KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

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DEPARTMENT OF BIOCHEMISTRY AND BIOTECHNOLOGY

THE EFFECT OF DRYING METHODS (CATALYTIC FLAMELESS INFRARED - CFIR, OVEN AND SOLAR DRYING) ON THE QUALITY OF SWEETPOTATO FLOUR

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (FOOD SCIENCE AND TECHNOLOGY).

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DECLARATION

I hereby declare that this work, submitted to the School of Graduate Studies, KNUST, Kumasi, is the result of my own investigation which has not been presented for any degree elsewhere and that all references to other people's work have been duly cited

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ABSTRACT

Conventional drying methods have many drawbacks that tend to reduce productivity. Infrared drying is one of the advance methods of drying technology that has higher drying rates and energy efficiency than most conventional methods. Catalytic flameless infrared (CFIR) drying is a new infrared drying technology that is being introduced into the food industry. In this work, the CFIR drying method was compared to solar and oven drying method to determine their effect on the proximate, physicochemical and pasting properties of sweetpotato (cv. Santom Pona) flour. Proximate compositions on six cultivars (Santom Pona, Apomuden, 199062.1, Faara, Cemsa 74-228 and Mohc) of sweetpotatoes were first determined. Since CFIR is a new technology in Ghana, drying conditions (drying temperature and time) were first investigated to help use the equipment. Proximate compositions on the six cultivars showed that moisture content ranged from 59.46±1.49 for Santom Pona to 84.71±2.93 in Apomuden. Ash content was highest in Mohc (4.88±1.52) and lowest in Santom Pona. Fibre content was also highest in Mohc (2.81±0.01) and lowest in Faara (0.90±0.00). Apomuden recorded the highest fat content (1.71±0.35) with Santom Pona recording the lowest (0.42±0.04). Protein content ranged from 1.27±0.62 (Mohc) to 4.22±0.33 (Apomuden). It was also observed that, drying temperature of 65°C and drying time of 120min produced good flour quality in terms of pasting profile. Comparing the three different drying methods, it was observed that, CFIR drying method produced flour with highest fat content (1.89±0.61), amylose content (37.87±0.00) and together with oven drying method, produced the highest bulk density. From the work, ash content ranged from 1.11±0.36% to 3.15±0.28%, fibre content ranged from 0.52±0.00% to 0.87±0.00%, protein content ranged from 1.12±0.36% to 3.15±0.94%, phosphorus content also ranged from 154.00±0.00mg/100g to 170.50±0.00mg/100g. Amylose content was observed to be between 23.09±0.00% (Solar drying) and 37.87±0.00% (CFIR drying). pH was least in CFIR (6.03) and highest in solar drying (6.23). Water solubility ranged from 20.31±0.15 to 27.87±0.90 whiles swelling power also ranged from 3.40±0.02 to 3.66±0.02 with CFIR recording the least. Bulk density was between 0.69±0.01g/ml and 0.81±0.04g/ml. For pasting properties, setback viscosity ranged from 25.50±2.12BU to 39±1.41BU, final viscosity ranged from 80.50±3.53 to 153.00±2.83BU with CFIR having the highest and solar drying having the least in both cases. Breakdown viscosity also ranged from 1.00±0.00 to 16.00±0.00BU, peak viscosity ranged from 62.50±0.71 to 138.50±2.12BU. CFIR also recorded the highest L^* value for colour. This study has shown that, in drying sweetpotatoes (cv. Santom Pona), drying method is very essential because, it has effect on the final flour quality. CFIR, being a new technology, has also been shown to produce flour of high physicochemical and pasting quality. Therefore, in setting up a flour or starch factory, CFIR could be an alternative drying system.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Infrared heating was first used in the 1930s for automotive paint curing applications. Now, infrared heating is being widely used for applications such as drying and polymerization of surface coatings and thermoforming in the automotive industry, ultra-pure water, plastics, and wood. However, only limited applications of infrared radiation are available in food and agricultural processes due to limited knowledge about the technology and lack of economic feasibility data (Laohavanich and Wongpichet (2008). Catalytic flameless infrared drying (CFIR) method is a technology which utilizes infrared radiation heat to dry fruits and vegetables. Infrared radiation heating offers many advantages over conventional drying methods under similar drying conditions, such as high heating rate and energy efficiency (Bilowicka, 1960; Ginzburg, 1969; Masamura *et al*., 1988; Abe and Afzal, 1997; Afzal and Abe, 1998). When it is used to dry moist materials, the radiation impinges the exposed material and penetrates it and then the radiation energy is converted into heat resulting in uniform drying (Pan and McHugh, 2004). Prolonged exposure of a biological material to infrared heat results in swelling and eventual fracturing of the material which is mostly detrimental in these kinds of materials (Jones, 1992). Fasina *et al*., (1996 and 1997) reported that infrared heating changes the physical, mechanical, chemical and functional properties of barley grains. In their work, barley grain kernel and bulk densities were reduced and the denaturation of grain proteins resulted when exposed to infrared radiations. Infrared heating of most fruits and vegetables has however yielded good results in terms of yield and final product quality including better functional properties and improved product colour (Lebert *et al*. 1992; Ratti and Mujundar, 1995; Tan *et al*., 2001; Gabel *et al*., 2004). Research on infrared drying has mostly been done in other parts of the world, as such, focused on exotic fruits and vegetables (wheat, barley, carrots, peas, paddy rice, and onions) which cannot thrive well in tropical regions. In Ghana, most of the vegetables used by local people are underutilized crops which are produced in small scale mostly because of their high perishability. Cocoyam, cowpea, Frafra potatoes, sweetpotato are some of the underutilized crops known in Ghana and can increase in importance by adding value through processing (Aboagye *et al.,* 2007). Of all these underutilized crops mentioned, sweetpotato has been found to show great socio-economic importance due to high nutritional qualities. (Antonio *et al.,* 2011).

Sweetpotato (*Ipomea batatas*), is a root crop that is grown in developing countries especially the tropics and subtropics. It is high yielding, but bulky and perishable because of its moisture content. However because of its high dry matter yield it could be an attractive source of flour in many places if efficient, economical methods of drying could be found. Sweetpotato is high in carbohydrates, vitamins (A and C) calories, minerals and carotenoids (Akpapunam and Abiante, 2006; Antonio *et al.,* 2011). It is ranked the seventh most important food crop globally behind wheat, rice, maize, potato, barley and cassava (CIP, 1999). It provides food security and farmers in Africa produce about 7 million tons of sweetpotato each year of which the majority are lost due to improper postharvest handling. (Akoroda, 2009; Akpapunam and Abiante, 2006; Moyo *et al*., 1998).

The utilization of particular types of sweetpotato for food depends mostly on local or regional food preferences. Among the great diversity of cultivars grown, two types are commonly recognized in the world. The staple types (non/low sweet or traditional type), grown throughout the tropics are mostly white, red or purple fleshed, although yellow-fleshed types are also popular in Africa (O'Sullivan *et al.,* 1997; Antonio *et al.,* 2011). The orange-fleshed types, preferred in the USA, typically have higher sugar and lower dry matter content, and are usually eaten only as supplementary or dessert vegetables (O'Sullivan *et al.,* 1997). In temperate countries, the sweet dessert types are preferred and have been used successfully for canning, and baby food. In Asia and some parts of Africa, the leaves are used as a vegetable (Ofori *et al.,* 2009). In China, which produces about 85% of the world's sweetpotato (Wang, 1998), sweetpotato is processed into industrial starch, alcohol, and flour for noodles and other products. In some regions of China, sweetpotato is a mainstay for livestock production, utilizing both the vines and undersized roots. In Ghana and most parts of Africa, sweetpotatoes are either eaten boiled or fried and the remaining converted to flour for other products (Moyo *et al.,* 1998).

Flour can be said to be a fine powder made from cereals or other starchy produce. Processing of sweetpotato into flour is perhaps the best way of creating a product that is not only functionally good, but also remain for an extended period without spoilage. Incorporation of sweetpotato flour into various products together with other flour has been reported by several authors (Palomar *et al.,* 1994; Pangloli *et al.,* 2000; Montreka and Adelia, 2003). Flour related products are mostly the staple diet of most countries, hence the availability of flour has often been a major economic issue (Adeleke and Odedeji., 2010).

1.2 Problem Statement

Fruits and vegetables may be processed so as to produce a high quality product for consumers and also to enable easy handling of goods. High moisture content crops like sweetpotato requires the removal of moisture during processing. There are many heating methods used for processing foods and agricultural products. The drying process induces a number of physico-chemical changes in the product, often reflected by colour, nutritional and functional behavior (Jimoh *et al.,* 2009). The conventional drying methods have many drawbacks, including low energy efficiency, long processing time, quality deterioration and environmental problems (Bomben, 1977; Vanlaanen, 2003). Hence, researchers have been trying alternative drying methods in other to achieve high drying product quality. One of the advanced methods of drying is to use thermal infrared radiation. However, only limited applications of infrared radiation are available in food and agricultural processes due to limited knowledge about the technology and lack of economic feasibility data. Most of the limited work on infrared heating has focused on grains and cereals (Fasina *et al.,* 1997), fruits and vegetables (Pan, 2004). However, underutilized root and tubers like sweetpotato have not yet been evaluated with this new technology.

1.3 Justification

Most homes, restaurants, workers' canteens, parties in Ghana do not serve sweetpotato-based foods to their consumers. This has been attributed to limited choices beyond the unprocessed storage root, and limitations in availability, storage, and handling for food processors (Kays 1985; Moyo *et al.,* 1998). An approach intended to increase consumption of sweetpotatoes is to convert sweetpotato slices into dried flour to be used as a functional ingredient in foods. Processing perishable sweetpotato tubers into intermediate product such as flour, which is more stable and less bulky, widens the potential opportunities and diversity for its utilization. Different drying methods have been employed to convert sweetpotato into flour. The common methods of drying include conventional oven, solar, and sun drying. However, these drying methods required to convert sweetpotato into flour utilizes a lot of energy and time which reduces productivity and also end up depleting most of the essential nutrient needed in food. The flameless catalytic infrared dryer uses natural gas (LPG or propane gas) as an energy source to dry samples under relatively shorter period of time. When using a new technology, it is important to establish the various conditions necessary for its effective use. Flameless catalytic infrared dryer is a new drying technology so the drying temperature and time necessary for its effective use must be established.

1.4 Objectives

The objective of the study was to determine the effect of three drying methods (catalytic flameless infrared, oven and solar) on some quality parameters of flour produced from sweetpotato

Specifically, the study was;

- To investigate the proximate compositions of six sweetpotato cultivars (Santom Pona, Apomuden, 199062.1, Faara, Cemsa 74-228 and Mohc)
- To determine the effect of catalytic flameless infrared (CFIR) drying temperatures and times combination on pasting properties of sweetpotato (cv. Santom Pona) flour

- To determine the effect of three drying methods (CFIR, oven and solar drying method) on the proximate composition, physico-chemical and pasting properties of sweetpotato (cv. Santom Pona) flour

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Drying Methods

Drying is probably the oldest and the most important method of food preservation practiced by humans. The removal of moisture prevents the growth and reproduction of microorganisms and minimizes many moisture-mediated deteriorative reactions. It brings about substantial reduction in weight and volume, minimizes packing, storage, transportation costs and enables storability of the product under ambient temperatures (Mujumbar, 1995). During drying, many changes take place including structural and physico-chemical modifications which affect the final product quality. (Baysal *et al.*, 2003).

Currently hot air oven drying is the most widely used method in post-harvest technology of agricultural products. Hence, works on the effect of hot air oven drying on several crops have been extensively carried out. Using this method, a more uniform, hygienic and attractively coloured dried product can be produced rapidly (Doymaz, 2004). According to Ogunlakin *et al.*, (2012), oven drying methods have better effect on nutritional and functional properties of cocoyam flour than direct sun drying method. In their work, protein levels ranged between 4.93-5.17%, fat was between 0.50-0.57% and ash between 2.47-2.87%, with oven drying having the highest values in each case. Functional properties like bulk density ranged between 0.8309-0.8892g/ml, while swelling power also ranged between 1.50-1.30, with oven drying method having lower values in both cases. Ogunlakin *et al.*, (2012) reported that, variations in protein may be due to protein denaturation of flour resulting from drying and also direct exposure of samples to sun during drying may cause millard reaction leading to loss of protein. Again, direct sun drying also caused oxidation of fat leading to the lower fat content observed in sun drying. However, the authors indicated that, the low fat content will enhance storage life of flour due to lowered chance of rancid flavor development. Despite the beneficial attributes of oven drying method over direct sun drying, it is an energy consuming operation.

Solar dryers are being increasingly used since they are more energy efficient option. Solar dryers could be an alternative to the hot air and open sun drying methods, especially in locations with good sunshine during the harvest season (Pangavhane, *et al.*, 2002). Solar drying can be useful for preserving agricultural products because of the several advantages it possess. Using a solar dryer, the drying time can be shortened by about 65% compared to sun drying because, inside the dryer, it is warmer than outside. The quality of the dried products can be improved in terms of hygiene, cleanliness, colour and taste. The product is also completely protected from rain, dust, and insects when using solar dryer. The most important feature of solar dryers is the fact that, the product does not include any kind of preservatives or other added chemical. Furthermore, the product is not exposed to any kind of harmful electromagnetic radiation due to the protection offered by solar panels (Tiris *et al.*, 1996). Although for agricultural products, solar dryers with solar air heater offer better control of required drying air conditions, solar tunnel dryers based on plastic tunnel greenhouses have a great potential since it does not require any other energy during operation. Therefore, solar dryer may become a more convenient alternative for rural sector and other areas in which electricity is scarce and in irregular supply. Though, other sources of energy may be used for drying of agricultural products, solar energy is preferred since it is abundant in Ghana. An average range of sunshine hours in Ghana is between 4.6 hours per day in July and 8.0 hours per day in November (www.climatetemp.info). Mean relative humidity for an average year is recorded as 81.0% and on monthly basis it ranges from 77% in February and March to 85% in June and July. The average temperature in Ghana is about 27°C and the average maximum temperature is 32°C (www. climatetemp.info). Despite the affordability and benefits of solar dryers, they have been found to use a lot of processing time in other to achieve effective drying. This has been a major problem in the food industry, especially to bigger companies. Hence, recent research has been focused on finding alternative drying methods that produce good quality produce and use less time.

2.2 INFRARED DRYING METHOD

One of the advanced methods of drying is the use of thermal infrared radiation. Researchers have been interested in developing and improving drying techniques with the greater emphasis on higher drying rates and energy efficiency (Pan and Thompson, 2002). Among the three modes of heat transfer, conduction and convection have been extensively studied. Radiation heat transfer, the fastest mode, has received less application in agriculture. Efforts have been made to determine the drying characteristics of important crops in response to electromagnetic energy spectrum (Shivare *et al*., 1994; Nindo and Bekki, 1994; Nindo *et al*., 1995; John and Otten, 1989). Infrared drying offers many advantages over conventional drying methods under similar drying conditions. When infrared radiation is used to heat or dry moist materials, the radiation impinges the exposed material, penetrates it and the energy of the radiation converts into heat (Ginzburg, 1969). The penetration depth of radiation depends on the material properties and radiation wavelength. When a material is exposed to radiation, it is heated intensely and the temperature gradient in the material reduces within a short period. In conventional drying, heat is mainly subjected to the surface of the food by convection from circulating hot air and then transfer of heat to the core takes place by conduction. This results in case hardening of the material and hinders mass transfer (Hebber and Rastogi, 2001). The penetration capability of infrared could reduce the case hardening with increased drying or mass transfer rate.

2.2.1 INFRARED RADIATION CHARACTERISTICS

Infrared radiation is part of thermal radiation (0.1-100 µm) which includes infrared, visible, and part of ultraviolet and is emitted as a result of vibrational and rotational motions of molecules, atoms and electrons of substance. The wavelength of infrared falls into the spectrum of 0.76 to 100 µm (Plate 1).

