THE PRODUCTION OF YAM FLOUR

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CERTIFICATION

This is to certify that this project was carried out by ANYAOGU DANIEL CHINEDU with the registration number CHE/2008/163 in partial fulfillment of the requirement for the award of the Bachelor of engineering (B.Eng) in Chemical Engineering.

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DEDICATION

This project is dedicated to the lord almighty for his love, kindness, mercies inspiration, wisdom, understanding, and ever abundant grace. My humble and enviable parent, Dr. and Mrs. Anyaogu for their support and love all this years.

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ABSTRACT

The project dealt on the production of yam flour from yam chips. The yams were peeled and washed, 100grams samples coded sample A to G were subjected to two different drying conditions. Some were dried using the sun drying method while the others were dried through oven drying method kept at constant temperature of 50^0C, sodium bi-carbonate was added to some of the samples, all these were done to obtain a flour with the best colour and texture quality. From the results obtained, it was observed that sample B (yam boiled with sodium bi-carbonate and dried with oven) gave the best result and quality when tested with hot water, this was as a result of the drying condition used, the constant temperature maintained and the presence of the sodium bi-carbonate used which helped in achieving the result. Generally, the samples dried through the oven drying method at 50^0C gave better colour and result of the yam flour when tested with hot water more than other samples dried by sun drying and this was due to the stability in temperature in the oven drying method used.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Of The Study

Yam (dioscorea spp.) is a multi-species crop that originated principally from Africa and Asia before spreading to other parts of the world (Hahn *et al*.,1987). It belongs to the family of dioscoreae within the genus dioscorea and serves as a staple crop in west Africa.(Asiedu *et al*., 1992). There are many cultivars of yam, though only six are important as staple foods in the tropics. the economically important species grown are Dioscorea rotundata(white yam),D.alata (yellow yam),D.bulbifera (aerial yam), D.esculenta (Chinese yam) and D.dumenterum (trifoliate yam). Yam tubers which is the most important part of the plants can be stored longer than other root and tuber crops. This ensures food security even in times of general scarcity. Yam is the third most important tropical root and tuber crop after cassava and sweet potato (fu et al., 2005). West Africa is the leading producer of yam and grows over 90% of the worldwide production (40 tonnes fresh tuber/year) followed by the west Indians where Jamaica is the leading producer (FAOSTAT,2004). Nigeria is the world's largest producer of yams followed by Ghana, ivorycoast and togo (FAO,2003). Both fresh tubers and yam flour are now exported from Ghana and Nigeria to developed countries such as united kingdom and united states of America. These are mostly patronized by emigrants from growing regions according to the Nigerian export promotion council (NEPC) Nigeria realized N56 billion in 2007. Sustainable production and utilization of yam are important steps in enhancing food security and alleviatind poverty particularly in west Africa where it is estimated to provide more than 200 dietary calories each day for over 60 million people (Nweke *et al*.,1991., FAO 2002).

Yam is consumed in different forms,mainly boiled,fried or baked.tubers are often dried and milled into flour for various product,boiled yams,poundes yams and amala are the forms of yam mostly consumed in west Africa especially Nigeria and benin (Akissoe *et al*.,2001). Yam production faces many constraints among which are production cost (mainly planting material and labour cost),post-harvset losses(low yields). Water yam (Dioscorea alata) posses a higher multiplication ratio and tuber yields as well as better storability than the preferred indigenous species such as D.rotundata, D.alata is popular and prevalent abakaliki agro ecological zone of ebonyi state Nigeria where it is called 'Mbala or Noula' (igbo names) (Udensi *et al*.,2008) even though D.alata is also eaten boiled,it is less preferred to D.rotundata varieties. D.alata can also be processed into flour and reconstituted into fufu though generally D.alata contains less sugar and has an extended shelf-life (Raemackers,2001) which ensures availability in times of scarcity.it is also known for its high nutritional content,with crude protein content of 7.4%,starch content of 75-84% and vitamin C content of ranging from 13.0-24.7mg/100g (Osagie.1992).breeders are therefore kein to improve the food quality of the species as it has good agronomic characteristics.

1.2 STATEMENT OF THE PROBLEMS

The principal problem in yam production that has been identified is the high cost of seed yam, high labour requirement, diseases, pest as well as high post harvest losses(Orkwor 1998).another constraint to yam production is the limited processing technology. About 30% of harvested yam tubers are lost to waste. The bulkiness of fresh transport and low margins for both farmers and traders are thus a matter of serious concern in the urban market (Cooke *et al*.,1988).

During the processing of yam through sun-drying method,the problem encountered is the loss due to potential contamination of the product variability in drying time, rain damage and so on. Ohweever, D.alata fresh texture is usually not firm as the D.rotundata (white yam) and less suitable than other species for the preparation of the most popular food product from yam in the west Africa region(Wireko-manu *et al*.,2011).

Finally, during the production of flour from yam, in the western part of Nigeria (the yorubas), the yam flour produced which is called “AMALA” is normally brownish in colour and dark in nature, hence does not have a good quality and colour. Technologies therefore have been discovered to bring about the production of yam flour that has a high quality and a good colour and texture.

1.3 OBJECTIVE OF THE STUDY

1.3.0 MOTIVATION

The growing need for the variety of food in Nigeria has become a primary concern for the urban and rural households in Nigeria. In recent times, the concern has raised much researcher's interest to do related studies. As reported in many different studies around the world, food security is a common problem.

1.3.1 OBJECTIVES

The present study aims at carryout an experiment on fresh yams, optimize the drying parameters and investigate the effect of drying conditions on the quality of the yam. To result to this, the present study which will address particular issues food drying could stimulate producers, farmers, agriculturists, educational practitioners on the phenomenon of drying to enhance the quality of yams to solve past harvest losses.

1.4 SCOPE OE THE WORK

- To carryout drying experiment on fresh yams and optimize the drying parameters.
- To determine the effect of drying on the quality properties
- Process the yam samples into chips and carryout approximate analysis of the fresh and dried samples.
- Production of flour from the yam chips
- Compare flour samples in terms of colour and texture evaluation.

CHAPTER TWO

2.0 LITREATURE REVIEW

2.1 YAM

2.1.1 ORIGIN AND CULTIVATION OF YAM

Yam (dioscorea spp) in an annual or perennial tuber bearing and climbing plant belonging to the family of DIOSCOREACEAE. Some species of yam originated from Africa before spreading to other parts of the world while some originated from asia and have spread to Africa (Hahn *et al* 1987). Today, yams are growm widely throughout the tropics and they have a large biological diversity including more than 600 species worldwide (Burkill.,1960. Coursey.1967) but only six are widely cultivated in west and central Africa. These cultivated species are D.esculenta, D.alata, D.bulbifera, D.dumetorum, D.cagenensis and D.rotundata. wild types of yams also exist and may be used as food after undergoing processing during the hunger seasons (Telteh and Saakwa, 1994). A few yam species are also grown and used as health food and medicinal purposes (Albrecht and Mc carthy,2006). In the west Africa yam zone which Is the principal producer on global basis, D.rotundata, D.cagenensis and D.alata are commonly grown.

