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EFFECTS OF VARIETY, HARVEST AGE AND PRE-TREATMENT ON THE DRYING CHARACTERISTICS AND BAKING QUALITY OF CASSAVA FLOUR

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CERTIFICATION

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

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ABSTRACT

Cassava is an important tropical crop that is widely grown and consumed in different forms across various countries in the tropics. It has great potentials for use in the bakery and other food industries for the production of value added products. The effects of harvest age, chipping, grating, toasting and citric acid pre-treatments on drying characteristics and baking quality of *Ampong*, *Broni* and *Otuhia* cassava varieties were investigated. Pre-treatment had the greatest influence on the drying characteristics as more than 50 % of the drying time was saved by toasting and grating pre-treatments. Henderson and Pabis, Page and Newton models adequately predicted the drying behaviour of the cassava varieties but the best prediction was achieved with the Page's model. The proximate composition of the cassava flour was significantly ($p \leq 0.05$) affected by harvest age, variety and pre-drying treatments. The flours obtained had satisfactory quality attributes in terms of protein, fat, fibre, ash, carbohydrate, moisture content, pH and cyanogenic potentials. The three cassava varieties produced flours with low cyanide contents of 2.48 mg HCN_{eqv}/kg to 6.99 mg HCN_{eqv}/kg dry matter. These values are below the WHO recommendation of cyanide content which is not to be greater than 10 mg HCN_{eqv}/kg dry matter of cassava flour (WHO/FAO, 2013). Hence the flours could be safely consumed by humans without any concern of cyanide toxicity. The water binding capacity, swelling power, water and oil absorption capacities of the cassava flours were significantly ($p \leq 0.05$) affected by variety, harvest age and pre-treatment while solubility was affected by only harvest age and pre-treatment. The *Otuhia* cassava variety had relatively lower gelatinization temperature and peak time values while *Otuhia* and *Ampong* varieties had higher peak and final viscosity values. The setback viscosity values of the flour from the three cassava varieties did not differ from each other. Grating pre-treatment had the highest peak viscosity value while the setback and final viscosity values of toasted and grated samples were higher than the others. The early gelatinization, high peak viscosity, setback and final viscosities generally exhibited by the flour samples were good indicators of their suitability for use in the bakery industry. Results from the baking experiment indicated that the specific volume and sensory attributes of bread samples containing 20% cassava flour produced from five different pre-treatments of *Otuhia* variety harvested at 14 months compared very well with the control sample. Composite bread with acceptable sensory qualities were produced from flour containing up to 40% toasted and 30% grated cassava which was not significantly different ($p \leq 0.05$) from bread containing 100% wheat flour.

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DEDICATION

This thesis is dedicated to the almighty God for His special grace in my life.

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CHAPTER ONE

GENERAL INTRODUCTION AND BACKGROUND

1.1 Background of the study

Cassava (*Manihot Esculenta Crantz*) is one of the most important energy crops widely grown and consumed in the tropics and many regions of the world (Ugwu and Odo, 2008; Ajala *et al.,* 2012). It is the third most important carbohydrate staple in the tropics and sixth global source of calories in human diet. The 2011 global estimate of cassava production was 276.8 million tonnes of which Africa produced 157.8 million tonnes representing about 57 % of global production (Ebah-Djedji *et al.,* 2012). West Africa alone contributes about 81.9 million metric tonnes equivalent to about 52 % of African production which is the highest agricultural product in the region. According to the Food and Agricultural Organisation of The United Nation (FAO) statistical records of 2013, Ghana was the 7th largest world producer of cassava with annual production value of about 16 million metric tonnes representing 10% of the total African production for that year while Nigeria was the largest world producer with a total annual production of 53 million metric tonnes which represented 19 % of the world production and 33.6 % of the continental production (FAOSTAT, 2015).

In some African countries like Nigeria and Ghana, the wide adaptation of high yielding disease resistant varieties and better pest management practices have resulted in a sharp rise in cassava production to the extent that it became the largest agricultural commodity produced in both countries (FAOSTAT, 2015). Hence, cassava was reported to represent 22 % of the agricultural gross domestic product (AGDP) in Ghana as compared to 5 % for maize, 2 % for rice, sorghum and millet, 14 % for cocoa, 11 % for forestry, 7 % for fisheries and 5 % for livestock (MoFA, 2005).

Cassava plays a particular important role in agriculture in developing countries especially in sub-Saharan Africa because it can grow at sub-optimal conditions and at a considerably lower cost than other crops, can tolerate lower soil fertility and drought stress and is a perennial crop that can be stored underground for several months after maturity (Ukwuru and Egbonu, 2013). Its wide harvesting periods allow it to act as a famine reserve and are invaluable in managing labour schedules. It offers flexibility to peasant farmers because it serves as either a substitute or cash crop.

The crop is amenable to agronomic as well as genetic improvement, has high yielding potential under good conditions and performs better than other crops under sub-optimal conditions (Ukwuru and Egbonu, 2013).

Historically, policy makers and researchers have paid very little attention to cassava as most of their efforts have been concentrated on cash crops or the more familiar grain crops. Cassava was regarded as the food for the poor and has played a very minor role in international trade or as source of industrial raw material. This misconception has persisted so long because of the lack of appreciation of the number of people who depend on this crop, the number of lives that have been saved during famine and disaster and the numerous ways by which cassava can be utilized in industries such as the bakery industry in producing value added foods.

The cost of calories from cassava is very low as compared to any other root or grain crop. Unfortunately, the tendency to treat cassava indifferently as a last resort in the absence of other food crops has obscured its varying uses and performances. It has also hindered the analysis of its importance in the global food system, blanketed the understanding of its future prospects, and handicapped formulation of appropriate policies to exploit its unreleased potentials (Al- Hassan, 1989).

1.2 Justification

In most countries of the West African sub-region, almost all the cassava produced are for direct human consumption and less than 5 % is used in industries (Ukwuru and Egbonu, 2013). Although cassava is the cheapest source of carbohydrate, its use as raw material is not properly harnessed in Ghana despite her position as one of the world's leading producers of the crop.

Measures that will increase the use of cassava as an industrial raw material especially in the food industry will accelerate the cassava transformation initiative of Ghana's Ministry of Food and Agriculture by extending the demand for the crop. One of the area where cassava can be effectively utilized as a source of industrial raw material is in the bakery industry for the partial substitution of wheat. The use of baked products as breakfast and snacks by most urban dwellers within the West African sub-region has increased the demand for the product and hence the increased wheat importation. The quantity of wheat imported in Ghana was about 450,000 tonnes per annum as at 2012 and 15 million tonnes in Nigeria (Ulrich *et al*., 2013; Ohimain, 2014). With an annual increase of 7.5%, Ghana's wheat import for 2016 is projected to be 600,000 metric tonnes (Ulrich *et al*., 2013).

As reported by Ulrich *et al*. (2013), the total cost of wheat import at factory gate is $490 per tonne which implies that Nigeria spent about $7.35 billion on wheat importation in 2012 while Ghana spent about $220 million and is expected to spend about $294 million in 2016. Hence a 20 % replacement of wheat flour imports with cassava flour will equate to an annual foreign exchange savings of $58.8 million and 88.2 million for 30% replacement by 2016. Unfortunately, efforts made in other developing technologies to promote the use of cassava as partial substitute for wheat in bread making (Satin, 1988, Eggleston *et al.*, 1993, Onwuamanam, 2007, Eduardo *et* *al.*, 2013) have not yielded the expected result in Ghana. The Ministry of Food and Agriculture acknowledged this in one of its reports which stated that "the use of composite flour has made little impact in Ghana as the microbial content and improper drying have restricted the use of cassava flour by large scale food processes" (MoFA, 2005). Hence, for cassava to be effectively used as a relevant industrial raw material, it has to be properly processed into flour. This stage of processing is usually encumbered with many problems which if not properly handled lead to the production of inferior quality flour which will be unwholesome for its intended end use. The possibility of replacing wheat flour with starchy tubers in food depends largely on their chemical and physical properties as this influence such flour behaviours as gelatinisation, peak and setback viscosities which affect the texture of the final product. For cassava flour to be very much accepted in the food industry, it has to meet the quality requirement in terms of physico-chemical characteristics, presence of cyanogenic glucoside and microbial safety (Eriksson *et al.*, 2014).

Nweke (2004) in his work on the new challenges in cassava transformation in Nigeria and Ghana stated that the amount of cassava used in food industries is very small due to the following reasons;

1. The composite cassava and wheat flour used in baking industry is made expensive by the viscosity enhancers such as egg, milk and gums.
2. The cassava variety, age of the cassava roots and growing environments are not standardized.

It is therefore necessary to study how certain pre-treatment methods and age at harvest affect the quality characteristics of the flour from three newly introduced cassava varieties in Ghana.

1.3 Aim and Objectives

The aim of this study is to contribute to sustainable production of quality cassava flour.

The specific objectives of the work are to:

(1) Determine the effects of pre-treatment on the drying characteristics of three new cassava varieties in Ghana and establish a thin layer model that best suits the drying processes.

(2) Determine the effects of pre-treatment, age at harvest and varietal differences on the quality characteristics of the flour produced from the new cassava varieties.

(3) Investigate how harvest age, variety and pre-treatment affect the production of cassava flour with relevant functional characteristics for use as composite baking material.

(4) Investigate the effects of substitution level on the quality characteristics of composite bread produced from the cassava flour.

CHAPTER TWO
LITERATURE REVIEW

2.1 Cassava

2.1.1 Origin and Distribution

Cassava (*Manihot Esculenta Crantz*) was first introduced in the Congo Basin from South America by the Portuguese explorers during the 16th and 17th centuries (DPP, 2010).

Currently, cassava is cultivated in about 40 African countries stretching through a wide belt from Madagascar in the Southeast to Senegal and Cape Verde in the Northwest. The crop is adapted to zones within latitudes 30° N and 30° S of the equator, at elevations up to 2,000 m above sea level, with a temperature range of 18 °C to 25 °C, and an annual rainfall regime of 50 to 5000 mm, and can equally grow well in very poor soils with a pH range of 4 to 9 (Okigbo, 1980).

The six countries that currently account for most of the cassava in Africa include Nigeria, Congo, Ghana, Cote d'Ivore, Tanzania and Uganda. The area planted with cassava increased almost four fold in Nigeria and Ghana between the early 1960's and the early 2000's (Nweke, 2004).

