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**KUMASI**

**COLLEGE OF AGRICULTURE AND NATURAL RESOURCES**

**FACULTY OF AGRICULTURE**

**DEPARTMENT OF HORTICULTURE**



# ASSESSMENT OF THREE DIFFERENT DRYING TECHNOLOGIES (SUN, SOLAR AND BIN) USED FOR THE PRODUCTION OF CASSAVA (*Manihot esculenta* Crants) CHIPS IN GHANA

**BY**

**BENJAMIN BENTIL**

**SEPTEMBER, 2011**

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**A THESIS SUBMITTED TO THE SCHOOL OF RESEARCH AND GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (MSc. POSTHARVEST TECHNOLOGY) DEGREE**

**BY**

**BENJAMIN BENTIL**

**SEPTEMBER, 2011**

## DECLARATION

I hereby declare that, except for specific references which have been duly acknowledged, this project is the result of my own research and it has not been submitted either in part or whole for any other degree elsewhere.

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# DEDICATION

To the glory of God Almighty

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# ABSTRACT

An experiment was conducted to assess three different drying technologies (sun, solar and bin) used for the production of cassava (*Manihot esculenta* Crants) chips in Ghana. The study was conducted at Caltech Ventures Limited, Hodzo – Ho, and the CSIR - Food Research Institute (FRI) in Accra in January, 2011. Parameter studied included moisture content, pH, total titratable acidity, starch yield, bulk density and pasting characteristics. From the results, bin drying at 4kg loading density had the lowest moisture content of 6.77%. pH value of 6.38 were recorded for bin drying at loading density of 2kg and 4kg respectively. The lowest total titratable acidity of 0.24 was recorded for 2kg loading density under bin and sun drying while solar drying was at 3kg loading density. The starch yield of the cassava flour was higher in the sun drying (67.74%) than bin drying. Loading density of 2kg under sun drying had the highest starch yield of 69.46%. Bulk density of the flour was high in bin drying (0.74g/cm$^3$). Pasting characteristics of the flour showed that cooking temperature of the flour was lowest in bin drying (67.93$^o$C). The cassava flour from sun drying technology had the highest final viscosity of 289.78BU. Loading density of 2kg recorded the highest final viscosity of 278.44BU. Solar drying at 4kg loading density also resulted in the highest final viscosity of 293.44BU. Bin drying at 4kg loading density recorded the highest breakdown of value 413.00BU. Among the technologies, the highest setback value of 108.22BU was recorded by the cassava flour produced by bin drying technology. Bin drying at 2kg loading density also recorded the highest setback value of 121.33BU. Generally, drying using sun and solar technologies produced flours of acceptable pasting qualities suitable for industrial use.

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# CHAPTER ONE

## 1.0 INTRODUCTION

Cassava is one of the most important crops grown in the tropics and a major carbohydrate staple. It is the third most important source of calories in the tropics after cereal crops (FAO, 2008). World production of cassava is estimated at 242 million tonnes, of which 54% (130 million tonnes) is produced in Africa. West Africa alone contributes about 68 million tonnes, equivalent to 52% of production. Ghana is the third African producer, after Nigeria and the Democratic Republic of Congo with a yearly production of approximately 10 million tonnes representing 8% of total cassava production on the continent (FAO Food Outlook, 2009).

In Africa, cassava production has more than quadrupled since 1961 from 33 million to 122 million tonnes in 2006 (IFAD, 2010). In countries like Nigeria and Ghana, wide adoption of high yielding varieties and better pest management has resulted in a sharp rise in production. Cassava is a perishable crop and a bulky product, which makes it costly to transport without initial processing. According to FAO (2011) between 35% and 40% of cassava produced in Ghana are lost through postharvest losses accounting for between 3.5 million tonnes to 4 million tonnes annually. This account for between 875 tonnes to one million tons of cassava chips worth about $200 million annually.

In Ghana, cassava is primarily produced for its roots which are a major and cheap source of carbohydrate in human diet, containing 20% amylose and 70% amylopectin, an important source of energy with a calorific value of 250 kcal/ha/day and is regarded as poor man's food, a more appropriate food crop for the tropical world (RMRDC, 2004).

In recent times, cassava has gained attention as a potential industrial crop. The tubers constitute an important component of livestock feed production in various parts of the world. The tubers are processed into cassava flour for bakery and confectioneries. Again, the high carbohydrate content and other qualities such as amylose and amylopectin ratio predispose cassava tubers for various industrial uses such as starch production, modified starch, ethanol, monosodium glutamate (MSG), glucose syrup, fructose syrup, sorbitol, sago, citric acid, adhesives, microbial enzymes, sweeteners among others.

Rising oil prices coupled with the need to address concerns about emission from transportation fuels and the requirements of the Kyoto Protocol on carbon emission has led to the promulgation of a mandatory blending of biofuels (ethanol) with fossil fuels in Europe by 2020, which will require cassava chips as the alternative raw material feedstock (UNCTAD, 2009). According to FAO Food outlook (2009) cassava chips production will become a major emerging market opportunity for bio fuels.

One huge challenge to cassava production and processing is its high moisture content of about 65% making it extremely perishable. According to IITA (1990), once tubers are harvested, they begin to deteriorate within 40-48 hours due to some physiological changes and decay by rot organisms.

There are two low cost methods of storage of fresh cassava root; in trenches and storage of roots in sawdust (NSPRI, 1979). However, these methods can only be used by small-scale holders and not applicable to large scale commercial production units.

Processing cassava into dry forms is therefore necessary to reduce the moisture content and convert it into a more durable and stable produce with less volume, which makes it easier for transportation to reduce post-harvest losses, also to eliminate or reduce the level of hydrocyanic acid (HCN) and to improve the palatability of the food product (CSIR-FRI, 2009).

The general objective of the project was to assess and evaluate the three different drying technologies used for cassava chips production in Ghana.

The specific objectives of the project include:

1. to assess the comparative performance of the three different drying technologies (sun, solar and bin drying),
2. to determine appropriate loading densities critical for the production of good quality cassava chips,
3. to determine the physicochemical properties of the flour produced using the different drying technologies, and
4. to carry out economic analysis on the three technologies.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

## 2.1 CASSAVA

### 2.1.1 Origin and Distribution

Cassava (*Manihot esculenta* Crantz) was introduced from Brazil, its country of origin, to the tropical areas of Africa, the Far East and the Caribbean Islands by the Portuguese during the 16th and 17$^{th}$ centuries. In the Gold Coast (now Ghana), the Portuguese grew the crop around their trading ports, forts and castles and it was a principal food eaten by both Portuguese and slaves. By the second half of the 18$^{th}$ century, cassava had become the most widely grown and used crop of the people of the coastal plains. The Akan name for cassava 'Bankye' could most probably be a contraction of 'Aban Kye' - Gift from the Castle (Korang-Amoakoh *et al*., 1987).

### 2.1.2 Morphology of Cassava Plant

Many cultivars or varieties of cassava are cultivated in the subtropical and tropical countries of the world. They can be distinguished by their morphological characteristics such as leaf size, colour and shapy branching habit, plant height, color of stem and petiole, tuber shape and colour, maturity period and yield (IITA, 1990). The cassava plant is a shrubby woody, short-lived perennial, growing to a height of three metres or more with an erect glabrous stem marked by prominent knobbly leaf scars with varying degrees of branching (Kochhar, 1981). The cassava plant is made up of a shoot system and a root system. The shoot system consists of stem, leaves, and flowers and the root system consists of feeder roots and tubers (IITA, 1990).

The cassava stem varies greatly in height, branching habit and colour (from silvery-grey through various shades of reddish-brown to bark-brown, often streaked with purple) and are usually woody with large pith. The older part of the stem consists of prominent knob-like scars, which are the nodal positions where leaves were originally attached. Each nodal unit consists of a node, which subtends a leaf and an inter-node. There are two types of branching. In fork branching, the main stem grows for a while before producing (usually) three branches at the apex of the stem while in lateral branching, after a certain period of growth lateral branching sets in and branching occurs on any part of the main stem at some distance from the apex (IITA, 1990).

The leaves are spirally arranged on the stem (in technical terms, the phyllotaxis is a two-fifth spiral), palmately compound (3-7, abovate-lanceolate acute lobes) with long petioles subtended by small deciduous stipules. They are usually dark green but red, yellow and various shades of purple pigmentation occur in the foliage (IITA 1990).

The flowers are borne in auxiliary resemes with both sexes in the same inflorescence, the females occurring near the base. Sepals are five and pale yellow or tinge with red, glabrous without, puberulous within and apetalous (IITA, 1990).

The root consists of adventitious root which develop into fibrous root system which absorb water and nutrients from the soil (IITA, 1990). The root tubers develop as a result of secondary thickening of the adventitious roots (tuberization) because of cambium activity. The development of the tuber consists mainly in a diameter of the root. The tubers are commonly unbranched and are about 50cm long and 10cm in diameter, but if they are more metre long branching may occur (Cobley, 1976). A mature tuber consist of three distinct anatomical regions the outer skin or periderm which seals off the surface of the tuber, a thin rind or cortex usually white, but may be tinged pink or brown and the core or pith (flesh) which consist mainly of parenchyma rich in starch with few xylem bundles and latex tubes usually white but may be yellow or tinged red; this is the edible portion (IITA 1990).

Cassava also contain cyanogenic glucosides, mainly linamarin, and in a small proportion, lotaustralin which may be hydrolysed by the endogenous enzyme linamarse to liberate hydrogen cyanide (HCN) (Mahungu *et al*., 1994). According to Bokanga (1994) valine and isoleucine are the precursor in the synthesis of linamarin and lotaustralin respectively. All tissues of cassava contain cyanogenic glucosides. The cyanogenic potential (CNP) of leaves including the petioles is usually the highest in the plant and may be 5 to 20 times of that of the root cortex. Cassava varieties are often classified according to the levels of HCN in the tuber and leaves. The major groups include:

(a) Cassava with high HCN level of 10mg per 100mg fresh weight or more (IITA cultivar TMS 50395).

(b) Intermediate type with HCN level of 5 to 10mg per 100mg fresh weight (IITA cultivars TMS 30572 and TMS 30555).

(c) Cassava with low HCN level-less than 5mg per 100mg fresh weight, the HCN is often concentrated in the peel (IITA cultivars TMS 30001 and TMS 4(2) 1425).

## 2.2 POST HARVEST PROBLEMS OF CASSAVA

### 2.2.1 Tuber Deterioration

Cassava tubers are highly perishable and begin to deteriorate two to three days after harvesting. Unfortunately, apart from delayed harvesting there are no effective methods available for prolonged storage of the tubers. Therefore, post-harvest handling of the root crop is extremely important. Approximately, 30% of cassava produced is consumed by the producers, whilst the rest is sold on markets and a large proportion of this is processed into various indigenous products such as *gari*, agbelima and kokonte. After harvesting, cassava roots are susceptible to spoilage and begin to deteriorate 48 hours after harvesting if no preservation measures are taken. According to Cock (1985), postharvest deterioration of cassava is related to two separate processes: physiological changes and microbial changes. Physiological deterioration often start within 24 hours after harvest, while microbial deterioration usually beings within a week. Therefore, cassava root must be processed as soon as possible after harvest to stop the physiological process and the subsequent deterioration

### 2.2.2 Storage Problems

Cassava tubers can be kept in the ground prior to harvesting for up to about 2 years, but once they have been harvested they begin to deteriorate within 40-48 hours. The deterioration is caused by physiological changes and, subsequently, by rot and decay. Mechanical damage during the harvesting and handling stage also renders the crop unsuited to long term storage. Deterioration of cassava has an adverse effect on the processed product, and thus the crop must be stored properly. Traditional and modern methods of storage have been devised to combat postharvest losses (IITA 1990). In the traditional method, mature cassava crop is left in the ground until needed. The tubers are vulnerable to attack by rodents and nematodes. Tubers also become fibrous, lignified and consequently unsuitable for many food preparations. Other traditional methods, base on the principle of preventing moisture loss from the tubers, include: storing harvested tubers in pits, piling into heaps and watering daily, coating with a paste of mud and storing under water. Improved storage methods used for fresh cassava are based on techniques involving freezing, gamma irradiation, control of storage environment (relative humidity and temperature), waxing and storage in polyethylene bags, trenches as well as sawdust.

