubility/swelling power (r = + 0.151), amylopectin and WBC (r = +0.7) which was not significant. A strong positive correlation was observed between amylose and solubility (r = +0.723), amylose and swelling power (r = +0.720) but not significant (Table 4.7). Whereas a negative correlation was observed between granule size and solubility (r = -0.370), granule size and WBC (r = -0.566), solubility and WBC (r = -0.366), amylopectin and WBC (r = -.424) with no significant differences, a strong negative correlation was observed between solubility and swelling power (0.891), amylopectin and amylose (r = -1.000) which was significant (Table 4.7). Nonetheless, from Table 4.7 with regards to the SAD dried cultivars there was a positive correlation between amylose and solubility (r = +0.307), amylose and WBC (r = +0.312), granule size

and colour (r = +0.65) which was not significant. A strong positive correlation which was significant was observed between granule size and swelling power (r = +0.893), swelling power and WBC (r = +0.81), amylopectin and swelling power (r = +0.887). There was a negative correlation between amylose and swelling power (r = -0.606), amylose and colour (r = -0.065), solubility and WBC (r = -0.331), amylopectin and WBC (r = -0.098), amylopectin and amylose (r = -0.703) which was not significant while a strong negative correlation but significant was observed between granule size and solubility (r = -0.859), solubility and swelling power (r = -0.0913). However the correlation between amylopectin and amylose (r = -0.703) was not significant.

Table 4.7: Evaluation of Functional and Physicochemical properties of Yam Cultivars under Open sun drying (OSD)

	Amylose	Solubility	Swelling power	WBC	pH	L value	a value	b value	Amylopectin	Granule size
Amylose	1									
Solubility	-.786*	1								
Swelling power	.535	-.925**	1							
WBC	-.608	.956**	-.992**	1						
pH	.562	-.938**	.999**	-.994**	1					
L value	.698	-.930**	.905**	-.938**	.907**	1				
a value	-.443	.864**	-.955**	.946**	-.948**	-.858**	1			
b value	-.352	.829*	-.975**	.948**	-.969**	-.807*	.937**	1		
Amylopectin	-1.000**	.786*	-.534	.607	-.561	-.699	.443	.351	1	
Granule size	.543	-.875**	.856**	-.862**	.871**	.712*	-.742*	-.838**	-.541	1

**. Correlation is significant at the 0.05 level (2-tailed).*

***. Correlation is significant at the 0.01 level (2-tailed).*

Table 4.8: Evaluation of Functional and Physicochemical properties of Yam Cultivars under Solar drying (SD)

	Solubility	Swelling power	WBC	pH	L value	a value	b value	Amylopectin	Granule size	Amylose
Solubility	1									
Swelling power	-.891**	1								
WBC	-.366	.009	1							
pH	.894**	-.629	-.738*	1						
L value	-.641	.912**	-.346	-.268	1					
a value	.656	-.923**	.317	.296	-.988**	1				
b value	.956**	-.927**	-.310	.828*	-.707	.743*	1			
Amylopectin	.151	.151	-.424	.341	.369	-.433	-.030	1		
Granule size	-.370	.501	-.566	.001	.605	-.541	-.344	.000	1	
Amylose	-.150	-.152	.425	-.341	-.370	.434	.030	-1.000**	-.001	1

***. Correlation is significant at the 0.01 level (2-tailed).*

**. Correlation is significant at the 0.05 level (2-tailed).*

Table 4.9: Evaluation of Functional and Physicochemical properties of Yam Cultivars under Solar adsorption drying (SAD)

	Amylose	Solubility	Swelling power	WBC	pH	L value	a value	b value	Amylopectin	Granule size
Amylose	1									
Solubility	.307	1								
Swelling power	-.606	-.913**	1							
WBC	.312	-.331	.081	1						
pH	-.001	.884**	-.709*	-.541	1					
L value	-.065	-.496	.364	.810*	-.429	1				
a value	.225	-.592	.424	.100	-.795*	-.171	1			
b value	.105	.902**	-.783*	-.255	.950**	-.197	-.875**	1		
Amylopectin	-.703	-.758*	.887**	-.098	-.396	.398	.088	-.492	1	
Granule size	-.513	-.859**	.893**	.307	-.597	.678	.128	-.581	.882**	1

***. Correlation is significant at the 0.01 level (2-tailed).*

**. Correlation is significant at the 0.05 level (2-tailed).*

CHAPTER FIVE

5.0 CONCLUSION

The drying methods had an effect on the drying rate of the yam. The drying rate of the SAD dried samples was fastest due to combination of solar and adsorption drying system compared to the SD and the OSD.