The world's production of cassava was estimated to be 184 million tonnes in 2002 rising to 242 million tonnes in 2008 (FAO, 2011). The majority of the production in 2002 was in Africa where 99.1 million tonnes were grown; 51.5 million tonnes were grown in Asia and 33.2 million tonnes in Latin America and the Caribbean. Nigeria is the world's largest producer of cassava while Thailand is the largest exporter of dried cassava chips with a total of 77% of the world's export in 2005 (FAO, 2011).

Whereas other crops like yam, maize, cowpea, sorghum etc., are eco regional specific, cassava is probably the only crop whose production cuts across all ecological zones in the tropics (Taye, 1996).

2.1.2 Taxonomy and Varieties

Cassava belongs to the family *manihoteae* of the *gemnius manihot* and species of *manihot esculenta* with a binomial name *Manihot esculenta crantz* (Onwueme, 1978).

Many cultivars or varieties of cassava are cultivated in the tropical and sub-tropical countries of the world. The varieties are distinguished by their morphological characteristics such as leaf size, colour and shape, branching habits, plant height, colour of stem and petiole, tuber colour and shape, maturity period and yield (Okigbo, 1980). Cassava has been broadly classified into two major groups, the bitter (or toxic) and the sweet (or non-toxic) varieties in line with the level of the cyanogenic glycosides contained in the crop. The bitter varieties contain the cyanogenic glycoside at a level greater than 100 mg/kg of fresh root and the cyanogenic glycoside is distributed throughout the tuberous root while the sweet varieties contain cyanogenic glycoside at a level lower than 50 mg HCN equivalent /kg fresh root weight and is confined mainly to the peels (Nassar, 2005). In between the toxic and the non-toxic varieties is the average or moderate toxic variety with cyanogenic glycoside concentration of 50-100 mgHCN $_{\text{equiv.}}$/kg of edible fresh tuber. The natural out-crossing behaviour of cassava results in the production of many new hybrids from self-sown stem cuttings and seeds, from which farmers could select desirable types for propagation. By this process, lots of new local varieties that are adaptable to the various agro-ecological zones are continually created (FAO, 2005).

In order to identify these local varieties Doku (1996) gave a detailed description of 91 varieties based on the size of the leaves, petiole and stem colours branching habits, height and inner skin colour of tubers. Unlike the unconscious selection methods used by the farmers, the research institutes adopted systematic methods of breeding and selection for developing high yielding varieties with very good resistance to pest and diseases.

The process of developing these varieties within the West African sub-region have been accomplished by the various scientific research institutes of the respective countries in the sub-region with the International Institute of Tropical Agriculture

(11TA) located in Ibadan, Nigeria as the major collaborating institution. In line with this, the IITA reported that the institute has developed more than 40 improved cassava varieties in the last 45 years. The latest of these varieties include the two most recently released varieties IITA-TMS-1982132 and IITA-TMS-1011206 now known as UMUCASS 42 and UMUCASS 43 respectively. These varieties which were released in collaboration with the Nigerian Root Crop Research Institute (NRCRI) at Umudike, Nigeria are pro-vitamin A and have the capacity of yielding 49 to 53 tonnes/ha in contrast to the local varieties that yield less than 10 tonnes/ha (IITA, 2013).

In order to reverse the low productivity trend of cassava and other root and tuber crops in Ghana, the government of Ghana since 2006 adopted and implemented root and tuber crops improvement strategies. Under this programme, improved cassava varieties that have early maturing and harvesting ability, good root shape, white flesh and good plant type that have very good tolerance to common diseases and pests have been developed and disseminated to local farmers (Owusu and Donkor, 2012). Research efforts aimed at progressive improvement of the cassava varieties have been on-going over the years in Ghana by relevant institutions such as the Kwame Nkrumah University of Science and Technology (KNUST), University of Cape Coast, Savannah Agricultural Research Institute (SARI), Crop Research Institute (CRI) and the Ministry of Food and Agriculture (MoFA). Four special varieties (*Gari*, *Queen, Ankra* and *Williams*) which were very resistant to cassava mosaic virus disease, and high yielding (7-10 t/ha) and good taste were released in 1935 and widely grown in the country. Later in 1965, four new varieties namely; K357, K162, K680 and K491 were released to the farmers with K680 having the best yield potential of about 19 t/ha.

These varieties have moderate resistance to cassava mosaic and good cooking quality and palatability (Korang-Amoakoh *et al.,* 1987). The CRI latter released *Afisiafi, Gblemo and Abasafitaa* varieties in 1993 while KNUST released *Tekbankye variety*. These varieties are high yielding and early maturing and can be harvested at 12 months with 35 t/ha yield. They can also tolerate cassava mosaic virus and moderately resist cassava mealy bug pests. The research efforts of the Universities, SARI and CRI led to the release of eleven new varieties in 2005. These varieties were *Agbelifia, Bankye hemaa, Essan bankye* and *Dokuduade* released by CRI; *Nyerikobya, Fillindiakong* and *Eskamaye* which were released by SARI; *Capevars bankye* and *Bankye botan* released by the University of Cape Coast; *Ifad bankye* and *Nkabom* released by KNUST. These varieties produced average yield of about 48 t/ha and are very tolerant to cassava bacteria blight and mosaic virus diseases. Some of the varieties also have some degree of tolerance to anthracnose, cassava root rot and brown leaf spot. The CRI in 2010 released additional four new varieties namely; *Ampong, Otuhia, Sika bankye* and *Broni bankye.*

2.1.3 Morphology, Growth and Development of Cassava

The cassava plants are perennial woody shrubs which grow to a height of 1-4 m and are mainly propagated from stem cuttings but under natural conditions and during plant breeding programmes, propagation is by sexual seeds (Agordjo, 2012; Indira *et al.*, 1997). Plants propagated from seeds have typical primary root system similar to dicotyledonous species. The radical of the geminating seed grows vertically downwards and develops into a taproot from which adventitious roots originate. The taproot and some of the adventitious roots develop late into storage roots. Plants grown from stem cuttings have adventitious roots that rise from the basal root surfaces and occasionally from the basal buds under the soil. These roots develop into fibrous root system, and only a few of them bulk and become storage roots (Hayford, 2009). The cassava tuberous roots are made up of the peel (10-20%), the cork layer (0.5-2.0%) and the fleshly edible portion (80-90%) (Onwueme, 1978; Nassar, 2005).

The growth of cassava is divided into the following five major stages (Hayford, 2009).

(1) The emergence or sprouting
(2) Onset of leaf formation and development
(3) Development of stem and leaf (canopy establishment)
(4) High carbohydrate translocation to root and
(5) Dormancy stage

The first stage which is the sprouting stage starts with the emergence of the first adventitious roots from the basal cut surface of the stake at 5-7 days after planting

(DAP). In the second stage, Sprouts and leaves are observed at 10-12 days, followed by the emergence of all the sprouts at 15 to 90 days. During this period, the true leaves start to expand at about 30 DAP when the photosynthesis process commences its positive contribution to the plants growth while the fibrous roots also start to grow, replacing the adventitious roots as it penetrates 40-50 cm into the soil while enhancing effective water and nutrients absorption .

Some of the fibrous roots start forming storage roots distinct from fibrous roots at 60-90 DAP.

The third stage which ranges from 90-180 DAP is a period of maximum growth rate of stems and leaves. At this stage, branching method and the structure of the plant is well defined while the leaves trap greater part of the available light on the plant cover from 120-150 DAP. The ratio of canopy size and dry matter partition to leaf and stem is maximum at this stage while storage root continues to bulk through this period.

The fourth stage is characterized by rapid bulking of storage roots with accelerated translocation of sugar and conversion into starch in roots.

The fifth stage is the dormancy stage which sprang from 300-360 DAP. During this stage the plant experiences leave shedding and reduction in the leaf production rate. Translocation of sugar and its conversion to starch in the root continues. This stage also marks the completion of the growth cycle and onset of new vegetative growth period, dry matter accumulation and dormancy.

2.1.4 Cassava Tuber and Its Composition

Cassava is a major source of energy in most rural communities in West Africa and many tropical countries. The cassava plant is one of the highest producers of carbohydrate among crop plants and is known to produce higher calories per day compared with rice, wheat, maize, sorghum and most other popular food crops. Cassava consists of a fibrous layer (the peel) and a core inner portion. The peel forms about 10-15% of the entire tuber weight. The chemical composition of cassava varies according to the variety, age, location and environmental conditions. Cassava contains cyanogenic glucosides (in the form of Linamarin and Lotaustralin) which are hydrolysed to produce toxic cyanide when the cells are ruptured. Even though cassava tubers are very rich in calories, they are low in fats, protein and some essential vitamins and minerals. Hence, its nutritional value is lower than those of other staples like yam, maize etc. The average nutritional composition of fresh cassava root is as presented in Table 2.1 (Kwatia, 1986). Fresh cassava roots contain about 59-65% moisture, 0.5 to 1.5% protein, 30-35%, carbohydrates on fresh weight basis and 80-90% on dry matter basis. Eighty percent of the carbohydrate contained in the roots is in form of starch. The starch content reaches its peak value between the 10th and 11th month after planting. Apea-Bah *et al.* (2011) observed that the peak starch yield is affected by variety. Since fresh cassava roots are low in protein and essential vitamins and minerals, cassava based diet requires additional protein source to avoid the danger of nutritional deficiency (Balagopalan *et al.*, 1988).

Table 2. 1 Average nutritional composition of fresh cassava (wet basis)

Component	Per 100g edible portion
Food energy	146 calories
Moisture	59.4g
Carbohydrate	38.1g
Protein	0.7g
Fat	0.2g
Fibre	0.6g
Ash	1.0g
Calcium	50.0mg
Vitamin C	25.2mg
Energy	157Kcal

Source: Kwatia(1986)

2.1.5 Cyanogenic Glucosides in Cassava

Cassava is generally regarded as a potentially toxic crop when consumed in the raw state due to the presence of cyanogenic glucoside in the crop (Mburu, 2013). This cyanogenic compound is synthesized in the leaves and transported to the tuber and every other part of a mature cassava plant except in the seeds (Conn, 1994). Its concentration in the tuber increases outwardly from the centre of the tuber with the highest glucoside content in the peel (Gondwe, 1974). The cyanogenic glucoside is made up of two compartments: the linamarin which forms 95% of the total cyanogens and the lotaustralin which makes up the remaining 5% (Balagopatan *et al.*, 1988). The cassava tissue cell which houses the cyanogens also contains the cyanogenic enzyme known as linamarase. The cyanogens and the cyanogenic enzymes are differentially compartmentalised (Fig. 2.1) such that the cyanogens are enclosed in the cell vacuoles while the enzymes (linamarase) are contained in the cell wall (White *et al.*, 1994).