## 2.3 CASSAVA PROCESSING

The roots of sweet cassava varieties are eaten raw, roasted in an open fire, or boiled in water or oil. The cyanogens in the roots are destroyed by slowly cooking the roots. Starting with cold water, gradual heating promotes the hydrolysis of the cyanogens (FAO, 1977).

Dried cassava roots are stored or marketed as chips, balls and flour. Chips and balls are milled into flour at home by pounding with a pestle and mortar in preparation for a meal. There are two broad types of dried cassava roots: fermented and unfermented. Preparing unfermented dried cassava roots by sun- or smoke-drying is the simplest method of cassava preparation. Since this method is inefficient in the elimination of cyanogens, it is used mostly for preparing sweet cassava varieties, which have low cyanogen content.

In the case of fermented dried cassava roots, the fermentation is accomplished in one of two ways: stacking in heaps or soaking in water for a number of days. The fermentation process, whether in water or in heaps, influences the taste of the final product. The longer the fermentation period, the stronger is the sour taste. Taste is an important attribute, especially for consumers who eat fermented cassava products and who desire the strong sour taste.

The recent introduction of a grater has eliminated stacking and fermentation and therefore saves time. The roots are simply peeled, washed and grated11. The pulp is placed in a perforated container, covered and a weight put on it for about three hours and the cyanogens are squeezed out along with effluent. The half-dried pulp is then dried in the sun (Alyanak, 1997).

In Africa, cassava is sun-dried on virtually any surface in the open air such as a large flat rock in the field, on the shoulders of a paved road, on flat roof tops, in a flat basket, or even on bare ground. Bright colour is an important attribute desired by consumers. The colour of dried roots depends on the method and duration of the fermentation, on the method of drying, the efficiency of the drying energy and the cleanliness of the drying environment.

Two forms of pasty cassava products are common in Africa: uncooked and steamed pastes. The most popular is called uncooked paste because it is stored or marketed without cooking. To prepare the uncooked paste, the roots are soaked in water for three to five days, during which time the roots soften and ferment. The soaked roots are manually crushed and sieved by shaking it in a basket in a sack under water, thereby separating the pulp into the sack while collecting the fibre in the basket. Cooked cassava pasty products have been recently introduced in Nigerian urban markets.

Every evening in major cities in the cassava growing areas of Nigeria, it is common to find women selling cooked cassava paste wrapped in plastic bags. As women go home from work or from the market, they stop and buy some for the evening meal. Although more research is needed on preparation methods, cooked cassava paste is a promising food for busy urban consumers.

Steamed paste (for example chickwangue in the Congo) is a product that can be stored or marketed in a steamed form. To prepare the paste, fibre is removed by hand from roots fermented by soaking in water. The roots are then stacked in a heap to further ferment. The pulp is ground with a stone or pounded in a mortar. The resulting fine pulp is firmly wrapped in leaves and steamed.

The double fermentation as well as the steaming imparts a long shelf-life to steamed paste. The sour flavour achieved through extended fermentation is a characteristic that is cherished by regular customers. It is also a turn-off to potential new consumers. Steamed paste is stored or marketed in a ready-to-eat form. Preparing steamed paste is expensive because many steps are involved and each one requires additional inputs. For example, grinding and sieving are labour-intensive. The soaking step is water-use intensive and steaming is fuel wood-use intensive. In the Congo, steamed paste - chickwangue- is prepared entirely by women.

In Africa, there are three common types of granulated cassava products: gari, attieke and tapioca. The methods for making granulated cassava products originated in Brazil. To prepare gari, fresh cassava roots are peeled, washed and grated. The resulting pulp is put in a porous sack and weighted down with a heavy object for three to four days to express effluent from the pulp while it is fermenting. The de-watered and fermented lump of pulp is pulverized and sieved and the resulting semi-dry fine pulp is toasted in a pan. The grating, effluent expressing, pulverization, toasting and the addition of palm oil are adequate to reduce cyanogens to a safe level (Hahn, 1989).

Fermentation imparts a sour taste to gari. The duration of fermentation varies depending on consumer preference for sour taste. The COSCA study found that commercial gari processors in Nigeria ferment cassava for different lengths of time depending on the market. Toasting extends the shelf-life so that gari can be easily transported to urban markets. If kept in a dry environment, gari will store better than grain because gari is not known to be attacked by weevils (Okigbo, 1984).

The second type of granulated cassava products is attieke, a type of steamed cassava that is found only in the Côte d'lvoire. Attieke is made in much the same way as gari with more or less the same inputs. However, instead of toasting, attieke is steamed. Attieke is available in a wet form and it has a shorter shelf-life than gari.

The third type of granulated cassava product is tapioca, which is primarily consumed in Benin, and Togo13. To prepare tapioca, cassava is grated and then put in water, pressed and kneaded to release the starch. The starch is permitted to settle at the bottom of the container and the water is drained off. The operation is repeated several times to prepare a high quality product. The damp starch is spread on a pan and toasted in the same way as gari, to form a coarse granular product.

## 2.4 EQUIPMENT AND MACHINES USED IN GHANA

The major intervention in cassava processing was the introduction of a medium-scale motorized cassava grater by the Agricultural Engineers Ltd in 1966. The cassava grater presented a great innovation in cassava processing since grating is central to traditional processing of cassava in Ghana. Since then, several equipment manufactures including engineering firms, research institutes, university departments, small-scale artisanal shops, blacksmiths and mechanics have developed and produce various types of cassava processing equipment. Cassava processing machinery manufactured locally are drum graters, horizontal disc graters, cassava chippers, screw presses, hydraulic presses, cassava dough disintegrators, sieving machines, grading machines, plate mills, hammer mills and mechanical dryers.

Over the past three decades there has been a gradual but steady increase in the adoption of cassava processing equipment in the cassava processing industry. The adoption of mechanized cassava processing appears to have escalated in recent years through assistance provided by non-governmental organizations to various local communities. In the last few years, the export of cassava chips has been introduced into the country through the activities of a private company, the Transport and Commodity General Ltd. This activity which is promoted by the Government is being explored actively by several potential exporters and it is envisaged in the foreseeable future that cassava may be considered as a cash crop rather than as a food crop.

The processing of cassava is a widespread and important activity in the informal sector of the Ghanaian economy. Strides have been made in recent years towards upgrading and adopting a mechanized approach to cassava processing but there are constraints to the adoption of the technologies which need to be addressed. The export of cassava chips is offering new opportunities to the cassava processing industry. Cassava grater, cassava screw press, cassava chippers and slicers,

### 2.4.1 Cassava Grater

The cassava grater (stationary or mobile) has become a permanent feature of cassava processing in rural communities. These graters can grate at least 5 tonnes of fresh tubers per day, and thus only one is needed to handle all the gari/starch processing operation of a rural industry. A typical cassava grater incorporates a cylindrical, rotating, wooden drum which is covered with a nail-pushed metal sheet (galvanized or tin). The rotary drum is set into a casing, with the critical dimension being the clearance between the lower part of the drum and the casing; this clearance determines the size of the grated particle. The output of the grater varies from 500kg to 1000kg per hour, depending on the diameter and speed of the rotary drum and the number of perforations per unit area of the drum surface; these parameters have not been standardized.

### 2.4.2 Slicing machine

A mechanized or manually operated slicing machine is an important investment for producing cassava slices of uniform thickness to ensure more uniform drying. It will save time and energy, improves productivity, increase the surface area available for drying and produce better quality chips and flour. Slicing machines are popular in Asia but uncommon in West Africa. The type used in Asia consists of a steel framework supporting a engine. The cutting drum is fitted with four blades which rotate at about 500rpm. The size of the cassava chip is 10cm x 10cm x 50cm; the optimal thickness of the chip is 6mm for through-flow drying and 10mm for cross-flow drying. The machine produces 1 tonne of chips per hour, and a single machine is adequate for a rural cassava processing industry.

### 2.4.3 Dryers

Drying is carried out to reduce moisture content and is essentially a process of simultaneous heat and moisture transfer. Heat is required to evaporate the moisture from the inside and the surface of a product by an external drying medium, usually air. In a number of agricultural crops, including cassava, the drying of single particles under constant external conditions exhibits a constant-rate moisture loss during the initial drying period, followed by a falling rate moisture loss. This implies that the drying rate decreases continuously during the course of drying.

### 2.4.3 Milling machine

The most common type of mill used in Africa for grinding chips into flour is a plate mill. This has stationary and rotating serrated plates. The clearance between these plates regulates the degree of fineness of the milled product. The output of the milled material depends on the size of the plate and the power of the motor or engine. Another type of milling machine, the hammer mill has a series of reversible, flexible hammers fixed radially inside the casing. The material is fed through the hopper. And moved over the wire mesh screen by the hammer; the size of the milled particle is regulated by the screen.

## 2.5 CASSAVA DRYING TECHNOLOGIES IN GHANA

Drying has been identified as the biggest challenge in industrial production for cassava. Drying aims at reducing the water content of cassava to less than 15%. The recommended water content varies from the type of final product ranging from 9% to 15% (Wenlapatit, 2004; International Starch Institute, 1999; and IITA, 2005). Four factors that influence drying of cassava (chips, flour and starch). These are temperature, airflow, humidity and tumbling frequency (IITA, 2005).



Cassava drying is best done at temperatures between 40$^{o}$C and 60$^{o}$C, at temperatures of about 60$^{o}$C gelatinization of cassava starch sets in (FAO, 1977). Wenlapatit (2004) recommends the same drying temperatures, however adds that when the water content drops to 35-40%, the drying temperature can be raised to 170$^{o}$C to 200$^{o}$C without gelatinization setting in. While drying, hot dry air needs to flow through the dryer so as to pickup moisture from the products being dried. On a hot summer day humidity is low hence the dry atmospheric air can be used for effective drying. However, the drying potential can be enhanced through pre-heating/drying of the drying air. The preheating may be imperative in the wet season. When drying, the cassava is placed on a non-perforated material, usually plastic sheet or concrete floor, thus products at the base will not dry; hence frequent tumbling helps expose the products giving even drying.

The IITA (2005) identify four methods of cassava drying, namely natural, artificial, rotary and flash drying. Natural drying, also called sun-drying, is where cassava mash is spread on a plastic sheet and exposed to the sun for drying. Drawbacks inherent in this method of drying are susceptibility to damage, contamination and slow drying rates. An improvement to the natural drying is the solar drying.

Artificial drying is where a controllable source of energy is used for drying operations. Further classification to artificial drying is brought about by the source of energy used in the heating of the drying air. Such energy sources include electricity, biomass, solar, other renewable energy sources and fossil fuels (IITA, 2005).

### 2.5.1 Sun Drying

Sun drying is used mostly where the sliced roots are spread out on drying areas, or concrete floors of various dimensions. Experiments in Madagascar showed that the concentration of chips during drying should not exceed 10-15 kg/m$^2$, the required drying area space being about 250 m$^2$ for each ton per day of dried roots produced. To produce good quality chips, the roots must be sliced and dried as quickly as possible after harvest. The chips should be turned periodically in the drying period, usually two or three sunny days, until the moisture content reaches 13–15 percent. The chips are considered dry when they are easily broken but too hard to be crumbled by hand. The thickness of the slices also has an effect on the quality of chips. Thick slices may appear dry on the surface when their internal moisture content is still high.

When rain threatens during the drying process, the chips are collected by hand or by a tractor into piles under a small roof. Interrupted sun drying affects the quality of the finished chips and pellets. When the semidried chips are wet again by rain, they become soggy and upon completion of drying lose their firm texture. In rainy regions, where continuous sun drying is difficult, some form of artificial heat drying is required.