Different yam cultivars have different structural composition which makes them behave differently during drying. The varietal and cultivar differences of the yam greatly influenced their drying behaviour. The greater the granule sizes the higher the drying rate. On the average, the *D. rotundata* samples had larger granule size than the *D. alata* samples. For the *D. rotundata* samples, Pona recorded the largest granule size compared to the others with Dente recording the least. It was observed that the Pona yam samples dried faster for the first day than the others.

The drying methods had significant effect on the physicochemical properties of the flour of the selected *Dioscorea rotundata* and *Dioscorea alata* cultivars. The SAD dried samples averagely had larger granule size compared to the SD and OSD dried samples. In view of this high swelling power (SP), water binding capacity (WBC) and high amount of amylose as well as good retention of the whitish yam colour was observed. The opposite was observed for solubility (S), amylopectin content and pH with SD and OSD recording higher values.

Matches, a *D. alata* yam sample had high S, amylose content, amylopectin content, and pH but with low retention colour, SP and WBC.

The interrelationship between functional and physicochemical properties was established through correlation analysis. Therefore, physicochemical properties (amylose and granule size) can be determinants of the solubility, swelling power and water binding capacity in yam flours.

5.1 RECOMMENDATIONS

Further studies should be conducted on the effect of the SAD on the heat sensitive component of nutrients in yam.

Investigation should be inquired into the effect of granule size on the amylose/ amylopectin content of extracted yam starch.

In details, more work needs to be carried out to develop diverse and novel technologies for using other adsorbents such as clay, activated charcoal etc which are low cost and readily available for drying to complement silica gel.

For effective energy usage and management, efficiencies of the dryer systems need to be investigated.

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APPENDIX

APPENDIX 1. Calculation of % Moisture content

$$\% \text{ Moisture (wb)} = \frac{(weight\ of\ dish + fresh\ sample) - (weight\ of\ dish + dry\ sample)}{weight\ of\ sample} \times 100$$

$$\% \text{ Moisture (db)} = \frac{(fresh\ sample) - (dry\ matter)}{dry\ matter} \times 100$$

APPENDIX 1.2. Calculation of % Solubility and Swelling Power

$$\text{Solubility} = \frac{weight\ of\ dried\ sample\ in\ supernatant}{weight\ of\ sample} \times 100$$

$$\text{Swelling Power} = \left(\frac{weight\ of\ sediment}{weight\ of\ sample} \times 100\right) \times 100 - \%\ solubility$$

APPENDIX 1.3. Calculation of % Water binding capacity

$$\% \text{ WBC} = \frac{bound\ water}{weight\ of\ sample} \times 100$$

APPENDIX 1.4. Calculation of % Amylose

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

APPENDIX 2. Two-way Anova Analysis

APPENDIX 2A. Solubility and Swelling power

Dependent Variable: **Solubility**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	223.331[a]	5	44.666	149.462	.000
Intercept	2801.088	1	2801.088	9372.992	.000
Drying methods	7.176	2	3.588	12.007	.000
Cultivars	216.155	3	72.052	241.099	.000
Error	5.379	18	.299		
Total	3029.799	24			
Corrected Total	228.710	23			

a. R Squared = .976 (Adjusted R Squared = .970 Squared = .871)

Dependent Variable: **Swelling power**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	141.989[a]	5	28.398	32.026	.000
Intercept	1601.810	1	1601.810	1806.460	.000
Drying methods	10.983	2	5.492	6.193	.009
Cultivars	131.006	3	43.669	49.248	.000
Error	15.961	18	.887		
Total	1759.760	24			
Corrected Total	157.950	23			

a. R Squared =. 899 (Adjusted R

APPENDIX 2B. Amylose and Amylopectin

Dependent Variable: **Amylose**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	55.554[a]	5	11.111	3.924	.014
Intercept	46082.865	1	46082.865	16277.150	.000
Drying methods	29.447	2	14.724	5.201	.016
Cultivars	26.107	3	8.702	3.074	.054
Error	50.960	18	2.831		
Total	46189.379	24			
Corrected Total	106.514	23			

a. R Squared = .522 (Adjusted R Squared = .392) Squared = .382)