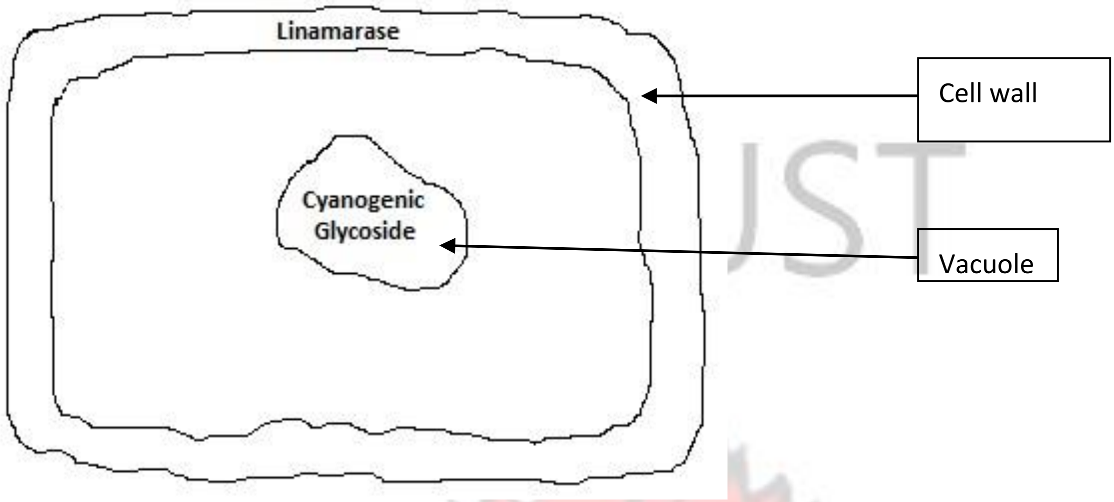


Figure 2. 1 The Positions of cyanogenic glycoside and linamarase in the plant cell. Source: Conn (1994)

As a result of the compartmentalisation of the cell, the cyanogens in its undisturbed state is inert and harmless but if the tissues are macerated or crushed, the compartmentalisation is broken down leading to the release of the cyanogens which is spontaneously decomposed into toxic hydrogen cyanide (HCN) by the enzyme linamarase. This situation could arise when the cell structure of the crop is disrupted during cassava processing or by a predator (Moller and Seigler, 1999; Mkpong *et al.*, 1990; White *et al.*, 1994). The toxicity of cassava is associated with its ability to release hydrogen cyanide from the stored cyanogenic glucosides (Ermans *et al.*, 1980). The cyanide toxicity results from the conversion of the residual cyanogens in cassava to hydrogen cyanide inside the human body after consumption. The consumption of cassava with high cyanogens concentration can result in illness or even death depending on the concentration level. For the cassava roots to be safe for use as food, it has to undergo various degrees of processing depending on the type of variety so as to eliminate or reduce the cyanogenic potential to a safe level of 10 mg HCN equivalent per kg of cassava flour as recommended by the Food and Agriculture Organisation of the United Nations and World Health Organisation (FAO/WHO, 2013) and the African Organization of Standards (ARSO, 2012). Normally when small quantities of hydrogen cyanide are consumed, the cellular enzymes and thiosulphates in the tissues detoxify it to form thiocyanate which is relatively harmless and is excreted in urine (Salkowski and Penny, 1994). However, the consumption of food substances that can release as much as 100 mg of HCN in the human body within a period of 24 h results in a rapid absorption of large quantities of cyanide in the human body to the extent that the body's detoxification mechanism is overwhelmed leading to what is referred to as acute cyanide poisoning.

The acute cyanide poisoning can lead to a total blockage of cellular respiration which can eventually result in the death of the individual (Salkowski and Penney, 1994; Rosling, 1994; Deshpande, 2002).

On the other hand, chronic cyanide toxicity results when humans are exposed to a level of cyanide concentration that is a little lower than the acute level over a prolonged time period. Conditions attributed to chronic cyanide intake such as malnutrition growth retardation in children, some types of pancreatic disorder, congenital malfunctioning and neurological disorder associated with diminished visual acuity, have been observed in chronic cassava consuming populations (Banea *et al.*, 2000; Rosling, 1994). In a healthy human tissue, about 50 mg cyanide can be effectively converted to thiocyanate per day which is gradually excreted in the urine (Schultz, 1984; Banea *et al.*, 2012).

There is a wide variation in the cyanogenic glycoside content in different cassava varieties. Although most of the varieties contain 15-400 mg of cyanide per kg of fresh weight, occasionally some varieties of cassava contain as much as 1,300 to 2000 mg cyanide/kg of fresh cassava tuber (Padmaja, 1995; Mburu, 2013).

Cassava has been categorized into three major groups on the basis of the cyanogenic glucoside content as bitter, average toxic and sweet cassava. The cassava varieties with cyanogenic glucoside content above 100 mg HCN per kg fresh weight of the edible portion of cassava is classified as bitter cassava (toxic) while those with less than 50mg HCN per kg are classified as sweet cassava (or non-toxic) and those whose glucoside concentration fall between 50 and 100 mg, HCN equivalent per kg are termed average (or moderate} toxic (Jansz and Uluwaduge, 1997; Nhassicot *et al.*, 2008; CSIR/FRI, 2012; Kobawila *et al.,* 2005; Koch *et al.*, 1992; CIAT, 2007).

The classification of cassava as sweet and bitter has been used over the years by many farmers as an indicator of the level of toxicity of various cassava varieties. It has also been observed by various researchers that there is a wide variation in the level of cyanogenic glucosides in different cassava varieties irrespective of their classification as sweet or bitter varieties (Raji *et al.*, 2007, CIAT, 2007). Aalbersberg and Limalevu (1991) in their research work in Fiji Island on some cassava varieties reported a wide variation of the cyanide level in these varieties from 14 mg cyanide kg^{-1} to 121 mg cyanide kg^{-1} (Table 2.2)

Table 2. 2 Effect of variety on cyanogenic concentration in cassava roots in Fiji Island

Variety	Total cyanide mgHCN$_{eqv.}$/Kg
Yabbia Damu	101
Yabia Vula	93
Vulatolu 11	21

Aikavitu	42
Vilatolu	70
Variety	121
Coci(selection)	55
Niumea	38
Sokobale	36
Merelestia	14
Coci	55
New Guinea	80
Navollau	101

Source: Aalbersberg and Limaeru (1991)

Gomez *et al.* (1985) also observed an appreciable variation in the cyanide concentration of four cassava cultivars *(Mcol 113, MCol 22, CM 342-170 and Mcol 1684)* at the CIAT research farm in Columbia. They however observed higher variability in the cyanide concentration in the leaves and peels than in the root parenchyma. The *MCol 1684* cultivar which was classified as high cyanide (or toxic) variety had higher cyanide concentration in the parenchyma (900 to 1000 mg $HCN_{eqv.}$/kg dry matter) than the other three cultivars which had cyanide concentrations in the range of 100 to 200 mg/kg dry matter, while the local cultivar *(M col 113*) had a lower cyanide concentration in the parenchyma.

Maziya-Dixon *et al*. (2007) also observed a significant ($p \leq 0.01$) genotype variation and genotype by year interaction on cyanogenic glucoside content of some cassava varieties harvested in 2001 and 2002 at 12 months of age from the research farm of the International Institute of Tropical Agriculture, Ibadan, Nigeria (Table 2.3).

Table 2. 3 Cyanogenic potentials of cassava clones harvested from 11TA research farm at Ibadan at 12 months of age

2001 Harvest		2001 Harvest	
Clone Name	Cyanogenic Potential	Clone Name	Cyanogenic Potential
30001	17.28	30474	7.36

30040	11.46	30555	14.02
30211	6.56	30055p32	14.09
30474	4.34	30572	18.54
30555	6.74	4(2)1425	13.95
96/0097	5.73	95/1009	4.69
96/0160	6.04	95/1038	11.26
96/0249	14.19	96/0016	13.63
96/0304	15.99	96/0023	13.04
96/0415	7.17	96/0035	35.85
Z95/0594	8.96	Z95/0432	25.87
Z95/0633	15.58	Z95/0594	12.97
Z95/0680	19.51	Z95/0680	12.62
Z95/0826	7.22	Z95/0826	18.21
Z95/0961	16.47	Z95/0961	43.72

Source: Maziya -Dixon *et al.* (2007)

Mburu (2013) in her work on eight different cassava varieties in Kenya observed a significant difference in the cyanide concentration of all the eight cultivars studied (table 2.4).

Table 2. 4 cyanide concentration of eight different cassava cultivars in Kenya

Cultivars	Cyanogenic Potential (mgHCN$_{eqv}$./kg)
990183	55.04
99014	44.27
99005	47.76
990245	48.68
990006	49.6
MM96/5280	45.88
Ex-manakari	46.76
1960067	49.14

Source: Mburu(2013)

Research findings of Sunee *et al.* (2006) on Kasetsart 50 (KU 50) cassava variety which is the most widely grown variety in Thailand indicate a significant variation in the cyanide composition of fresh cassava roots harvested at 6, 8, 10 and 12 months after planting. This variation was equally reflected in the cassava flour produced from the processed roots (Table 2.5).

Table 2. 5 Total cyanide content of cassava roots and dried flour from the roots

Root age (months)	Total cyanide content of fresh cassava roots mgHCN$_{eqv.}$/kg dried sample	Total cyanide content of dried cassava flour mgHCN$_{eqv.}$/kg dried sample
6	1427	18.89
8	1,259.50	15.59
10	799.9	0.76
12	533.7	1.3

Source: Sunee et al.(2006)

2.1.6 Cassava Processing and Pre-Treatment

The primary purpose of cassava processing as a component of the post-harvest food chain is to eliminate undesirable constituents and improve its organoleptic and other properties. Over the years, researchers and cassava growing and consuming communities have used various processing and pre-treatment methods to modify the physio-chemical properties of cassava to enhance its suitability for use as food and in different industries. Eriksson (2013) in his work asserted that since cassava contains toxic compounds, it requires some special pre-treatment and processing methods that will enhance total or partial elimination of the cyanogenic glucoside level to make the product safe for human consumption while maintaining or enhancing its quality for use in specific food industries. Some of the processing operations which are widely used in various places are fermentation, soaking, cooking, roasting and drying.