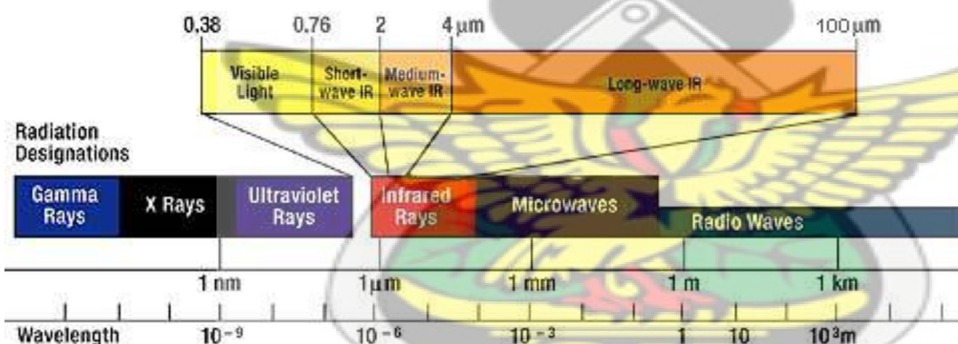

Plate 1. Electromagnetic Spectrum Source: Pan (2004)

Based on wavelengths, the infrared can typically be categorized into near infrared (NIR or short-wave infrared) (0.76-2 µm), medium infrared (MIR) (2-4 µm) and far infrared (FIR) (4-100 µm) (Table 1). At a given wavelength, emitted infrared radiation energy depends upon the material of the body and the conditions of the surface as well as the surface temperature. The NIR is associated with high temperature and energy emission which causes product discoloration and quality deterioration in agricultural and food products. The FIR is associated with low temperature and energy emission and may not be enough to meet the energy requirement in most agricultural processes. Therefore, the useful temperature of infrared radiation should be in a range of 150 to 2,200°C which corresponds to the wavelength of 2.0 to 4.0 µm.

Table 2.1. Peak wavelengths and temperatures of a blackbody at various infrared radiations

Infrared Radiations	**Wavelength (µm)**	**Temperature**
Near Infrared (NIR)	0.8 – 2.0	3623 -1448K (3350-1175°C)
Medium Infrared (MIR)	2.0 – 4.0	1448 – 723K (1175- 450°C)
Far Infrared (FIR)	4.0 - 100	723 -28K (450 - -245°C)

Source: Pan *et al*., (2004)

Recent research has focused on medium and far infrared application for drying foods and agricultural products (Pan, 2004). In general, there are two different types of infrared emitters, electric and gas-fired emitters. The electric emitters include lamp quartz tubes and carbon and ceramic emitters that emit NIR, MIR and FIR depending upon the operation temperature. For gas-fired emitters, catalytic flameless gas-fired emitter has gained better acceptance for some applications due to safety concerns of open flame and emitters made with glass (Pan, 2004). Since air is primarily a mixture of oxygen and nitrogen, neither of which absorbs infrared radiation, infrared energy can be transferred from the heating element to the product surface without heating the surrounding air and then the energy transfer is highly efficient (Jones 1992).

2.2.2 EFFECT OF INFRARED ON FRUITS AND VEGETABLES

Most fruits and vegetables have high moisture contents and are highly perishable. To prolong the shelf life of these commodities, different ways of drying as a tool for preservation have been investigated. Infrared drying has received considerable attention because of advantages such as shorter drying time, higher heat transfer rate, less energy requirement and superior product quality compared to conventional hot air drying (Sandu, 1986; Ratti and Mujumdar, 1995; Afzal *et al*., 1999; Tan *et al*., 2001). The heat flux emanating from infrared drying is 6-10 times higher than from convection hot air drying (Therien *et al*., 1991). Since water is the main component of many biological materials, variations in infrared penetration capabilities can partially be explained by the absorption curve of water. According to Ginzburg (1969), the penetration depth for infrared in raw potato is 6mm for wavelength of 1μm and 4.76mm for wavelength of <1.25μm. Afzal *et al*. (1999) found that within a temperature range of 40°C to 70°C, a combined hot air-FIR drying process in comparison with convective drying reduced total energy required to between 60% and 70%. Yamazaki (1992) reported that, in order to further improve the drying rate, drying conditions must be such that the temperature of the product is above the boiling point of water. Such conditions may help with developing a positive partial vapor pressure gradient within the material that drives the moisture from within the material toward the surface. To obtain internal high vapor pressure and at the same time maintain high product quality, moisture within the material being dried should be vaporized and evaporated at lower temperatures. A vacuum or lower pressure condition coupled with the FIR heater could speed up the drying process and improve quality (Ratti and Mujumdar, 1995). Ratti and Mujumdar (1995) recommended that a heater that radiates infrared maximally even at low temperatures should be used with a reduced pressure where high temperature in an enclosed chamber is undesirable. Welsh onion drying in the FIR–vacuum and FIR–convection systems showed the three characteristic drying rate features: rising–rate, constant–rate, and falling–rate periods. Drying rate increased with increased radiant power input and was higher under the reduced–pressure condition than that under the convective condition. For optimum drying rates vis-à-vis produce quality and energy savings in the drying of Welsh onion, it was recommended that FIR-vacuum operation at 0.17 W/cm2 radiant power input be used (Mongpraneet *et al*., 2002a and 2002b). In the convective condition, drying should be done at higher radiant power input levels for better reconstitution. To dry heat-sensitive particulate materials, a combined radiant-convective drying method or an intermittent irradiation drying mode may be used (Zbicinski *et al*., 1992).

When a combination of intermittent infrared and continuous convection heating was used to dry various osmotically pretreated samples of potato, reduced color change, with high drying rates was obtained with appropriate choice of infrared intermittence as well as osmotic pretreatment (Tan *et al*., 2001). In the study of drying kinetics of mint, Lebert *et al*. (1992) showed that temperature was the main factor in controlling the rate of drying. High solid onions dehydrated using a catalytic flameless gas-fired infrared (CFG IR) dryer had a significantly higher drying rate at 70°C onion surface temperature when compared to the forced air convection (FAC) drying (Gabel *et al*., 2004). Since onion quality was very sensitive to the drying temperature, intermittent heating was achieved by using a control system that maintained the onion surface temperature at 70°C. It was shown that air recirculation within the CFIR did not contribute to increase in the drying rate in the study.

An increase in drying rate with an increase in radiation intensity has been reported in several studies on infrared drying (Bilowicka, 1960; Ginzburg, 1969; Masamura *et al*., 1988; Abe and

Afzal, 1997; Afzal and Abe, 1998). For rice drying, using NIR took 7 minutes to reduce the moisture content from 20 to 14.8% compared to 30 minutes used for hot air drying. However, even though higher level of radiation intensity increased the drying rates, it was detrimental to the quality of rice due to the increase in material temperature (Rao 1983).

2.3 SWEETPOTATO

2.3.1 SWEETPOTATO PRODUCTION

Sweetpotato (*Ipomea batatas*) is among the world's most important versatile and underutilized food crops. Annual sweetpotato production world wide was about 133 million tons and currently ranks as 5th most important crop on fresh weight basis. In Africa, the production of sweetpotato is highest in east Africa with the annual production of 5506.42 thousand tonnes representing about 45.8% of the total production (Akoroda, 2009) and is widely practiced in regions surrounding the lake Victoria in Uganda, Northwestern Tanzania (Onueme., 1978; Oggema *et al*., 2007) as well as central and western Kenya where the crop occupies a national status as a food security crop (Munga *et al*., 2000). In West Africa, which is the second largest production region in Africa with annual production of 3801.44 thousand tonnes representing 31.6%, Nigeria has been found to be the largest producing country. World sweetpotato cultivation area stood at 7.70 million ha of which, 93% is found in the Asian countries. Africa's sweetpotato hecterage is highest in West Africa (Akoroda, 2009) and together with east Africa account for 77.4% of the continents production. Between 2005 and 2006, sweetpotato usage per person in Africa stood at 10.76Kg/year. In Ghana, sweetpotato usage stood at 3.98% out of 90,000 tonnes of fresh tuber produced (Akoroda, 2009). Hence, processed products are seen as essential to future expanded utilization of sweetpotato, and infrared drying technology may have a role to play.

Table 2.2 Some Attributes of Released Sweetpotato varieties in Ghana

Cultivar Name	Tuber Flesh Color	Dry Matter Content (%)	Overall Tuber Acceptance (γ)
CRI-Apomuden	Reddish orange	21.9	3
CRI-Otoo	Light orange	32.2	3
CRI-Ogyefo	White	40.1	3
CRI-Histarch	Cream	40.0	3
Sauti	Yellow	40.2	4
Faara	White	36.1	4
Okumkom	White	30.7	2
Santom pona	Light Yellow	34.4	2

Source: Akoroda, (2009)

γ > 1- bad, 2- fair, 3- good, 4- very good

Several varieties of sweetpotatoes have been released by the Council for Scientific and Industrial Research (CSIR) - Crop Research Institute (Ghana) with improved qualities for farmers. Some of these unique qualities range from dry matter content to overall acceptability (Table 2.2). Recent releases possess improved yields and nutritional quality. Some released varieties have been targeted at reducing provitamin A deficiency in the country. The orange fleshed sweetpotatoes like CRI-Apomuden have recently been released to achieve this purpose. They posses high carotene and vitamin content which can help eradicate the problem of malnutrition in most local communities.

2.3.2 NUTRITIONAL QUALITY OF SWEETPOTATO

Sweetpotato is an important alternative source of carbohydrate, taking the fourth place after rice, corn and cassava (Zuraida, 2003). Fresh sweetpotato storage roots contain 16 to 40% of dry matter, of which 75% to 90% is composed of carbohydrate such as starch, sugars, cellulose, pectin and hemicellulose (Collins and Walter, 1985) depending on the cultivar. Sweetpotato roots have been shown to contain substantial amount of ascorbic acid (vitamin C), moderate quantities of thiamin (vitamin B_1), riboflavin (B_2) and niacin, some panthothenic acid (B_5), pyridoxine and its derivatives (B_6), folic acid and have also been reported to contain satisfactory quantities of tocopherol (vitamin E) (O'Sullivan *et al*., 1997).

Sweetpotato, the orange fleshed type, is the only starchy staple which contains appreciable amounts of beta-carotene which is a precursor of provitamin A and is equaled only by carrots in this aspect (Woolfe, 1992). Sweetpotato starch has also been found to be easily digestible, making it a useful ingredient in the preparation of weaning meals. It has been reported that sweetpotato leaves contain proteins and fibres which are important for addressing protein deficiency and colon diseases (Hiroshi *et al.,* 2000; Olayiwola *et al.,* 2009). A report from Wireko *et al.,* (2010), shows that the content of vitamins and minerals in sweetpotato are comparable to most fruits. Woolfe (1992) observed that sweetpotatoes are rich in dietary fibre, minerals, vitamins and antioxidants such as phenolic compounds, anthocyanins, tocopherol, and beta-carotene. Not only is it an excellent source of vitamin A, copper, panthothenic acid and folic acid (Hou *et al*., 2000) but also, a red –fleshed sweetpotato cultivar grown in the Andean region has been reported to be higher in antioxidant activity and phenolic acid content than a cultivar of blueberry, a fruit which is popularly known to contain high levels of antioxidants (Cevallos Casals and Cisneros-Zevallos, 2003; Wireko *et al.*, 2010). A high antioxidant capacity as reported by Wu *et al* (2004) in purple fleshed sweetpotato has been compared to most fruits such as avocado, cherries, apples, appricot, grapefruit, orange, pears and vegetables such as brocolli, cabbage, eggplant and lettuce. Comparing sweetpotato nutritional quality to other crops, Harnowo *et al.*, (1994) observed that, sweetpotato produced the highest amount of vitamin A and apart from rice, had the next highest fat content (Table 2.2). Aside cassava, it was the next highest in terms of calcium and vitamin C content.

Table 2.3. Nutritive value of sweetpotato per 100g to other food source

Material	Energy (cal)	Carbohydrate (g)	Protein (g)	Fat (g)	Vitamin A (SI)	Vitamin C (mg)	Ca (mg)
Sweetpotato	123	27.90	1.80	0.70	7,000	22	30
Rice	300	78.90	6.80	0.70	0	0	6
Cassava	146	34.70	1.20	0.30	0	30	33
Corn	361	72.40	8.70	4.50	350	0	9

Source: Harnowo *et al*., (1994)

2.3.3 PROCESSING AND UTILIZATION SWEETPOTATOES

The utilization of particular types of sweetpotato for food depends mostly on local or regional food preferences. In temperate countries, the sweet dessert types are preferred and have been used successfully for canning and baby food (O'Sullivan *et al*., 1997). In Asia and some parts of Africa, the leaves are used as vegetables (Ofori *et al.*, 2009). In China, which produces about 85% of the world's sweetpotato, starch and flour are produced from sweetpotato for noodles (Tang *et al.*, 1990; Marter and Timmins, 1992; Wang, 1998). Processing the perishable sweetpotato tuber into intermediate products such as flour and starch, which are more stable and less bulky, widens the potential opportunities for its utilization. In Indonesia, around 80% of the sweetpotato production is used as food and about 10% as feed. A diverse range of sweetpotato processing enterprises exist in East and Southeast Asia where sweetpotato is also processed into starch, flour, frozen intermediary products, and snack foods for export to Japan, Taiwan, and Korea (Wheatley 1996). Sweetpotato is used primarily for human food, but it is also for animal feed, alcohol, starch, and various industrial purposes. Many food products in Indonesia such as tomato sauce, ketchup, dried-cake, spongy cake, and biscuit utilize sweetpotato as part of the ingredient. Tomato ketchup is one of food products which use heavily sweetpotato as an ingredient. A survey showed that 60% of the raw material used in tomato ketchup is of sweetpotato (Suismono *et al*. 1994). In Uganda which is the leading producer in Africa, sweetpotato is a major staple (Venegas and Bashaasha, 1991) and is used for the preparation of buns, *chapattis*,and *mandazi* (Hagenimana and Owori, 1997). Agbo and Ene (1994) reported that consumption patterns in Nigeria indicating that most people consume boiled sweetpotato roots as food, as well as fried slices or chips and roasted roots. Sometimes, the tubers are eaten in the form of pounded *foofoo* or dried and milled for sweetening of gruel or *ogi* porridge.

In Ghana, most of the roots produced are consumed in the form of 'Ampesi' (boiled and eaten with stew or eaten alone), 'Koliko' (fried chips) and 'Oto' (boiled and mashed tubers with pepper, onions, tomatoes) (Missah *et al*., 1993). Reports by Ellis *et al*. (2001) showed that certain varieties produced in Ghana, like Santom Pona and Hi-Starch could be used for the production of gari (grated and fried) with very good appearance, crispiness, colour and acceptable mouthfeel with some other varieties showing good pasting characteristic making them suitable as a good substitute for wheat flour as well as good product for composite flour preparation. Okumkom variety has been found to have a relative high water binding capacity which is an important criterion for the production of all types of bakery products (Oduro *et al*., 2003). Okumkom and Faara contain an appreciable amount of β- Amylase, as reported by Dziedzoave *et al*., (2010), which is good for the production of glucose syrups. The use of sweetpotato flour in Ghana has however been very minimal as most of the crops are typically produce as food, eaten by the farmer's family or locally marketed in an unprocessed form. This typically results in postharvest losses due to rotting of fresh tubers. Therefore, it is necessary for processors to resort to converting most of the harvested sweetpotatoes to flour in order to minimize postharvest losses.

2.3.3.1 FLOUR

Flour can be defined as a fine powder made from cereals or other starchy produce. Processing of sweetpotato into flour is perhaps the best way of creating a product that is functionally useful and can also be stored for an extended period without spoilage. Incorporation of sweetpotato flour into various products has been reported by numerous authors (Palomar *et al.*, 1994; Pangloli, *et al.*, 2000; Montreka and Adelia, 2003; Chen *et al.*, 2003a). Different products can be prepared by incorporating sweetpotato flour with other flours using various methods such as baking, roasting, steaming, boiling and deep fat frying. Sweetpotato flour is used by baking industry and is incorporated in the baking of bread to retain its freshness. It also imparts a distinctive, pleasing flavour and improves toasting qualities. It can be used advantageously in crackers, pastries, yeast raised doughnuts, cake and cake mixes (Anterlina, 1994).

Flour, mostly made from wheat, is the key ingredient in bread production which is a staple in the diet of many countries. Therefore, the availability of flour has often been a major economic issue. Flour can also be made from legumes and nuts, cassava, sweetpotato and yam (Sanni *et al.*, 2006). There have been several attempts to use sweetpotato flour (SPF) in different food products such as butter cookies, pretzels, cakes, hotcake mixes, and instant porridges, and as a composite with wheat in the production of noodles and bread (Angue and Inocencio 1992, Truong 1992, Amante 1993, Collado and Corke 1996). These products have specific quality requirements, and quality standards for sweetpotato flour should be devised for each end use. Sweetpotato varieties for industrial purposes should have high starch content and generally white flesh varieties are preferred. Starch content in sweetpotato varies from 5.30 to 28.40% (Bradbury and Holloway 1988). The processing of fresh sweetpotato into flour can improve storage and increase its utilization, as a raw material for various food industries (Antarlina 1994).