Dependent Variable: **Amylopectin**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	56.927[a]	5	11.385	3.839	.015
Intercept	75539.772	1	75539.772	25468.015	.000
Drying methods	34.798	2	17.399	5.866	.011
Cultivars	22.129	3	7.376	2.487	.093
Error	53.389	18	2.966		
Total	75650.089	24			
Corrected Total	110.317	23			

a. R Squared = .516 (Adjusted R

APPENDIX 2 C. WBC and p H

Dependent Variable: **WBC**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2638.075[a]	5	527.615	4.680	.007
Intercept	519557.227	1	519557.227	4608.495	.000
Drying methods	1746.804	2	873.402	7.747	.004
Cultivars	891.271	3	297.090	2.635	.081
Error	2029.302	18	112.739		
Total	524224.604	24			
Corrected Total	4667.377	23			

a. R Squared = .565 (Adjusted R Squared = .444)

Dependent Variable: **p H**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.392[a]	5	.478	3.067	.036
Intercept	983.424	1	983.424	6304.468	.000
Drying methods	1.368	2	.684	4.386	.028
Cultivars	1.024	3	.341	2.189	.125
Error	2.808	18	.156		
Total	988.624	24			
Corrected Total	5.200	23			

a. R Squared = .460 (Adjusted R Squared = .310)

APPENDIX 2D. Colour L and a values

Dependent Variable: **Colour L value**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	660.631[a]	5	132.126	16.096	.000
Intercept	155077.134	1	155077.134	18891.413	.000
Drying methods	439.750	2	219.875	26.785	.000
Cultivars	220.881	3	73.627	8.969	.001
Error	147.760	18	8.209		
Total	155885.525	24			
Corrected Total	808.391	23			

a. R Squared = .817 (Adjusted R Squared = .766)

Dependent Variable: **a value**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	11.566[a]	5	2.313	13.625	.000
Intercept	.005	1	.005	.030	.864
Drying methods	8.938	2	4.469	26.323	.000
Cultivars	2.628	3	.876	5.160	.009
Error	3.056	18	.170		
Total	14.627	24			
Corrected Total	14.622	23			

a. R Squared = .791 (Adjusted R Squared = .733)

APPENDIX 2 E. b value and Granule size

Dependent Variable: **b value**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	33.022[a]	5	6.604	20.426	.000
Intercept	1399.954	1	1399.954	4329.810	.000
Drying methods	14.899	2	7.450	23.041	.000
Cultivars	18.122	3	6.041	18.683	.000
Error	5.820	18	.323		
Total	1438.795	24			
Corrected Total	38.842	23			

a. R Squared = .850 (Adjusted R Squared = .809)

Dependent Variable: **Granule size**

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	679.667[a]	5	135.933	21.033	.000
Intercept	10584.000	1	10584.000	1637.639	.000
Drying methods	361.000	2	180.500	27.928	.000
Cultivars	318.667	3	106.222	16.436	.000
Error	116.333	18	6.463		
Total	11380.000	24			
Corrected Total	796.000	23			

a. R Squared = .854 (Adjusted R Squared = .813)

APPENDIX 3. One-way Anova Analysis

Solubility		Sum of Squares	df	Mean Square	F	Sig.
Pona	Between Groups	2.949	2	1.475	606.007	.000
	Within Groups	.007	3	.002		
	Total	2.957	5			
Dente	Between Groups	.072	2	.036	.111	.899
	Within Groups	.975	3	.325		
	Total	1.048	5			
Lilii	Between Groups	4.061	2	2.030	13.388	.032
	Within Groups	.455	3	.152		
	Total	4.516	5			
Matches	Between Groups	3.744	2	1.872	19.270	.019
	Within Groups	.291	3	.097		
	Total	4.036	5			

Swelling power		Sum of Squares	df	Mean Square	F	Sig.
Pona	Between Groups	.184	2	.092	612.111	.000
	Within Groups	.000	3	.000		
	Total	.184	5			
Dente	Between Groups	.777	2	.389	57.573	.004
	Within Groups	.020	3	.007		
	Total	.797	5			
Lilii	Between Groups	19.182	2	9.591	11.843	.038
	Within Groups	2.430	3	.810		
	Total	21.612	5			
Matches	Between Groups	4.350	2	2.175	5931.318	.000
	Within Groups	.001	3	.000		
	Total	4.351	5			