Fermentation as a processing method has been reported by various researchers to enhance nutritional properties of cassava through the biosynthesis of vitamins, protein and essential amino acids by improving the quality of protein and the digestibility of fibres (Achinewhu et *al.,* 1998). Fermentation also enhances the micronutrient bioavailability as well as the degradation of anti-nutritional factors and softening of the cells of cassava roots which favour contacts with the enzymes and its substrate (Essers *et al*., 1996; Vasconcelos *et al*., 1990). Fermentation has equally been used in the production of *gari, akyeke/atioke, bikedi,* cassava dough and many other cassava based foods commonly produced in the cassava production areas of the world (Tetchi *et al.,* 2012; Kobawila *et al*., 2005; Westby, 2002).

Three principal fermentation types are practised widely in various parts of Africa. These are fermentation of roots under a pool of water, grated root fermentation and mould fermentation (Westby, 2002). Reports from various research works indicate appreciable reduction of the cyanogenic potentials of cassava as a result of fermentation. Kemdirim *et al.* (1995) reported more than 30% and 50% reduction in cyanogens levels in the production of fermented cassava flour and *gari r*espectively.

Enidiok *et al.* (2008) also reported 41% reduction while Iyayi and Losel (2000) reported more than 50% reduction in cyanogen level during fermentation. Other researchers such as Cardoso *et al.* (2005); Oyewole and Ogundele (2001) and Djoulde *et al.* (2007) reported various levels of reduction of the cyanogenic potentials of cassava after fermentation.

In many parts of the world where cassava is widely grown, drying is commonly accepted as an efficient method of processing cassava roots since it results in more shelf-stable products with relatively reduced cyanogenic potential. In most cassava growing regions of Africa, sun drying is the most commonly adopted cassava processing method and the sun-dried cassava pieces are usually processed further into other preferred forms (Westby, 2002). Drying of peeled cassava roots is usually preceded by relevant pre-treatment practises such as toasting, chipping, steeping in water or other liquid chemical products that may enhance or modify the physicochemical qualities of the end product. The drying mechanism does not in itself play much role in detoxifying the product but rather the pre-treatment that precedes drying (Esser *et al.,* 1996). Bainbridge *et al.* (1998) identified two separate treatment stages that play effective role in the reduction of cyanogen. The first stage ruptures the cellular compartments and brings the degradation enzymes into contact with the bound and inactive forms of the cyanogen. The second stage eliminates the products formed from the reactions and favours the evaporation of HCN.

Tivana (2012) and Esser *et al*. (1996) reported that the efficiency of cyanogenic reduction during drying depended on moisture content of the root, rate of moisture loss (which is controlled by drying conditions) and the extent of tissue disruption. As the cells break open during some of the pre-treatment processes that involve size reduction, the endogenous enzymes are brought into contact with their substrates, hence initiating the hydrolysis of cyanogen to volatile hydrogen cyanide and acetone (Lubulwa, 1999) which are eliminated during drying.

Other pre-treatment method such as mincing and rasping that involved cell break up were reported by Janz and Uluwaduge (1997) to have reduced the cyanogenic glucoside level in cassava roots by more than 70%. Cardoso *et al.* (2005) in their work on the effect of processing method on the cyanide concentration of flour reported that when crushing and drying is used as is the case in processing unfermented high quality cassava flour (HQCF), the cyanogenic potential of the fresh cassava tubers should not exceed 250 mg HCN/kg fresh root so as to obtain flour with less than 10 mg HCN/ kg which is the safety level by the World Health Organisation (WHO). Sakyi-Dawson *et al.* (2006) also reported that both processing methods and varietal differences affected the cyanogenic potentials, chemical composition as well as the viscosity of the flour.

Westby and Choo (1994) reported that pre-treating cassava roots by grating before drying resulted in the removal of 95% of linamarin from the pulp within 3 h. Vasconcelos *et al*. (1990) also reported that micro-organisms played only minimal role in the cynogenic reduction of grated cassava roots while grating played a major role in linamarin hydrolysis. They further asserted that even though linamarin is rapidly hydrolysed by grating, cyanide retention remains high in the paste until an effective post grating operation is used in eliminating the free cyanide. Hence, the process of toasting or drying after grating and dewatering is relatively efficient as free HCN and cyanohydrin are continuously eliminated into the atmosphere leaving very small free HCN (3.4 mg/kg. dry weight).

Fermentation of roots by soaking in water was also reported to be very effective in total cyanogens reduction as Westby and Choo (1994) reported the removal of more than 90% of total cyanogens from cassava roots after three days of fermentation and about 33% of the initial linamarin was found in the water while no accumulation of free HCN was noted in the soaked roots. Duffour (1994) also reported that grating cassava root after 6 days of soaking and fermenting the resulting mash for 4 days into *farina* resulted in 98% removal of the available HCN. Ogbo (2003) improved the organoleptic properties of retted cassava product using alkali (NaOH) pre-treatment of the roots. This pre-treatment method was able to remove the characteristic offensive odour associated with retted cassava products.

Tunde-Akintunde and Ayala (2010) in their work observed that blanching and soaking pre-treatments affected the drying characteristics of cassava chips. They noted that the 3 days soaking pre-treatment of cassava chips resulted in a higher mean drying rate relative to blanching and soaking pre-treatments.

Ooye *et al*. (2014) also reported that the proximate composition and the cyanogenic potential of cassava flour obtained from two different cassava varieties were significantly affected by pre-treatment. They observed that slicing pre-treatment resulted in flour samples with higher protein, ash and fibre contents relative to other pre-treatment methods studied. It was also observed from their work that the starch content of the flour obtained from sliced and grated samples were comparable.

In a research work on two bitter cassava varieties, Kemdirim *et al.* (1995) reduced the HCN content of the pulp by 52% and 57% by fermenting it for 96 h during *gari* production. The HCN content was equally reduced by 38% by soaking the sliced tissues for 24 h prior to sun drying in cassava flour production.

2.1.7 Economic and Social Importance of Cassava

Cassava is presently one of the most important tropical root crops which is primarily grown for its starchy tuberous roots that is rich in dietary energy (Onwueme, 1978; Agordjo, 2012).

Cassava production by small scale farmers is mostly on marginal and sub-marginal lands in humid and sub-humid tropics. Its ability to grow on poor soil and under difficult climate as well as the flexibility in its harvesting age make it a crop of last resort for farmers' family and their domestic animals in the tropics (Hillocks *et al.*, 2002; Aerni, 2005; Kawano, 2003). Dixon *et al.* (2003) reported that in 2002, cassava was consumed by over 700 million people worldwide and so many African countries were growing the crop exclusively for food. In many southern, eastern and central parts of Africa, cassava is still regarded as famine reserve crop or as rural staple food and it is mostly consumed as dried roots, boiled and eaten or prepared as cassava dough (Nweke, 2005). In some other countries where it is also used as urban food staple as is the case in most West African countries, cassava is produced and processed into varieties of low cost convenient foods for sale in the urban centres and foreign markets (Nweke, 2005).

Cassava is equally used as livestock feed as well as industrial raw material. Opportunities for market diversification are excellent in some African countries like, Nigeria, Ghana, Democratic Republic of Congo, Uganda, and a host of African countries (Benesi *et al.,* 2004). In developing countries where the production of cereals is inadequate for human consumption, cassava is potentially the major energy source in meeting the increasing needs for animal ration.

It has been scientifically shown that cassava is a good source of carbohydrate, which can be effectively used as substitute for maize or barely and that cassava based feeds are particularly suitable for swine, dairy cattle and poultry when supplemented by other food that are rich in proteins and vitamins. In European countries, most of the animal feed industries make use of dried cassava roots as ingredients and large quantities of cassava chips, pellets and meals are imported into these countries for this purpose (Sanni *et al*., 2005).

Cassava starch has been identified as potential substitute for wheat and maize based starch in various industries. Cassava starch is widely used in numerous food and nonfood industries and also as raw material for production of chemicals used in plastics and leather tanning industries (FAO, 1977). The high paste clarity and high paste viscosity as well as high freeze-thaw stability are some remarkable properties of cassava starch that make it suitable and advantageous for use in many industries (Ukwuru and Egwuonu, 2013).

Cassava starch is used either as native or modified starch. Food, metallurgical, pharmaceutical, paper, and most textile industries use native starch in its traditional form. The native starch is modified by altering its chemical and physical properties to make it suitable for specific use in many industries such as food, pharmaceutical, textile, petroleum and paper pulp industries.

Various types of starch are extensively used in the paper industry for different purposes. Cassava starch is a dominant source of starch in Nigeria, Ghana and most West African countries and it possesses very good properties such as strong film, clear paste, good water holding properties, stable viscosity, low dirt and fibre content and uniformity of lots (Sriroth *et al*., 1999).

These properties make cassava very suitable for the paper industry in West Africa. Cassava starch is widely used as a popular base in the manufacture of adhesives particularly those designed to bond papers in some forms to itself or to other materials like glass, mineral wool and for non-paper substances such as charcoal in charcoal briquettes, mineral wool in ceiling tiles and in ceramics before firing (Graffham *et al*., 1998).

The residue resulting from large-scale production of starch is naturally rich in organic matters which make it suitable as substrate for microorganism in the manufacture of products like organic acid, flavour, aroma compounds, maltose, malto-dextrin, etc. (Pandy *et al.*, 2000).

Monosodium glutamate (MSG) which is used in the form of crystal or powder to add flavour in foods such as meats, vegetable sauce and gravies is a product of cassava starch which is hydrolysed into glucose by boiling with sulphuric acid or hydrochloric acid solution in enclosed converters under pressure. The glucose is converted to glutamic acid by bacterial fermentation after filtration. The glutamic acid is refined, filtered and treated with caustic soda to produce MSG which is eventually centrifuged and dried in a drum drier (Sanni *et al.*, 2005).

Cassava flour has also been used with wheat flour at various levels of substitution for the production of baked products such as bread, biscuit, cookies, meat or fish pie (Taiwo *et al*., 2002; Adebayo *et al*., 2010).

2.2. Drying of Agricultural Materials

2.2.1 Drying Mechanism

Drying is an important unit operation in the processing of agricultural products.

Various researches have been done on investigating the drying theories of various agricultural products. Research work by Lewis (1921) and Sherwood (1929) are among the earliest works on drying theories. Sherwood in his works classified general drying mechanism under these three conditions:

1. Evaporation of water takes place at the solid surface and the resistance to the internal diffusion of liquid is minimal when compared with the overall resistance to the removal of vapour from the surface.
2. Evaporation of water takes place at the solid surface and the resistance to the internal diffusion of liquid is high when compared with the resistance to the removal of vapour from the surface.
3. Evaporation of water takes place in the interior of the solid and the resistance to the internal diffusion of liquid is great as compared with the total resistance to the removal of vapour.