Comparing sweetpotato flour to wheat flour (Table 2.4), Anterlina (1994), observed that, sweetpotato flour contains higher fibre (1.95%), and ash (2.13%) than wheat flour (fibre = 0.62 and ash = 0.50). The high fibre and ash content observed makes sweetpotato flour suitable for industrial application such as dietary fibre, pureed infant foods, sprayed-dried powders and thickeners (Lii *et al.,* 2003; Ahmed *et al.*, 2006; Grabowski *et al.*, 2008). Such products have good advantages as a food ingredient in relation to other cereals, especially with respect to wheat, due to its hypoallergenic effect (Antonio *et al.*, 2011). Onuh *et al.*, (2004), reported that, red skin sweetpotato has lower protein content (1.2%) than the white variety (2.3%). Differences in nutritional content of flour can be attributed to production practices, environmental conditions and genetic factors (Woolfe, 1992; Antonio *et al.*, 2011)

The most important protein in flour necessary for baking is gluten. Gluten proteins found in wheat flours give structure to baked goods. Base on gluten content, flours are categorized into soft (pastery) and hard (All-purpose) flour (Bennion, 1995c). Soft flour contains less than 10 % protein, while hard flours have more than 10 % protein. Soft flours are preferred in soft baked goods, such as cakes. Such products have been found to require only small amount of gluten formation. All-purpose flour (hard), however, can be used for products like noodles, cookies and most bakery products requiring high gluten content (Bennion, 1995c).

Table 2.4. Nutrient content of sweetpotato flour compared to wheat flour

Component	Sweetpotato Flour	Wheat Flour
Moisture content (%)	7	7
Protein (%)	5.12	13.13
Fat (%)	0.50	1.29
Ash (%)	2.13	0.50

Carbohydrate (%)	85.26	85.04
Fibre (%)	1.95	0.62
Energy (cal/100g)	366.89	375.79

Source: Anterlina, (1994)

To determine the suitability of sweetpotato flour for specific requirements such as soups, sauces, snacks, knowledge on functional and physico-chemical characteristics of its starch is essential. Functional qualities such as water absorption index, swelling power, solubility index, foaming capacity, dispersability, bulk density, pasting characteristics are usually affected by processing parameters like temperature and time (Adeleke and Odedeji, 2010).

2.3.3.2 FUNCTIONAL PROPERTIES OF FLOUR

With the increasing use of sweetpotato composite flours in food formulations, information on functional properties is essential. Such properties of plant foods are determined by the molecular composition and structure of the individual components and their interactions with one another. The functional properties of the flour are provided not only by the starch but also by other flour constituents. Flour functional properties are different from those of starch since extra constituents available in flour (non-starch carbohydrates, protein, and fat) modify access of water into the starch granules (Moorthy and Ramanujam, 1986). Modified or speciality flours in snack foods serve as functional ingredients, contributing to desirable attributes such as increased expansion, improved crispness, reduced oil pickup, and better overall eating quality (Adeleke and Odedeji, 2010). Starch-based coatings and adhesives can replace fat or oil in low fat baked snacks, while resistant starch provides high fiber nutritional value foods. Sweetpotato flour possess several of these attributes of modified or speciality flour and have been used in some cases (Lii *et al.*, 2003; Ahmed *et al.*, 2010; Grabowski *et al.*, 2008). Sweetpotato starch also has other numerous useful functional properties such as thickening, coating, gelling, adhesion, and encapsulation. Some of these functionalities are unique to the polymer as a result of the structure of linear amylose (17–25% of starch), highly branched amylopectin and organization of the polymer (Hoover, 2001). Amylose content has been reported by several authors to greatly influence flour functional properties. Ashogbon and Akintayo, (2012) observed that, differences in amylose content (21.88% to 26.04%) affected swelling power and solubility of rice starch. According to their reports, lower amylose content starches swell more than those of higher amylose structure. According to Tester and Morrison (1990), amylopectin contributes to swelling of starch granules whereas amylose and lipids inhibit swelling. Similar observations were also made by Brabet *et al*., (1999) on sweetpotato germplasm. They reported amylose content between 18.6% and 27.1%. According to Tsakama *et al*., (2010), sweetpotato amylose content is normally between 8.5% and 38%. Phosphorus is one of the non-carbohydrate constituents present in starches, which significantly affects the functional properties of starches (Karim *et al.*, 2007). According to Tsakama *et al.*, (2010), phosphorus binds to water which results in increase granular swelling. The crystalline order in starch granules is often the basic underlying factor influencing its functional properties. Collapse of crystalline order within the starch granules manifests itself through irreversible changes in properties such as granule swelling, pasting, and starch solubility (Hoover, 2001).

Investigating the functional properties of sweetpotato and wheat flour blends Adeleke and Odedeji (2010) showed that swelling power and solubility was influenced by protein content of the samples. In their work, swelling power ranged between 1.27% and 2.45% whiles solubility ranged from 6.01% to 8.63% with 100% sweetpotato flour having the lowest in all cases. Adejumo *et al*., (2011) reported that, cassava solubility ranges from 17.2% to 27.2%. Compared to cereals, sweetpotato has been observed to have lower swelling power than solubility (Sandhu and Singh, 2007). According to Sandhu and Singh, (2007), corn solubility ranged from 9.7% to 15.0% while swelling power was between 13.7% and 20.7%. The swelling power and solubility index of *Brachystegia eurycoma* starch was reported to be 10.05% and 5.95% respectively while that of *Brachystegia eurycoma* flour was 9.64% and 5.34% respectively (Ikegwu *et al.,* 2010). Starches usually have higher swelling power and solubility than flour because of the presence of other compounds in flour (Moorthy and Ramanujam, 1986). Reporting on rheological and functional properties of "achi" flour, Ikegwu and Ekwu (2009) showed that, swelling power increased when temperature and time increased during processing. Swelling power is an indication of water absorption index of granules during heating (Loose *et al.,* 1981). It was suggested that, increase in temperature enhanced penetration of water into granules of the flour. It was also suggested that increasing temperature weakened the intra-granular binding forces of starches. Moorthy and Ramanujam (1986) suggested that, swelling power of granules reflects associative forces within the granules. This facilitates granule swelling and leaching which leads to increased solubility. Similar result has been reported for Jack bean starch (Yusuf *et al.,* 2007; Ancona *et al.,* 1997) banana starch (Bell-operez *et al.,* 1998) and Bambara groundnut starch fractions (Lawal *et al.,* 2004). King (2005) and June *et al.,* (1991) reported that starch granules in suspension swell when heated, as the temperature is raised, hydrogen bonds continue to be disrupted, water molecules become attached to liberated hydroxyl groups and the granules continue to swell. This mechanism is even more pronounced with short wavelength radiations like electron beam and infrared radiations (Fasina *et al.,* 1996; Pimpa *et al.,* 2007). According to Pimpa *et al.*, (2007), radiations easily cleave glycosidic bonds through free radical formation to form smaller carbohydrate units. Either one or combination of these characteristics is required in most food processes where the properties of unmodified starch are not optimal. It has been shown that, functional properties of starch and starch-containing materials such as flour are also influenced by composition and structure of the plant genotype, its botanic origin, organization among starch granules, and their concentration (Anterlina, 2004).

2.3.3.3 PASTING PROPERTIES OF FLOUR

When starch-based foods are heated in an aqueous environment, they undergo a series of changes including enormous swelling, increased viscosity, translucency and solubility. These changes are defined as gelatinization (Ikegwu *et al.*, 2010). Pasting encompasses the changes that occur after gelatinization upon further heating including swelling of granules, leaching of molecular components from the granules and eventual disruption of granules (Tester and Morrison, 1990). Gelatinization and pasting are two of the most important properties that influence quality and aesthetic considerations in the food industry, since they affect texture and digestibility as well as the end use of starchy foods (Adebowale *et al*., 2005). The pasting profile of a material has important bearings on its suitability for different applications. Pasting temperature has been found to relate to resistance of a starch to swelling. It indicates the maximum temperature required for cooking and the associated energy cost (Eniola and Delarosa, 1981). Pasting temperature has been reported to relate to water binding capacity. A higher pasting temperature implies higher water binding capacity, higher gelatinization and lower swelling property of starch due to a high degree of association between starch granules (Eniola and Delarosa, 1981; Numfor *et al*., 1996). Adeleke and Odedeji, (2010) recorded a pasting temperature of 80.90°C for sweetpotato flour and 82.25°C for wheat flour. Characterization of pasting properties of most flours focuses on the breakdown viscosity, setback, final viscosity and peak viscosity. Rapid visco analyzer (RVA) provides a good method for measuring these functional properties and describing flour potential end-use just as the Brabenda viscoamylograph (BV), which is usually used but consumes more time and sample (Brabet *et al.*, 1998).

Peak viscosity is the ability of starch to swell freely before physical breakdown (Sanni *et al*., 2004). Several authors have determined the peak viscosities for different starch and flours. Adeleke and Odedeji (2010) observed peak viscosity of sweetpotato flour to be 271.08 RVU (RVU= Rapid visco unit) and that of 100% wheat flour to be 131.42 RVU. High peak viscosity is an indication of high starch content (Osungbaro, 1990). It is also related to the water binding capacity of starch (Adebowale *et al*., 2005; Shimelis *et al*., 2006). The high peak viscosity displayed by 100% sweetpotato flour implies that the flour may be suitable for products requiring high gel strength and elasticity (Adebowale *et al*., 2005). Peak viscosity for *Brachystegia eurycoma* flour and starch has been reported to be 77.58 RVU and 267.08 RVU respectively (Ikegwu *et al.*, 2010).

The breakdown viscosity value is an index of the stability of starch (Fernande De Tonella and Berry, 1989). Breakdown viscosity is an important criterion that decides the application of starch in the food industry. Work done by Adeleke and Odedeji, (2010) on sweetpotato and wheat flour blends showed a breakdown viscosity range of 45.00 to 110.00 RVU with increasing values as more sweetpotato flour was added to blend. 100% SPF recorded the highest value suggesting higher stability of starch. However, its been reported that, the higher the breakdown viscosity, the lower the ability of the starch sample to withstand heating and shear stress during cooking (Adebowale *et al.*, 2005). Raphael *et al.* (2011) reported that, higher breakdown is considered inferior because viscosity rapidly lowers on heating leading to long and cohesive texture of the paste which is mostly not desired in food industry. A high breakdown viscosity is the result of an increased degree of collapse of swollen starch granules, leading to lower trough viscosity. Upon cooling, reassociation among starch molecules (retrogradation), particularly of amylose, brings about a rise in viscosity to a final level.

Setback is a measure of recrystallization of gelatinized starch during cooling (Ashogbon and Akintayo, 2012). High amylose content starches have been found to produce the highest setback viscosity (Chang and Liu, 1991; Gudmundsson, 1994; Adebowale and Lawal, 2003; Ashogbon and Akintayo 2012). The authors have observed that, high amylose content results in syneresis and retrogradation. In the work of Adeleke and Odedeji (2010), setback value for 100% sweetpotato flour was 85.25 RVU higher than that of 100% wheat flour (80.25 RVU). Setback values of *Brachystegia eurycoma* flour, starch and corn starch has been found to be 405.7 RVU, 233.58 RVU and 215.67 RVU respectively (Ikegwu *et al.*, 2010). The lower the setback value, the lower the retrogradation during cooling and the lower the staling of product (Adeyemi and Idowu, 1990). According to Raphael *et al.* (2011), high setback viscosity limits the use of starch in food industry. The differences observed in various flours and starches reflect the differences in thermodynamic behaviors of these starches during heating. These differences have been attributed to the amount and molecular weight of amylose leached from granules (Loh, 1992) as well as the presence of phosphorus (Tsakama *et al.*, 2010).

Final viscosity (sometimes called cold paste viscosity) is the change in viscosity after holding cooked starch at 50°C (Ikegwu *et al.*, 2010). Final viscosity is the most commonly used parameter to define the quality of a particular starch-based sample, as it indicates the ability of the material to form a viscous paste or gel after cooking as well as the resistance of the paste to shear force during stirring (Adeyemi and Idowu, 1990). High final viscosity leads to high peak viscosity and breakdown viscosity (Tsakama *et al.*, 2010). An increase in final viscosity has been attributed to reassociation of amylose molecules (Miles *et al.*, 1985; Tsakama *et al.*, 2010). According to Shimelis *et al.* (2006), the linear chains of amylose can orient parallel to each other, moving close enough to form bonds easily. Research on final viscosity of different starches and flours has been reported by several authors. Adeleke and Odedeji (2010) reported a sweetpotato flour final viscosity of 246.33 RVU. Corn starch final viscosity has been found to be 441.17 RVU whereas that of *Brachystegia eurycoma* flour and starch was 429.5 RVU and 462.82 RVU respectively (Ikegwu *et al.*, 2010). According to Juliano *et al.*, (1987) varietal differences together with differences in degree of interactions between starch and its associated compounds are responsible for the differences in final viscosities among starches and flours.

2.4 Colour

Colour is the stimulus that results from the detection of light after it has interacted with an object. The light may be reflected, transmitted, absorbed, or refracted by an illuminated object. If all the radiated energy is reflected back then the object is transparent and appears white. Similarly, if all the energy is absorbed then it appears black. Therefore colour arises from the presence of light in greater intensities at some wavelength than others and is mainly determined by the reflected light (Lewicki and Duszczyk, 1998). The colour appearance can change depending on amount of light, the light source, the observer's angle of view, size, and background differences. Individual's observation may be affected by all these factors and therefore instrumentation to measure colour provides a subjective and consistent method of colour determination (Giese, 2000).

Colour representation by the L*, a*, b* notation have been recommended by the CIE (Commission Internationale de l' Eclairage) in 1976. The calculation of L*, a*, b* for each colour is based on CIE XYZ values. They are commonly used in food industry (Perez-Magarino, and Gonzalez-Sanjose, 2003). L* is the degree of lightness of the colour. This refers to the relation between reflected and absorbed light. L* values equals to zero for black and 100 for white, a* (red-green) is the degree of redness (0 to 60) or greenness (0 to -60) and b *(yellow-blue) is the degree of yellowness (0 to 60) or blueness (0 to -60) (Perez-Magarino and Gonzalez-Sanjose 2003).

Colour of many foods is important quality attributes in marketing. Though it does not reflect nutrition or flavour, it is important as it relates to consumer preference based on appearance (Giese, 2000). Colour is a parameter that can be used as quality index measurements of raw and processed foods. The colour of the food material usually changes during processing like drying or dehydration. Most drying methods take relatively long period to completely remove moisture from samples. During drying, food material may change colour due to enzymatic or non-enzymatic reactions. Enzymatic reactions include the formation of brown colour pigments called melanins due to oxidation of phenols present in fruits and vegetables when exposed to air (Okyanus., 1997; Marshall *et al*., 2000; Garcia and Barrette, 2002). Non-enzymatic reactions are those resulting from Maillard reaction during heating and storage (Pimpa *et al.,* 2007). These colour changes (into brown) are desirable in case of meat and bakery products but are undesirable for fruits and vegetables.

Comparing sun drying method to oven drying method, Jimoh *et al*., (2009) observed a higher browning index for sun drying due to the activity of polyphenol oxidase during prolonged drying. However, CFIR drying has been shown to have shorter drying time and colour change is restricted to amount of temperature applied. Work done by Gabel *et al*. (2004), using CFIR dryer showed that, brown colour (b*) of onion increased with increasing temperature. Using electron beam irradiations on pure Sago starch, Pimpa *et al*. (2007), observed that, high energy irradiations caused an increase in a^* (redness) and b^* (yellowness). However, Kang *et al.* (1999) found no noticeable changes in a^* values among corn starches but observed a rise in b^* when they used gamma irradiation technology. Accordimg to Kang *et al*., (1999), different radiation technique and type of starches accounted for the changes. Greenwood and Mackenzie, (1963) suggested that, short wavelengths produce high energy which cleave starch molecules and cause caramelization of the monosaccharides. In starches, a high Lightness (L) and low chroma (a) are desired to meet consumer preference (Galvez and Ressureccion, 1993). However, flours usually contain other compounds resulting in higher a^* and b^* values (Ikegwu *et al*., 2010).