2.1.2 WATER YAM

Water yam (dioscorea alata) is also referred to as Asian greater yam and ten month yam (Martin, 1976). It is more important as food in west Africa and the caribbean than in asia and the America where it originated and also has been competing with the most important native species, D.roundata. it was introduced to Africa some hundred years ago from Malaysia through agriculturists and portugnese and Spanish seafarears,(Martin 1976) it is next to D.rotundata in terms of volume of production of extent of utilization. D.alata species is the highest yielding among the yam species and can store relatively longer that the other species (5-6 months) after harvest,D.alata is also known for its nutritional content with crude protein content of 7.4%, starch content of 75-84% and vitamin C content of ranging from 13.0 to 14.7mg/100g (Osagie,1992).

D.alata tubers have variable shapes, the majority being cylindrical,its tubers vary in numbers from one to five. The flesh of the tubers ranges in colour from white to purplish (FAO, 1994). The texture of its flesh is usually not firm as that of white yam and less suitable than other species for the preparation of most popular food product from yam (fufu and pounded yam especially in the west Africa region. However, it is reported that D.alata is a major staple food in cote‘d’ ivoire where it constitute about 65% of the yam owned in the country. (Orkwor, 1998).

2.2 AGRONOMIC CHARACTERISTICS OF YAM

Yam is a plant of the tropical climate and does not tolerate frosty condition (Coursey, 1967) it is grown and cultivated for its energy-rich tubers. And it is adaptable to fairly fertile soils and is suitable for inter-cropping with grains legumes such as cowpea, soya bean and variety of leafy vegetable. A well drained rich loamy soil however is the most favoured i.e for yam cultivation; yam requires a warm humid climate. However the crop possesses considerable drought. Resistance (IITA, 2009). Light intensity in known to affect growth and tuber formation. Short days between 10-11 hours promote tuber formation, while days longer than 12hours promote vine growth. This is usually the reason why yam vines are staked to ensure maximum interception of light by the leaves to promote yield (Coursey, 1982,Okezie,1987).

Traditionally, yams propagated vegetatively from whole tubers (seed yam) large tubers pieces (sets) or from minisets. The growth of yam starts with a sprout from the post dormant tubers (Passam.,1977,Onwueme,1978). Yams exibit a sigmoiodal growth pattern common to most annual plants. A period of slow growth during establishment is followed by phase of rapid exponential growth as the canopy reaches maximum area and finally growth rates decline as the canopy senesces(Solubo,1972).maturity has not been well defined in yam even though it is traditionally measured by dryness of vines (Okoli,1980). Osagie and Oputa (1981) also reported that the physiological stature of yam tuber as harvest may influence its storage period and food quality characteristics.

2.3 COMPONENT OF YAM

Yam tuber is the economically utilized part of the yam plant. Its chemical composition varies with species. It may vary due to the environmental condition of the places of cultivation(Onwueme.,1978). Yam is essentially a starchy food. its greatest single component is water accounting for about 65%-68% of the fresh weight. Carbohydrate on the other hand is the major component of the dry weight bases and second on the wet bases accounting for 20%-35% of the fresh weight (Dutta, 2003).

Most of the species contain carbohydrate which is mainly starch i.e. amylopectic branched chain starch exist in the cells in form of starch grains (Uguru.,1993). Sugar and protein are mainly in the quality of about 2-3% respectively with protein being mainly in sulphur containing amino-acid most of which are cost If the tuber is chilled (Purseglove, 1976). When cut, the tuber exudes mucilages and they are mostly glycoprotein containing the enzymes that help in the defence of the yam tubers under the soil against external attack or when injured (Asiedu,1992). Yam has small amount of alkaloids, vitamins and minerals like iron,phosphate.zins. alkaloids and steroids for examples dioscorine and diosgenien respectively are found in yam and they create a bitter taste which discourage pest from eating the tuber. This quantity could kill if taken in a large quantity in its raw state.

Table 1: Components Of Yam

COMPONENT	COMPOSITION
Moisture	70
Starch	28
Sugar	0.5
Fat	0.1-0.3
Crude protein	1.1-2.8
Crude fibre	0.66-1.4
Ash	0.7-2.1
Vitamin C	5-8mg/100g
Vitamin B1	0.09mg/100g
Vitamin B2	0.03mg/100g
Vitamin A	-

Source: Enwere (1998)

2.4 UTILIZATION AND PROCESSING OF YAM

By far, the greatest part of the world's yam crop is consumed fresh. Tuber utilization is mostly as boiled or pounded yam. For use in fresh form, tubers are stored between harvest. The use of yam tubers has been in home food with little industrial involvement. (Rasper and Coursey,1967). Changes in wholesomeness during storage include wound repair diseases and pest of stored tubers. Hence yam tubers are lost after 4-5 months of storage. drying of (ingured) tubers soon after harvesting and converting into slices or milling into flour as fufu ensure the availability of yams in various forms. Traditionally, processed yam product are made in most yam-growing area, usually as a way of utilizing tubers that are not fit for storage. Usually, fresh yam is peeled,boiled and pounded until a sticky elastic dough is produced (Coursey,1967; Osagie,1992).

The only processed yam product traditionally made at village level is yam flour. Except by the yoruba people in Nigeria, yam flour is regarded as inferior substitute for freshly pounded yam because it is often made from damaged tubers. Yam flour is favoured in the Yoruba area where the reconstituted food in known as amala (Akissoe *et al.*,2001). To a limited extent, yam flour is also manufactured in ghana where it is known as KOKONTE. The nutritional value of yam flour is the same as that of pounded yam.

2.4.1 Processing Of Yam Flour

The tuber are sliced to a thickness of about 10mm,more or less, depending on the dryness of the weather, the slices are parboiled and allowed to cool in the cooking water,the parboiled slices are peeled and dried in the sun to reduce the moisture content. The dried slices are then grounded in a wooden mortar and repeatedly sieved to produce a uniform texture. Today, small hand-operated or engine driven corn mills or flourmill are increasingly used. Treatment with sodium bisulphate is often used to prevent phenolic oxidation during drying which darkens the product especially with white guinea yam D.rotundata. (ukpabi, 2010) blanching in place of sodium bisulphate achieves similar results. The yam flour is redehydrated and reconstituted into fufu and eaten with soup containing fish,meat /or vegetables.