### 2.5.2 Solar Drying

Agricultural and other products have been dried by the sun and wind in the open air for thousands of years. The purpose is either to preserve them for later use, as is the case with food; or as an integral part of the production process, as with timber, tobacco and laundering. In industrialized regions and sectors, open air-drying has now been largely replaced by mechanized drying is faster than open-air, and fan to force it through at a high rate. Mechanized drying is faster than open-air drying, uses much less land and usually gives a better quality product. But the equipment is expensive and requires substantial quantities of fuel or electricity to operate.

The heat required to evaporate water is 2.26 kJ/kg. Hence approximately 250MJ (70kWh) of energy are required to vaporize the 100kg water. There is no fixed requirement for solar heat input to the dryer. This is because the incoming ambient air can give up some of its internal energy to vaporize the water (becoming colder in the process). Indeed if the ambient air is dry enough, no heat input is essential.

Nevertheless, extra heat is useful for two reasons. First, if the air is warmer then less of it is needed. Second, the temperature in the rice grains themselves may be an important factor, especially in the later stages of drying, when moisture has to be 'drawn' from the centers of the grains to their surfaces. The temperature will itself depend mainly on the air temperature but also on the amount of solar radiation received directly by the rice.

In a natural convention system, the flow of air is caused by the fact that the warm air inside the dryer is lighter than the cooler air outside. The difference in density creates a small pressure difference across the bed of grain, which force air through it.

### 2.5.3 Mechanized Drying Systems

Batch-in-Bin dryers, cabinet dryers, flash dryers, and oven dryers. The batch-in-bin drying process involves using a bin as a batch dryer. A3 to 4-foot deep layer of grain is placed in the bin and the fan heater stared. Tropical drying temperatures are 10 to 160F with airflow rates of 8 to15 cfm/bushel. Drying begins at the floor and progresses upward. Grain at the floor of the bin becomes excessively dry while the top layer of the batch remains fairly wet. The grain is cooled in the bin after it is dried. Some batch-In-bin dryers hold the grain being in a layer near the roof. After the grain is dried it is dropped to bin floor where it is cooled. As the grain is moved from bin, the grain is mixed, and the average moisture content going into final storage should be low enough that mold growth will not be a problem.

A stirring device can be added to provide more uniform drying and moisture content and to increase the capacity of the bin dryer. Research conducted at lowa state University indicates that with a stirring device there is less than 1 percentage point moisture variation between upper and lower layers of a batch of grain. This research also indicates there is some reduction in resistance to airflow, permitting an increase batch size in the typical bin. Stirring allows depths of up to 7 8 feet for corn. There is a tendency for fine materials to migrate to bin floor as the stirring device is in operation (Pierre, 1989).

## 2.6 FACTORS AFFECTING DRYING OF CASSAVA CHIPS

Geometry (shape and size) of the cassava chips, the chip loading per unit drying area, air speed, temperature, humidity, radiation, as well as dry matter content of the fresh chips are known to affect drying time. According to FAO (1977) the shape of the chip influences how fast it dries. Because cassava chips are white they reflect much of the sunlight that falls on them. Hence in sun-drying systems the chips are dried more by the passage of air over them than by the direct effects of the sun's rays. The initial drying of the chips occurs as the water on the chip surface evaporates and is then replaced by water vapour diffusing from the inner layers of the chips. Although diffusion and the rate of drying are fastest in small chips, when they are in a thick layer they can easily become compacted, which prevents free air movement through the mass. As a result, for effective drying the chip's shape should permit air to readily pass through a large mass of chips. The optimal chip geometry for natural drying is a bar 5 x 1 x 1 centimeters (Cock 1985).

In artificial heat dryers, drying time is reduced and high quality product is guaranteed. The optimum cassava chip size for natural drying on cement floor or trays is a rectangular shape with dimensions 8 x 8 x 50 mm (Roa, 1974). When three different geometrical shapes-rectangular bars 10 x 10 x 50 mm, slices 10 mm thick, and cubes 10 x 10 x 10 mm were compared in drying trials using static bed dryers with 100 mm layers it was found that the cube-shaped cassava chips had the highest drying efficiency. The load of cassava chips per unit area measured in kilograms of fresh product per square meter is a function of the air flow through the chip layer. Chip load for natural drying on cement floor is restricted due to the reduced airflow at the soil level, and depending on the climatic condition, the optimum load is 5kg/m² (Best, 1979).

Hinrichs and Kleinbach (2002), pointed out that the sun energy can be put to various uses including drying. The solar radiation received on the earth's surface is affected by the latitude of a particular place, season, time of day, and the degree of cloudiness. Optimum radiation is received when the surface is tilted at an angle equal to the latitude of the place. Coating of surfaces with black paint is a better absorber of radiant energy.

## 2.7 FUNCTIONAL AND PASTING PROPERTIES OF CASSAVA FLOUR

Bulk density is defined as the ratio of weight of the flour to the flour volume in grammes per centimeter cube (Subramanian and Viswanathan, 2007). It is a measure of heaviness of a flour sample. According to Bhattachrya and Prakash (1994) bulk density of flours increases with increase in starch content. Bulk density is indicative of the space the flour would occupy and the amount of packaging material required.

According to Schmidt (1981), considerably high protein concentration is usually required for the gelation of globular proteins. The gelling capacity of flours has been attributed to denaturation, aggregation and thermal degradation of starch (Enwere and Ngoddy, 1986). Variations in the gelling properties of different flours may be due to variations in the ratios of different constituents such as carbohydrates, lipids and proteins that make up the flours. Pasting characteristics of starches have implication on cooking quality and texture of food products (Moorthy, 1994). Pasting characteristics help selecting thickeners and binders (Aryee *et al*., 2006). If used as thickeners, retrogradation should be minimal.

The pasting temperature gives an indication of cooking temperature. If the pasting temperature is high it suggests that the starch granules have high capacity to resist swelling.

According to Adebowale *et al*. (2005) peak viscosity is the maximum viscosity developed by a starch-water suspension during heating.

Setback value is used to measure the stability of the paste after cooking. During setback retrogradation of starch molecules occur. It is therefore important for food processing. The final viscosity is indicative of the viscosity at which the cooked paste would be consumed suggesting the final consistency.

# CHAPTER THREE

## 3.0 MATERIALS AND METHOD

## 3.1 LOCATION OF EXPERIMENT

The experiment was carried out at the premises of Caltech Ventures Limited, Hodzo - Ho in the Volta Region. The experiment was conducted in January, 2011. The laboratory analysis of cassava flour produced was done at the Food Research Institute (FRI) in Accra.

## 3.2 SOURCE OF EXPERIMENTAL MATERIALS

Cassava tubers were obtained from farms of Caltech Ventures Limited, Hodzo – Ho in the Volta Region. Twelve (12) months old Afisiafi cassava variety - TMX 30572 tubers were harvested and used in producing chips for the experiment.

## 3.3 METHOD

### 3.3.1 Sample Preparation

Harvested tubers were manually peeled with broad bladed stainless steel knives. Peeled tubers were washed thoroughly with clean water in washing containers. A 10 kg fresh weight of cassava tuber was used as experimental unit. The washed tubers were then transferred to a cassava chipping machine for chipping. Moisture content of the chips was recorded immediately after tubers had been chipped. The chips were then dried under three different drying technologies namely sun, solar and bin at different loading densities. Drying in the bin technology was at 65$^{o}$C. Drying temperatures for sun and solar technologies were also monitored daily until drying was complete. Duration of drying was also recorded for the three technologies.

### 3.3 EXPERIMENTAL DESIGN

The experimental design used was a 3x3 Factorial Completely Randomized Design (CRD). The experiment was replicated three times.

### 3.4 TREATMENTS

Two factors were used in the experiment. The first factor consisted of three drying technologies; sun drying, solar drying and bin drying. The second factor consisted of three loading densities comprising of 2kg, 3kg and 4kg of fresh cassava chips.

#### 3.4.1 Treatment Combinations

The treatment combinations used in the experiment included:

- Sun drying + 2 kg fresh cassava chips
- Sun drying + 3 kg fresh cassava chips
- Sun drying + 4 kg fresh cassava chips
- Solar drying + 2 kg fresh cassava chips
- Solar drying + 3 kg fresh cassava chips
- Solar drying + 4 kg fresh cassava chips
- Bin drying + 2 kg fresh cassava chips
- Bin drying + 3 kg fresh cassava chips
- Bin drying + 4 kg fresh cassava chips

## 3.5 PARAMETERS STUDIED

### 3.5.1 Moisture Content of Flour (%MC)

Moisture content of the flour was determined using an Electronic Moisture Analyzer - Satorius MA45 (Sartorius GMBH, Gorttingen, Germany). 5g of flour sample was weighed into a container and the moisture content was measured.

### 3.5.2 pH

The pH meter (model BA 350 EDT instruments) was standardized with standard buffer solution 4. 0. and 7.0. 10g of flour sample was weighed into a 250ml beaker and 20ml of distilled water added to obtain a slurry. The pH was then measured by inserting directly the electrodes into 10ml of slurry in a beaker. The pH electrodes were allowed to stabilize before recording (Bainbridge *et al*., 1996).

### 3.5.3 Total Titratable Acids

10mls of flour slurry was transferred into a 250ml conical flask. 4-5 drops of phenolphthalein indicator was added and titrated against 25ml 0.1M NaOH solution until the mixture turns pink. The titer volume was recorded and the % Titratable acidity (%TTA) as lactic acid was calculated by multiplying the titer volume by 0.09 (Bainbridge *et al*., 1996).

### 3.5.4 Starch Content

The starch content of the flour was determined by preparing slurry with 10g of flour in water through cheese cloth. The extracted starch was allowed to settle in the beaker after which it was decanted. It was then spread on a petri dish and dried in hot air oven at 50$^{o}$C over at least 24 hours. It was weighed and expressed as percent of the flour weight.

### 3.5.5 Bulk Density

Bulk density was determined using the Milson and Kirk (1980) method.10gm each of the samples was placed in a 50ml clean dry measuring cylinder and an initial volume occupied by each of the sample without tapping was determined. After 500 manual taps, occupied volumes was determined. Bulk density was calculated as the ratio of weight to volume respectively.

### 3.5.6 Pasting Profile

A smooth paste was made of the prepared flours (40g) in 420ml distilled water (8.8% slurry) for viscoelastic analysis using Brabender Viscoamylograph (Viskograph-E, Brabender Instrument Inc. Duisburg, Germany) equipped with a 1000cmg sensitivity cartridge. The smooth paste was heated at a rate of 1.5°Cmin$^{-1}$ to 95°C and maintained for 15min. It was then cooled at 1.5°Cmin$^{-1}$ to 50°C and maintained for 15min. Viscosity profile indices were recorded for pasting temperature, peak temperature, peak viscosity,viscosity at 95°C,viscosity after 15min hold at 95°C (95°C Hold), viscosity at 50°C, viscosity after 15min hold at 50°C (50°C Hold), breakdown and setback as described by Walker *et al.* (1988).

### 3.5.7 Cost Benefit Analysis

The cost benefit analysis of cassava chip and flour production was carried out for all treatments in order to assess their profitability and quality.

### 3.6 DATA ANALYSIS

Data collected on all parameters studied were statistically analyzed using analysis of variance (ANOVA). Statistix (version 9) statistical software was used in analyzing the data. Differences between treatment means were determined using Tukey HSD test at P=0.05.

# CHAPTER FOUR

## 4.0 RESULTS

### 4.1 MOISTURE CONTENT OF CASSAVA FLOUR (%)

Table 4.1: Effect of drying technology on moisture content of cassava flour

| Drying technology | Moisture content (%) |
|---|---|
| Sun | 9.10 |
| Solar | 8.64 |
| Bin | 7.10 |
| Lsd (0.01) | 0.02 |

The moisture content of the cassava flour produced from the drying technology is presented in Table 4.1. The flour from the bin drying recorded the lowest moisture content of 7.10% than the solar drying (8.64%). The sun drying recorded the highest moisture content of 9.10%. The three drying technologies were statistically different ($P<0.05$) from each other.