The several benefits of sweetpotatoes as well as the potential improvement products by catalytic flameless infrared drying (CFIR) necessitated this study to screen various sweetpotato varieties for their nutritional and functional properties. Knowledge about the nutritional composition of locally bred sweetpotatoes represents a foundational step in the incorporation of these varieties into local food systems and national programmes to encourage its usage in the country. The study was also expected to reveal the functional properties of sweetpotatoes which could help in addressing the usage of such important crop in the bakery and local food preparations.

Furthermore, the study was directed towards providing alternative means of drying in the food industry. Solar and oven drying are commonly used in Ghana. Introducing CFIR into the industry will help preserve most high-moisture crops having short shelf life and prevent postharvest losses.

CHAPTER THREE

3.0 MATERIALS AND METHOD

The work was divided into three stages which have been described below.

3.1 STAGE I: Determining proximate composition of some released sweetpotato varieties

This stage was to help select a suitable variety for the drying process.

3.1.1 Experimental Design

The study was conducted according to a completely randomized design. Six different varieties (Santom Pona, Apomuden, 199062.1, Faara, Cemsa 74-228 and Mohc) were tested. The experiment was carried out in triplicate and analysis of variance (ANOVA) was carried out on the data obtained. The differences in means were assessed with Least Significant Difference (LSD) test using *Statgraphic* software.

3.1.2 Source of material

Sweetpotato tubers (Santom Pona, Apomuden, 199062.1, Faara, Cemsa 74-228 and Mohc) were obtained from the Council for Scientific and Industrial Research – Crops Research Institute, Fumesua, Kumasi. A Gallenkamp Drying Oven (model XOV 880, Gallenkamp Co. Ltd., England) was also obtained from the Biochemistry Department of KNUST. In stage II of the work a catalytic flameless infrared dryer was acquired from Catalytic Drying Technologies LLC, Independence, KS, U.S.A. A thermocouple was obtained from Kwame Nkrumah University of Science and Technology (KNUST) Physics department to monitor temperature changes alongside a Raytek® (Raynger®) infrared thermometer. An LP gas was obtained to supply energy to the dryer and a step-down transformer to regulate the electric power flow used to ignite the gas as energy supply. In stage III of the experiment a locally manufactured solar dryer from the Biochemistry department (KNUST) was added to the oven and CFIR dryers in other to compare the quality of flour produced.

3.1.3 Sample preparation for drying

Roots were washed, peeled and sliced into an average thickness of 5mm (dimension; 5mm x 5mm x 5mm) with a sharp knife. A micrometer screw gauge was used to measure the average thickness of slices. Samples were peeled and sliced while submerged under water to slow down the rate of enzymatic reactions. They were then placed on tissue papers to remove excess water.

3.1.4 Proximate Composition

All the proximate composition analysis was carried out according to AOAC (2000). Below is a description of how proximate analysis was done.

3.1.4.1 Moisture Content Determination

Two grams of sweetpotato slices were weighed and transferred to a previously washed, dried and weighed crucible. The crucible containing the sample was placed in a Gallenkamp oven (model XOV 880, Gallenkamp Co. Ltd., England) set at 105 ºC for twenty-four (24hr) hours. Moisture content was calculated using the formula:

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

Where: W_1 = Weight of crucible, W_2= Weight of crucible + slices,

W_3 = Weight of crucible + Dry sample

3.1.4.2. Total Ash Determination

Two grams of sweetpotato slices were weighed and transferred to previously weighed porcelain crucible and placed in a Gallenkamp muffle furnace (model AS 260D, Gallenkamp Co. Ltd., England) (preheated to 600 ºC) for 2 hours. The porcelain crucible was removed after 2 hours and placed in a dessicator, allowing it to cool after which it was weighed and the ash content calculated as

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

Where: W_1 = Weight of porcelain crucible, W_2= Weight of porcelain crucible + slices, W_3 = Weight of porcelain crucible + Ash

3.1.4.3 Protein/ Total Nitrogen Determination

Two grams (2.00 g) of sweetpotato slices were digested with 25 ml conc. H_2SO_4 in a Kjeldahl digestion flask in the presence of a catalyst (selenium) and antibumping agent until the mixture was clear. The clear, digested sample was transferred to a 100 ml volumetric flask and made to the mark after cooling to room temperature. Distillation / condensation apparatus was set up. The distillation apparatus was flushed with distilled water. Twenty five millilitres of 2 % boric acid was poured into a 250 ml conical flask with two drops of mixed indicator (4 ml of 0.l % methyl red solution + 20 ml of 0.1 % in 95 % alcohol bromocresol green solution) added to it and placed under the condenser with the tip of the condenser completely immersed in the boric acid solution. Ten milliliters of the digested sample solution and 20 ml of 40 % NaOH were transferred into the decomposition tube. Ammonia liberated during the distillation process was collected by the boric acid solution (for 5 minutes) turning it bluish green. The distillate was titrated with 0.1N HCl solution until the solution became colourless and then pink. The titre values obtained were used to calculate the nitrogen and hence the protein content (Kirk and Sawyer, 1991).

$$\%\text{Total Nitrogen } (\%N) = \frac{100\ (\text{Sample titre value} - \text{Blank titre value}) \times 0.1 \times 0.01401 \times 100}{\text{Sample weight} \times 10}$$

$$\%\ \text{Protein} = \%N \times 6.25$$

3.1.4.4. Crude Fat Determination

Two grams of sweetpotato slices obtained from moisture determination were transferred into a 22 x 80 mm paper (serving as a thimble). A 250 ml round bottom flask was accurately weighed and then 150 ml of petroleum ether, BP 60- 80 ºC was poured into the flask. The thimble was placed in glass tube which was fixed between the flask and a condenser connected to a soxhlet extracter and refluxed for 16 hours on low heat application by the heating mantle. The flask was removed and evaporated on a steam bath. The flask containing the extracted fat was subjected to drying in a Gallenkamp oven at 105 ºC for 30 minutes, after which it was cooled to room temperature in a dessicator and then accurately weighed for the calculation of fat in the flour (AOAC, 2000).

$$\%Fat = \frac{W_2 - W_1}{W_3} \times 100$$

Where: W_1 = Weight of empty flask

W_2 = Weight of flask + fat

W_3 = Weight of slices taken

3.1.4.5 Crude Fibre Determination

The sweetpotato sample from crude fat determination was transferred to a 750 ml Erlenmeyer flask and 0.5 g of asbestos was added. Two hundred millilitres (200 ml) of 1.25 % boiling H_2SO_4 was added and the flask immediately set on a hot plate and connected to a condenser. It was then refluxed for 30 minutes. At the end of 30 minutes of digestion, the flask was removed and its contents filtered immediately through a cheese cloth in a funnel and then washed with boiling water until washings were no longer acidic. The entire procedure was repeated but this time with 200 ml of 1.25 % boiling NaOH. After, the residue was transferred to a previously washed, dried and weighed crucible (using funnel with water from a wash bottle) and then washed with 15 ml of alcohol. The crucible together with its contents was subjected to drying for one hour at 100 ºC in an oven, cooled in a dessicator and then reweighed. The sample was then subjected to ignition in an electric furnace for 30 minutes, cooled and reweighed. The crude fibre content of the sample was then calculated and reported as percentage.

$$\%\text{Crude Fibre} = \frac{\text{weight of sample before ashing - weight of sample after ashing}}{\text{Weight of flour sample}} \times 100$$

3.2 STAGE II: Time and Temperature combination experiment

CFIR drying is a technology that is now being introduced into the food industry. Most crops are dried according to the amount of heat suitable to minimize the loss of nutrients and final product quality. Therefore, before new drying equipment is used, it is necessary to determine the most suitable temperature and time combination that produce the least product quality. Hence the preliminary stage is set out to achieve this purpose.

3.2.1 Experimental Design

A factorial design was used for this stage of the experiment with two factors (Time and Temperature) varied at three levels. Temperatures used for the work were, 60°C, 65°C and 70°C while drying times used were 60min, 90min and 120min. time and temperature ranges were chosen from the work Gabel *et al.*, (2006). The drying was done in triplicate.

3.2.2 Sample preparation for drying

Sweetpotato roots were prepared as described in 3.1.3

3.2.3 Drying Experiment

A bench top catalytic infrared emitter (Plate 3), donated by Catalytic Drying Technologies LLC, was used for infrared drying. The bench top model has a circular heating surface of 613.36 cm^2, and LP gas was the fuel used to start the initial reaction delivered at 28 cm of water column (w.c) pressure. The total heat energy output of the unit was 1.47kW/h (5,000 BTU/h).

100g of sweetpotato slices were evenly spread on an aluminium plate of about 3mm thick and placed under the infrared emitter. The distance from the emitter surface to the drying bed (samples) was 150mm (15cm). A thermocouple was placed just above the samples without touching to measure temperature of infrared radiations on samples. This was confirmed by further using a digital infrared thermometer with black body emissivity of 0.93. The gas was switched on first to allow gas to fill all part of emitter containing the platinum catalyst. Then electricity was supplied for 15min to heat up the system and provide conditions for infrared ignition. After ignition, infrared radiation was produced by the reaction of gas with the platinum catalyst using the power supplied by the electricity. When the thermocouple recorded the rise in temperature produced from the reaction, the electric power was cut off and gas was used as the power supply for the continued reaction. When temperature got to a desired level, the gas valve was turned off to regulate the temperature. When temperature begins to go down (a maximum of 2°C was allowed), the gas is turned on to increase temperature to the desired level again. The time interval for turning off and on of gas was 1min. Temperature was regulated this way till the desired time for drying was achieved. The total time for turning off and on the gas was added to the drying time to make up for the infrared lost during the turning off period. After drying time was complete, dried samples were immediately placed in a dessicator to cool and then packaged in a ziplock bag. Samples were then milled with a laboratory hammer mill (Siemens-Schurkt, Germany) and sieved through 300 micron sieve to produce uniform sized flour. Flour were then stored in opaque polythene bags in a refrigerator at 4°C. Pasting analysis were then carried on the flours and the effects of the drying time and temperature assessed.

3.3 STAGE III: Comparing CFIR dryer to Oven and Solar Dryers

3.3.1 Experimental Design

The study was conducted according to a completely randomized design and three different drying methods (catalytic flameless infrared drying, solar drying and oven drying) were tested. The experiment was carried out in triplicate and analysis of variance (ANOVA) was used to determine significant data obtained. The differences in means were assessed with Least Significant Difference (LSD) test using *Statgraphic* software.

3.3.2 Sample preparation for drying

Sweetpotatoes were prepared as described in 3.2.3. Sweetpotato slices were weighed and dried according to the different drying methods described below. The dried samples were milled with a hammer mill into flour of average size of about 212µm. flour samples were then packaged in a ziplock bag and stored at refrigeration temperature of 4°C for further analyses.

3.3.3 Drying slices

Drying was carried out in three dryers described below.

3.3.3.1 Solar Drying

Solar drying was achieved by direct sun radiation and greenhouse effect. A plastic film covered the solar dryer of 176cm long x 213cm wide. Four wire mesh boxes (65cm x 79cm) placed 92cm above the ground in each solar dryer, were loaded with 100g sliced sweetpotato (5mm thick) placed on aluminium trays. Each of the mesh was separated from each other by glass panel. Temperature and humidity were taken 3 times daily (morning, afternoon and evening). The temperature/humidity within the solar dryer ranged from 27 to 50°C /14 to 52% compared to the external ambient range of 24 to 36°C/24 to 52% (Plate 1). The drying process took 3 days and dried samples were then milled with a laboratory hammer mill (Siemens-Schurkt, Germany) and sieved through 300 micron sieve to produce uniform sized flours. Flours were then stored in an opaque polythene bag and kept at a refrigeration temperature of 4°C.

Plate 2: A modeled Solar Dryer

Plate 3: A Gallenchamp Oven Dryer

Plate 4: A Benchtop model Catalytic Flameless Infrared dryer

3.3.3.2 Oven Drying

About 100g of sweetpotato slices (5mm thick) were oven dried to constant weight in a Gallenchamp oven dryer (model XOV 880, Gallenkamp Co. Ltd., England) (plate 2) operated at 65°C at an air velocity of 2.5 ms^{-1} until constant weight was obtained. Samples were then milled with a laboratory hammer mill (Siemens-Schurkt, Germany) and sieved through 300 micron sieve to produce uniform sized flours. Flours were then stored in an opaque polythene bag and kept at a refrigeration temperature of 4°C.

3.3.3.3 Catalytic Flameless Infrared (CFIR) Drying

This was done as described in section 3.2.4 at a temperature of 70°C for 120min.

3.4 Colour Measurements

Sweetpotatoes flour colour was measured using a Minolta chromameter.the instrument was first calibrated by using a white tile as the standard (control). Sweetpotato flour was tightly packed in a clean petri dish and covered with another petri dish. The petri dish containing the flour was then placed on the white tile and the Minolta chromameter was placed over the dish. A light from the Minolta chromameter was flashed on the sample and the colour intensity was recorded. The sweetpotato flour colour was reported in terms of 3-dimensional colour values on the following rating scale; Lightness L* (black [0] to light [100]), a* (red [60] to green [- 60]), b* (yellow [60] to blue [-60. This was done in triplicate and then subjected to statistical analysis.

3.5 Functional Property Determination

3.5.1 Water Solubility (WS)

Water solubility index (WSI) was measured according to the method of Ahmed *et al*., (2010). Two and a half grams of sweetpotato flour and 30 mL water were vigorously mixed in a 50-mL centrifuge tube; the mixture was incubated in a water bath at 30°C for 30 min, and centrifuged at 2090 x g for 15 min. The supernatant was collected in a preweighed Petri dish and the residue was weighed after oven drying overnight at 105°C. The process was carried out in triplicate for all flour samples.The amount of solids in the dried supernatant as a % of the total dry solids in the original 2.5 g sample was an indicator of WSI.

WS = (Dry weight of supernatant / Dry weight of sample) X 100

3.5.2 Swelling Power Capacity

Swelling capacity (SC) was calculated from the following equation described by Lai and Chang (2004):

SC = Weight of sediment / [dry weight of sample X (1- WS%/100)]

WS = (Dry weight of supernatant / Dry weight of sample) X 100

3.5.3 Bulk Density Determination

Fifty grams of flour was weighed and placed in a 100ml measuring cylinder. It was then tapped continuously until a constant volume was obtained. The process was carried out in triplicate for all the sweetpotato flours. The bulk density was calculated as;

$$\text{Bulk Density (BD)} = \frac{\text{weight of flour (g)}}{\text{Volume of flour (ml)}}$$

3.6 Pasting Determination

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

3.7 Physicochemical Properties of Flour From Dryers

3.7.1 Proximate Composition

All the proximate composition analysis on flour were carried out according to AOAC (2000) as described in section 3.1.4

3.7.2 pH Determination

Ten grams of flour was homogenized in 50ml of distilled water and stirred to mix well. A pH meter was standardized with buffer solutions of 4.0 and 7.0. It was then used to take readings by inserting the probe in the flour solution

3.7.3 Amylose Content Determination

The amylose content of the flour was determined based on the iodine colorimetric method of Williams *et al.* (1958) and Juliano (1971). About 0.1 g of the flour/starch sample was solubilised with 1 ml of 95% ethanol and 9 ml of 1 N NaOH, and heated in a boiling water bath for 10 min. Nine millilitres of distilled water was added to 1 ml of the extract to make a total volume of 10 ml. 0.5 ml of the diluted extract was pipetted into a beaker, 0.1 ml I N acetic acid and 0.2 ml iodine solution (0.2 g I_2+2.0 g KI in 100 ml of distilled water) was added to develop a dark blue colour. The coloured solution was made up to 10 ml with distilled water and allowed to stand for 20 min to fully develop colour. The solution was vortexed and its absorbance was read on a spectrophotometer (Helios Gamma UVG 121108, Thermo Electron Corporation, England) at 620 nm**.** Absorbance of standard corn starch amylose with known amylose concentration was used to estimate the amylose content in the sample as follows

$$\%\text{Amylose} = \frac{\%\text{Amylose of standard x Absorbance of sample}}{\text{Absorbance of standard}}$$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Proximate composition of sweetpotato varieties