2.5 FLOUR

Flour is a powder which is made by grounding cereal grains, other seeds or root (like cassava). It is the main ingredient of bread which is a staple food for many cultures, making the availability of adequate supplies of flour a major economical and political issue at various times of history. Wheat flour is one of the foods in European, north America, middle eastern etc and is one of the defining ingredient in most of their styles bread and pastries. Maize flour has been important in Mesoamerica cuisine since ancient times and remains a staple in mexico and parts of central America. Rye flour is an important constituient of bread in much of central Europe. Yam flour is very evident in Africa and is used in the production of pounded yam, etc.

2.5.1 ETYMOLOGY

The English word for "flour" originally a variant of the word "flower". Both derived from the old French "fleur" or flour, which had the literal meaning of "blossom" and a figurative meaning of "finest". The phase "fleur de farine" meant "the finest part of the meal" since flour resulted from the elimination of coarse and unwanted matter from the grain during milling.

2.5.2 HISTORY

It was discovered around 6000BC that wheat seeds could be crushed between millstones to make flour. The Romans were the first to grind the seeds on cone mills in 1879,at the beginning of the industrial era, the first steam mill was exerted in London in the 1930s,some flour began to be enriched with iron, niacin, thiamin, and riboflavin in the 1940s,mills started to enrich flour and folic acid was added in the list in the 1990s.

2.5.3 COMPOSITION

Flour contains high proportion of starched, which are a subset of complex carbohydrate also known as polysaccharides. The kinds of flour used in cooking includes all purpose flour, self raising flour and cake flour including bleached flour. The higher the protein content, the harder and stronger the flour and the more it will produce crusty and chewy breads, the lower the protein content the softer the flour which is better for cakes and pie crusts.

2.5.4 BLEACHED AND UNBLEACHED FLOUR

Bleached flour also called “refined flour” has had the germ and bean removed and is typically referred to as “white flour” but is simply any refined flour with a whitening agent added.

Unbleached flour is simply flour that has not undergone bleaching and therefore does not have the colour of “white flour”. Example of this would be graham flour.

2.6 TYPES OF FLOUR

There are two types of flours, the wheat and non-wheat flour ground from tubers.

- **Wheat flour:** it is the most produced type of flour, Its varieties clean, white or brown or strong or hard If they have gluten content, they are called “soft” or “weak” flour content if the gluten content is low.
- **Acorn flour:** it is made from ground acorn and can be used as a substitute for wheat flour. it is used in the native American,Korean also use it in making dotorimule.
- **Cassava flour:** made from the roots of cassava plant in a purified form(pure starch),it is called tapioca flour.
- **Coconut flour:** made from ground coconut meat and has highest fiber content of any flour, having a very low concentration of digestible carbohydrate makes an excellent choice for those looking for restriction from carbohydrate intake.

- **Rice flour:** is a ground kernels of rice. It is used in western countries and especially for people who suffer from gluten intolerance, since rice does not contain gluten. Brown rice flour has higher nutritional value than white rice flour.
- **Sorghum flour:** made form grinding whole grain of sorghum plant. It is called jowar in India.
- **Potato flour:** often confused with potato starch, is peeled, cooked potato mashed mostly drum dried and ground potato flakes using the whole potato and thus containing the protein and source of fibres of the potato having an off-white slight yellowish colour. Dehydrated potatoes or instant mashed potatoes can also granular flakes. Potato flour is cold-water soluble. However, it is not used often as it ends to be heavy.
- **Potato flour:** obtained by grounding the tubers to pulp and removing the fibre and protein by water washing. Potato starch(flour) is very white starch powder used as a thickening agent. Standard(native) potato starch needs boiling to thicken in water,giving a transparent gel because the flour made from neither grain or legume,it is used as substitute for wheat flour in cooking by jews during Passover when grains are not eaten.

2.6.1 YAM FLOUR

Yam flour is produced by grinding dried yams into powder. A yam is hearty tuber does not have the sweet taste of sweet potato, but instead may have flavors that range from bland to earthly, slightly smoky in taste, or nutty and only moderately sweet.

The production process of producing instant yam flour is quite simple, it involves slicing, parboiling and milling of the product to yield flour. The machinery and equipment required for production can be sourced for locally though the promoter can also source the machine abroad.

2.6.2 HOW TO BUY FLOUR

Look for tightly sealed bag or boxes. Flours in torn packages or in open bins are exposed to air and insect contamination.

2.6.3 HOW TO STORE FLOUR

Flour must be kept cool and dry. All flour, even white flour, have a limited shelf life. Millers recommend that flours be stored not more than "6 months". The main changes that occurs is the oxidation of oils when flour is exposed to air. The result of this is rancid off flavors. During hot weather, store flour in the refrigerator. Flour should not be stored near soap powder, onions or other foods and product with strong odors.

Throw away flours if it smells bad, changes colour or is invested with weevils.

Yam tubers

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Peeling

↓

slicing

↓

washing and sulphiting in 0.1% Na & k meta bisulphate

↓

dicing and sulphiting

↓

steam blanching

↓

drying in conventional hot air oven at 50-60 degree centigrade

↓

Tempering

↓

Drying

↓

Milling

↓

Sieving and milling

↓

Instant yam flour

↓

Cooling

↓

Packaging

↓

Storage

Fig 1. Steps involved in the conversion of tubers into flour

Source: Enwere (1998)

2.7 DRYING

Drying involves the application of heat to vaporize the volatile substance (moisture) and some means of removing water vapor after its separation from the solid (Gupta and Jayamaran 2006). The drying process is a heat and mass transfer phenomenon where water migrates from the interior of the material being drying and to the surface from where it evaporates. Heat is transferred from the surrounding air to the surfaces of the wet material. A part of this heat is transferred to the interior of the wet material, causing a rise in temperature and formation of the water vapor, the remaining heat is utilized in the evaporation of the moisture from the surface (El-ghetany 2006), drying is one of the oldest method for the preservation of agricultural wet materials such as fruits and vegetables. Drying of agricultural wet materials enhances their storage life, minimizes losses during storage and saves shipping and transportation cost. (doymazzoos). The main objectives of drying are summarized as follows. (Sokhansany and Jayas 2006). A dry food wet material is less susceptible to spoilage caused by the growth of bacteria, molds and insects. The activity of many microorganism and insects is the inhibited in an environment in which the equilibrium relative humidity is below 70%, likewise the risk of unfavorable oxidate and enzymatic reactions that shorten the shelf-life of the food is reduced. Many favorable qualities and nutritional value of food may be enhanced by drying. Palatability is improved and likewise digestibility and metabolic conversion and increased. Drying also changes, colour, flavor, and often the appearance of the food item. The acceptance to the changes varies by the end user.