Table 4.2: Effect of loading density on moisture content of cassava flour

| Loading density | Moisture content (%) |
|---|---|
| 2kg | 8.06 |
| 3kg | 8.38 |
| 4kg | 8.40 |
| Lsd (0.01) | 0.02 |

Table 4.2 shows the moisture content of the cassava flour produced from the loading density. The flour from the loading density of 2kg recorded the lowest moisture content of 8.06% with loading density of 4kg recording the highest moisture content of 8.40%. Significant differences ($P<0.05$) were observed among the loading densities.

Table 4.3: Effect of drying technology and loading density on moisture content of cassava flour (%)

| Drying technology | Loading density | | | Mean |
| --- | --- | --- | --- | --- |
| | 2kg | 3kg | 4kg | |
| Sun | 8.54 | 9.01 | 9.75 | 9.10 |
| Solar | 8.37 | 8.86 | 8.67 | 8.64 |
| Bin | 7.27 | 7.27 | 6.77 | 7.10 |
| Means | 8.06 | 8.38 | 8.40 | |

Tukey HSD $_{(0.05)}$: Technology = 0.02; loading density = 0.02; Technology x loading density = 0.06

The effect of drying technology and loading density on moisture content of the cassava flour is presented in Table 4.3. The moisture content of the flour ranged from 6.77% to 9.75%. Bin drying at loading density 4kg recorded the lowest moisture content of 6.77% while bin drying at 4kg recorded the highest moisture content of 9.75%. Significant differences (P<0.05), were observed among the drying technologies and the loading densities.

## 4.2 pH OF CASSAVA FLOUR

Table 4.4: Effect of drying technology on pH of cassava flour

| Drying technology | pH |
| --- | --- |
| Sun | 6.24 |
| Solar | 6.01 |
| Bin | 6.37 |
| Tukey HSD $_{(0.05)}$ | 0.04 |

Table 4.4 shows the pH of the cassava flour produced from the drying technology. The flour produced from the solar drying recorded the lowest pH of 6.0 followed by sun drying with a pH of 6.24. Bin drying recorded the highest pH of 6.37. The three drying technologies were significantly different (P<0.05) from each other.

Table 4.5: Effect of loading density on pH of cassava flour

| Loading density | pH |
|---|---|
| 2kg | 6.19 |
| 3kg | 6.23 |
| 4kg | 6.21 |
| Tukey HSD $_{(0.05)}$ | 0.04 |

The pH of the cassava flour produced from the loading density is presented in Table 4.5. The flour from the loading density of 2kg recorded the lowest pH of 6.19, followed by 4kg with a pH of 6.21. 3kg loading density recorded the highest pH of 6.23. Significant difference (P<0.05) was observed between 2kg and 3kg loading densities.

Table 4.6: Effect of drying technology and loading density on pH of cassava flour

| Drying technology | Loading density | | | Mean |
|---|---|---|---|---|
| | 2kg g | 3kg | 4kg | |
| Sun | 6.08 | 6.31 | 6.33 | 6.24 |
| Solar | 6.11 | 6.03 | 5.91 | 6.01 |
| Bin | 6.38 | 6.36 | 6.38 | 6.37 |
| Means | 6.19 | 6.23 | 6.21 | |

Tukey HSD Lsd: Technology = 0.04;loading density = 0.04; Technology x loading density = 0.10

Table 4.6 shows the effect of drying technology and loading density on pH of the cassava flour. The pH of the flour ranged from 5.91 to 6.38. Solar drying at loading density 4kg recorded the lowest pH of 5.91% while bin drying at 2kg recorded the highest pH of 6.38%. Significant differences ($P<0.05$) were observed among the drying technologies and the loading densities.

## 4.3 TOTAL TITRATABLE ACIDITY (TTA) OF CASSAVA FLOUR (%)

Table 4.7: Effect of drying technology on total titratable acidity of cassava flour

| Drying technology | TTA (%) |
|---|---|
| Sun | 0.25 |
| Solar | 0.25 |
| Bin | 0.25 |
| Tukey HSD $_{(0.05)}$ | 0.005 |

The total titratable acidity of the flour produced from the drying technology is presented in Table 4.7. The TTA of the flour recorded was 0.25% for sun, solar and bin drying. The effect of drying technologies were not significantly different ($P>0.05$) from each other.

Table 4.8: Effect of loading density on total titratable acidity of cassava flour

| Loading density | TTA (%) |
|---|---|
| 2kg | 0.24 |
| 3kg | 0.25 |
| 4kg | 0.25 |
| Tukey HSD $_{(0.05)}$ | 0.005 |

Table 4.8 present the total Titratable acidity of cassava flour produced from the loading density. The flour from the loading density of 2kg recorded the lowest TTA of 0.24%.

Loading densities, 3kg and 4kg had a TTA of 0.25% respectively. Significant differences (P<0.05) observed among the loading densities.

Table 4.9: Effect of drying technology and loading density on TTA of cassava flour (%)

| Drying technology | Loading density | | | Mean |
|---|---|---|---|---|
| | 2kg | 3kg | 4kg | |
| Sun | 0.24 | 0.25 | 0.25 | 0.25 |
| Solar | 0.25 | 0.24 | 0.25 | 0.25 |
| Bin | 0.24 | 0.25 | 0.25 | 0.25 |
| Means | 0.24 | 0.25 | 0.25 | |

Tukey HSD $_{(0.05)}$ Technology = 0.005; loading density = 0.005; Technology x loading density = 0.01

The effect of drying technology and loading density on total titratable acidity of the cassava flour is presented in Table 4.9. The TTA of the flour ranged from 0.24% to 0.25%. There was however, no significant differences (P>0.05) observed among the drying technologies and the loading densities.

## 4.4 STARCH YIELD OF CASSAVA FLOUR (%)

Table 4.10: Effect of drying technology on starch yield of cassava flour

| Drying technology | Starch content (%) |
|---|---|
| Sun | 67.74 |
| Solar | 66.43 |
| Bin | 50.47 |
| Tukey HSD $_{(0.05)}$ | 1.09 |

Table 4.10 shows the effect of drying technology on starch yield of cassava flour. The sun drying produced the highest starch yield of 67.74%. The solar drying also produced a starch content of 66.43%. The bin drying however produced the lowest starch content of 50.47%. Significant differences ($P<0.05$) were observed among the three drying technologies.

Table 4.11: Effect of loading density on starch yield of cassava flour

| Loading density | Starch content (%) |
|---|---|
| 2kg | 61.59 |
| 3kg | 61.70 |
| 4kg | 61.34 |
| Tukey HSD $_{(0.05)}$ | 1.09 |

The effect of loading density on starch content of cassava flour is presented in Table 4.11. The starch yield was high in the loading density 3kg (61.70%), followed by 2kg (61.59%) with 4kg recording a starch yield of 61.34%. There was no significant differences ($P>0.05$) observed among the loading densities.

Table 4.12: Effect of drying technology and loading density on starch yield of cassava flour (%)

| Drying technology | Loading density | | | Mean |
|---|---|---|---|---|
| | 2kg | 3kg | 4kg | |
| Sun | 69.46 | 68.13 | 65.64 | 67.74 |
| Solar | 65.95 | 66.25 | 67.08 | 66.43 |
| Bin | 49.36 | 50.72 | 51.31 | 50.47 |
| Means | 61.59 | 61.70 | 61.34 | |

Tukey HSD $_{(0.05)}$ Technology = 1.09; loading density = 1.09; Technology x loading density = 2.61

The effect of drying technology and loading density on starch content of the cassava flour is presented in Table 4.12. The starch yield ranged from 49.36% to 69.46%. Bin drying at 2kg produced the least starch content of 49.36%. However, sun drying at 2kg produced the highest starch content of 69.46%. Significant differences (P<0.05) were observed among the drying technologies and the loading densities.

## 4.5 BULK DENSITY OF CASSAVA FLOUR (g/cm$^3$)

Table 4.13: Effect of drying technology on bulk density of cassava flour

| Drying technology | Bulk density (g/cm$^3$) |
|---|---|
| Sun | 0.62 |
| Solar | 0.66 |
| Bin | 0.74 |
| Tukey HSD $_{(0.05)}$ | 0.02 |

Table 4.13 shows the bulk density of cassava flour produced from the drying technology. Sun drying produced the flour with the lowest bulk density of 0.62 g/cm$^3$, bin drying on the other hand had the highest bulk density of 0.74 g/cm$^3$. The effect of three drying technologies on bulk density were statistically different (P<0.05) from each other.

Table 4.14: Effect of loading density on bulk density of cassava flour

| Loading density | Bulk density (g/cm$^3$) |
|---|---|
| 2kg | 0.66 |
| 3kg | 0.68 |
| 4kg | 0.67 |
| Tukey HSD $_{(0.05)}$ | 0.02 |

Table 4.14 shows the effect of loading density on bulk density of cassava flour produced. The flour from the loading density of 2kg recorded the lowest bulk density of 0.66 g/cm$^3$. 3kg loading density recorded the highest bulk density of 0.68 g/cm$^3$. Significant difference ($P<0.05$) in bulk density observed between the loading density 2kg and 3kg.

Table 4.15: Effect of drying technology and loading density on bulk density of cassava flour

| Drying Technology | Loading density | | | Mean |
|---|---|---|---|---|
| | 2kg g | 3kg | 4kg | |
| Sun | 0.62 | 0.63 | 0.60 | 0.62 |
| Solar | 0.65 | 0.67 | 0.66 | 0.66 |
| Bin | 0.72 | 0.74 | 0.74 | 0.74 |
| Means | 0.66 | 0.68 | 0.67 | |

Tukey HSD $_{(0.05)}$ Technology = 0.02; loading density = 0.02; Technology x loading density = 0.04

The effect of drying technology and loading density on bulk density of the cassava flour is presented in Table 4.15. The bulk density of the flour ranged between 0.60 g/cm$^3$ and 0.74 g/cm$^3$. Sun drying at 4kg produced flour with the lowest bulk density of 0.60 g/cm$^3$ while bin drying at 3kg and 4kg produced flours with higher bulk densities of 0.74 g/cm$^3$ respectively. No significant differences ($P>0.05$) were observed among the drying technologies and the loading densities.

## 4.6 PASTING CHARACTERISTICS OF CASSAVA FLOUR

### 4.6.1 Gelatinization Temperature (Cooking Temperature)

Table 4.16: Effect of drying technology on gelatinization temperature of cassava flour

| Drying technology | Cooking temperature ($^oC$) |
|---|---|
| Sun | 69.00 |
| Solar | 68.59 |
| Bin | 67.93 |
| Lsd (0.01) | 1.46 |

Effect of drying technology on gelatinization temperature of cassava flour is presented in Table 4.16. The flour from sun drying recorded the highest cooking temperature of 69$^o$C, followed by solar drying with a cooking temperature of 68.59$^o$C. Bin drying however, recorded the lowest cooking temperature of 67.93$^o$C. There were no significant differences ($P>0.05$) observed among the drying technologies.

Table 4.17: Effect of loading density on gelatinization temperature of cassava flour

| Loading density | Cooking temperature ($^oC$) |
|---|---|
| 2kg | 67.96 |
| 3kg | 68.98 |
| 4kg | 68.59 |
| Lsd (0.01) | 1.46 |

Table 4.17 shows the effect of loading density on the cooking temperature of the cassava flour. The flour from the 3kg loading density recorded the highest cooking temperature of 68.98$^o$C followed by 4kg (68.59$^o$C). On the other hand, 2kg loading density recorded the lowest cooking temperature of 67.96$^o$C. There were no significant differences ($P>0.05$) observed among the loading densities.