WBC		Sum of Squares	df	Mean Square	F	Sig.	**pH**		Sum of Squares	df	Mean Square	F	Sig.
Pona	Between Groups	1664.047	2	832.024	1608.241	.000	Pona	Between Groups	.037	2	.018	369.333	.000
	Within Groups	1.552	3	.517				Within Groups	.000	3	.000		
	Total	1665.599	5					Total	.037	5			
Dente	Between Groups	1708.132	2	854.066	3328.395	.000	Dente	Between Groups	.068	2	.034	684.000	.000
	Within Groups	.770	3	.257				Within Groups	.000	3	.000		
	Total	1708.902	5					Total	.069	5			
Lilii	Between Groups	317.350	2	158.675	443.516	.000	Lilii	Between Groups	.020	2	.010	196.000	.001
	Within Groups	1.073	3	.358				Within Groups	.000	3	.000		
	Total	318.424	5					Total	.020	5			
Matches	Between Groups	81.964	2	40.982	101.003	.002	Matches	Between Groups	4.050	2	2.025	20252.167	.000
	Within Groups	1.217	3	.406				Within Groups	.000	3	.000		
	Total	83.181	5					Total	4.051	5			

Amylose		Sum of Squares	df	Mean Square	F	Sig.	**Amylopectin**		Sum of Squares	df	Mean Square	F	Sig.
Pona	Between Groups	7.435	2	3.717	6.947	.075	Pona	Between Groups	7.446	2	3.723	1772.960	.000
	Within Groups	1.605	3	.535				Within Groups	.006	3	.002		
	Total	9.040	5					Total	7.453	5			
Dente	Between Groups	7.423	2	3.711	1.390	.374	Dente	Between Groups	7.482	2	3.741	1.404	.371
	Within Groups	8.010	3	2.670				Within Groups	7.993	3	2.664		
	Total	15.433	5					Total	15.475	5			
Lilii	Between Groups	7.464	2	3.732	3.514	.164	Lilii	Between Groups	7.441	2	3.720	7.124	.073
	Within Groups	3.186	3	1.062				Within Groups	1.567	3	.522		
	Total	10.651	5					Total	9.007	5			
Matches	Between Groups	38.911	2	19.456	9.159	.053	Matches	Between Groups	49.916	2	24.958	11.815	.038
	Within Groups	6.373	3	2.124				Within Groups	6.337	3	2.112		
	Total	45.284	5					Total	56.253	5			

L value		Sum of Squares	df	Mean Square	F	Sig.	a value		Sum of Squares	df	Mean Square	F	Sig.
Pona	Between Groups	187.428	2	93.714	377.018	.000	Pona	Between Groups	2.025	2	1.012	809.813	.000
	Within Groups	.746	3	.249				Within Groups	.004	3	.001		
	Total	188.174	5					Total	2.028	5			
Dente	Between Groups	122.334	2	61.167	455.281	.000	Dente	Between Groups	1.812	2	.906	836.354	.000
	Within Groups	.403	3	.134				Within Groups	.003	3	.001		
	Total	122.737	5					Total	1.815	5			
Lilii	Between Groups	36.672	2	18.336	59.942	.004	Lilii	Between Groups	.549	2	.275	34.749	.008
	Within Groups	.918	3	.306				Within Groups	.024	3	.008		
	Total	37.590	5					Total	.573	5			
Matches	Between Groups	238.427	2	119.214	615.455	.000	Matches	Between Groups	7.396	2	3.698	61.138	.004
	Within Groups	.581	3	.194				Within Groups	.181	3	.060		
	Total	239.009	5					Total	7.577	5			

b value		Sum of Squares	df	Mean Square	F	Sig.
Pona	Between Groups	.462	2	.231	42.555	.006
	Within Groups	.016	3	.005		
	Total	.479	5			
Dente	Between Groups	9.361	2	4.681	285.116	.000
	Within Groups	.049	3	.016		
	Total	9.411	5			
Lilii	Between Groups	5.428	2	2.714	93.797	.002
	Within Groups	.087	3	.029		
	Total	5.515	5			
Matches	Between Groups	5.267	2	2.634	163.066	.001
	Within Groups	.048	3	.016		
	Total	5.315	5			

APPENDIX 4. Plates of different drying methods of yam slabs

APPENDIX 4 A. Open sun drying (OSD)

APPENDIX 4 B. Solar drying (SD)

APPENDIX 4 C. Adsorption drying at night

APPENDIX 5. Laboratory analysis of yam flour samples

APPENDIX 5A. Light microscope being used to view yam flour granules

APPENDIX 5 B. Gallenhamp Orbital Shaker being used to agitate samples