Packaging, handling and transportation of a dry wet material are easier and cheaper because of the weight and volume of the wet material are less in the dried form. A dry wet material flow easier than a wet material thus, gravity forces can be utilized for loading and unloading and short-distance handling. Food wet materials are dried for improved milling, mixing or segregation. A dry material takes far less energy than wet material to be milled. A dry material mixes with other material uniformly and less sticky compared to a wet material. Drying has also been used as a means of food sanitation, insects and other microorganism are destroyed during the application of heat and moisture diffusion.

2.7.1 DRYING BEHAVIOR

Apart from weather condition, the drying behavior of agricultural crop during drying depends on the (Bux, 2002)

- Size and shape
- Initial moisture content
- Final moisture content
- Product
- Bulk density
- Thickness of the layer
- Mechanical and chemical pre-treatment
- Turning intervals

- Temperature of the grain
- Temperature, humidity of air in contact with the grain
- Velocity of air in contact with the grain

2.7.2 GENERAL PRINCIPLE

Drying can be described as the process of thermally removing moisture to yield a solid dry material. Moisture can be found as bound or unbound in the wet solid. Moisture, which exerts a vapor pressure less than that of pure liquid is called bound moisture while moisture in excess of bound moisture is called unbound moisture. When a wet solid is subjected to thermal drying, two processes occur simultaneously.

1. Transfer of energy (mostly heat) from the surrounding environment to evaporate the surface moisture.
2. Transfer of internal moisture to the surface of the solid and its subsequent evaporation due to process 1 above.

Energy transfer as a heat from the surrounding environment to the wet solid can occur by convection, conduction or radiation and in some case as a result of a combination of these effects. In most cases heat is transferred to the surface of the wet solid and then to the interior. However, the die-electric, radio frequency (RF), or the microwave freeze drying, energy is supplied to generate heat internally within the solid and flows through the external surface in process 1 above, the removal of water as vapor from the material surface depends on the external conditions of temperature, humidity, and velocity of the air, area of exposed air and pressure. In the process 2, the movement of moisture internally within the solid is a function of the physical nature of the solid, the temperature and its moisture content, in drying operation, anyone of these processes can be a limiting factor governing the rate of drying, although they both proceed simultaneously throughout the drying cycle. During a complex operation involving transient transfer of heat and mass along with several rate processes, such as physical and chemical transformation which in turn may cause changes in wet material quality as well as the mechanism of heat and mass transfer. Physical changes that may occur include shrinkage, puffing, crystallization and glass transition in some cases desirable or undesirable chemical or biochemical reactions may occur leading to changes in colour, texture, odor or other properties of solid wet material. Drying occurs by affecting vaporization of the liquid by supplying heat to the wet feedstock. Heat may be supplied by convection (direct dryers), conduction (contact or indirect dryers), radiation or volumetrically by placing the wet material in a microwave or RF electron magnetic field. Transport of moisture within the solid may occur by any one or more of the following mechanism of mass transfer.

1. Liquid diffusion, if the wet solid is at a temperature below the boiling point of the liquid.
2. Vapor diffusion. If the liquid vaporizes within the material.
3. Knudsen diffusion, if the drying takes place at a very low temperature and pressure e.g. in freeze drying.

4. Surface diffusion (possible although not proven), hydrostatic pressure differences, when internal vaporization rate exceeds the rate of vapor.
5. Transport through the solid to the surrounding, combination of the above mechanism. Since the physical structure of the drying solid is subject to change during drying, the mechanism of the moisture transfer may also change with elapsed time of drying.

2.7.2.1 EXTERNAL CONDITIONS

The essential external variables are temperature, humidity, velocity and direction of air, the physical form of the solid, the desirability of agitation and the method of supporting the solid during the drying operation.

External drying operations are especially important during the initial stages of drying when unbound surface moisture is removed in certain cases, for example, in material like ceramics and timber in which considerable shrinkage occurs, excessive surface evaporation after the initial free moisture have been removed sets up high moisture gradients from the interior to the surface. This is liable to the cause over drying and excessive shrinkage and consequently high tension within the material, resulting in cracking and war ping. In these cases, surface evaporation should be retarded through the employment of high air relative humidity while maintaining highest safe rate of internal moisture by heat transfer, surface evaporation is controlled by diffusion of vapor from the surface of the solid to the surrounding atmosphere through a thin film of air in contact with the surface since drying involves the inter-phase transfer of mass when the gas is brought in contact with a liquid in which it is essentially insoluble. It is necessary to be familiar with the equilibrium characteristics of the west solid; also, since the mass transfer is usually accomplished by the simultaneous transfer of heat, due consideration must be given to the enthalpy characteristics.

2.7.2.2 INTERNAL CONDITIONS

As a result of heat transfer to a wet solid, a temperature gradient develops within the solid while moisture evaporation occurs from the surface, this produces a migration of moisture from within the solid to the surface which occurs through one or more mechanism, namely diffusion, capillary flow, internal pressures setup by shrinkage during drying and in the case of indirect (conduction) dryers, through a repeated and progressive occurring vaporization and recondensation of the moisture to the exposed surface an appreciation of this internal movement of moisture is important when it is the controlling factor, As it occurs after the critical moisture content, in a drying operation carried to low final moisture content. Variables such as air velocity and temperature which normally enhances the rate of surface evaporation are the decreasing importance except to promote the heat transfer rates longer residence time and where permissible higher temperature become necessary. Temperature gradient set up in the solid will also create a vapor-pressure gradient which will in turn result in moisture vapor diffusion to the surface, this will occur simultaneously with liquid moisture movement.

2.7.2.3 DRYING MECHANISM

Moisture in solid can either be bound or unbound. There are two method of removing unbound moisture evaporation and vaporization. Evaporation occurs when the vapor pressure of the moisture of the solid surface is equal to atmospheric pressure. This is done by raising the temperature of the moisture to the boiling point. The boiling point where evaporation takes place is the temperature which could be lowered by the pressure if the dried material is sensitive to heat further, in vaporization, convection drives the drying by the means of the heat transfer from pressing warm air through the wet material while the temperature of the warm air decreases, the specific increases because of the moisture content of the wet material. Drying behavior of the solid can be described by measuring the function of the moisture content versus time. Continuous weighing humidity difference and intermittent weighing are the used method (Mujunda 2006).