Six (6) sweetpotato varieties were evaluated for their proximate compositions and have been shown in Table 4.1. It was observed that, fresh tuber moisture content ranged from 56.30%±1.96 to 84.90%±1.71 (Table 4.1). These results were similar to those obtained by Soares *et al.*, 2002. Sweetpotatoes, like most roots and tubers, generally possesses high moisture content that influences its shelf life (Antonio *et al*., 2011). The highest moisture content was observed in Apomuden, which is an orange fleshed sweetpotato genotype. The orange fleshed sweetpotatoes are generally low dry matter genotypes containing high amount of beta carotenes which help in preventing vitamin A deficiencies (Hagenimana and Owori,, 1997). The least moisture content was observed in Faraa but was however found to be nonsignificant ($p>0.05$) from that of Ciemsa 74-228 and Santom Pona. Ash content which indicates the mineral contents of the tubers ranged from 1.4%±0.01 to 4.88%±1.52 (Table 4.1). These values were higher than that observed by Soares *et al* (2002) and Ruiz (1984). According to Antonio *et al*., (2011), the chemical composition of sweetpotato depends on the variety, soil type, and period of cultivation. The differences observed among the various varieties were nonsignificant ($p>0.05$). Mohc variety had the highest ash content, whiles Faara had the least. This indicates that, Mohc could have a high mineral content than all the other varieties. Fibre analysis showed that, Santom Pona was least (0.90%±0.00) in fibre with Mohc having the highest (2.81%±0.01) (Table 4.1). The fibre content observed was similar to that of Soares *et al.*, (2002) and Ruiz (1984). Fibre is mostly preferred in many diets because of their ability to prevent constipation and other numerous health benefits. Mohc varieties will be preferred by most food companies who want to solve fibre related problems. Fat content was observed to range from 0.42%±0.04 for Santom Pona to

1.71%±0.35 for Apomuden (Table 4.1). Fat content was higher than that observed by Ruiz (1984). Onuh *et al*., (2004), observed fat content in sweetpotato to be 0.4% and attributed the differences to production practices and environmental conditions. The high carotenes in orange fleshed sweetpotatoes (Apomuden) have been observed to be fat soluble (Hagenimana and Owori,, 1997), and therefore could be responsible for the highest fat content observed. Protein content ranged from 1.27±0.62% to 4.22±0.33% which was within that reported by Mais, (2008). Apomuden recorded the highest protein content with Mohc having the least. However studies by Onuh *et al.*, (2004) recorded higher protein content in white variety instead of the orange fleshed variety and attributed the differences to production practices, environmental conditions and genetic factors. The high protein, water and fat content observed in Apomuden make it suitable for eating as snacks by simply boiling but difficult to process into flour. It can be employed in famine communities to help alleviate hunger and also solve several health issues. The lowest moisture content observed in Santom Pona indicates a higher dry matter content which is mostly preferred during drying and flour production (Akoroda, 2009). According to Akoroda (2009), high dry matter materials are good for drying. This quality together with low fat content made Santom Pona a preferred choice for the drying experiment

Table 4.1 Proximate composition of sweetpotato cultivars

Varieties	*Moisture (%)*	*Ash (%)*	*Fiber (%)*	*Fat (%)*	*Protein (%)*
199062.1	66.71±2.93^{c}	2.09±0.05^{a}	2.16±0.40^{b}	0.78±0.66^{d}	2.35±0.30^{d}
Apomuden	84.90±1.71^{d}	3.41±0.01^{b}	1.92±0.01^{c}	1.71±0.35^{b}	4.22±0.33^{e}
Cemsa 74-228	59.73±0.83^{a,b}	2.32±1.45^{b}	1.72±0.11^{d}	1.07±0.31^{c}	2.16±0.00^{c}
Faara	60.30±1.96^{a}	1.4±0.01^{a}	0.93±0.04^{a}	1.06±0.76^{c}	2.19±0.00^{c}
Mohc	61.14±4.28^{b}	4.88±1.52^{b,c}	2.81±0.01^{e}	0.79±0.47^{d}	1.27±0.62^{a}
Santom Pona	59.46±1.49^{a,b}	3.69±0.61^{c}	0.90±0.00^{a}	0.42±0.04^{a}	1.92±0.06^{b}

Means with the same superscripts within columns are not significantly different ($p<0.05$)

4.2 Suitable Time and Temperature Combination for Catalytic Flameless Infrared Drying

When using a new technology, it is important to establish the various conditions necessary for its effective use. Catalytic flameless infrared dryer (CFIR) is a new drying technology as such; the drying temperature and time necessary for its effective use must be established. A way of determining these conditions especially in flour is to know how varying these conditions would affect the pasting properties of flour produced from such a technology. The results of pasting properties and moisture content of sweetpotato flour produced from different drying temperatures and drying times are as presented in table 4.2. Moisture was high in flour produced from drying temperature of 60°C for 60min (7.61) and lowest at drying temperature of 70°C for 90min. However, moisture contents of flour produce were generally low, which could be an indication of stable shelf-life when properly packaged and stored. Moisture content observed was within the standard recommendation of 13% maximum of edible flour (Sanni *et al.,* 2005). Generally, moisture decreased as drying time was increasing except for a deviation which was observed at drying temperature of 70°C for 90min (Table 4.2). Drying time did not have significant effect on moisture content of flour ($p>0.05$) but drying temperature had significant effect on flour moisture content ($p<0.05$). This might be due to the drying mechanism of flameless catalytic infrared dryer. Normal drying occurs by establishing moisture gradient by first heating the upper layer of the sample and by the mechanism of simple diffusion, moisture move from the lower portion (high moisture region) of the sample to the upper portion (lower moisture region). This process requires significant time to effectively dry samples completely. However, catalytic flameless infrared (CFIR) dryer produces infrared radiations which easily penetrate and uniformly dry samples within the shortest possible time.

Table 4.2 Time and Temperature Effect on Moisture and Pasting Properties of Flour

Temp (°C)	**Time (min)**	**Moisture (%)**	**Setback (BU)**	**Breakdown (BU)**	**Peak viscosity (BU)**	**Final viscosity (BU**	**Pasting temperature (°C)**	**Pasting time (min)**
60	**60**	7.61	34	13	117	133	78.8	19.55
60	**90**	7.32	41	20	151	165	78.5	19.45
60	**120**	6.83	37	17	139	152	78.9	20.00
65	**60**	7.06	35	11	115	131	78.8	19.55
65	**90**	6.19	40	12	131	150	78.3	19.40
65	**120**	6.35	42	20	160	172	78.0	19.25
70	**60**	6.38	31	9	111	125	78.4	19.40

70	**90**	4.69	31	10	129	142	78.4	19.40
70	**120**	6.25	32	14	132	150	78.2	19.20

Statistical significances showed in Appendix I

When starch-based foods are heated in aqueous environment, they undergo series of changes known as gelatinization and pasting. These are two important properties influence quality and aesthetic considerations in the food industry because they affect texture and digestibility as well as the end use of starchy foods (Adebowale *et al.*, 2005). From the work, peak viscosity which is the ability of starch to swell freely before breakdown (Sanni *et al.*, 2004) ranged from 111BU to 160BU (BU= Brabender unit). Flour produced from drying temperature of 65°C for 120min had the highest (160BU) and flour produced from drying temperature of 70°C for 60min had the least (111BU). A higher peak viscosity implies flour may be suitable for products requiring high gel strength and elasticity (Adeleke and Odedeji, 2010). Peak viscosity generally decreased as drying time increased except for a drying temperature of 60°C where peak viscosity increased at 90min and decreased at 120min. Drying time significantly affected peak viscosity (p=0.026) (Appendix I), though drying temperature had no significant effect on peak viscosity. For a given drying time, peak viscosity decreased as drying temperature increased. For example, for drying temperature of 60min, peak viscosity at 60°C was 117BU which decreased to 115BU at drying temperature of 65°C and further decreased to 111BU at drying temperature of 70°C.

Setback viscosity showed variations in sweetpotato flour produced under different infrared drying temperature and time. Setback is a measure of the stability of paste after cooking. It is a phase where during cooling of mixture, a reassociation between the starch molecules occurs to a greater or lesser degree. It therefore affects retrogradation or reordering of starch molecules which is associated with syneresis and weeping (Sanni *et al*., 2004). Low setback value indicates high stability after cooking (Etudiaye *et al*., 2009). Setback values ranged from 31BU to 42BU with flour produced from drying temperature of 70°C for 60min having the lowest setback value. The highest setback value was observed at a drying temperature of 65°C for 120min.

Breakdown viscosity value is an index of the stability of starch (Fernande and Berry, 1989). Breakdown viscosity value ranged from 9BU to 20BU with flour produced from drying temperature of 70°C for 60min having the lowest and 65°C for 120min having the highest, suggesting high starch stability. Final viscosity was highest flour produced from drying temperature of 65°C for 120min (172BU) and lowest in flour from 70°C for 60min. Final viscosity is the most commonly used parameter to determine a particular starch-base sample quality (Sanni *et al*., 2006). It gives an idea of the ability of a material to form gel or viscous paste as well as the resistance of paste to shear force during stirring. Flour from drying temperature of 65°C for 120min with high final viscosity, showed that, the associative forces between the starch molecules are relatively weak. Generally, final viscosity, setback and breakdown viscosity showed a unique characteristic. As both drying temperature and time increased, viscosities rose and dropped again. For example, for drying temperature of 60°C, setback viscosity was 34BU at 60min which increased at 90min to 41BU but decreased again to 37BU at 120min. Again, for specific drying time, 60min, setback viscosity was 34BU at 60°C which increased to 35BU at drying temperature of 65°C and then decreased to 31BU at drying temperature of 70°C. These observations were also made in most cases for breakdown and final viscosities. Sweetpotato flour normally has high viscosities because their starch molecules have long chain of starch granules (Hoover, 2001). Infrared radiations, like most radiations with shorter wavelengths, are capable of breaking bonds within and between molecules. This phenomenon observed in setback, breakdown and final viscosity might be due to the fact that, different infrared radiation intensity produces corresponding temperatures. Increasing infrared radiation produces a corresponding increase in temperature. Therefore, at 65°C, infrared radiation emitted might have broken more of the long chain starch granules, rendering it more accessible to easy water binding enhancing more starch granule swelling which would lead to increasing viscosity. Flour produced from such drying temperatures is good as thickening agents because of the high final viscosity. The decrease in viscosity at 70°C might be due to the degradation (rupturing) and uncoiling of starch chains as well as breaking of hydrogen bonds within the starch granule because of the kind of radiation emitted at this temperature. This phenomenon was also observed by Zaidul *et al* (2007) in their gamma irradiation experiment on rice. According to them, starch fragmentation makes it difficult to form dense interlaced and interconnecting structure of the exudates released when starch granules swell. Flour produced from such drying temperatures is good for products like porridge, noodles and bread because of their low setback viscosities. The viscosities obtained in this experiment were close to that observed by Adeleke and Odedeji, (2010), indicating that, CFIR dryer is effective and efficient. Because final viscosity is generally used to determine the overall quality of a particular starch base products (Sanni *et al*., 2006; Adeleke and Odedeji, 2010) , a drying temperature of 65°C and drying time of 120mins (2hrs) was chosen as the best treatment method for drying Santom Pona due to highest final viscosity values obtained by such drying conditions. Similar conditions were also achieved by Pan, (2004) for effective drying of onions using this drying technology. This condition was then used to dry Santom Pona roots and compared with oven drying and solar drying methods to determine the quality of CFIR drying method.

4.3 Proximate Composition of Sweetpotato (Santom Pona) Flour from Drying Methods

The proximate composition of sweetpotato (Santom Pona) flour is presented in Table 4.3. Moisture content of the flour varied from 6.27%±0.00 to 8.94%±0.00. According to Sanni *et al.*, (2005), the maximum moisture content of flour should be about 13%. This enables flour to be stored over a longer period without spoilage by microorganisms that require high moisture to survive. It was observed that, moisture content was not statistically different among the different drying methods. Catalytic flameless infrared (CFIR) dried flour had the least moisture (6.27%±0.00) content while flour produced from solar drying had the highest moisture content (8.94%±0.00). According to Pan (2004), the mode of drying by CFIR is different from conventional drying methods and is relatively faster. Ash content was varied significantly ($P<0.05$) among the flour samples and ranged from 1.11%±0.36 (CFIR dried flour) to 3.15%±0.28 (Solar dried flour). These values were similar to that reported by Bradbury and Holloway (1988). The highest ash content observed in solar dryer indicates that, solar drying is less detrimental to minerals. This might be the reason why most processors now prefer solar dryers to open sun drying. The low ash content observed in sweetpotato flour for CFIR could be due to the ability of infrared radiations to cause the volatilization of some minerals. Fibre content of flour significantly varied from 0.52%±0.00 (CFIR dried flour) to 0.87%±0.00 (Oven dried flour). The fibre content was less than that observed for Soares *et al.,* (2002) but similar to that of Ogunlakin *et al.*, (2012) in cocoyam. Protein content of the sweetpotato flours ranged from 2.72% for CFIR flour to 4.08% for oven dried flour. The protein contents were within the acceptable range of 1.0 to 8.5% (Mais, 2008). Catalytic flameless infrared (CFIR) dried flour had the least protein content because, infrared red radiation has the ability to denature proteins in samples (Fasina *et al.,* 1996). Though, flour from CFIR drying methods has been found to produce least nutritional values, these values were within literature range. Hence, CFIR can be employed by processors where least processing time is required. Fat content was also observed to vary significantly (P<0.05) from 1.06%±0.94 to 1.89%±0.61. Flour obtained from CFIR drying method was observed to have higher fat content while solar dried flour had the least fat content. According to Ikegwu *et al*., (2010), the presence of fat and proteins affects the functional properties of flour. Higher fat content reduces pasting viscosity (Ikegwu *et al*., 2010). The lower fat content observed in solar drying indicates that, flour can be stored over a longer period of time without developing rancid flavors (Ogunlakin *et al*., 2012).

Table 4.3 Proximate Composition of Flour from Different Drying Methods

Flour Sample	*Moisture (%)*	*Ash (%)*	*Fibre (%)*	*Fat (%)*	*Proteins (%)*
CFIR Flour	6.27±0.00[a]	1.11±0.36[a]	0.52±0.00[b]	1.89±0.61[a]	1.12±0.36[a]
Oven Flour	6.38±0.00[a]	2.08±0.18[a]	0.87±0.00[a]	1.12±0.35[b]	2.08±0.18[a,b]
Solar Flour	8.94±0.00[a]	3.15±0.28[b]	0.73±0.00[a,b]	1.06±0.94[c]	3.15±0.94[b]
Undried Santom Pona	59.46±1.49	3.69±0.61	0.90±0.00	0.42±0.04	1.92±0.06

Means with the same superscripts within columns are not significantly different (p<0.05)

Comparing flour from processed sweetpotato (Santom Pona) flour to that of undried Santom Pona, it was observed that, proximate compositions varied. Moisture content was observed to be highest in the undried sweetpotato. This shows that, sweetpotato in its raw state possesses a lot of moisture and drying is an efficient way of reducing moisture in sweetpotatoes. Ash and fibre contents in undried sweetpotato were higher than that of sweetpotato flours. Fat and protein contents in undried sweetpotato were found to be lower than that of flours. This could be attributed to the processing methods as stated by Antonio *et al.,* (2011).

Proximate composition, together with other chemical components of flour determines their pasting and swelling power of flour (Ikwegu *et al*., 2010). Though proximate composition of flour is similar to that reported for other sweetpotato flours, it has been shown to be lower than many legumes and cereals. The fat, protein, fibre and ash content were lower than that reported for achi flour (Ikwegu *et al*., 2010), mung bean flour (Amarteidio and Moholo, 1998) and Bambara groundnuts (Sirivongpaisal, 2008). The results confirm that, sweetpotato like other roots and tuber flours are lower in nutritional components compared to cereal flours. This might be part of the reasons why most flour products are made from cereals.

4.4. Chemical Properties of Sweetpotato flour from Different Drying Methods

Amylose content of the flour significantly varied between 23.09%±0.00 and 37.87%±0.00 with CFIR flour having the highest concentration with solar flour having the lowest amylose contents (Table 4.4). The results obtained are comparable to that obtained by Ashogbon and Akintayo, (2012), and Brabet *et al.*, (1999). According to Brabet *et al.*, (1999), the acceptable literature range for amylose content of sweetpotato flour and starch is between 8.5% and 38%. The amylose content of sweetpotato flour from Santom Pona was however found to be higher than that of corn (Sandhu and Singh, 2007), cassava (Nuwamanya *et al.*, 2010; Raphael *et al.*, 2011) but similar to that reported for maize (Raphael *et al.*, 2011). Variability in amylose contents of flours have been reported to be due to differences in genotype, environmental factors, flour processing methods, and methods used to determine flour property (Collado and Corke 1997; Garcia and Walter 1998; Oduro *et al*. 2000). Amylose content is among the most important traits of flour based products. When an aqueous suspension of flour is heated above a critical temperature, starch granules swell irreversibly and amylose leaches out into the aqueous phase resulting in increasing viscosity (pasting). The higher amylose content observed in CFIR dryer could be due to the fact that, irradiations are known to degrade starch molecules of samples (Rosenthal, 1992; Greenwood and Mackenzie, 1963).