Sherwood explained that no particular product drying is restricted to one of the above conditions. The first drying condition is exemplified by the drying resistance of very wet solid which is similar to the evaporation of liquid from the liquid surfaces. In this case the drying rate is usually constant, the liquid content decreases as the drying progresses and the drying mechanism changes to one of the other cases. The drying rate decreases with an initial period of constant rate of drying and the moisture at which the drying rate starts falling is called the critical moisture content.

Sherwood further classified the drying rate period into three stages as follows:

1. Constant rate period
2. First falling rate period
3. Second falling rate period.

Charkraverty (1963), however, noted that normal agricultural product drying does not fall within the constant rate drying period but practically takes place within the falling rate period. The drying process of agro products is usually approached from the point of view of:

1. The equilibrium rate relationship and
2. The drying rate relationship

The equilibrium rate relationship comes into play when there is a continual exposure of the food product to air supply at constant temperature and humidity with fixed partial vapour pressure. During this period, the product loses moisture by evaporation or absorbs moisture from the air stream until the vapour pressure of the product moisture equals the fixed partial pressure of the vapour. The moisture in the solid food product is in equilibrium condition with the surrounding gas. The food moisture content at which this condition is attained is referred to as equilibrium moisture content. The drying rate relationship involves the constant rate period and the falling rate period. In the constant rate period, the rate of evaporation under any set of given air conditions is essentially the same as the rate of evaporation from a free liquid surface under the same condition independent of the nature of the solid. The rate of drying during this period is dependent upon the:

a. Difference between the temperature of wetted surface at constant air velocity and relative humidity.
b. Difference in the humidity between the air stream and the wet surface at constant air velocity and temperature.
c. Air velocity at constant air temperature and humidity.

Drying of agricultural products is completely accomplished in the falling rate period. This begins with a constant rate period which corresponds with the drying cycle during which the entire surface is no longer wetted and the wetted surface is decreased continuously until the period ends. The fall in the drying rate is as a result of the inability of the moisture to move freely from the centre to the surface of the body at rates similar to the evaporation of moisture from its surface to the surrounding. During the falling rate period, there is usually increase in temperature both at the surface and within the solid. The falling rate period is largely controlled by the nature of the product and depends on the movement of moisture within the material from the centre to the surface by liquid diffusion. The effect of changes in air velocity during this period is so insignificant relative to the constant rate period (Ayim, 2011).

2.2.2 Drying Models

Over the years, it has been understood that drying is an energy intensive-operation with grave industrial consequences and must be performed with optimal energy utilization. This calls for accurate understanding of the characteristic behaviour of a particular food substance during drying.

Mathematical modelling enables the researcher to gain insight into the comparative performance of various drying systems, provides quantitative description of drying behaviours, helps to predict qualitative changes during drying and enables the engineer to choose the most appropriate method and the most suitable operating condition for drying a particular food product (Strumillo and Kudra, 1986; Satimenhin *et al.*, 2010).

Amongst the mathematical models that have been used by various researchers in describing the drying behaviour of agricultural products, thin layer drying models are the most popular (Ayim, 2011; Satimehin *et al.*, 2010). Drying of fruits, grains, root tubers and other agricultural products have been successfully predicted using thin layer drying models (Afzal and Abe, 1998; Olawale and Omole, 2012; Ademiluyi *et al.*, 2008; Koua *et al.*, 2013; Hii *et al.*, 2008).

The three categories of the thin layer drying equations as reviewed by Jayas *et al.* (1991) are theoretical, semi theoretical and empirical models. The most frequently used models by researchers (Jayas *et al.*, 1991; Saeed *et al.*, 2008; Satimehin *et al.*, 2010) are lump parameter-type equations such as the Newton equation as presented in equation (2.1) below

$$MR = \frac{M_t - M_e}{M_o - M_e} = \exp(-kt) \qquad (2.1)$$

where,

MR= moisture ratio (-)

M_t = moisture content at time, t (% db)

M_e = equilibrium moisture Content (% db)

M_o = initial moisture content (% db)

K= drying constant (h^{-1}) t= time (h)

Equation 2.1 was modified to obtain another equation by Henderson and Pabis (1961) with an additional constant as presented in equation (2.2)

MR= a exp (-bt) (2.2) where, a = empirical drying constant b = empirical drying constant (h^{-1}) t=time (h)

Another model which has been widely used by many researchers (Hutchinson and Otten 1983; Li *et al*., 1987; Ajibola *et al*., 1987; Goyal *et al.*, 2006,) is the Page's model given in equation (2.3) as

$$MR = \exp(-kt)^{y} \qquad (2.3)$$

where, k= empirical drying constant (h^{-1})

y= empirical drying constant.

The Page's model was further modified to obtain the logarithmic model as stated in equation (2.4) and this model has been used by various researchers to effectively describe the thin layer drying characteristics of some agricultural products (Doymaz, 2004, Olawole and Omole, 2012).

$$MR = a \exp(-kt) + c \qquad (2.4)$$

where, k = empirical drying constant (h^{-1})

a, c = empirical drying constants.

2.2.3 Evaluation of the Drying Models

The suitability of the thin layer drying model for describing the drying processes of specific agricultural products can be determined by using the goodness of-fit statistics to evaluate the quality of the fitted model. Some of these statistical measures are described as follows:

a. Coefficient of determination (R^2)

Coefficient of determination refers to the ratio of the sum of squares (SSR) to the total sum squares (SST). The value of the coefficient of determination explains the proportion of variance accounted for in the dependent variable by the evaluated model. It explains the degree of fitness of the data to the model. The higher the value of the R^2, the better the goodness of fit of the data to the model. The total sum of square (SST) and the reduced sum of square error (SSE) are calculated from the following formulae

$$SST = \sum_{i=1}^{N} (Yi - Y)^2 \tag{2.5}$$

$$SSE = \sum_{i=1}^{N} (MRpre\ i - MRexp\ i)^2 \tag{2.6}$$

Where N= the number of sampling times

MR*exp i*= ith experimental moisture ratio MR*pre*

i = ith predicted moist ratio.

The coefficient of determination (R^2) has been used by various authors for evaluating the thin layer drying models of various agricultural products (Satimehim *et al.*, 2010; Olawale and Omole, 2012; Radhka *et al.*, 2011; Khazeal and Daneshmandi, 2007; Akram *et al.*, 2013)

2.2.4 Effects of Drying on Food

The two major processes that occur during drying are addition of heat to the food and removal of moisture from the food. The nutritional value of the food can be positively or negatively affected by these processes. Heating can generally improve the digestibility of foods, making some nutrients more available as is the case of the protein in legumes which is made more digestible by heating because of inactivation of anti–nutrients like trypsin inhibitors (Morris *et al.,* 2006).

However, many food products go through several changes during their drying and storage periods. These changes reduce the product quality relative to fresh materials (Fellows, 2009). The chemical and physical changes that occur during processing or drying of agricultural products lead to the improvement of certain characteristics of the final products but the nutritive and organoleptic properties are lost in most cases (Karel and Young, 1989; Wiset *et al.*, 2001; Garcia *et al.*, 1988). The proper handling of the drying process therefore ensures that the product maintains its nutritive value while the shelf life is equally extended.

Drying is associated with some physiochemical changes which affect some quality properties such as colour, texture, nutritional content, sorption characteristics and porosity. Hence the products obtained from the drying may be completely different from the original products depending on the types and methods of drying. High temperature and rapid drying lead to more pronounced changes in food texture than lower temperature and moderate drying rates. As water evaporates during drying, there is migration of solute from the inner part of the food product to the outer surface leading to solute concentration at the surface. The chemical and physical changes of the solutes as a result of high temperature leads to the formation of impermeable hard skin referred to as “case hardening” and this reduces the drying rate and produces food with moist interior and dry surface (Achanta and Okos, 1995). This problem can be minimized by controlling the drying conditions to minimise the drying gradient between the surface and the inner part of the food and reduction of the slice thickness of food (Baidoo, 2014). Abioye (2012) observed an optimum drying condition in yam slices dried with an oven drier at 70°C and 10mm slice thickness.

Studies on the effect of drying methods on functional properties of cassava showed that sundried samples gave significant lower values of swelling power, water binding capacity and solubility relative to oven dried samples (Akintunde and Akintunde 2013). The authors also observed a higher peak viscosity, trough viscosity; break down viscosity, set back viscosity and final viscosity in oven dried samples than sun dried sample. Elizabieta *et al*. (1994), Olanipekun *et al*. (2009), and Gunaratne and Hoover (2002) observed a similar trend of higher values of swelling power, water binding capacity and solubility at higher drying temperature values.

Akintunde and Akintunde (2013) and Moorthy *et al.* (1993) explained that the increase in solubility and swelling power as the drying temperature increased could be as a result of higher granule swelling, permitting the exudation of amylose and also a higher structural damage leading to the weakening of associated forces bonding the micellar network.

2.3 Quality Indices of Cassava Flour

2.3.1 High Quality Cassava Flour Production and Quality Requirement

The concept of high quality cassava flour (HQCF) was first introduced by the International Institute of Tropical Agriculture (IITA), Ibadan, as an alternative to wheat in food and non-food industry (Falade and Akingbala, 2008). HQCF is odourless smooth, white and unfermented cassava flour which is rapidly processed from healthy cassava shortly after harvest. The flour should also be bland to taste and must not contain extraneous matters such as sand particles and peel fragments (Dziedzoave *et al.*, 2003). It can be used as raw material in the food and allied industries for the production of nodules, pastries, baby foods, alcoholic drinks, biscuits and as stew and soup thickeners. It can equally be used in the manufacture of pharmaceutical drugs and glucose syrups. The most important potential use is however as a composite flour together with wheat flour in the production of high grade foods like bread. The production process of HQCF differs from that of other conventional fermented cassava flour like *agbelina* and *gari* since it does not involve elaborate fermentation which results in a low pH and sour taste that discourages its inclusion in industrial products (Dziedzoave *et al*., 2006). The production of HQCF involves harvesting of fully matured cassava roots, peeling the roots, washing, chipping, or grating, pressing, disintegration, sifting, drying, milling, packaging and storage. A summary of the processing operation is as presented in fig 2.2.