In the drying process, two drying period generally occurs as the initial constant-rate period and falling rate period. Constant rate drying occurs with evaporation of pure water. Moisture-movement is controlled by internal resistance in the falling rate period. In the beginning, the solid usually at a colder temperature than its ultimate temperature. During the constant rate period, the surface of the solid is initially very wet and a continuous film of water exists on the drying surface. This water is entirely unbound water that acts as if the solid were not present. The rate of evaporation under the given aim condition is independent of the solid and essentially the same as the rate from the free liquid surface (Gean koplis 1993). The transition moisture content at which the departure from the constant rate drying is first noticed is termed the critical moisture content indicated by point C at the point there is insufficient water on the surface too maintain a continuous film of water in the food system, where liquid movement Is likely to be controlled by capillary and gravity forces, a measurable constant rate period is found to exist with structured food, liquid movement is by diffusion and therefore the water that is evaporated from the surface is not immediately replenished by movement of liquid from the intern of the food. Such food are likely to dry without exhibiting any constant rate period. Finally, the vapor pressure of the solid becomes equal to the partial vapor pressure of the drying air and no longer further drying occurs. The limiting moisture content at this stage to which a material can be dried under a given drying condition is referred to as the equilibrium moisture content.

2.7.3 DRYING TECHNIQUES AND DRYERS

There are several types of dryers and drying method, each better suited for a particular situation are commercially used to remove moisture from a wide variety of fruits and vegetables. Conventional drying process ranges from natural sun-drying to industrial drying (Leon *et al* 2002). Some of the most common types of drying processes and dryers are introduced in the following sections:

- **Sun drying:** sun drying has the advantages of simplicity and a small capital investment. On the other hand, there are many technical problems which are uncertainties like rain and cloudiness, contamination from outer sources and lack of control over drying condition. It requires large areas and long drying time. The final wet material may be contaminated from dusts and insects and suffer from enzyme and microbial activity. It is limited to climates with hot sun dry atmosphere with strong winds. In any case of drying, economically feasible drying should be fast.

- **Hot air drying:** in this method, heat air is brought into contact with wet material to be dried to facilitate heat mass transfer, convection is mainly involved. Two important aspects of mass transfer are the transfer of water to the surface of the material that is dried and the removal of water vapor from the surface. The hot air dryers generally used for drying a piece-form fruits and vegetables are cabinet, kiln, tunnel, belt-trough, bin, pneumatic and conveyor dryers. Energy source to heat the air would be electrically or renewable energy resource such as solar and geothermal energy. At solar dryers, solar radiation is consumed by air and heated air is ducted in the drying chamber.

- **Cabinet dryer:** a cabinet dryer can be a small batch tray dryer. Heat from the drying medium to the wet material is transferred by convection. The convection current passes over the wet material, not through the wet material. It is suitable for drying of fruits, vegetables and meat and its wet material. The main feature of a cabinet dryer is its small size and versatility. The main problem with cabinet dryer is difficulty in even distribution of heated air over or through the drying material.
- **Tunnel dryer:** the tunnel dryers are of many different configurations in general having rectangular drying chambers. Tunnel dryers basically a group of truck and tray dryers widely used due to their flexibility for the

large scale commercial drying of various types of fruits and vegetables. Truckloads of the wet material are moved at intervals into one end of the tunnels. The whole string of truck is periodically advanced through the tunnel until these are removed at the other end of the tunnel. Air movement, circulation, and heating method vary in tunnel dryers. Three different flow arrangements are counter flow, parallel flow, and combined flow. These dryers are simple and versatile in comparison with other types of dryers. Food pieces of any shape and size can be handled. If the solid trays are incorporated fluids can also be dried.

- **Bell-trough dryer:** belt-trough dryers are agitated bed, through flow dryers used for the drying of cut vegetables of small dimension. They consist of the metal mesh belts supported on two horizontal rolls; a blast of hot air is forced through the bed of material on the mesh, the belts are arranged in such a way to form an inclined trough so that wet material travels in spiral path and partial fluidization is caused by an upward blast of air.
- **Pneumatic conveyor dryer:** pneumatic conveyor dryers are generally used for the final drying of powders or granulated materials are extensively used in making of potato granules. The feed material is introduced into fast moving stream of heated air and conveyed through ducting of sufficient length to bring about desired drying. The dried material is separated from the exhaust air by a cyclone or filter.
- **Fluidized bed dryer:** the fluidized bed the type of dryer was originally used for the final drying of potato granules. In fluidized bed drying, hot air is forced through a bed of food particles at a sufficient high velocity to

overcome the gravitational forces on the wet materials. A major limited range of particle that can be effectively fluidized.

- **Microwave drying:** in microwave drying, the wet material is exposed to very high-frequency electromagnetic waves. The transfer of these waves to the wet material is similar to the transfer radiant heat. The advantages of using microwave energy are penetrating quality, which effect a uniform heating of materials upon which radiation impinges; selective absorption of the radiation by liquid water; and capacity for easy control so that heating may be rapid if desired.
- **Spray drying:** the spray drying method is most important for drying liquid food wet materials and has received much experimental study. Spray drying by definition is the transformation of a feed from liquid state to a dried form by spraying into a hot, dry medium. In general it involves atomization of the liquid into spray and contact between the spray and the drying medium, followed by separation of dried power from the drying medium.
- **Freeze drying:** freeze-drying, which involves a two-stage process of first freezing of water of the food materials followed by the application of heat to the wet material so that ice can be directly sublimed to vapor, is already a commercially established process. The advantages of freeze-drying are; shrinkage is minimized; movement of soluble solid is minimized; the porous structure of the wet material facilities rapid dehydration; and retention of the volatile flavor compounds is high.
- **Osmotic dehydration:** osmotic dehydration is a water removed process that consists of placing foods, such as pieces of fruits or vegetables, in

hypertonic solution. As this solution has higher osmotic pressure and hence lower water activity, driving force for water removal arises between solution and food, whereas the natural cell wall acts as a semi permeable membrane. Direct osmotic dehydration is therefore a simultaneous water and solute diffusion process.

2.7.4 MODELING OF DRYING CURVE

For every product, there is a representative curve that describes the drying characteristics for the product of a specific temperature. Velocity and pressure conditions. This curve is referred to as the drying curve for a specific product. Fig 2.1 shows a typical drying curve. Variation in the curve will occur principally in relative rate to carrier velocity and temperature. Drying occurs in three different periods, or phases, which can clearly be defined.