Irradiations can cleave the glycosidic bonds of amylopectin units into amylose units (Pimpa *et al*., 2007) and this phenomenon could have resulted in the increased amylose content in flour. The amylose portion of starches affects the swelling and hot paste viscosities of their flour (Shimelis *et al*., 2006). Schoch and Maywald (1968) stated that, as the amylose increases, the swelling tends to be restricted. The higher amylose content observed in flour makes it desirable to be used for products such as noodles (Lii and Chang, 1981) and bread production (Gianibelli *et al.*, 2005; Vignaux *et al.*, 2005; Hung *et al.*, 2005). CFIR dried flours could therefore be more preferable when such products are to be manufactured. The highest amylose content observed for CFIR drier could make it potentially important instrument for the production of syrups. Amylase is usually employed to breakdown starches into amylose in high fructose syrups. This process can therefore be enhanced when CFIR is used together with the enzyme. Amylose content together with other chemical components has a good bearing on pasting properties.

pH values ranged from 6.04±0.01 to 6.23±0.00 which were within the acceptable range for storing flour (Adebowale *et al*., 2005). This was similar to reports from Brabet *et al*., (1999), Abo-El-Fetoh *et al.*, (2010) and Tsakama *et al.*, (2010). High pH flours have been found to increase stability which is due to increased hydrophilic characters at these pH's (Adebowale *et* *al*., 2005). However pH values between 5 and 7 are said to generally stimulate retrogradation (Tsakama *et al*., 2010). Generally, sweetpotato starches, like other roots and tubers are susceptible to retrogadation (Hoover, 2001). CFIR dried flour had the least pH value which could be due to the breakdown of starch molecules (Pimpa *et al.*, 2007). Report from Sokhey and Chinnaswamy (1993) showed that, lower pH of irradiated starch could be as a result of –COOH formation due to the breakdown of starch molecules. Since starch forms the major part of flour, this could be the reason why CFIR had the lowest pH. pH have also been known to affect pasting properties of flour together with phosphorus content (Karim *et al*., 2007)

Table 4.4 Some Chemical Properties of Sweetpotato flour from Different Drying Methods

Flour Type	*Amylose Content (%)*	*Phosphorus mg/100g*	*pH*
CFIR Flour	37.87±0.00[a]	154.20±0.00[a]	6.04±0.01[a]
Oven Flour	32.56±0.00[b]	160.90±0.00[b]	6.3±0.00[b]
Solar Flour	23.09±0.00[c]	170.50±0.00[c]	6.23±0.00[c]

Means with the same superscripts within columns are not significantly different ($p<0.05$)

Phosphorus content observed in the work ranged from 154.20±0.00 mg/100g for CFIR flour to 170.50±0.00 mg/100g for solar flour. Phosphorus content recorded was higher than reports by Soares *et al,* (2002), Antonio (2006) and Unifesp, (2008). The higher phosphorus content might be attributed to the variety, soil type and period of cultivation (Ruiz, 1984). There are several minerals present in sweetpotato roots (Antonio *et al*., 2006). However, phosphorus has been found to affect functional properties of flour and starch related products by negatively affecting setback viscosity (Tsakama *et al*., 2010; Moorthy, 2002; Hoover, 2001). The lower phosphorus content observed in CFIR flour could be attributed to the deleterious effect of infrared radiations (Pimpa *et al.,* 2007). The high energy radiations might have caused the volatilization of phosphorus. Hence, when using CFIR, close monitoring should be done to control the loss of several volatile minerals.

4.5 Functional Properties of Sweetpotato (Santom Pona) Flour from Drying Methods

Swelling power and Solubility: Functional properties of sweetpotato flours are presented in Table 4.5. Swelling power varied significantly (P= 0.022) from 3.40±0.02 for CFIR flour to 3.66±0.02 for solar dried flour. Swelling power is an indication of water absorption index of granules during heating (Loos *et al*., 1981). Moorthy and Ramanujam (1986) stated that, the swelling power of granules reflects the extent of associative forces within the granules. CFIR had the lowest swelling power whereas solar dried flour had the highest with solubility pattern also following similar trend. Unlike grains and cereals, sweetpotato like many roots and tubers has high solubility and low swelling power (Sandhu and Singh, 2007; Adejumo *et al*., 2011). Swelling power was close to that reported by Adeleke and Odedji (2010) and higher than that of Ogunlakin *et al.*, (2012). Comparing to other crops, sweetpotato flour swelling power was lower than corn (Sandhu and Singh, 2007), and red bean (Lii and Chang, 1981). The lower swelling power observed for Sweetpotato flour shows that, it cannot be used for the production of confectionary goods (Ikegwu *et al*., 2010). It was however close to that reported for *Brachystegia eurycoma* (achi) flour. Solubilty was also higher than what was reported by Adeleke and Odedeji (2010) but similar to that reported for cassava (Adejumo *et al.*, 2011). The lowest swelling power and solubility observed in CFIR might be due to the amylose and protein content. According to Hoover (2001), swelling power and solubility are a function of amylopectin units of starch granules. High amylopectin results in high swelling power and solubility. Hence, highest amylose content in CFIR flour indicates lowest amylopectin which may lead to low swelling and solubility. According to Pomeranz (1991), formation of protein-amylose complex in flours maybe responsible for low swelling power. Shimelis *et al.*, (2006) reported that, starch and protein interact due to the attraction of their opposite charges and form inclusion complexes during gelatinization which restrict swelling.

Table 4.5.1 Effect of Drying Methods on Functional properties of Sweetpotato Flour

Flour Type	*Water Solubility (%)*	*Swelling power (%)*	*Bulk Density (g/ml)*
CFIR Flour	20.31±0.15[a]	3.40±0.02[a]	0.81±0.04[a]
Oven Flour	23.65±1.68[a]	3.58±0.02[b]	0.81±0.00[a]
Solar Flour	27.87±0.90[b]	3.66±0.02[c]	0.69±0.01[b]

Means with the same superscripts with columns are not significantly different ($p<0.05$)

Bulk Density: Bulk density ranged significantly ($p=0.0173$) from 0.69g/ml±0.01 to 0.81g/ml±0.04. Bulk density indicates the ease with which flour can be packed and also relates to mouth feel and flavor of the food the flour is incorporated. Bulk density of flours (Table 4.4), were similar to that of Ogunlakin *et al.*, (2012), Onuh *et al.*, (2004) and Etudaiye *et al.*, (2009). Together with oven drying method, CFIR had high bulk density. According to Pan, (2004), CFIR dried materials often produce high quality grinding ability. Generally, the high bulk density indicates that, flour from CFIR and Oven drying method can easily be packed during packaging (Etudaiye *et al.*, 2009).

Pasting Properties of flours: There has been over reliance on wheat flour for most bakeries and flour related products but Ghana does not grow wheat. As such, knowledge on sweetpotato flour pasting properties is required when sweetpotato is to be used as alternative flour source. When starch-based foods are heated in aqueous environment, they undergo a series of changes including enormous swelling, increased viscosity, translucency and solubility. These changes are defined as gelatinization (Ikegwu *et al.,* 2010). Pasting encompasses the changes that occur after gelatinization upon further heating including swelling of granules, leaching of molecular components from the granules and eventual disruption of granules (Tester and Morrison, 1990). Pasting properties are greatly influenced by plant source, starch content, interaction among the components, and testing conditions (Liu *et al*. 2006). Results of pasting properties of sweetpotato (Santom Pona) flour dried using different drying methods have been shown in Table 4.5.1. There were significant differences (p<0.05) in the pasting profile of the flours.

Table 4.5.2 Effect of Drying Methods on Pasting Characteristics of Sweetpotato Flour

Flour Type	*Moisture (%)*	*Setback (BU)*	*Breakdown Viscosity(BU)*	*Peak Viscosity (BU)*	*Final Viscosity (BU)*	*Pasting Temp ◦C*	*Pasting time (min)*
CFIR Flour	6.27±0.00[a]	39.0±1.41[a]	16.00±0.00[a]	138.50±2.12[a]	153.00±2.83[a]	79.0±0.00[a]	12.5±0.71[a]
Oven Flour	6.38±0.00[b]	28.50±0.71[b]	1.00±0.00[b]	62.50±0.71[b]	87.00±1.41[b]	79.9±0.28[b]	10.5±0.71[b]
Solar Flour	8.94±0.00[c]	25.50±2.12[b]	5.00±0.00[c]	64.00±1.41[b]	80.50±3.53[b]	79.2±0.00[a]	12.0±0.00[a]

Means with the same superscripts within columns are not significantly different (p<0.05)

Pasting temperature ranged from 79±0.00°C to 79.9±0.28 with flour from CFIR having the least. It was found that, there were no difference between CFIR flour and solar dried flour statistically but was statistically different (p=0.0236) from that of oven dried flour. Pasting temperature has been reported to be related to water binding capacity. A higher pasting temperature implies a higher water binding capacity and higher gelatinization (Numfor *et al.,* 1996). Pasting temperatures was observed to be comparable to that reported for 100% sweetpotato flour by Adeleke and Odedeji, (2010). It was however observed to be lower than some legumes and cereals reported by Ikwegu *et al.*, (2009). Pasting temperature is one of the pasting properties which provide an indication of the minimum temperature required for sample cooking, energy costs involved and other component stability (Shimelis *et al.*, 2006). Hence, a low pasting temperature observed in flour produced from CFIR, require a low temperature to cook such flour products and a reduction in energy cost. The difference observed between the various drying methods might be due to differences in granule sizes of flour as a result of the different processing methods. According to Janchud et al., (2003), larger starch granules are associated with lower pasting temperature. Pasting time, which is an indication of the cooking time, ranged from 10.5±0.71min (oven) to 12.5±0.71min (CFIR). According to Abo-El- Fetoh (2010), paste temperature and time are influenced by factors conditions of the thermal process employed to induce gelatinization.

Peak viscosity, which is the ability of starch to swell freely before their physical breakdown, ranged between 62.50±0.71 BU (Oven) to 138.50±2.12 BU (CFIR). The peak viscosities observed were similar to that of Ikegwu *et al.*, (2010).The relative high peak viscosity of sweetpotato flour is an indicative that, flour may be suitable for products requiring high gel strength and elasticity (Ikegwu *et al.*, 2010). CFIR had the highest peak viscosity indicating that, associative forces within the starch granules might have been weakened allowing easy granule swelling (Hoover, 2001; Tsakama *et al.,* 2010). According to Pimpa *et al.,* (2007), short wavelength radiations have the ability to weaken and cleave bonds in molecules.

The breakdown viscosity, a measure of the resistance to heat and shear, of flours varied significantly ($p<0.05$) between 1.00±0.00 and 16.00±0.00 BU. Comparing to *Brachystegia eurycoma,* and corn (Ikegwu *et al.,* 2010), sweetpotato breakdown viscosity was lower. Breakdown viscosity is an important criterion that decides the application of starch in food industry. High breakdown viscosity is considered inferior because, flour viscosity rapidly lower on heating under shear. This results in long and cohesive texture of its paste which is not desired in food industry (Raphael *et al.,* 2011). It was observed that, CFIR flour had higher breakdown viscosity with solar flour having the least. Since breakdown viscosity is an estimation of paste resistance to disintegration in response to heat and shear, lower breakdown viscosity indicates a lower peak viscosity (Aina *et al.,* 2009). The highest breakdown for CFIR flour also shows that, flour will have the lowest ability to withstand heating and shear stress during cooking (Adebowale *et al*., 2005).

Setback, which is difference between the breakdown viscosity and the viscosity at 50 °C, determines the tendency of starch to retrogradation. It is the phase where during cooling of the mixture, a re-association between the starch molecules occurs to a greater or lesser degree and therefore affects retrogradation or re-ordering of the starch molecules. The setback value for the flours ranged between 25.50±2.12 and 39.0±1.41 BU. The setback viscosity was lower than that observed by Adeleke and Odedeji, (2010). High setback viscosity limits the use of starch in food industry (Raphael *et al.,* 2011). Flour with high setback viscosity would tend to have stiffer paste (Seog *et al.,* 1987). Low setback viscosity shows high starch paste stability during processing. Setback varied significantly ($p= 0.0062$) from CFIR flour to solar flour (Table 4.5). Flours from CFIR showed higher tendency to retrograde due to their higher setback viscosity. According to Ashogbon and Akintoya (2012), highest amylose content produced highest setback viscosity.

This is because setback viscosity is a function of amylopectin unit (Pimpa *et al.,* 2007). Hence, the high setback viscosity observed in CFIR flour could be as a result of this phenomenon. The highest setback viscosity observed in CFIR makes flour susceptible to weeping when used as filling in frozen product application (Aina *et al.,* 2009). However, the lower setback viscosity by ssweetpotato flour when compared to "achi" and corn flour (Ikegwu *et al.,* 2010) makes it more stable.

Final viscosity ranged from 80.50±3.53 BU to 153.00±2.83 BU with CFIR showing the highest viscosity. Final viscosity was close to that of 100% wheat flour reported by Adeleke and Odedeji (2010) but lower than that of 100% sweetpotato flour of their work. Comparing to "achi" and corn flour (Ikegwu *et al.*, 2010), sweetpotato (Santom Pona) was also observed to be lower in final viscosity. According to Juliano *et al*., (1987), varietal differences contribute to pasting characteristics of starches due to differences in amylopectin molecular structure. Other reasons for the differences in final viscosity maybe due to inherent differences in structure of starch molecules, as well as different degrees of interactions between starch and its associative compounds (Zhang and Hamaker, 2008). CFIR dryer produced flour with the highest final viscosity. This might be due to the increased amylose content observed for CFIR flour. According to Ashogbon and Akintayo, (2012), an increase in final viscosity might be due to reassociation of amylose molecules. Final viscosity is the most commonly used parameter to determine a particular starch-based sample quality (Sanni., 2006). It gives an idea of the ability of a starch to form gel after cooking. Garcia and Walter Jr (1998) described ideal starch molecules for many food products as one that at low concentrations produce a smooth texture with a heavy bodied paste, remain soft and flexible at low temperature and retain its thickening power at high temperatures. Hence CFIR would be preferred by most processors. Sweetpotato processed from CFIR dryer with high viscosities showed that the associative forces between the starch molecules are relatively weak. This might be due to the fact that, the radiations produced in addition to the heat has the ability to cleave hydrogen bonds in starch granules compared to solar and oven drying (Pimpa *et al.,* 2007).

4.6 Effects of Drying on the CIE L*, a*, b* Colour Parameters of Sweetpotato (cv.Santom pona) Flour

The colour of flour due to the presence of polyphenolic compounds, ascorbic acid, carotenes and other chemical compounds has impact on quality. Any pigmentation in the flour is carried over to the final product (Galvez and Resurreccion, 1993). Usually, low a^* and high Lightness (L^*) are preferred for most flour and starches. When compared to the control (white tiles = 97.51), results showed a decrease in lightness values, L*, from CFIR to oven flour (Table 4.6). The L* values ranged between 85.39±0.15 and 86.46±0.12. The trend of the results was in the order: CFIR>Solar>Oven. The trend implies that the CFIR produced flour which was lighter and oven drying produced flour with relatively much darker colour. This could be due to the fact that, CFIR dryer dries product much faster than the rest of the dryers. It is known that, the presence of moisture in sample facilitates enzymatic browning, which in sweetpotatoes is sometimes referred to darkening. Therefore, the quick removal of moisture from samples by CFIR helps in preventing enzymatic browning, hence producing the lightest flour among the other dryers. Generally, sweetpotato (Santom Pona) flour had high whiteness (L^*) when compared to other crops. Reports from Ikegwu *et al.,* (2010), showed an L^* value of 81.33 for *Brachystegia eurycoma* starch, which is less than that observed for the sweetpotato flours. This indicates that, flour will be more acceptable by consumers.