Table 4.18: Effect of drying technology and loading density on cooking temperature ($^{o}C$) of flour

| Drying Technology | Loading density | | | Mean |
|---|---|---|---|---|
| | 2kg | 3kg | 4kg | |
| Sun | 68.80 | 69.10 | 69.10 | 69.00 |
| Solar | 67.37 | 69.23 | 69.17 | 68.59 |
| Bin | 67.70 | 68.60 | 67.50 | 67.93 |
| Means | 67.96 | 68.98 | 68.59 | |

Tukey HSD $_{(0.05)}$ Technology = 1.46; loading density = 1.46; Technology x loading density = 3.50

The effect of drying technology and loading density on cooking temperature of cassava flour is shown in Table 4.18. The cooking temperature of the flour ranged from 67.37$^{o}$C to 69.23$^{o}$C. Solar drying at loading density 3kg recorded the highest cooking temperature of 69.23$^{o}$C while solar drying at 2kg recorded the lowest cooking temperature of 67.37$^{o}$C. No significant differences ($P>0.05$) were observed among the drying technologies and the loading densities.

### 4.6.2 Maximum Viscosity (BU)

Table 4.19: Effect of drying technology on maximum viscosity of cassava flour

| Drying technology | Maximum viscosity (BU) |
|---|---|
| Sun | 482.22 |
| Solar | 478.67 |
| Bin | 538.11 |
| Lsd (0.01) | 6.83 |

Table 4.19 shows the effect of drying technology on maximum viscosity of flour. The bin drying technology had the highest maximum viscosity of 538.11BU, followed by sun drying (482.22BU) with solar drying recording the lowest maximum viscosity of 478.67BU. Significant difference (P<0.05) were observed among the drying technologies.

Table 4.20: Effect of loading density on Maximum viscosity of cassava flour

| Loading density | Maximum viscosity (BU) |
|---|---|
| 2kg | 502.33 |
| 3kg | 494.56 |
| 4kg | 502.11 |
| Tukey HSD $_{(0.05)}$ | 6.83 |

Table 4.20 shows the effect of loading density on maximum viscosity of flour. Loading density of 2kg recorded a maximum viscosity of 502.33BU, followed by 4kg (502.11BU). The lowest maximum viscosity of 494.56BU was recorded in the 3kg loading density. There were significant differences observed among the three loading densities (P<0.05).

Table 4.21: Effect of drying technology and loading density on maximum viscosity (BU) of flour

| Technology | Loading density | | | Mean |
|---|---|---|---|---|
| | 2kg g | 3kg | 4kg | |
| Sun | 477.00 | 483.33 | 486.33 | 482.22 |
| Solar | 483.00 | 473.33 | 479.67 | 478.67 |
| Bin | 547.00 | 527.00 | 540.33 | 538.11 |
| Means | 502.33 | 494.56 | 502.11 | |
| Tukey HSD $_{(0.05)}$ | Technology = 6.83; loading density = 6.83; Technology x loading density = 16.31 | | | |

Effect of drying technology and loading density on maximum viscosity of cassava flour is shown in Table 4.21. Bin drying at 2kg loading density had the highest maximum viscosity of 547.00BU followed by bin drying at 4kg (540.33BU) and bin drying at 3kg (527.00BU). The lowest maximum viscosity of 473.33BU was recorded in solar drying at 3kg loading density. Significant differences ($P<0.05$) existed between the bin drying technology at different loading densities and sun and solar drying at different loading densities.



### 4.6.3 Final Viscosity of Cassava Flour (BU)

Table 4.22: Effect of drying technology on final viscosity of cassava flour

| Technology | Final viscosity (BU) |
|---|---|
| Sun | 289.78 |
| Solar | 287.56 |
| Bin | 231.44 |
| Tukey HSD $_{(0.05)}$ | 4.53 |

Table 4.22 shows the effect of drying technology on final viscosity of cassava flour. The flour from sun drying recorded the highest final viscosity of 289.78BU, followed by solar drying (287.56BU). Bin drying recorded the lowest final viscosity of 231.11BU. The effect of the three drying technologies on final viscosity were significantly different ($P<0.05$) from each other.

Table 4.23: Effect of loading density on final viscosity of cassava flour

| Loading density | Final viscosity (BU) |
|---|---|
| 2kg | 278.44 |
| 3kg | 261.89 |
| 4kg | 268.44 |
| Tukey HSD $_{(0.05)}$ | 4.53 |

Table 4.23 also shows the effect of load density on final viscosity of cassava flour. Flour produced from 2kg loading density recorded the highest final viscosity of 278.44BU, followed by 4kg loading density (268.44BU). 3kg loading density recorded the least final viscosity of 261.89BU. There were significant differences (P<0.05) observed among the loading densities.

Table 4.24: Effect of drying technology and loading density on final viscosity of flour

| Technology | Loading density | | | Mean |
|---|---|---|---|---|
| | 2kg g | 3kg | 4kg | |
| Sun | 285.00 | 293.00 | 291.33 | 289.78 |
| Solar | 287.33 | 281.67 | 293.67 | 287.56 |
| Bin | 263.00 | 211.00 | 220.33 | 231.44 |
| Means | 278.44 | 261.89 | 268.44 | |

Tukey HSD $_{(0.05)}$ Technology = 4.53; loading density = 54.53; Technology x loading density = 10.83

The effect of drying technology and loading density on final viscosity of the cassava flour is presented in Table 4.24. The final viscosity of the flour ranged from 211.00BU to 293.00BU. Sun drying at 3kg loading density recorded the highest final viscosity of 293.00BU while bin drying at loading density 3kg recorded the lowest final viscosity of 211. Significant differences (P<0.05) were observed among the drying technologies and the loading densities.

### 4.6.4 Breakdown of Cassava Flour (BU)

Table 4.25: Effect of drying technology on breakdown of cassava flour

| Drying Technology | Breakdown |
|---|---|
| Sun | 275.44 |
| Solar | 277.22 |
| Bin | 369.78 |
| Tukey HSD $_{(0.05)}$ | 4.71 |



The effect of drying technology on breakdown of cassava flour is presented in Table 4.25. The flour from the bin drying recorded the highest breakdown value of 369.78BU, followed by solar drying (277.22BU). The sun drying recorded the lowest breakdown value of 275.44BU. The effect of the three drying technologies were significantly different (P<0.05) from each other.

Table 4.26: Effect of loading density on breakdown of cassava flour

| Loading density | Breakdown (BU) |
|---|---|
| 2kg | 282.89 |
| 3kg | 318.33 |
| 4kg | 321.22 |
| Tukey HSD $_{(0.05)}$ | 4.71 |



The effect of loading density on breakdown of cassava flour is presented in Table 4.26. Flour from 4kg loading density recorded the highest breakdown value of 321.22BU, followed by 3kg loading density (318.33BU). 2kg loading density, however, recorded the lowest breakdown value of 282.89BU. There were significant differences (P<0.05) in flour breakdown observed among the loading densities.

Table 4.27: Effect of drying technology and loading density on breakdown of cassava flour

| Technology | Loading density | | | Mean |
|---|---|---|---|---|
| | 2kg | 3kg | 4kg | |
| Sun | 274.33 | 274.00 | 278.00 | 275.44 |
| Solar | 281.00 | 278.00 | 272.67 | 277.22 |
| Bin | 293.33 | 403.00 | 413.00 | 369.78 |
| Means | 282.89 | 318.33 | 321.22 | |

Tukey HSD $_{(0.05)}$ Technology = 4.71; loading density = 4.71; Technology x loading density = 11.24

The effect of drying technology and loading density on breakdown of the cassava flour is presented in Table 4.27. The breakdown value of the flour ranged from 274.00BU to 413.00BU. Bin drying at 4kg loading density recorded the highest breakdown of 413.00BU while sun drying at 3kg recorded the lowest breakdown value of 274.00BU. Significant differences (P<0.05) were observed among the drying technologies and the loading densities.

### 4.6.5 Setback (BU)

Table 4.28: Effect of drying technology on setback of cassava flour

| Technology | Setback (BU) |
|---|---|
| Sun | 106.78 |
| Solar | 105.67 |
| Bin | 108.22 |
| Tukey HSD $_{(0.05)}$ | 4.39 |

The effect of drying technology on setback of cassava flour is presented in Table 4.28. The highest setback value of 108.22BU was recorded by the flour produced from bin drying, followed by flour from sun drying (106.78BU). The flour from solar drying recorded the lowest setback value of 105.67BU. Regarding setback, there were no significant differences (P>0.05) among the drying technologies.

Table 4.29: Effect of loading density on setback of cassava flour

| Loading density | Setback (BU) |
|---|---|
| 2kg | 110.78 |
| 3kg | 101.33 |
| 4kg | 108.56 |
| Tukey HSD $_{(0.05)}$ | 4.39 |

The setback values of cassava flour produced from the loading density is presented in Table 4.29. The flour from 2kg loading density recorded the highest setback value of 110.78BU, followed by 4kg loading density (108.56BU). The lowest setback value of 101.33BU was recorded by 3kg loading density. There were significant differences (P<0.05) observed among the loading densities.

Table 4.30: Effect of drying technology and loading density on setback of cassava flour

| Technology | Loading density | | | Mean |
|---|---|---|---|---|
| | 2kg g | 3kg | 4kg | |
| Sun | 106.00 | 107.33 | 107.00 | 106.78 |
| Solar | 105.00 | 98.67 | 113.33 | 105.67 |
| Bin | 121.33 | 98.00 | 105.33 | 108.22 |
| Means | 110.78 | 101.33 | 108.56 | |

Tukey HSD $_{(0.05)}$ Technology = 4.39; loading density = 4.39; Technology x loading density = 10.48

The effect of drying technology and loading density on setback of the cassava flour is presented in Table 4.30. The setback value of the flour ranged from 98.00BU to 121.33BU. Bin drying at 2kg loading density recorded the highest setback value of 121.33BU while bin drying at 3kg loading density recorded the lowest setback value of 98.00BU. Significant differences ($P<0.05$) were observed among the drying technologies and the loading densities.



## 4.7 EFFICIENCY AND ECONOMIC ANALYSIS OF THE THREE DRYING TECHNOLOGIES

Table 4.31: Efficiency of the drying technologies in drying fresh cassava chips

| Technology | Initial moisture content of cassava chips (%) | Final moisture content of chips (%) | | | | |
|---|---|---|---|---|---|---|
| | | 1hr | 2hrs | 3hrs | 24hrs | 48hrs |
| Sun | 55.4 | - | - | - | 19.2 | 10.9 |
| Solar | 55.4 | - | - | - | 19.6 | 10.2 |
| Bin | 55.4 | 21.5 | 18.8 | 12.3 | - | - |

Table 4.31 shows the efficiency of the three drying technologies used in the cassava chip production. Initial moisture content of the fresh cassava chips was 55.4%. Bin drying technology took the shortest drying time of 3 hours to attain a final moisture content of 12.3%. Solar drying technology took 48 hours of drying time to attain a moisture content of 10.2% followed by sun drying technology which also took 48 hours to attain a final moisture content of 10.9%.

Table 4.32: Rate of moisture loss in the three drying technologies

| Technology | Rate of moisture loss (%) | | | | |
|---|---|---|---|---|---|
| | 1hr | 2hrs | 3hrs | 24hrs | 48hrs |
| Sun | - | - | - | 65.34 | 14.98 |
| Solar | - | - | - | 64.62 | 16.96 |
| Bin | 61.19 | 4.87 | 11.73 | - | - |

Table 4.32 shows the rate of moisture loss in the drying technologies. Bin drying technology reduced the initial moisture content of the cassava chip by 61.19% an hour after drying with a 4.87% reduction 2 hours after drying and a further reduction of 11.73%, 3 hours after drying. In the sun drying technology, initial moisture content was reduced by 65.34%, 24 hours after drying and further by 14.98%, 48 hours after drying. Solar drying technology on the other hand reduced the moisture content of the fresh chip by 64.62%, 24 hours after drying and further by 16.96%, 48 hours after drying.