The first phase, initial period, is where sensible heat is transferred to the material and the contained moisture. This is the heating up of the material from the inlet condition to the process condition, which enables the subsequent process to take place. The rate of evaporation increases dramatically within the period with mostly free moisture being removed. In some instances, pre-processing can reduce or eliminate this phase. For example, if the feed material is coming out from a reactor or if the feed material is pre-heated by a source of waste energy, the inlet condition of the material will already be at a raised temperature.

The second phase, or constant rate period, is when the free moisture persists on the surface and the rate of evaporation alters very little as the moisture content reduces. During this period, drying rates are high and higher inlet air temperature than in subsequent drying stages can be used without effect to the product. There is a gradual and relatively small increase in the product temperature during this period.

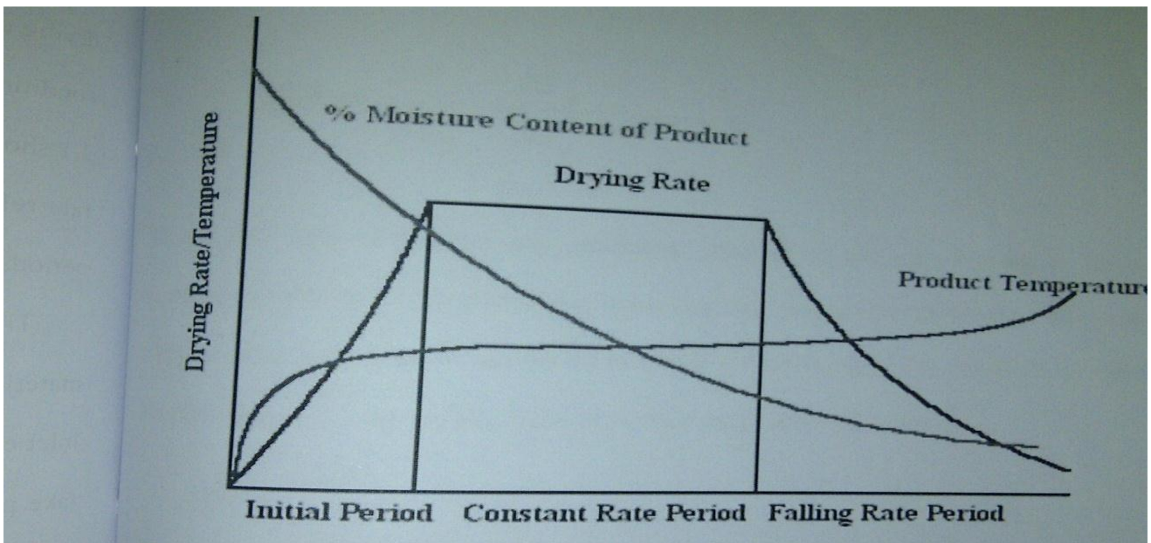

Fig 2.1; Drying Curve

Interestingly, a common occurrence is that the time scale of the constant rate period may determine and affect the rate of drying in the next phase.

The third phase or the falling phase during the migration of the moisture from the inner interstices of each of the particle to the outer surface becomes the limiting factor that reduces the drying rate.

2.7.4.1 MATHEMATICAL MODELING OF DRYING CURVES

The moisture ratio (MR) of the yam drying experiment was calculated

Using the following equation

$$MR = \frac{M_d - M_e}{M_0 - M_e}$$

Where M, Mo, and Me are moisture content at any drying time, intial and equilibrium moisture content (kg water/kg dry matter), respectively. The values of Me are relatively little compared to those of M or Mo, the error involved in the simplification is negligible, thus moisturing ratio was calculated as:

$$MR = \frac{M_d}{M_0}$$

For drying model selection, drying curves were fitted to nine well known drying models which are given in table 2.1

Table 2.1

Mode no.	Model name	Model
1	Newton	$MR = \exp(-kt)$
2	Aghbashlo et al	$MR=\exp(-k_1t/1+k_2t)$
3	Page	$MR = a\exp(-kt)$
4	Henderson and Pabis	$MR = \exp(-kt^n)$
5	Logarithmic	$MR = a\exp(-kt)+c$
6	Tow term	$MR = a\exp(-k_0t)+b\exp(-k_1t)$
7	Wang and Singh	$MR = 1+ at+ bt2$
8	Modified Henderson and Pabis	$MR=a\exp(-kt)+b\exp(-gt)+c\exp(-h$
9	Midilli et al.	$MR = a\exp(-kt^n)+bt$

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2.8 WEIGHING MACHINE

Scaling weighing or balance weighing, mechanical or electronic device is commonly used in households, scientific laboratories, business, and industry to measure the or mass of an object or substance was used in weighing the sliced yam before it was due for any application used. This is a simplest weighing mechanism is the equal-arm balance. An equal-arm balance consist of a bar with two pans hanging from each end a support (called a fulcrum) at the centre of the bar upon which the bar can balance. The Egyptians used a balance of this type about 2500BC to weigh the kilograms of sweet potato before storage, to know the weight of each after storing for a long period of time. To use this, an equal-arm balance, an object of unknown weight is placed in one of the pans, and objects of known weight are added to the other pan until the bar holding the pan is balanced; then the weight of the unknown load is the same as the known weight in the other pan.

Modern balance that uses the same principles as the equal-arm balance and the steelyard can make very precise weight measurements. Precision balances used in specific laboratories can measure the weight of small amounts of material down the nearest 1 millionth of a gram (3.53 hundred million of an ounce). Such weighing devices are enclosed in a glass or plastic to prevent wind drafts and temperature variations from affecting the measurements.

CHAPTER THREE

3.0 METHODOLOGY

The experiment was carried out to study the effect of the different drying method on the quality, colour and texture of the yam samples to used to obtain the yam flour and also to know and determine the effect of the drying parameters e.g. temperature, moisture content on the white yam(dioscorea rotundata).

3.1 MATERIALS AND REAGENTS

The white yam were purchased from ogbete market in enugu town,enugu state. The electrical oven used was obtained from caritas university amorji nike, enugu state.

The reagents used were water (H_20) and sodium bi-carbonate (baking powder)

3.2 EQUIPMENTS USED

The following equipments were used for the experiment carried out:

- An electrical drying oven
- A electrical heating mantle
- A sieve
- Beaker
- Spoon
- Knife
- Petri-dishes for drying

- An electrical electronic scale
- Polythene bag
- A bowl
- A manual grinder

3.3 PROCEDURE

The white tubers were washed, peeled and rewashed then sliced to about 2mm thickness, weighed and washed again. The sliced yams were now separated into different samples. Each of them was weighed using an electronic scale and 100grams of each of the different samples were separated.