Table 4.6 Drying effect on CIE L*, a*, b* colour parameters of sweetpotato flour

Flour Type	*L*	*a*	*B*
CFIR Flour	86.46±0.12[a]	+3.89±0.02[a]	+7.87±0.12[a,b]
Oven Flour	85.39±0.15[b]	+4.10±0.03[b]	+7.78±0.13[a]
Solar Flour	85.77±0.01[c]	+4.27±0.01[c]	+8.01±0.03[b]
Control	97.51	+0.29	+1.88

Means with the same superscripts are not significantly different ($p<0.05$)

Sweetpotato redness (a^*) and yellowness (b^*) were found to be higher when compared to the control (Table 4.6). This might be attributed to the presence of polyphenolic compounds, ascorbic acid, carotenes, proteins, and fat. Compared to achi starch (a= 2.36), sweetpotato flour was also observed to be higher (Ikegwu *et al*., 2010). This might be due to the fact that, starch contains less chemical compounds than flours. Redness values, a*, ranged from +3.89±0.02 to +4.27±0.01 with CFIR having the least red value while solar dryer produced the highest red coloured flour. The higher a* value could be due to the longer exposure of samples to heat during the drying. CFIR dries samples by uniformly distributing heat to all parts of the sample (Gabel *et al.*, 2006). However, solar and oven drying methods first dry the upper layer of the sample and moisture move by diffusion through the moisture gradient created. This allows only the surface of the sample to be constantly exposed to heat which might change colour at the end of drying. The relative high a^* and b^* values observed for CFIR compared to the control might also be due to radiation effect. Greenwood and Mackenzie, (1963) suggested that, short wavelengths produce high energy which cleave starch molecules and cause caramelization of the monosaccharides. However, comparing to the other drying methods, CFIR dryer was realized to produce a better flour quality. This flour quality produced by CFIR dryer will therefore be more acceptable by consumers.

The incorporation of sweetpotatoes into local foods and snacks will help increase its potential as a cash crop in Ghana. Van de Fliert *et al.,* (2000) reported that sweetpotato is favoured because of its high productivity, low management and input requirement, which makes it an easy and potential profitable enterprise. However, the lack of ready market for harvested sweetpotatoes roots lead to postharvest losses. Therefore, converting these excess sweetpotatoes into flour for products like bread, noodles and porridges, reduces postharvest losses. In Ghana, wheat flour is used for most of these products. However, Ghana does not produce wheat. The attributes observed in sweetpotato flour makes it a better alternative to wheat flour in the country. According to Sanni *et al.*, (2006), good quality flour should have high starch stability (final viscosity). The use of CFIR dryer has proven to produce flour of high stability. Aside producing high quality flour, CFIR help in reducing processing time and energy. According to Pan (2004), using CFIR dryer can save energy up to 24% ($0.78). This will help enterprises cut down cost and increase their profit margin.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Sweetpotatoes were observed to have high proximate content and varied according to varieties. Apomuden which is an orange fleshed cultivar had higher protein (4.22%). Mohc variety had high fibre content (2.81%) making it suitable for high fibre diets. Santom pona had least moisture content (59.46%) which is an indicator of high dry matter content and good for flour products. CFIR produced flour of highest final viscosity (172BU) at a drying temperature of 65°C and a drying time of 120min indicating high quality flour. Pasting viscosities of flour increased as CFIR drying time and temperature increased and then declined as time and temperature continued to increase. Comparing flour made from CFIR dried slices to that of solar drying and oven drying, CFIR dryer produced flour with the highest fat (1.89%), amylose content (37.87%) and lowest pH value (6.04). CFIR dried flour also produced flour bulk density of 0.81g/m which makes it good during packaging. Pasting properties showed that, CFIR dryer produced flour with the least cooking temperature (79.0%) which helps save energy, highest final viscosity (153BU), lowest swelling power and solubility (3.40±0.02 and 20.31±0.15 respectively). CFIR dried flour was also the brightest with an L value of 86.46. These qualities observed for CFIR dryer make it a good alternative drying system.

5.2 LIMITATIONS OF THE WORK

Most new systems experience a lot of challenges and limitations and this was also observed in the case of CFIR drying equipments. The limitations in using this CFIR dryer were;

The equipment used for the work was a benchtop model which is different from the factory model. Therefore results obtained could change when using the factory model.

Another limitation was in the area of temperature regulation of the equipment. Ideally, the equipment was supposed to be fitted with a thermostat in order to regulate the temperature but the model used for the work was lacking. The method used in regulating the temperature might also have influenced the results

The temperature and time used for the work was chosen from literature, hence lower or higher temperatures and times could yield a lot more good results which were not investigated.

Some quality parameters of sweetpotato flours were not determined in this work. Hence CFIR dryer might also improve some quality parameters of sweetpotato flour which were not investigated.

.5.3 RECOMMENDATION

Based on the above limitations the following recommendations have been put forward for any onward research in future.

Further studies can be done using factory model (Larger infrared equipment) in order to obtain a more comprehensive results

Further studies on continuous drying process should be carried out, so as not to turn dryer on and off at all times.

Other temperature and time range should also be research into so as to bring out the full potential of the equipment

Again, studies on the ability of CFIR to convert carotenes in orange fleshed sweetpotatoes to provitamin A should be done because of its possible catalytic ability. The detail insight of CFIR interaction with food components, changes in taste and flavour of foods.

Further studies should also be carried out on different crops to determine the effect of CFIR on them.

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APPENDIX I

1A ANOVA TABLES–SUITABLE CFIR DRYING TEMPERAURE AND TIME

Analysis of Variance for Moisture (%)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	2	3.7211	3.7070	1.8535	4.72	0.071
Temp (oC)	1	3.2837	3.2837	3.2837	8.36	0.034
Time (min)	1	0.4374	0.4233	0.4233	1.08	0.347
2-Way Interactions	1	0.1097	0.1097	0.1097	0.28	0.620
Temp (oC)*Time (min)	1	0.1097	0.1097	0.1097	0.28	0.620
Residual Error	5	1.9642	1.9642	0.3928		
Total	8	5.7950				

Analysis of Variance for Setback (BU)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	2	78.445	78.109	39.055	2.82	0.151
Temp (oC)	1	58.279	58.279	58.279	4.21	0.095
Time (min)	1	20.167	19.831	19.831	1.43	0.285
2-Way Interactions	1	1.270	1.270	1.270	0.09	0.774
Temp (oC)*Time (min)	1	1.270	1.270	1.270	0.09	0.774
Residual Error	5	69.173	69.173	13.835		
Total	8	148.889				

Analysis of Variance for Breakdown (BU)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	2	102.508	102.632	51.3160	7.69	0.030
Temp (oC)	1	48.508	48.508	48.5079	7.27	0.043
Time (min)	1	54.000	54.124	54.1240	8.12	0.036
2-Way Interactions	1	0.148	0.148	0.1476	0.02	0.888
Temp (oC)*Time (min)	1	0.148	0.148	0.1476	0.02	0.888
Residual Error	5	33.344	33.344	6.6689		
Total	8	136.000				

Analysis of Variance for Peak viscosity (BU)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	2	1504.40	1500.65	750.33	5.75	0.051
Temp (oC)	1	213.74	213.74	213.74	1.64	0.257
Time (min)	1	1290.67	1286.92	1286.92	9.86	0.026
2-Way Interactions	1	1.21	1.21	1.21	0.01	0.927
Temp (oC)*Time (min)	1	1.21	1.21	1.21	0.01	0.927
Residual Error	5	652.38	652.38	130.48		

Analysis of Variance for Final viscosity (BU)

```
Source                       DF    Seq SS    Adj SS    Adj MS      F       P
Main Effects                  2   1396.45   1400.74    700.37    6.38   0.042
  Temp (oC)                   1    192.29    192.29    192.29    1.75   0.243
  Time (min)                  1   1204.17   1208.45   1208.45   11.00   0.021
2-Way Interactions            1      6.30      6.30      6.30    0.06   0.820
  Temp (oC)*Time (min)        1      6.30      6.30      6.30    0.06   0.820
Residual Error                5    549.24    549.24    109.85
Total                         8   1952.00
```


1B ANOVA TABLE –PROXIMATE COMPOSITION OF SWEETPOTATO TUBERS

ANOVA Table for Ash by Samples

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	16.0854	5	3.21707	4.03	0.0598
Within groups	4.7901	6	0.79835		
Total (Corr.)	20.8755	11			

ANOVA Table for Fibre by Samples

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	5.41317	5	1.08263	37.28	0.0002
Within groups	0.174242	6	0.0290403		
Total (Corr.)	5.58741	11			

ANOVA Table for Protein by Samples

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	9.77442	5	1.95488	20.03	0.0011
Within groups	0.58554	6	0.0975899		
Total (Corr.)	10.36	11			

ANOVA Table for Fat by Samples

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	1.86195	5	0.372391	1.55	0.3020
Within groups	1.43916	6	0.23986		
Total (Corr.)	3.30112	11			

1C ANOVA TABLE-PROXIMATE COMPOSITION OF *Santom pona* FLOUR FROM DRYING METHODS

ANOVA Table for Moisture by Samples

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	9.12973	2	4.56487		0.0000
Within groups	0.0	3	0.0		
Total (Corr.)	9.12973	5			

ANOVA Table for Ash by Samples

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	4.15606	2	2.07803	25.93	0.0128
Within groups	0.240449	3	0.0801496		
Total (Corr.)	4.39651	5			

ANOVA Table for Fibre by Samples

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.122246	2	0.0611231		0.0000
Within groups	0.0	3	0.0		
Total (Corr.)	0.122246	5			

ANOVA Table for Protein by Samples

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	2.19747	2	1.09873		0.0000
Within groups	0.0	3	0.0		
Total (Corr.)	2.19747	5			

ANOVA Table for Fat by Samples

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.861037	2	0.430518	0.94	0.4818
Within groups	1.37299	3	0.457662		
Total (Corr.)	2.23402	5			

1D ANOVA TABLE – SOME CHEMICAL COMPOSITION OF Santom pona FLOUR FROM DIFFERENT DRYING METHODS

ANOVA Table for pH by Flour Type

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0732333	2	0.0366167	439.40	0.0002
Within groups	0.00025	3	0.0000833333		
Total (Corr.)	0.0734833	5			

ANOVA Table for Amlyose by Flour Amylose

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	224.072	2	112.036	28008991.50	0.0000
Within groups	0.000012	3	0.000004		
Total (Corr.)	224.072	5			

ANOVA Table for Phosphorus by Flour Amylose

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	270.503	2	135.252	1423.70	0.0000
Within groups	0.285	3	0.095		
Total (Corr.)	270.788	5			

1E ANOVA TABLE- FUNCTIONAL PROPERTIES OF Santom pona FLOUR FROM DIFFERENT DRYING METHODS

ANOVA Table for Solubility Index by Flour Type

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	57.4489	2	28.7245	23.58	0.0146
Within groups	3.6547	3	1.21823		
Total (Corr.)	61.1036	5			

ANOVA Table for Swelling Power Index by Flour Type

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0705862	2	0.0352931	87.94	0.0022
Within groups	0.001204	3	0.000401333		
Total (Corr.)	0.0717902	5			

ANOVA Table for Bulk Density by Flour Type

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.020296	2	0.010148	20.88	0.0173
Within groups	0.00145773	3	0.00048591		
Total (Corr.)	0.0217537	5			

1F ANOVA TABLE- PASTING CHARACTERISTICS OF *Santom pona* FLOUR FROM DIFFERENT DRYING METHODS

ANOVA Table for Setback by Flour Pasting

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	201.0	2	100.5	43.07	0.0062
Within groups	7.0	3	2.33333		
Total (Corr.)	208.0	5			

ANOVA Table for Breakdown by Flour Pasting

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	241.333	2	120.667		0.0000
Within groups	0.0	3	0.0		
Total (Corr.)	241.333	5			

ANOVA Table for Peak Viscosity by Flour Pasting

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	7552.33	2	3776.17	1618.36	0.0000
Within groups	7.0	3	2.33333		
Total (Corr.)	7559.33	5			

ANOVA Table for Final Viscosity by Flour Pasting

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	6436.33	2	3218.17	429.09	0.0002
Within groups	22.5	3	7.5		
Total (Corr.)	6458.83	5			

1G ANOVA TABLE – CIE L*, a*, b* COLOUR PARAMETERS OF *Santom pona* FLOUR FROM DIFFERENT DRYING METHODS

ANOVA Table for L by Flour Colour

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	2.37952	2	1.18976	98.55	0.0000
Within groups	0.10865	9	0.0120722		
Total (Corr.)	2.48817	11			

ANOVA Table for a by Flour Colour

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.285717	2	0.142858	269.26	0.0000
Within groups	0.004775	9	0.000530556		
Total (Corr.)	0.290492	11			

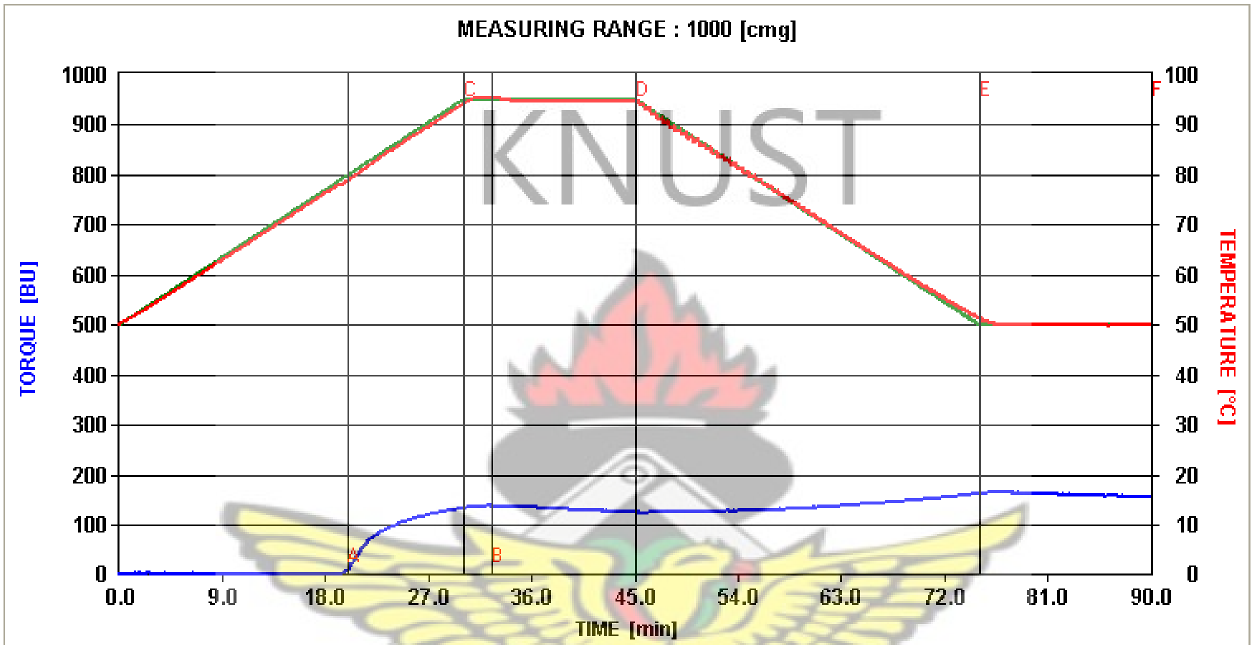
ANOVA Table for b by Flour Colour

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.105717	2	0.0528583	4.55	0.0431
Within groups	0.104575	9	0.0116194		
Total (Corr.)	0.210292	11			