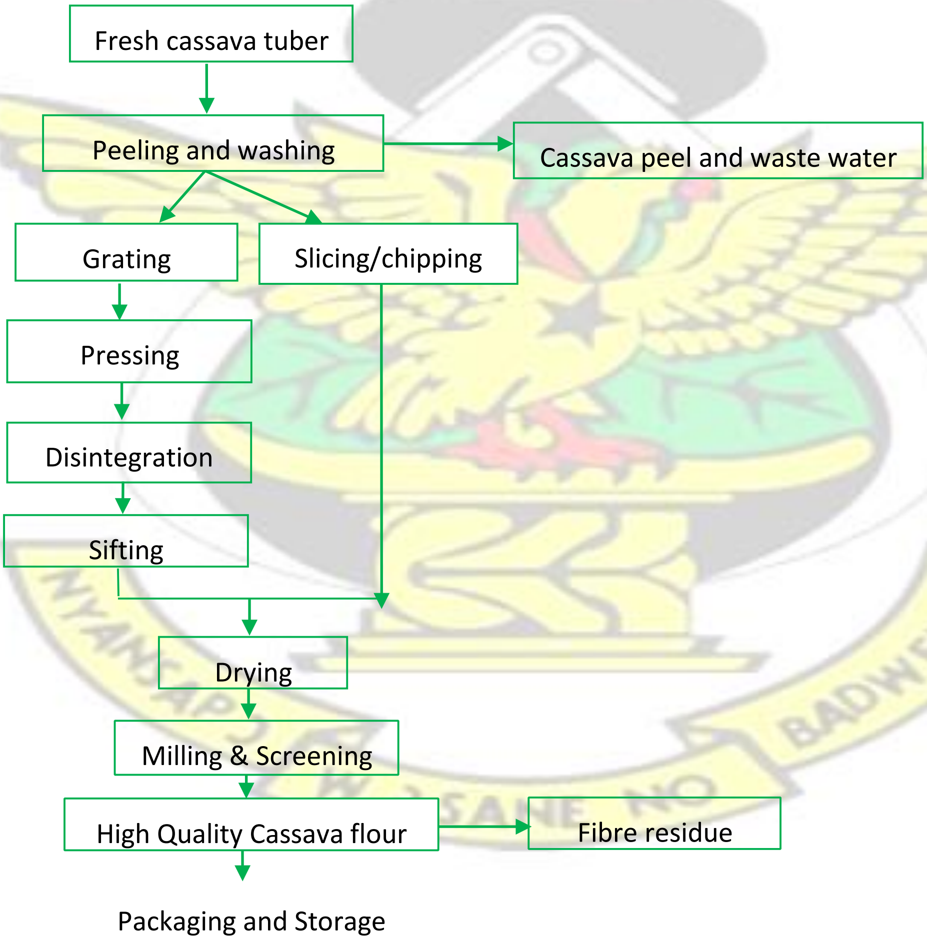


Figure 2. 2 Flow chart for high quality cassava flour production

Source: Dziedzoave *et al.* (2003)

The production process starts with the peeling of healthy cassava tubers which is done within 24 h after harvesting. The tubers are chipped or grated after peeling and washing. The resulting cassava chips from the chipping operation are then dried in a hot-air mechanical dryer or a solar dryer. Alternatively, the cassava tubers could be crushed by means of a grater, so as to disintegrate the cassava tissues and free the moisture so that pressing can be more easily effected. Pressing is accomplished by the use of a manual screw press or a hydraulic press. The resulting cake is then sifted or screened to remove the fibres to improve the product smoothness before drying in a hot air mechanical or solar dryer. The dried product is further milled in attrition or hammer mill to very fine particle sizes and finally sieved with a 250 µm screen fitted into a motorized flour sifter. The final product which is now fine, smooth high quality cassava flour is then packaged in a polyethylene-lined sack for storage and use by the end users.

The resulting high quality cassava flour is expected to meet certain quality standards including those set by relevant regulating bodies like the Food and Agriculture Organization (FAO) and African Organisation for Standards (ARSO) for it to be fit for use as composite flour in the baking industry.

The particles size should be such that not less than 90% of the flour shall pass through 250 µm sieve while the total hydrogen cyanide content of the cassava-wheat composite flour shall not be greater than 10 mg/kg (ARSO, 2012; FAO/WHO, 2013). The cassava flour is also expected to be homogenous in size, practically free of filth and foreign matters, not rancid, with moisture content not exceeding 13.5% (wb) while the protein content of the composite flour (wheat- cassava) should not be less than 8% by mass on dry weight basis and the yeast and moulds content not greater than 10^4 (ARSO, 2012;

EAS, 2010). EAS, 2010 also recommends that the total ash content and crude fibre content of the composite flour should not be greater than 4%
and 5% respectively.

2.3.2. Proximate Composition of Cassava Flour

The proximate composition of feed-stuff represents the main constituents of food which partitions the major nutrients into six components: water, ash, crude protein, ether extracts which represents the fats and oils, crude fibre and the nitrogen free extract (NFE) which represents the soluble carbohydrates and other digestible and easily utilizable non-nutrition substances. The proximate composition of food nutrients is affected in diverse ways by processing and pre-treatment methods depending on the nutrients’ sensitivity to the prevailing processing and pre-treatment conditions. The nutrient retention or destruction in any particular food may differ with a combination of conditions like the nutrient concentration in the food, the crop variety or the age at which the crop is harvested. The assessment of the processing effect on a particular food crop should consider whether the food is a major source of a particular nutrient (Ayim, 2011). The loss of protein in processing soy bean will be of greater relevance than the loss of fat or carbohydrate while the loss of digestible carbohydrate in cassava will be of greater concern than the loss of vitamin C from the same source.

Heating, in combination with pre-treatment, are major processing activities that stabilize the food for storage and modifies the functional properties to enhance its utilisation for various purposes. However, they significantly affect the nutritional quality of the end products in diverse ways (Kramer, 1977). Bender (1966) stated that most processing activities such as drying and cooking have negligible effect on the carbohydrate content of foods. Erbersdobler (1985) reported that mild heating improves the digestibility of protein and carbohydrate but inappropriate temperature or processing times can lead to certain degrees of damages. Jones *et al*. (1990) and Arthey and Ashurt (2001) independently reported that total fibre content is not completely changed by heating but rather causes increase in insoluble fibre content due to the complex nature of its component with amino acid and protein. Dehydration also affects fat quality as the peroxides formed when proteins react with fats and vitamins favour organoleptic rancidity, strong odours and off flavour (Karel and Young 1985), hence the need to exclude oxidizing agents while drying. Various degrees of variation in the proximate composition of cassava flour with age at harvest have been reported by researchers. Sunee *et al*. (2006) reported that protein and fat content of cassava flour decreased progressively from 8 month harvest age of roots to 12 months harvest age. They equally reported a decrease in fibre content with age even though the decrease was not significant. The ash content of the flour was also not significantly affected by the harvest age from 8 months to 12 months. Safo-Kantanka and Acquistucci (1996) reported that the average amount of ash in cassava flour was not greatly influenced by the harvest age while significant differences were established in fibre and fat contents. They also observed significant differences in the fat, protein and ash contents of the cassava flour between the varieties they studied.

The proximate composition of cassava flour is also affected by the processing method. Ooye *et al.* (2014) reported that the ash and protein content of some cassava varieties were significantly affected by processing methods and the cassava varieties. They observed that slicing method resulted in the production of cassava flour with higher protein, fibre and ash contents relative to grating and reconstitution methods.

The starch content of the flour for the varieties studied was not significantly affected by the processing method.

2.3.3 Functional and Visco-Elastic Properties

Functional and visco-elastic properties provide relevant information on the behaviour of components of food products during processing. Such information is very vital in the successful incorporation of novel and/or unconventional food ingredients in the existing food formulation. Blending wheat flour with non-wheat flour might result in some technological difficulties which can impair the baking qualities of the product (Akubor and Ukwuru, 2003).

The dough properties play a vital role in the quality of baked products whereas the visco-elastic properties of the flour are also a source of understanding of the dough handling behaviour in the preparation of bakery products (Nasir *et al.,* 2009).

Some of the vital functional properties are water absorption capacity (WAC), oil absorption capacity (OAC), water binding capacity (WBC), swelling power (SWP) and solubility. WAC refers to the total amount of water held by a starch gel under a specific state or condition. It is therefore a measure of the ability of food products to entrap large amount of water such that exudation is prevented (Chen and Lin, 2002; Pinnavaia and Pizzirani, 1998). Previous works on WAC of starch-based food materials indicate that it is highly dependent on the crystalline properties of the starch (Agama-Acevedoa *et al*., 2008; Abiodun and Akinoso, 2014).

Shittu *et al.* (2008) in their work on the functional properties of baking flour reported that baking quality is a function of WAC of the flour. Jackel (1987) also reported that flour with increased WAC would result in favourable characteristics of final products as the products will remain soft for a longer period with improvement in texture and reduced cost. Ezeocha *et al*. (2011) also reported that WAC is affected by the size and shape of starch-based food products as well as the presence of protein, lipids and salts in such food while WBC is affected by the presence of minerals like phosphorous. Abiodun and Akinoso (2014) further observed in their work on the functional properties of trifoliate yam that the water absorption capacity, solubility and swelling power (SWP) were more dependent on pre-treatment methods than the harvesting periods.

SWP which is a measure of the maximum increase in volume and weight undergone by the starch granules when they are allowed to freely swell in water is an indicator of the strength of the hydrogen bonding between the granules (Afoakwa *et al*., 2012; Safo-Kantanka and Acquistucci, 1996).

The solubility and (SWP) of cassava flour was reported by Afoakwa *et al*. (2012) to be dependent on the cassava variety, the growing environment and the harvest age of the crop. Moorthy and Ramanujan (1986) reported differences in SWP and solubility between cassava varieties in India while Safo-Kantanka and Acquistucci (1996) also observed in their work on some cassava varieties in Nigeria and Ghana that the swelling power and solubility differed significantly among the varieties.

Rasper (1969) explained that the swelling and solubilisation characteristics of various starches which are indicators of the strength of the micellular network within the starch granules affect its rheological properties. Rasper (1982) further reported that the ability of starch granule to swell and yield a viscous paste is among the most important practical properties of starch because of its effect on the rheological behaviour.

Water binding capacity (WBC) is a measure of the associative forces between the starch granules of food ingredients. It is an indicator of the magnitude of the molecular surfaces of the starch granules available for binding with water molecules (Afoakwa *et al*., 2012). Aryee *et al.* (2006) in their work on flour from different cassava genotypes obtained water binding capacity values of 113.66- 201.99% while Shittu *et al*. (2007) reported WBC values of 234.53% to 276.63% from their work on some cassava mosaic disease (CMD) resistant clones. Afoakwa *et al*. (2012) equally reported WBC values of 234.53% to 276.63% in their work on six different cassava varieties which were significantly different from each other. They attributed the high values of water binding capacities obtained from the CMD resistant varieties to the weak associative forces within the starch granules which allows for the availability of more molecular surfaces for binding with water molecules.