Sample A was boiled in a beaker using 250ml of water and was dried in an oven afterwards. Sample B were boiled with 250ml of water and 5grams of bi-carbonate and dried in an oven afterwards. Sample C was soaked in 250ml of water over night and dried with the sun drying method. Sample D was soaked in 250ml of water and 5grams of bi-carbonate was added to it and was dried with an oven afterwards. Sample E was dried directly using sun drying method. Sample F was soaked overnight in 250ml of water and 5grams of bi-carbonate was added to it and was dried through sun drying. Sample G was boiled with 250ml of water with 5grams of bi-carbonate added to it and was sun dried afterwards.

The general processes used are summarized below:

YAM TUBER

↓

PEELING(WITH SHARP KICTHEN KNIFE)

↓

WASHING (WITH CLEAN WATER)

↓

SLICING (TO 2mm THICKNESS)

↓

SOAK IN (5GRAMS OF HCO_3)

↓

DRAINING (OF WATER AND SODIUM BI-CRABONATE)

↓

DRYING

↓

MILLING

↓

SEIVING

↓

YAM FLOUR

Figure 2. YAM FLOUR PROCEESING FLOW DIAGRAM

The experiment were carried in two different drying methods, the first was through an electric oven kept at a constant temperature of 50 degrees for the various samples being dried. 100grams of each of the samples were sliced and dried in the oven. An electric oven dryer was used and it had an automatic control system to regulate the temperature. Before starting the experiment, the oven was thoroughly cleaned and the various samples were introduced into the oven and the heating element turned on to supply the required temperature which was kept constant and was monitored closely to avoid alteration and instability. The drying lasted for about 2-3days due to a little bit of instability of electrical supply.

The other type of drying process used was sun drying and it lasted for about 4-10days for samples due to the instability and fluctuations in weather and heat supply from the sun.

3.4 DETERMINATION OF MOISTURE CONTENT

The moisture content of the samples was determined using the hot oven method of AOAC (2010). Two grams of each of the samples was put into a washed and dried crucible and placed in the oven at temperature 50 degrees until the weight was constant. The samples were cooled and weighed. The weight loss was obtained as moisture content and was calculated as:

$$\%\text{MOISTURE CONTENT} = \frac{W_2 - W_3}{W_2 - W_1}$$

WHERE

W_1=Initial weight of empty crucible

W_2= weight of crucible + sample before drying

W_3=final weight of crucible + sample after drying

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 EFFECT OF TOTAL TIME ON THE DRYING YAM SAMPLES

The drying characteristics of the various yam samples varied according to the drying conditions. The rates were analyzed as total drying time. The total drying time to reduce the moisture content of the samples from approximately 90% dry weight to 10% dry weight basis varies for the different samples depending upon the operating conditions, drying time varied from 2-3days for the samples dried using an oven and 4-10 days for the other samples dried using sun drying method due to some fluctuations in weather and electrical supply for both methods.

TOTAL DRYING TIME (DAYS) TO DRY THE VARIOUS SAMPLES TO APPROXIMATELY 10% UNDER DIFFERENT DRYING CONDITIONS.

SAMPLES	**BATCH SIZE(grams)**	**TIME (days)**	**MOISTURE CONTENT AT TEMP. 50-60 DEGREES**
SAMPLE A	100	2	75.0
SAMPLE B	100	3	80.5
SAMPLE C	100	5	75.4
SAMPLE D	100	3	83.6
SAMPLE E	100	4	75.0
SAMPLE F	100	10	79.0
SAMPLE G	100	9	76.2

It was observed that the total drying time upon the various samples varied due to the drying condition used and the fluctuations in the weather which made it very difficult for the temperature of the sun to be determined during the experiment.

For sample A (yam boiled and dried in oven at 50^0C), it took a shorter time for the sample to dry and the moisture content in it was a little bit lower when compared to other samples.

For sample B (yam boiled with sodium bi-carbonate and dried with oven at 50^0C),it was observed it took a greater time to dry in the oven at the temperature of 50^0C and it gave a better result more than sample A earlier seen and the other samples.

For sample C (yam soaked in water over night and sun dried), it also took a longer time to dry due to the fluctuation in the temperature and instability of the weather and had a lower moisture content.

Sample D (yam soaked in sodium bi-carbonate overnight and dried in the oven at 50^0 C) took a shorter time to dry when compared to sample C and that was due to a little bit of stability in the temperature used in the oven.

Sample E (yam peeled and dried directly in sun) took a shorter time to dry due to the low moisture content in it when compared to others boiled and soaked which had greater moisture content.

Sample F (yam soaked in sodium bi-carbonate overnight and sun dried) took a longer time greater than other samples to dry, this was due to the fact that it contained greater and higher moisture content and also due to the soaking with sodium bi-carbonate, the instability in the weather and heat supply in the sun also contributed to the result gotten.

Sample G (yam boiled with sodium bi-carbonate and sun dried) took a greater time to dry also due to the temperature instability and heat supply from the sun, also its moisture content was lower when compared to samples B, D, E AND F.

Generally it could be observed that the oven drying method gave more of the better result in the total time of drying and this was due to the stability in the constant temperature provided by the oven utilized for the drying operations.

4.2 EFFECT OF BATCHSIZE ON THE DRYING TEMPERATURES

The typical effect of the batch size at temperature 50-60degrees show that the drying rate increases with very significant decrease in batch size. At 100grams of the batch size used, it is noticed that it reduces by 43%.

TIME(days)	BATCH SIZE(grams)	MOISTURE CONTENT AT TEMP. 50-60 DEGREES
SAMPLE A	100	75.0
SAMPLE B	100	80.5
SAMPLE C	100	75.4
SAMPLE D	100	83.6
SAMPLE E	100	75.0
SAMPLE F	100	79.0
SAMPLE G	100	76.2

4.2.1 REHYDRATION CHARACTERISTICS

The shape and sizes of the sliced yam samples differed significantly from the fresh ones due to shrinkage resulting from the removal of large quantities of water.

4.3 COLOUR

Colour is an important quality parameter for the dried processed yam flour, the basic aim of the experiment was to subject the different samples to different drying conditions at specified temperature to ascertain the best method that could give flour with the best colour (white), texture and quality. Generally the browning of the material is more pronounced in higher temperatures. The various samples of the yam flour had different colours due to the drying conditions they were subjected to.

For sample A, it was observed that the flour samples after been processed were looking a little bit brownish in colour due to the effect of the oven drying method used and its colour changed from its original white colour and it never gave the desired result.