Table 4.33: Economic analysis of the three drying technologies

| Technology | Cost of cassava per kg (GH¢) | Peeling cost per kg (GH¢) | Washing cost per kg (GH¢) | Chipping cost per kg (GH¢) | Labour Cost for drying per kg (GH¢) | Electricity cost per kg (GH¢) | Firewood cost per kg (GH¢) | Milling cost per kg (GH¢) | Total cost per kg (GH¢) | Flour recovery (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Sun | 0.045 | 0.02 | 0.01 | 0.01 | 0.01 | - | - | 0.006 | 0.101 | 38.4 |
| Solar | 0.045 | 0.02 | 0.01 | 0.01 | 0.01 | - | - | 0.006 | 0.101 | 38.0 |
| Bin | 0.045 | 0.02 | 0.01 | 0.01 | 0.01 | 0.0034 | 0.03 | 0.006 | 0.134 | 36.6 |

Table 4.33 shows the economic analysis of the three drying technologies. Cost of cassava per kg, peeling per kg, washing of cassava per kg, chipping of cassava per kg, labour cost for drying chips and the milling cost were the same for the three drying technologies. However, bin drying technology attracted an additional cost of electricity and firewood. The total cost of production for both Sun and Solar drying technologies were GH¢0.101 each for a kg of cassava flour produced whereas Bin drying technology recorded a total cost of GH¢0.134 for a kg of cassava flour produced. The flour recovery from the three drying technologies was highest in sun drying technology (38.4%), followed by solar drying technology (38.0%) and lowest in bin drying technology (36.6%).

# CHAPTER FIVE

## 5.0 DISCUSSION

### 5.1 MOISTURE CONTENT (%) OF CASSAVA FLOUR

The moisture content of flours from the different drying technologies and loading densities used were within the range of 6.77% - 9.75%. The moisture content of the flours produced gives an indication of the quality of the flours. According to CSIR-FRI (2009), high quality cassava flour must be within the moisture content range of 9-12%. Also Apea-Bah *et al.* (2011) working on quality of flour from four cassava varieties reported moisture content range of 6.34-14.58% which were within the range specified by Codex Alimentarius Commission (1989) for edible cassava flour. The moisture content of the flours suggests that, the flours would have longer shelf life.

### 5.2 pH AND TOTAL TITRATABLE ACIDITY OF CASSAVA FLOUR

The pH of the flours ranged between 6.01 and 6.38. According to CSIR-FRI (2009), high quality cassava flour has pH of 6-7. On the other hand, Apea-Bah *et al.* (2011) reported that pH between 5.07 and 6.65 gave a good quality flour. pH is an important parameter in determining the quality of cassava flour since pH of 4 or less results in flours with appreciable level of fermentation and hence starch breakdown. From the study it is clear that the flours did not show appreciable levels of fermentation.

Total titratable acidity of the flour for the drying technology was high (0.25%) and ranged between 0.24%-0.25% for both loading density as well as drying technology and loading density. The Council for Scientific and Industrial Research - Food Research Institute's training manual specifies a lower acidity (<0.25%) for a high quality cassava flour (CSIR-FRI, 2009). The quality of the cassava flour produced from the different drying technologies and high loading densities may be slightly affected since their acidity was higher than the recommended.

### 5.3 STARCH YIELD OF CASSAVA FLOUR

The starch yield of the cassava flour ranged between 50.47-67.74% for the drying technology and 61.34-61.70% for the loading density. Also, the starch content in the flour from drying technology and loading density ranged between 49.36-69.46%. The starch yield was lower than what was recommended by CSIR-FRI (2009) for high quality cassava flour (>70%). Apea-Bah *et al.* (2011) working on the age of harvest on flour quality of four cassava varieties, reported that, starch yield of 53.6-75.5% for Afisiafi , 67.3- 73.8% for Tekbankye, 64.1-75.7% for Abasafitaa and 63.8-76.0% for Gblemoduade. The starch yield of the Afisiafi variety TMX30572 used in the experiment was lower in the bin drying technology than that reported by Apea-Bah *et al*. (2011). Higher drying temperature used by bin drying resulted in the cooking of starch, therefore reducing the starch yield in the cassava chips dried by the bin drying technology.

### 5.4 BULK DENSITY OF CASSAVA FLOUR

The bulk density of the flour ranged from 0.62-0.74 g/cm$^3$ for the drying technology and 0.66-0.68 for loading density. The bulk density of flours from the drying technology and loading density also ranged between 0.60-0.74 g/cm$^3$. According to Adejuyitan *et al*. (2009) bulk density is a measure of the heaviness of flour produced. Shittu *et al*. (2005) also reported bulk density as an important parameter that determines the suitability of flours for ease of packaging and transportation of particulate foods. Hsu *et al*. (2003) working on yam flour reported bulk density of 0.49-0.63g/cm3. Elkhalifa *et al*. (2005) and Onimawo *et al*. (2003) noted that fermentation results in a reduction in bulk density. This probably explains the lower bulk densities observed in the flours produced from sun and solar drying technologies. Nelson-Quartey *et al*. (2007) concluded in their work that flours with lower bulk density were desirable in infant food preparation. The flour produced using sun and solar drying methods had relatively lower bulk density making it more suitable for infant formulations.



### 5.5 PASTING CHARACTERISTICS OF CASSAVA FLOUR

Pasting properties of flours are important indices in predicting the pasting behavior during and after cooking (Richard *et al.* 1991). The cooking temperature of the flour was found to be within range reported for maize (69-78$^{o}$C) by Sefa-Dedeh *et al*. (2004). Ubbor and Akobundu (2009) also reported 62.0$^{o}$C for cassava pulp flour. The pasting temperature gives an indication of the temperature at which the flour would be cooked. It also gives indication of possibility of scorching. Higher pasting temperatures are likely to induce scorching before a paste is well cooked. This highlights the need for continuous stirring when cooking with flours that have high pasting temperatures. Since sun drying resulted in higher pasting temperature (69$^{o}$C) than the rest. It suggests it cooks at a higher temperature and therefore would need higher energy and longer cooking time for cooking.

The final viscosity of 289.78BU was recorded for cassava flour from sun drying, 278.44BU for 2kg loading density and 293BU for sun drying at 3kg loading density. The cassava flour produced using solar drying at 4kg loading density (293.67BU) had relatively higher final viscosity. The variation in the final viscosity might be due to a simple kinetic effect of cooling on viscosity and the re-association of the starch molecules in the sample. The final viscosity gives an indication of the ability of starch based food to form a viscous paste or gel after cooking and cooling (Claver *et al*., 2010). According to Osungbaro *et al*. (2010), the final viscosity is the most commonly used parameter used to determine the quality of starch-based food. It is therefore expected that using cassava flours produced using sun and solar drying would result in products with higher final viscosities.



Breakdown values of 369.78BU was recorded for flour from bin drying,  321.22BU for flour from 4kg loading density and 413BU  for bin drying at 4kg loading density. The rate of starch breakdown depends on the nature of the material, temperature and degree of mixing and shear applied to the mixture (Maziya-Dixon *et al*., 2004). Adebowale *et al*. (2005) reported that the higher the breakdown in viscosity, the lower the ability of the sample to withstand heating and shear stress during cooking. The results shows that bin drying resulted in flours with lower ability to withstand heating and shear stress during cooking.

The highest setback value of 108.22BU recorded by the cassava flour produced from bin drying technology, 110.78BU from flour from 2kg loading density and 121.33BU for flours from bin drying at 2kg loading density.  This means that the cassava flour will remain stable even when subjected to long periods of constant high temperature. Setback values have been reported to correlate with the ability of starches to gel into semi solid pastes. This property indicate that the flour possesses the highest ability to remain stable  when subjected to long periods of constant high temperature and ability to withstand breakdown during cooking. Osungbaro *et al*. (2010) working on cassava-sorgum flour meals reported that set back value of 81.75BU for 100% fermented cassava flour. Sanni *et al* (2001) reported that lower setback viscosity during cooling of Gari indicates a highest resistance to retro-gradation. The results shows that the flours produced from bin drying at 2kg loading density (121.33BU) and solar drying at 4kg loading density (113.33BU) possess lower resistance to retro-gradation making them more stable at higher temperatures during cooking.



## 5.6 EFFICIENCY AND ECONOMIC ANALYSIS OF THE THREE DRYING TECHNOLOGIES

The bin drying technology was more efficient in drying fresh cassava chips considering the time used in attaining the required moisture content than the solar and the sun drying technologies. The differences in the rate of drying were mainly due to differences in drying temperatures applied in the various technologies. The average temperatures recorded in the sun drying technology was 33°C, solar drying technology was 39°C and bin drying technology was 65°C. According to IITA (2005), temperature, humidity and airflow were very critical in drying of cassava chips. Temperature range of 40°C to 60°C is reported as the best drying temperatures for cassava if gelatinization of cassava starch is to be avoided (FAO, 1977). It can be observed that sun drying was more efficient in reducing moisture content of the cassava chips than solar drying technology at 24 hours after drying than solar drying. This is probably attributable to environmental factors such as the air speed, relative humidity and temperature of the atmosphere around the chips. IITA (2005) reported environmental factors such as ambient temperature, wind speed, relative humidity and chip sizes as factors that influence drying. In both the sun and solar drying technologies, the first

24 hours of drying was very critical since the rate of moisture loss is high if fermentation is to be avoided. Again, for bin drying technology, the first hour of drying is also very critical considering the percentage reduction in moisture content.

The economic analysis of the three drying technologies showed that sun and solar drying technologies were more economical in terms of total cost of flour production than bin drying technology which attracted an additional cost of electricity and firewood. Also in terms of flour recovery, both sun and solar gave a higher flour yield than bin drying. This is can be explained by the high drying temperature used by bin drying resulted in the cooking of starch thereby reducing the starch yield in the dried cassava chips.

## CHAPTER SIX

## 6.0 SUMMARY, CONCLUSION AND RECOMMENDATION

### 6.1 SUMMARY

The study was conducted to assess and evaluate three different drying technologies used for cassava chips production in Ghana at Caltech Ventures Limited, Hodzo - Ho and laboratory analysis of cassava flour carried out at CSIR - Food Research Institute (FRI) in Accra.

Moisture content of the cassava flour was lower in the bin drying (7.10%) technology. Loading density of 3kg had a lower moisture content of 8.38%. Also, the moisture content in the bin drying technology at loading density of 4kg recorded the lowest value of 6.77%, followed by bin drying at 2kg and 3kg with moisture content of 7.27%.

pH of the cassava flour was highest in the bin drying technology (6.37) with loading density of 3kg also recording a higher pH value of 6.23. However, bin drying technology at loading density of 2kg and 4kg had a higher pH value of 6.38.

Total titratable acidity of the flour was high (0.25%) in the three drying technologies. The loading density of 2kg gave a relatively lower acidity of 0.24. However, sun drying at 2kg, solar drying at 3kg and bin drying at 2kg had lower acidity of 0.24.

The starch yield of the cassava flour was higher in the sun drying technology (67.74%). The loading density of 3kg also had a relatively higher starch yield of 61.79%. Also sun drying at loading density of 2kg had the highest starch yield of 69.46%.

Bulk density of the flour was high in bin drying (0.74 g/cm$^3$) and lower in sun drying (0.62 g/cm$^3$). For the loading density, 3kg had a relatively high bulk density of 0.68 g/cm$^3$. Bulk density of 0.74 was recorded in bin drying at 3kg and 4kg while sun drying at loading density had the lowest bulk density 0.60 g/cm$^3$.

Gelatinization temperature or cooking temperature of the flour was lower in the bin drying (67.93$^o$C) and higher in the sun drying technologies (69$^o$C). Loading density of 2kg had a lower cooking temperature of 67.96$^o$C and higher cooking temperature of 68.98$^o$C in loading density of 3kg. Also, a lower cooking temperature of 67.37$^o$C was recorded in solar drying at loading density of 2kg and a higher cooking temperature of 69.23$^o$C in solar drying at loading density of 3kg.