Studies on the visco-elastic properties of flour are very useful in determining the gelatinisation of the starch suspension from various crop varieties as well as their pasting characteristics in the process of heating and subsequent cooling (Jane *et al*., 1999; Afoakwa and Sefa-Dedeh, 2002). Observations from various studies have shown that as heating progresses to a certain temperature, the viscosity suddenly increases to a maximum value (referred to as peak viscosity value) after which further heating leads to reduction in viscosity (Afoakwa *et al*., 2010; Beleia *et al*., 2006). Gelatinisation leads to disruption of the weak associative bonds in the amorphous region of the starch granules which increase the water binding sites and subsequently results in increased hydration of the starch granules and WBC of the starch (Afoakwa *et al*., 2012; Wooten and Bamunuarachi, 1978). Aryee *et al*. (2006) reported that cassava genotypes with high gelatinisation temperature are not suitable for use directly as brewery adjunct but should be pre-gelatinised so that it can fall within the range of barley malt. Studies have shown that attaining gelatinisation at a lower temperature improves the bread making quality of cassava flour while high peak viscosity and a low breakdown

viscosity (paste stability) of the flour gives acceptable bread quality (Defloor *et al.*, 1994; Adeyemi and Omolayo, 1984). Afoakwa *et al*. (2012) reported a slight variation in the gelatinisation temperature (64.7 °C to 68.9 °C) for six cassava varities evaluated while Aryee *et al.* (2006) observed a similar trend in the variation of pasting temperature (66.8 ℃ to
70.4 ℃) of cassava flour from 31 different varieties they studied.

Peak time, which is the time duration taken for flour to get to the maximum (peak) viscosity, is an indicator of how quick the products from the flour will cook. Afoakwa *et al*. (2012) observed significant differences in the peak time among the cassava varieties studied. Peak viscosity is a very important aspect of the viscoelastic properties of flour products as it is a measure of the ability of the flour to form strong paste. Peak viscosity indicates the highest viscosity value during the heating cycle (Jimoh *et al.,* 2007; Sakyi-Dawson *et al.*, 2006). Safo-Kantanka and Acquistucci (1996) observed a significant variation in the peak viscosity of flour from different cassava varieties at different harvest ages.

Setback viscosity is a measure of the retro-gradation potential of food products. Food products with lower setback viscosity have greater tendency for retro-gradation while high setback value is associated with a more cohesive paste and has been reported to be significant in most domestic products such as pounded yam, which requires high paste stability, high viscosity and high setback (Adeniji *et al*., 2010; Oduro *et al*., 2000; Niba *et al*., 2002). Flour with a low setback viscosity value indicates that products from such flour materials will be non-cohesive on cooling hence unsuitable for situations where starch stability is required at low temperature as is the case with adhesives, fillings and products requiring refrigeration (Aryee *et al*., 2006).

Breakdown viscosity is a measure of the tendency of swollen starch granules to rupture when held at high temperature under continuous shearing while final viscosity is the most common parameter used to describe the ability of starch granules to maintain the viscous paste formed during and after cooling (Mahasukhonthachat *et al*., 2010; Morthy, 2002; Oke *et al*., 2013).

2.4. Composite Flour Technology

Composite floor technology refers to the process of mixing different types of flour to economically produce good quality food products. Wheat is mainly used in the production of wide varieties of baked foods which have been adopted by various classes of people in the society as breakfast and snacks especially among the urban dwellers. Due to high cost of wheat flour and corresponding high foreign exchange burden placed on developing countries by the importation of wheat, various nations are making efforts to develop programmes to assess the feasibility of substituting or blending wheat with locally produced food crops (Ohimain, 2014). A variety of flours produced from a wide range of tropical crops grown in these developing nations have been successfully used to substitute various proportions of wheat flour in the production of bread and other baked foods.

Eduardo *et al.* (2013) reported that in baked products, dough rheology and subsequently bread quality parameters, are influenced by hydrocolloids. They further deduced that the improvement in composite bread quality parameter such as increased volume due to pectin addition results from the improvement of dough development and gas retention by increasing dough viscosity and stability.

Barcenas *et al*. (2009) reported that in composite bread production, the addition of HM-pectin initiates an interaction between the hydrocolloid (HM-pectin) and wheat starch causing an increased paste viscosity and improved gel network during heating.

The twin action of improved gel network and increased viscosity is strengthened by the gas-holding ability of the expanding cells in the dough which consequentially resulted in a higher loaf volume. Lazaridou *et al*. (2007) also reported that HM – pectin at 2% was the only hydrocolloid of the five tested (*Carboxyl methylcellulose, Xanthan, Agarose, Oat* $\boldsymbol{\beta}$*-glucan*) that significantly improved the dough rheology and the volume of gluten–free bread. Eduardo *et al*. (2013) in their work also reported that the bread volume was influenced by addition of pectin to wheat- fermented cassava composite flour. This was attributed to the increase in paste viscosity which slowed down the rate of gas diffusion and allowed its retention during the early stage of baking.

Pyler (1988) in his work reported that the gluten fraction contained in wheat is made of two major protein groups (gliadins and glutenins) which are responsible for the visco-elastic properties needed in producing a cohesive gluten network for structure and gas retention in wheat bread. Gliadins are responsible for the extensibility and cohesiveness of dough while glutenins are responsible for elasticity. This peculiar property of wheat flour which is absent in other carbohydrate-based flours results in the technological difficulties usually encountered in total or partial replacement of wheat flour with flours from other crop sources. Total or partial replacement of wheat flour with other gluten free flour produce dough that lack the cohesive and elastic nature of traditional wheat breads (Marston *et al*., 2014).

A variety of flours from crop sources such as maize, arrow root, rice, cassava, sorghum, potato, soy beans, plantain etc. have been used in partial and total replacement of wheat flour in baking experiments. As earlier mentioned, these flours lack gluten and hence depend on other ingredient or special pre-treatment to develop a gas holding network to provide structure and volume in bread. The starch contained in these gluten–free flour have differing pasting, gelling, thermal and textural properties based on their chemical and structural composition (Marston *et al*., 2014). When the starch is heated or adequately cooked, water absorption causes the starch granules to swell and get disrupted creating a viscous slurry or paste. Schober *et al.* (2005) reported that pre-gelatinisation of starch contained in the flour for production of gluten free bread can improve the bread quality by lowering the gelatinisation temperature, speeding up the gelatinisation process and increasing the dough viscosity and ability to trap air cells while improving the overall crumb volume and structure.

Schober (2009) also reported that addition of hydrocolloids such as hydroxyprophyl methyl cellulose (HPMC) in gluten free bread formulation leads to a reaction between these gums and other starch molecules resulting in the improvement of the rheological properties along with better texture and stability in the final baked product. The hydrocolloid which is a surface active substance helps stabilizing foams, aids in aeration and allows for development of small bubbles while preventing gas cell coalescence hence resulting in large loaf volumes with softer crumb structures.

Elkhalifa and El-Tinay (2002) in a research trial produced acceptable bread and biscuit quality by blending wheat flour with 10% and 20% sorghum flour respectively. Udofia *et al*. (2013) produced bread with an encouraging degree of acceptability from wheat, cassava and soya beans composite flour in a ratio of 0.66:0.17:0.17. Mepba *et al.* (2007) were able to produce organolepticaly acceptable bread and biscuit from wheat-plantain composite flour using up to 80:20 and 60:40 ratios of wheat to plantain as maximum acceptable level of substitution for bread and biscuit respectively. Bamidele *et al.* (2006) also produced composite bread with acceptable quality using a blend of 10% plantain and 90% wheat flour. Value-added baked products have also been produced using composite flour as is the case with Nasir (2009) who successfully produced fibre and protein enriched bread and cookies by substituting 15% wheat flour with defatted maize germ flour. Nasir (2009) in his research reported that consumers' response to the purchase of defatted maize germ flour fortified cookies and bread was positive as 64% of the respondents preferred it to the 100% wheat flour product. Onuegbu *et al*. (2013) worked extensively on the efficiency of maize–wheat composite flour cake and bread production and observed that although the proximate composition and functional properties of maize–wheat composite flour differed slightly from that of 100% wheat, the bread produced from 10% and 5% wheat flour substitution did not differ significantly from those produced with 100% wheat flour in most sensory attributes as well as the overall acceptability. They also found that baking cake with 5%-20% wheat flour substitution with maize flour did not differ significantly from baking with 100% wheat flour in all their sensory attributes as well as the overall acceptability.

Esuoso and Bamiro (1995) indicated in their work on baking properties of bread fruit–wheat composite bread'' that the sensory attributes of bread produced from 100% wheat flour did not differ significantly from those produced with composite flour having up to 30% bread fruit substitution.

CHAPTER THREE

DRYING OF PRE-TREATED CASSAVA SAMPLES AND MATHEMATICAL MODELING OF THE DRYING PROCESS

3.1 INTRODUCTION

Thin layer drying is a very vital dehydration technique commonly used in food industries. The dried products that result from this process usually record minimum loss in their physical, nutritional and chemical qualities whereas their shelf life and onset of their microbial spoilage are extended (Orikasa *et al.*, 2010; Akpinar and Bicer, 2008). Most of the drying models that have been applied by various researchers in describing the drying process of different agricultural products contain exponential terms which indicate the contribution of a diffusion mechanism in thin layer drying. Factors like the condition and type of crop (morphology, pre-treatment, initial moisture content and dimension), drying temperature, thermal energy type (hot air, solar, infrared etc) and type of dryer (tray, tunnel, fluidised bed etc) have been established to affect the qualities and drying kinetics of the materials (Tunde- Akintude and Ayala, 2010; Orikasa *et al.*, 2010).

Mathematical modeling of drying processes is a very relevant component of drying technology which is based on the design of a set of equations to accurately describe the system as much as possible (Celma *et al.*, 2007; Addo *et al*., 2009). Olawale and Omole (2012), Akpinar (2006), Menges and Ertekin (2006), Mcminn (2006) and many other authors have outlined several thin layer models which explain the drying characteristics of agricultural products and can be used to estimate their drying time. Three of these models have been fitted to the drying data obtained in this study to investigate the most suitable ones in describing the drying characteristics of the pretreated cassava samples.

3.2 Materials and Methods

3.2.1 Source of Samples

Stem cuttingsof three newly-released cassava varieties (*Ampong, Broni Bankye* and *Otuhia*) were obtained from the experimental farm of Crop Research Institute (CRI) of the Centre for Scientific and Industrial Research (CSIR) in Fumesua, Ghana. These stem cuttings were planted on 25th March 2014 (Appendix 1 and 2) and the matured tubers were harvested at 10, 12 and 14 months after planting (Appendix 3).