For sample B, the flour was looking whitish and it gave a best colour and result when compared to other samples, this was due to the fact that the temperature was kept constant and also due to the presence of the sodium bi-carbonate in it which helped in making the colour change possible. Sample B actually gave the desired result i.e. fine texture, white colour yam flour and generally a good quality when tested with hot water.

Sample C gave a brownish colour due to the effect of the sun drying method used on the sample and the instability in the temperature used.

Sample D gave a better result close to that of sample B, although its colour was not as bright as that of sample B, it was close to the desired product, the presence of sodium bi-carbonate and the oven drying method used helped in making all this possible.

For sample E, a totally dark brown colour was observed when tested with hot water although it had a good texture it never gave the desired result.

Sample F of the flour gave a dark brown colour result, although it also had a good texture, it never gave the desired result.

For flour sample G, it was observed that the colour of the flour when tested with hot water was darkish. It never gave a good texture, quality and result.

Generally from observations, it was seen that flour sample B (yam boiled with sodium bi-carbonate and dried with oven) gave a better result, a good texture, colour, and quality when tested with water when compared with other samples, this was possible as a result of the constant temperature oven drying method used and kept at constant temperature and the presence of the sodium bi-carbonate which it was boiled with which helped in preventing it from turning brown as seen in other samples earlier.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This project work was undertaken to experiment the effect of the different drying conditions on the quality, texture and colour of the yam flour.

A fully developed yam of marketable grade variety were acquired from ogbete main market in enugu state. The yams were cut and sliced to 2mm thickness and were separated into different samples ranging from sample A-G,the samples were dried from moisture content of 90% (w.b) to the final moisture of 10% (d.b).

The project were performed with an oven drying method of which the oven was kept at constant temperature of 50^0C (degrees) which was also monitored to avoid alteration and also the sun drying method was used and the temperature was indeterminable.

The focus were on the effect of the drying temperature, moisture content and batch size on the quality and colour of the yam flour.the drying characteristics and the quality of the processed yam flour were analyzed, the total drying time to reduce the moisture content of the yam samples approximately from 90%(w.b) to 10% (d.b) for processing of the yam flour were also established.

From the result gotten, it was observed that the oven method of drying though not really stable gave a better result on the samples it was used for other than the sun drying method whose temperature could not be determined. Also the effect of the sodium bi-carbonate used on some of the samples was seen as it gave a better colour and result when compared to the other samples it wasn't used for. Finally, sample B which was yam boiled with sodium bi-carbonate and dried through the oven drying method at constant temperature of 50 degrees gave a best result, quality and colour when tested with hot water more than the other samples and this was as a result of the drying condition used and the presence of bi-carbonate in it which helped in achieving a flour with a brighter colour and better and quality.

5.2 RECOMMENDATIONS

From the experiment carried out and the results gotten, it could be seen that temperature variation had a great effect on the colour and quality of processed yam flours. To achieve a better and more acceptable result, the temperature should be kept low, constant and should be monitored closely to avoid alteration which might result in a poor quality of yam flour gotten as seen in the sun drying method used.

Also further studies should be carried out on the best chemicals which can be added to the yam samples to achieve better quality and result of flour. To make the results gotten more accurate, electricity supply should constant be during the time of the experiment as a instability of the supply might affect the drying time and the colour generally of the yam flour.

Finally based on the results of the study, studies should be carried out on how to improve on the colour, quality and nutritional value of the product.

REFERENCES

Adeleke, R. O., & Odedeji, J. O. (2010*). Functional Properties of Wheat and Sweet Potato Flour Blends*. Pakistan book of Nutrition, 9: 1775-1991.

Aghbashlo, M., & Kianmehr M.H. (2008) *Influence of Drying Condition on Wet Material*. Istbul: Highlander Press.

AOAC. (1984). *Official Method of Analysis of Wet material*. Washinton DC: Analytical Chemist Press.

Barbosa, D.C. (1993). *Concept of Drying Basis in Industries*. London: long man Publisher.

Burkill, I.H. (1960). *The Organography and Evolution of Dioscoreeaceae*, *the family of the yams*. Journal of Linnean Society of London, Botany 56: 319-412.

Coulson , J.M., & Richardson J. (2003). *Separation of Particle* Volume 6. India: Elsevier publisher.

Dutta, B. (2001). Economic Botany. Pp. 238 London, print.

Enwere, N.J. (1998). *Food of Plant Origin*. Afro-Orbis Publication Limited, Nsukka.

FAO (2003*). Production statistics*. Food and Agricultural Organisation, Rome, 48: 256.

Guarte, R.C. (1996). *Principle of Drying methods*. Stuttgart: Hohenheim University Press.

Holloman, A.F. (2000*). Inorganic Chemistry*. San Diego: Academic Press

Owueme, I.C. (1978). *The Tropical Tuber Crops*. John Wiley and Sons. Chichester, pp. 234-240

Pyke, M. (1981). *Food science and technology*. Some Modern technological processes (4th edition). John Murray London, 9: 217-219, 3: 73.

APPENDIX A

NOMENCLATURES AND DEFINITION OF TERMS

D.b--drying weight basis

W.b--Wet weight basis

A--constant, dimensionless

K--Drying rate constant, s-1

t--time of drying, s

Kg--kilograms

g--grams

Mathematical modeling

$MR=(M_d-M_E)/M_o-M_e)$, where M_d is the moisture content at each drying time, M_e and M_o is the final moisture and MR is the moisture ratio.

Mathematical modeling used:

1. NEWTON MODEL MR= exp(-kt)
2. AGBHBASHLO et al MR=exp(-k1t)/(-kt2)
3. WANG AND SINGH MR= 1+ at + bt2

Where t= drying time (hr), k empirical coefficient in the drying model(h-1), a,b,c, n: empirical constants in drying mode.

APPENDIX B

CALCULATION OF MOISTURE CONTENT

The moisture content was recorded in percentage dry weight basis and it was calculated using the equation:

$$\%\text{Moisture content} = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

WHERE

W_1= weight of crucible

W_2= weight of crucible + sample before drying

W_3= final weight of crucible + sample after drying

For sample A, moisture content = $\frac{105-30}{105-5} \times 100 = 75\%$

For sample B, moisture content= $\frac{110-25}{110-5} \times 100 = 80.5\%$

For sample C, moisture content= $\frac{127-35}{127-5} \times 100 = 75.4\%$

For sample D, moisture content= $\frac{115-23}{115-5} \times 100 = 83.6\%$

For sample E, moisture content= $\frac{100-25}{100-5} \times 100 = 75\%$

For sample F, moisture content= $\frac{110-26.7}{110-5} \times 100 = 79\%$

For sample G, moisture content= $\frac{110-30}{110-5} \times 100 = 76.2\%$