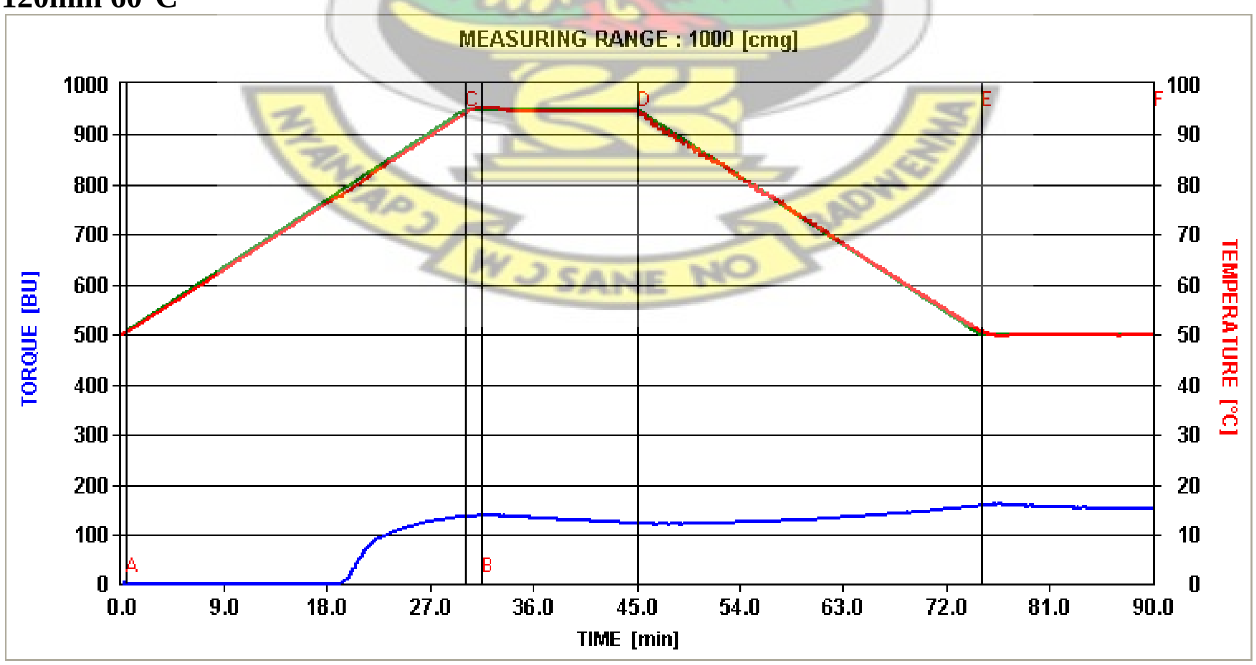
APPENDIX II

2A PASTING PROFILE- CFIR TIME AND TEMPERATURE GRAPH

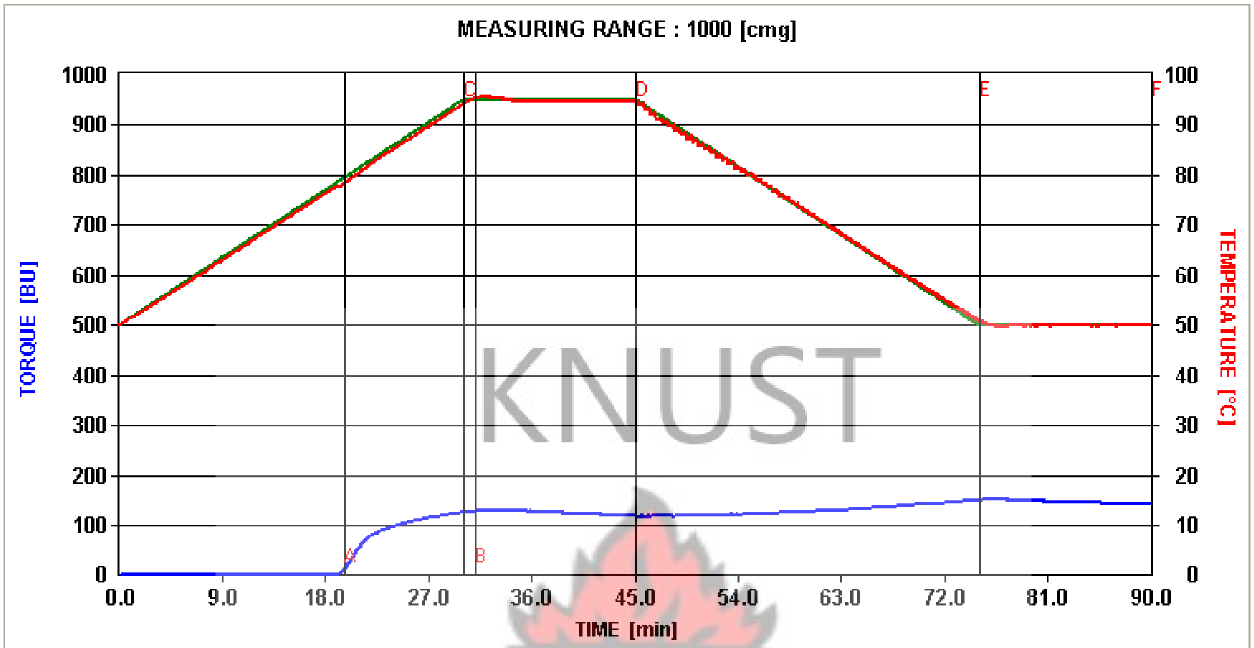
60°C. 120min.



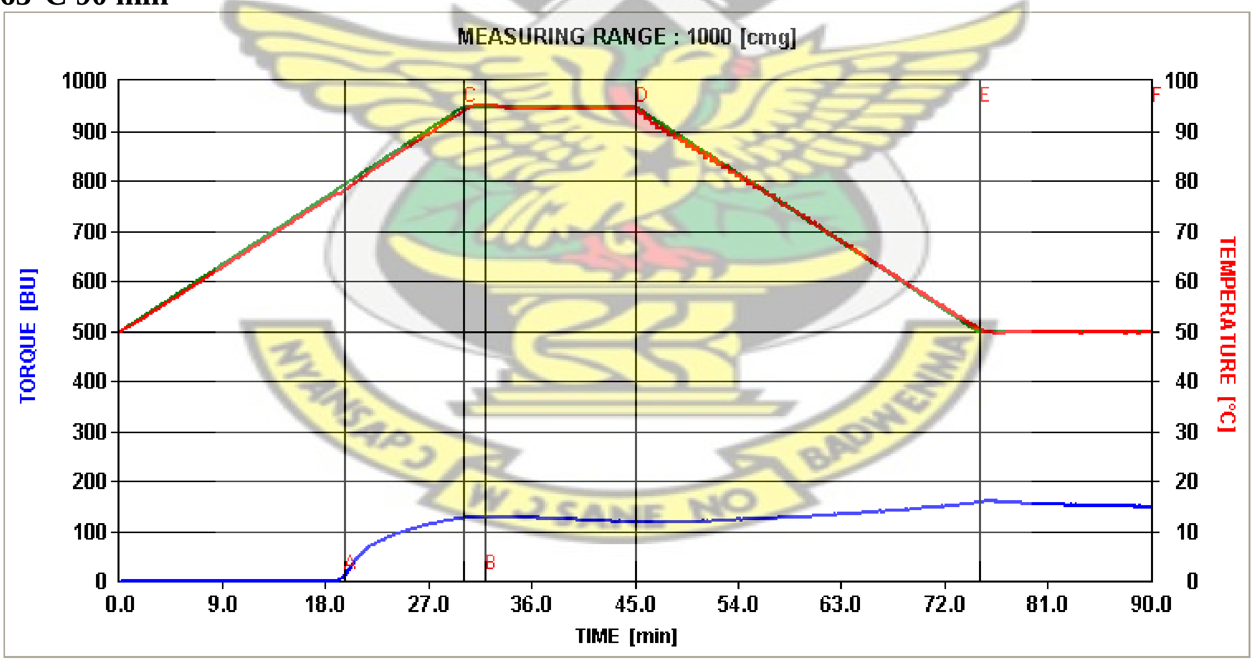
120min 60°C



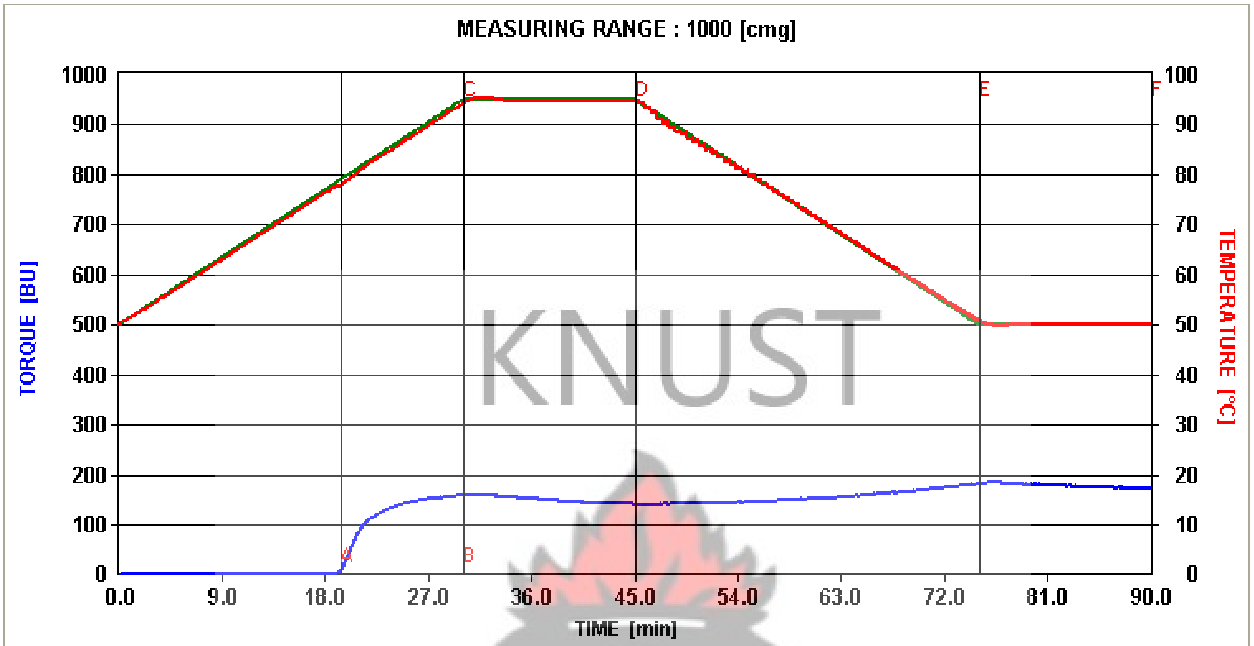
75°C 90 min



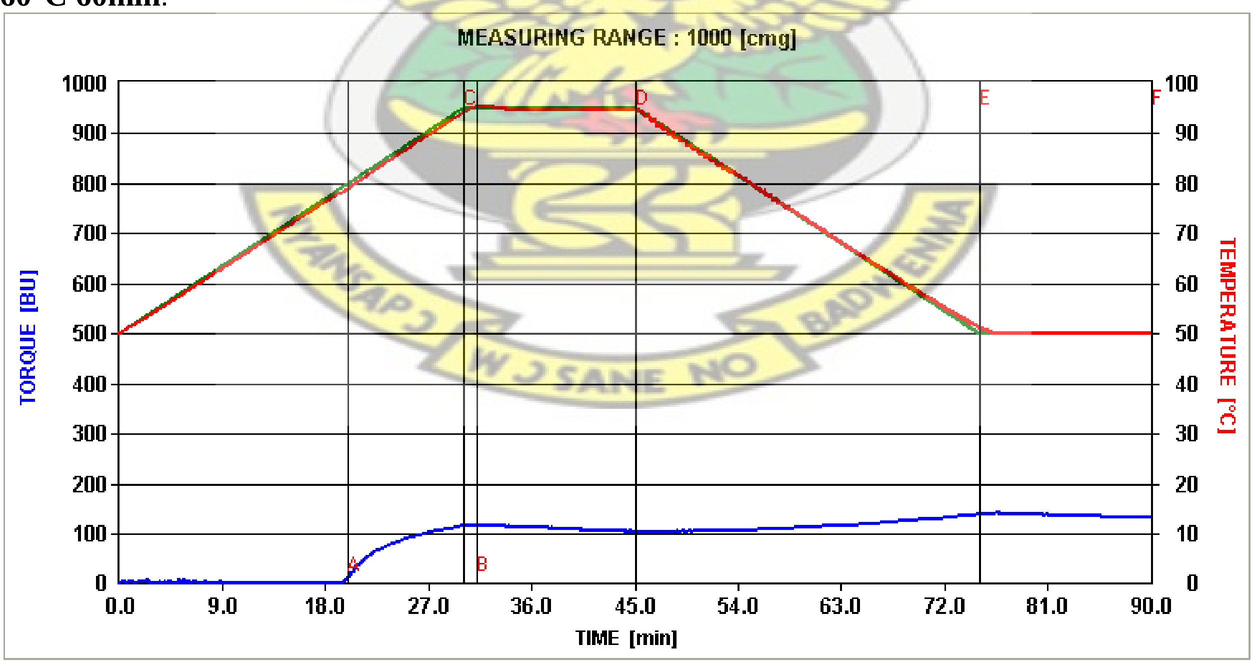
65°C 90 min



65°C 120 min

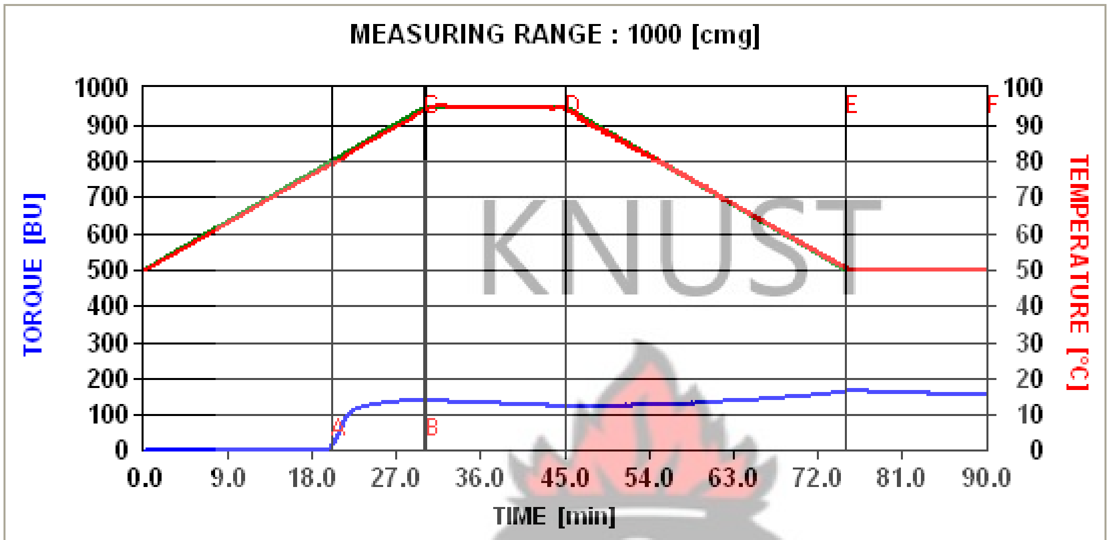


60°C 60min.

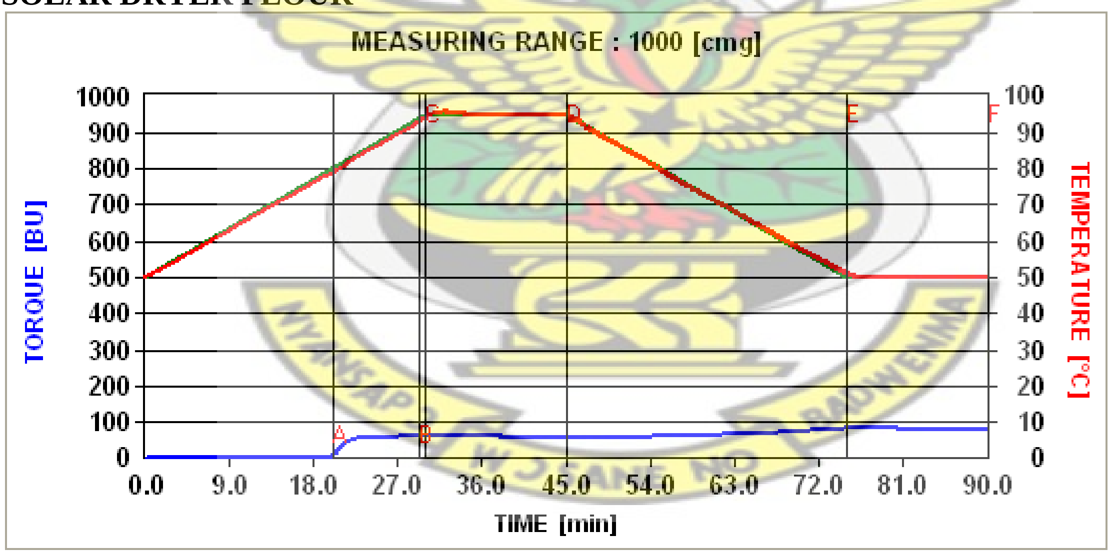


2B PASTING PROFILE- GRAPH OF *Santom pona* FLOUR OF DIFFERENT DRYING METHODS

CFIR FLOUR



SOLAR DRYER FLOUR



OVEN DRYER FLOUR