Maximum viscosity of the cassava flour was highest in the bin drying technology (538.11BU). Loading density at 2kg gave the highest maximum viscosity of 502.33BU. Bin drying at loading density of 2kg had the highest maximum viscosity of 547BU.

The cassava flour from sun drying technology had the highest final viscosity of 289.78BU. Loading density of 2kg recorded the highest final viscosity of 2.78.44BU. Sun drying at 3kg loading density also gave the highest final viscosity of 293BU.

Cassava flour from the bin drying technology recorded the highest breakdown value of 369.78BU with flour from 4kg loading density also recording the highest breakdown value of 321.22BU. Bin drying at 4kg loading density recorded the highest breakdown of value 413BU.

The highest setback value of 108.22BU was recorded by the cassava flour produced from bin drying technology. The flour from 2kg loading density recorded the highest setback value of 110.78BU. Bin drying at 2kg loading density also recorded the highest setback value of 121.33BU.

## 6.2 CONCLUSION

The study revealed that sun and solar drying gave higher starch yield than bin drying. Again, sun and solar drying technologies gave better flour when thicker final pastes than the bin drying technology irrespective of loading density. However, bin drying resulted in heavier flours, reduced cooling temperature and maximum viscosities and higher breakdown. Generally, sun and solar drying could be used to produce cassava flours of acceptable pasting properties if duration of drying is not of major concern.

## 6.3 RECOMMENDATION

- It is recommended that sensory qualities of the flour produced with the three technologies should be investigated for its suitability for industrial purpose.
- Further investigation should be conducted on storage of the flour produced from the three drying technologies.

- Drying temperature for the bin technology should not exceed $60^{o}C$ to avoid gelatinization of starch.

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# APPENDIX A: ANOVA TABLES

Appendix 1: Analysis of Variance Table for Moisture Content

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| rep | 2 | 0.0054 | 0.00270 | | |
| technolog | 2 | 19.6974 | 9.84868 | 40753.1 | 0.0000 |
| loaddensi | 2 | 0.6484 | 0.32421 | 1341.56 | 0.0000 |
| technolog*loaddensi | 4 | 2.4508 | 0.61269 | 2535.26 | 0.0000 |
| Error | 16 | 0.0039 | 0.00024 | | |
| Total | 26 | 22.8058 | | | |

Grand Mean 8.2800 CV 0.19

Appendix 2: Analysis of Variance Table for pH

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| rep | 2 | 0.01014 | 0.00507 | | |
| technolog | 2 | 0.60019 | 0.30009 | 244.24 | 0.0000 |
| loaddensi | 2 | 0.00956 | 0.00478 | 3.89 | 0.0420 |
| technolog*loaddensi | 4 | 0.17415 | 0.04354 | 35.43 | 0.0000 |
| Error | 16 | 0.01966 | 0.00123 | | |
| Total | 26 | 0.81370 | | | |

Grand Mean 6.2096 CV 0.56

Appendix 3: Analysis of Variance Table for Total Titratable Acid

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| rep | 2 | 2.222E-05 | 1.111E-05 | | |
| technolog | 2 | 2.222E-05 | 1.111E-05 | 0.73 | 0.4985 |
| loaddensi | 2 | 1.556E-04 | 7.778E-05 | 5.09 | 0.0195 |
| technolog*loaddensi | 4 | 1.556E-04 | 3.889E-05 | 2.55 | 0.0800 |
| Error | 16 | 2.444E-04 | 1.528E-05 | | |
| Total | 26 | 6.000E-04 | | | |

Grand Mean 0.2467 CV 1.58

Appendix 4: Analysis of Variance Table for Starch Yield

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| rep | 2 | 4.92 | 2.461 | | |
| technolog | 2 | 1665.13 | 832.567 | 1030.89 | 0.0000 |
| loaddensi | 2 | 0.61 | 0.304 | 0.38 | 0.6924 |
| technolog*loaddensi | 4 | 30.06 | 7.514 | 9.30 | 0.0004 |
| Error | 16 | 12.92 | 0.808 | | |
| Total | 26 | 1713.64 | | | |

Grand Mean 61.546 CV 1.46

Appendix 5: Analysis of Variance Table for Bulk Density

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| rep | 2 | 0.00001 | 3.704E-06 | | |
| technolog | 2 | 0.06625 | 0.03313 | 204.43 | 0.0000 |
| loaddensi | 2 | 0.00127 | 6.370E-04 | 3.93 | 0.0408 |
| technolog*loaddensi | 4 | 0.00117 | 2.926E-04 | 1.81 | 0.1771 |
| Error | 16 | 0.00259 | 1.620E-04 | | |
| Total | 26 | 0.07130 | | | |

Grand Mean 0.6704 CV 1.90

Appendix 6: Analysis of Variance Table for Cooking Temperature

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| rep | 2 | 3.8141 | 1.90704 | | |
| technolog | 2 | 5.2096 | 2.60481 | 1.80 | 0.1976 |
| loaddensi | 2 | 4.7919 | 2.39593 | 1.65 | 0.2225 |
| technolog*loaddensi | 4 | 4.1770 | 1.04426 | 0.72 | 0.5903 |
| Error | 16 | 23.1859 | 1.44912 | | |
| Total | 26 | 41.1785 | | | |

Grand Mean 68.507 CV 1.76

Appendix 7: Analysis of Variance Table for Maximum Viscosity

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| rep | 2 | 11.6 | 5.8 | | |
| technolog | 2 | 20009.6 | 10004.8 | 317.75 | 0.0000 |
| loaddensi | 2 | 352.9 | 176.4 | 5.60 | 0.0143 |
| technolog*loaddensi | 4 | 550.2 | 137.6 | 4.37 | 0.0141 |
| Error | 16 | 503.8 | 31.5 | | |
| Total | 26 | 21428.0 | | | |

Grand Mean 499.67 CV 1.12

Appendix 8: Analysis of Variance Table for Peak Viscosity

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| rep | 2 | 1.4 | 0.70 | | |
| technolog | 2 | 19668.5 | 9834.26 | 709.01 | 0.0000 |
| loaddensi | 2 | 1251.2 | 625.59 | 45.10 | 0.0000 |
| technolog*loaddensi | 4 | 3683.5 | 920.87 | 66.39 | 0.0000 |
| Error | 16 | 221.9 | 13.87 | | |
| Total | 26 | 24826.5 | | | |

Grand Mean 269.59 CV 1.38

Appendix 9: Analysis of Variance Table for Breakdown

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| rep | 2 | 2.7 | 1.4 | | |
| technolog | 2 | 52405.4 | 26202.7 | 1752.26 | 0.0000 |
| loaddensi | 2 | 8202.3 | 4101.1 | 274.26 | 0.0000 |
| technolog*loaddensi | 4 | 18381.0 | 4595.3 | 307.30 | 0.0000 |
| Error | 16 | 239.3 | 15.0 | | |
| Total | 26 | 79230.7 | | | |

Grand Mean 307.48 CV 1.26

Appendix 10: Analysis of Variance Table for Setback

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| rep | 2 | 9.56 | 4.778 | | |
| technolog | 2 | 29.56 | 14.778 | 1.14 | 0.3451 |
| loaddensi | 2 | 438.89 | 219.444 | 16.90 | 0.0001 |
| technolog*loaddensi | 4 | 742.89 | 185.722 | 14.30 | 0.0000 |
| Error | 16 | 207.78 | 12.986 | | |
| Total | 26 | 1428.67 | | | |

Grand Mean 106.89 CV 3.37

## APPENDIX B: BRABENDER VISCOGRAPH

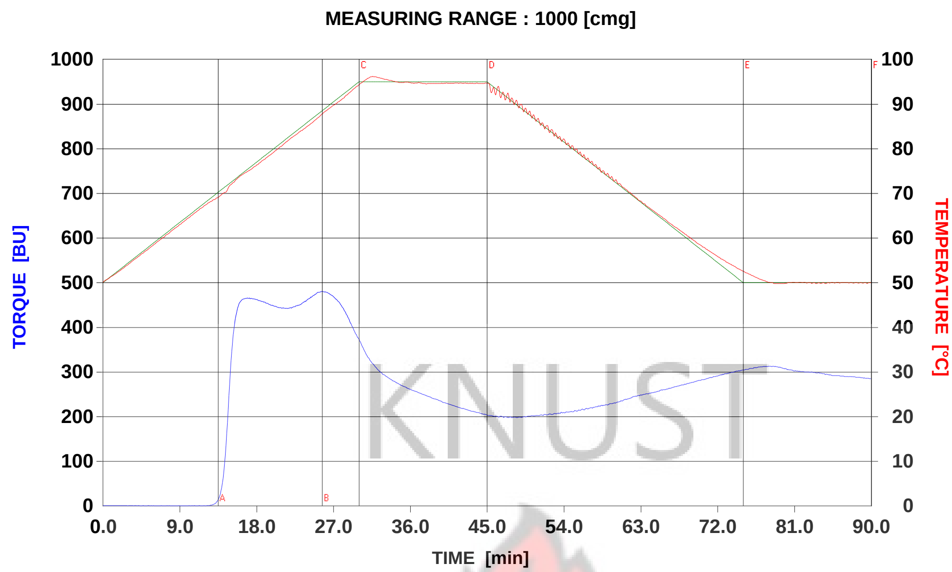


Figure 1: Sun drying at 2kg loading density

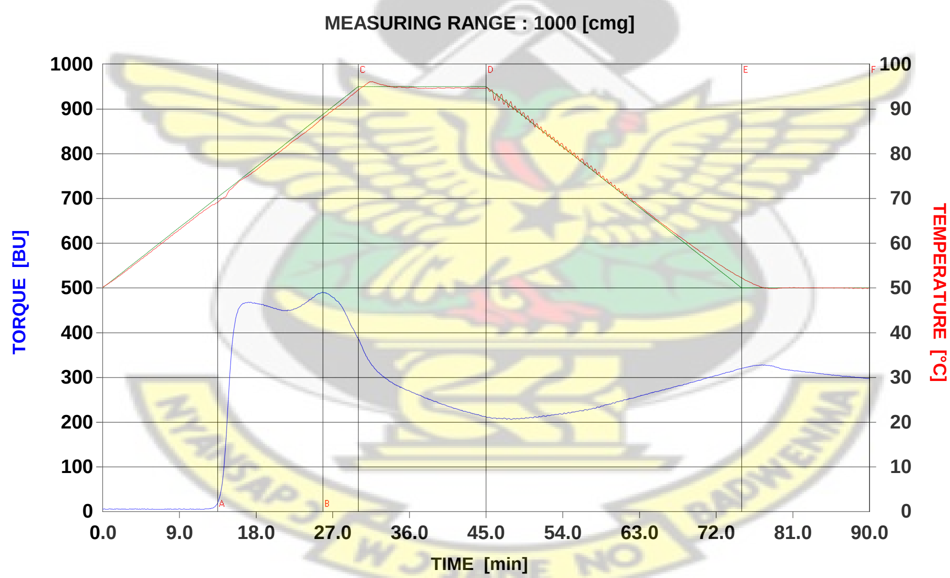


Figure 2: Sun drying at 3kg loading density

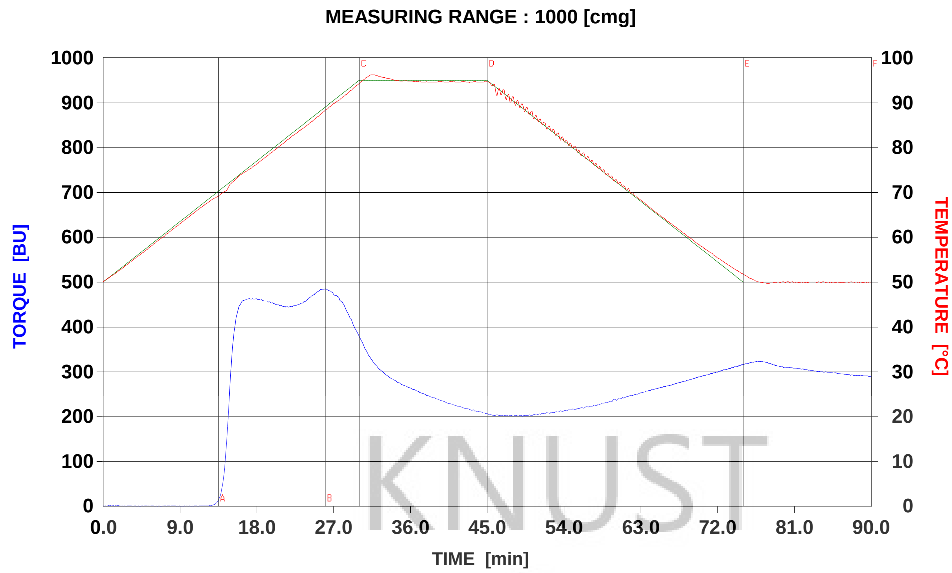


Figure 3: Sun drying at 4kg loading density

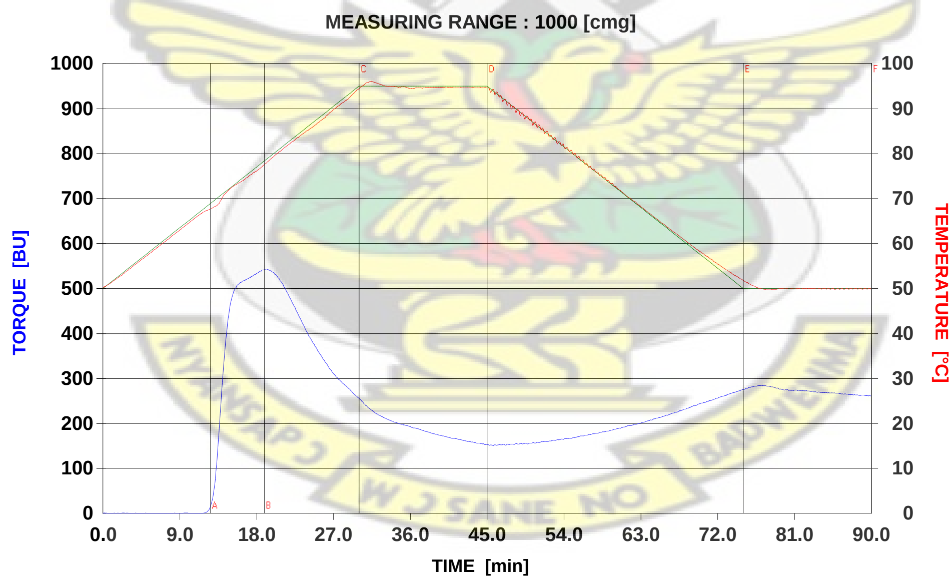


Figure 4: Bin drying at 2kg loading density

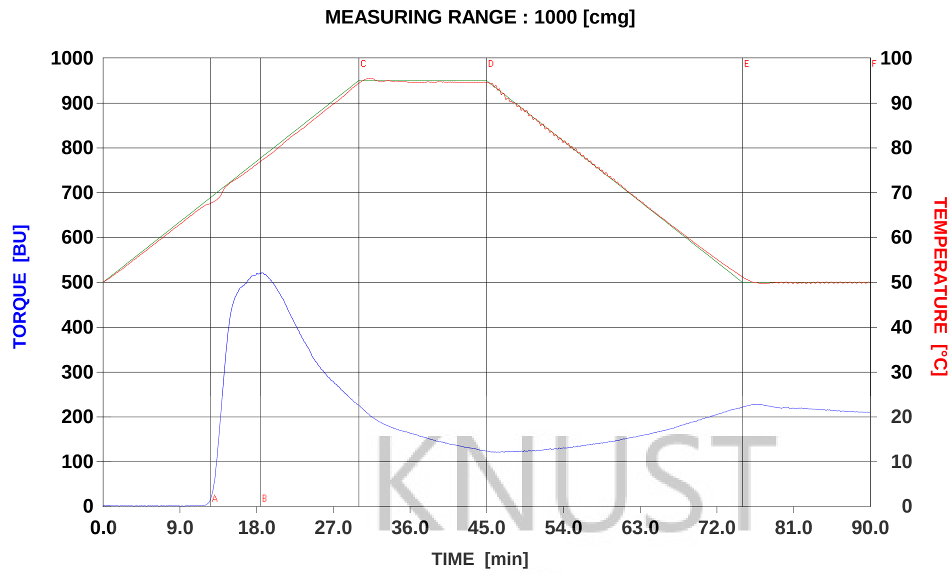


Figure 5: Bin drying at 3kg loading density

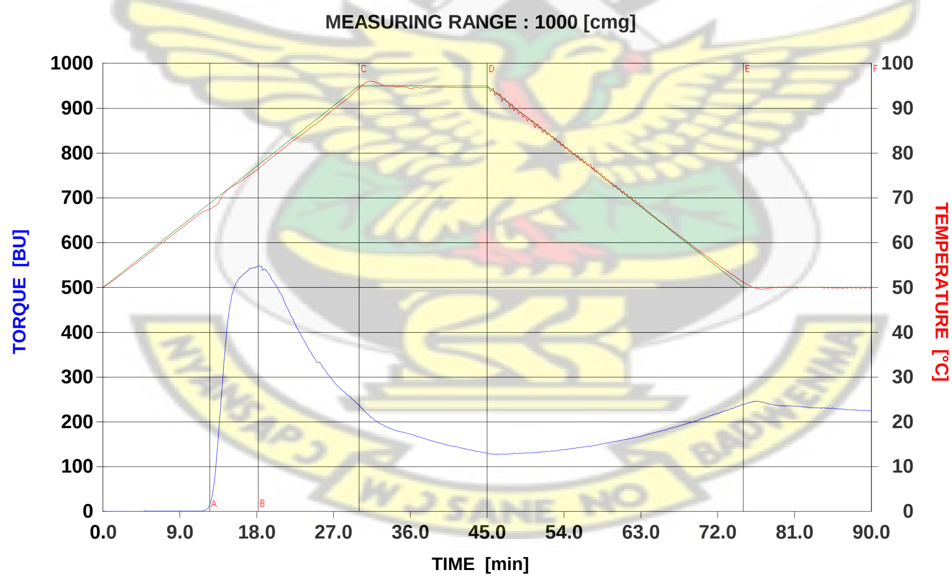


Figure 6: Bin drying at 4kg loading density

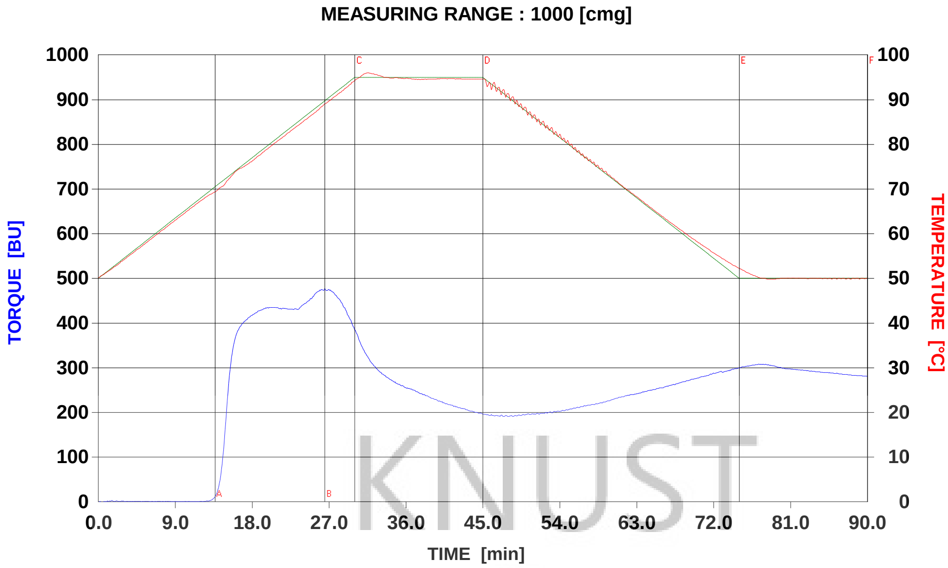


Figure 7: Solar drying at 2kg loading density

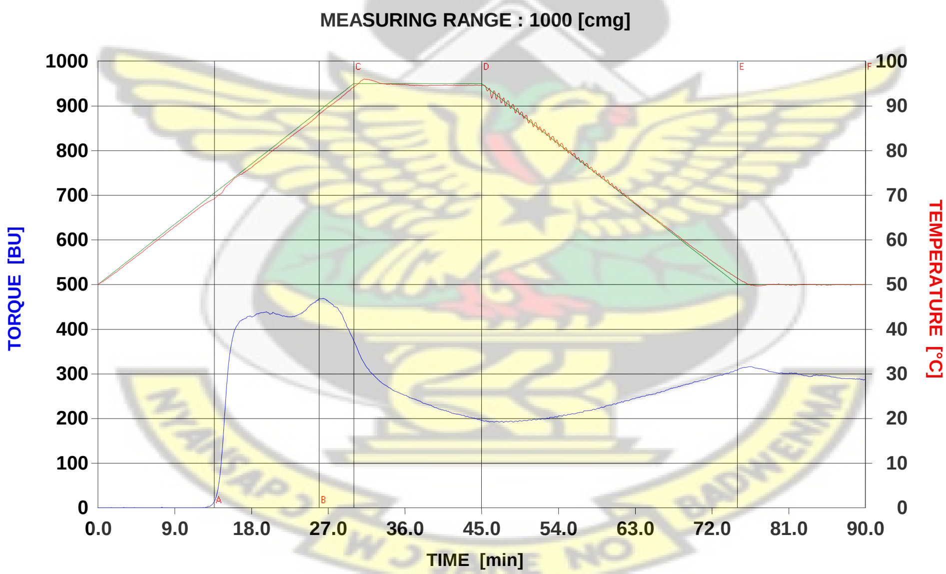


Figure 8: Solar drying at 3kg loading density

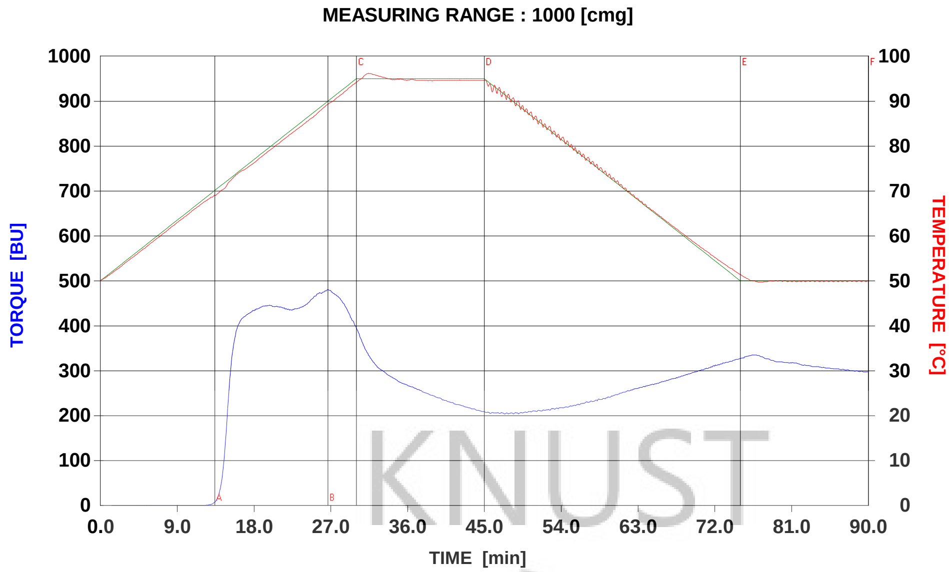


Figure 9: Solar drying at 4kg loading density