3.2.2 Sample Preparation and Pre-Treatment.

The cassava tubers were transported to the laboratory immediately after harvesting. The sample was divided into five lots corresponding to the five pre-treatment methods. Each of the five portions was manually peeled and thoroughly washed with clean water for the pre-treatment. The pre-treatments which the samples were subjected to were (1) chipping (2) grating and toasting (3) chipping and steeping in citric acid solution (4) grating and dewatering (5) steeping in citric acid, grating and toasting.

3.2.3 Experimental Design and Statistical Analysis

The experimental design used for the study was 3x3x5 factorial design in a completely randomized design (CRD) where the factors were the three levels of harvest age, three varieties and five levels of pre-treatment. Each experimental unit was replicated three times.The moisture ratio of the dried cassava was modelled using selected thin layer drying models while the model constants were obtained using SPSS statistics software version 20. Graphical descriptions of the data were done using Microsoft Excel (Microsoft Corporation 2010). The design layout is as presented in Table 3.1

Table 3. 1 Experimental Design Layout

Harvest age	Variety	Pre-treatment
10 months	*Ampong*	CH
		GT
		CCA
		GD
		CAGT
	Broni Bankye	CH
		GT
		CCA
		GD
		CAGT

	Otuhia	CH GT CCA GD CAGT
12 months	*Ampong*	CH GT CCA GD CAGT
		CCA GD CAGT
14 months	*Ampong*	CH GT CCA GD CAGT
	Broni Bankye	CH GT CCA GD CAGT
	Otuhia	CH GT CCA GD CAGT

CH=Chipping; GT=Grating and toasting; CCA=Chipping and steeping in citric acid solution; GD=Grating and dewatering; GAGT=Steeping in citric acid, grating and toasting.

3.2.4 Determination of the Optimum Toasting Time

A preliminary investigation was carried out (with *Ampong* cassava variety harvested at 18 months after planting) to determine the optimum toasting time of cassava with respect to the functional and pasting properties of the resulting flour. The cassava roots were harvested, peeled and reduced in size to mash by grating with the cassava grater shown in Appendix 3. The mash product was put in a porous bag and then dewatered using a mechanical screw jack. The compression was carried out for 12 h and the moisture content at the end of the process was 40% wet basis. The dewatered mash was then pulverized using a 4 mm size sieve to obtain a friable sample that was easily toasted.

The pulverised samples were divided into five portions which were consecutively toasted for 2, 4, 6, 8 and 10 min. The toasted samples were milled and packaged for further analysis. It was established that the most suitable toasting time was 6 min (Eje *et al*., 2015).

3.2.5 Pre-Treatment Methods

3.2.5.1 Chipping (T_1)

The first pre-treatment (T_1) process was chipping. The washed cassava tubers were chipped to a size of 10 x 10 x 50mm using a slicing machine. The machine has a rotating blade and an adjustable guard rail which can be adjusted to cut the sample to the desired thickness (Fig 3.1). The dimensions of the chips were chosen in line with the recommendation of Floreze and Bruno (2000) and Cock (1985) for the optimum chipping size of some tuber crops such as yam and cassava for effective drying.

Figure 3. 1 Slicing machine

3.2.5.2 Grating and Toasting (T_2)

The second lot of the samples (T_2) were size reduced to mash by grating with the cassava grater shown in Appendix 3, dewatered and pulverized as discussed in Section 3.2.4 above. The samples were toasted for 6 min in a toasting pan during when it was continuously stirred to avoid clogging. The average toasting temperature was maintained at 90 °C.

3.2.5.3 Chipping and Steeping in Citric Acid Solution (T_3)

The third lot of the samples (T_3) were chipped to the same sizes of 10 x 10 x 50 mm as in section 3.2.5.1 and further soaked in citric acid solution pre-mixed to a concentration of 20% m/v. The chips were allowed to remain in the solution for 24 h before they were transferred to the drying tray. This pre-treatment was done according to the recommendation by Owuamanam (2007).

3.2.5.4 Grating and Dewatering (T_4)

The fourth lot of the samples (T4) were reduced to mash by grating with the cassava grater shown in Appendix 4. The mashed product was put in a porous bag and then dewatered using a mechanical screw press. The compression continued for about 12 h during which the moisture content of the mash was reduced to about 40 % (wet basis) before the commencement of drying.

3.2.5.5 Steeping in Citric Acid, Grating and Toasting (T_5)

The fifth set of samples (T_5) were peeled, washed and steeped in citric acid solution (20% m/v) for 24 h. The samples were then grated, dewatered and toasted as described in section 3.2.5.2 above.

3.2.6 Drying

A mechanically ventilating hot air dryer was used in the drying experiment. The dryer consist of a blower, an inlet and outlet air vent, and a drying compartment with six large movable trays having a wire mesh base (Fig 3.2). Each of the large trays measures 80 x 43 cm and can hold three smaller aluminium trays with dimensions of 25 x 38 cm. A temperature sensor was fitted inside the drying chamber with an external digital display unit which was used to pre-set the dryer temperature to the desired value (fig 3.3). The dryer was operated for 8 min to attain the desired stable drying temperature. The initial moisture content of the samples was determined using the gravimetric method of moisture content determination (AOAC, 1990). The pretreated samples were arranged on the aluminium trays which were in turn placed on the larger trays with a wire mesh base (Fig 3.2).

Figure 3. 2 Mechanically ventilated hot air dryer with cassava samples for drying

Figure 3. 3 Mechanically ventilated hot air dryer showing the temperature display unit

Each of the larger trays contained three smaller aluminium trays. The chipped cassava samples were arranged in a single layer on the aluminium trays (Fig 3.4a) whereas the grated samples and the toasted samples were evenly spread on the tray (Fig 3.4b) such that the sample thickness was not more than 1 cm. The dryer was switched on and allowed to attain a pre-set temperature of 70 °C (Fig 3.3) before the samples were put into the drying chamber. The initial weight of each sample was 600g and as the drying progressed, the sample's weight was monitored after every one hour. The drying was continued until a constant weight was obtained after which the samples were removed cooled and packaged for milling. The instantaneous moisture content at time t of the samples was determined from the samples' weight using Equation (3.1).

$$\boldsymbol{MC_t} = \frac{w_t - (w_i \times d_m)}{w_t} = \frac{w_t - w_d}{w_t} \qquad (3.1)$$

where, MC_t = moisture content (% wb) at time t; w_t = instantaneous weight (g) of the sample; w_i = initial moisture content (% wb); d_m = dry matter ratio; w_d = weight of dry matter.

(a)

(b) Figure 3. 4 The pre-treated cassava samples (a) chipped samples (b) grated and toasted samples

The dried samples were then milled using an attrition mill to produce cassava flour. The resulting flour was sieved using a 250 µm sieve as recommended by the Africa Organization for Standardization on the maximum particle size of composite flour for baking (ARSO, 2012).

3.3.0 Evaluation of the Thin Layer Drying Models

The samples moisture ratio during drying was calculated using equation (3.2).

$$\boldsymbol{MR = \frac{M_t - M_e}{M_0 - M_e}} \tag{3.2}$$

where, MR = dimension less moisture ratio

M_t = moisture content (% db) at any time

M_e = equilibrium moisture content (% db)

M_o= initial moisture content (% db)

The values of the equilibrium moisture content (M_e) were relatively very small and hence Equation (3.2) was simplified to e

Equation (3.3) (Goyal and Bhargava, 2008).

$$MR = \frac{M_t}{M_0} \quad (3.3)$$

3.3.1 Determination of the Drying constants

The thin layer models listed in Table 3.2 were evaluated to select the ones that best fit the drying processes of the cassava flour

Table 3. 2 Some thin layer drying models

No.	Model	Model equation	Reference
1	Newton	MR = exp (-kt)	Ayensu, 1997; Liu and Baker-Arkema, 1997
2	Henderson and Pabis	MR = aexp (-kt)	Henderson and Pabis, 1961; Chhinnan, 1984
3	Page	MR = exp (-ktn)	Park et al. 2002; Akram et al. 2013

In order to evaluate the constants *k*, *n* and *a* in the models, the model equations were expressed in linear forms as follows:

Newton model

$MR= e^{-kt}$

$In\ MR = In\ e^{-kt}$

$$- In\ MR = kt \quad (3.4)$$

Henderson and Pabis model

$MR = ae^{-kt}$

$In\ MR = In\ a\ .e^{-kt}$

$In\ MR = ln\ a - kt$

$$-\ln MR = kt - In\ a \qquad (3.5)$$

For Page's Model

$MR \quad = exp(-kt^{n})$

$In\ MR = ln[exp(-kt^{n})]$

$In\ MR \quad = -\ kt^{n}$

$-In\ MR = kt^{n}$

$In\ (-\ In\ MR) = In(kt_{n})$

$$In\ (-\ In\ MR) = nlnt + lnk \qquad (3.6)$$

The drying constants were obtained by fitting the experimental moisture ratio data (MR) obtained from Equation (3.3) with the corresponding time (t) for each pretreated cassava sample into the three linearized models (Equation 3.4 to 3.6).The equations were subjected to linear regression analysis using SPSS statistical package version 20 to determine the constants. The constant so obtained were fitted to the three drying model equations in Table 3.2 to obtain the predicted values of moisture ratio (MR).

3.3.2 Fitness of the Models

The appropriateness and accuracy of the models were determined using the goodness of fit test of different models. Several criteria are available to evaluate the appropriateness of a model to experimental data. These are the coefficient of variation (R^2), the mean square deviation or reduced chi-square ($_{\chi}{}^{2}$) and the root mean square error (RMSE). While the R^2 value was directly obtained from the linear regression analysis the root mean square error (RMSE) and the reduced Chi-square or mean square deviation were calculated using equations (3.7) and (3.8).

$$\text{RMSE} = \sqrt{\frac{\sum_{i=0}^{n}(MR_{pre,i} - MR_{exp,i})^2}{N}} \qquad (3.7)$$

$$\chi 2 = \frac{\sum_{i=0}^{n}(MR_{exp.,i} - MR_{pre.,i})^2}{N-Z} \qquad (3.8)$$

Where N= number of observations

$M_{pre.,i}$ = predicted moisture ratio at i th observation

$M_{exp.,i}$ = experimental moisture ratio at the i th observation

Z = number of constants in the drying model.

A model is generally considered to be good when the values of the reduced chisquare ($\chi 2$) and the root mean square error (RMSE) are low tending to zero while the coefficient of determination (R^2) is high getting, close to 1 (Goyal and Bhargava, 2008; Ertekin and Yaldiz, 2004; Akram *et al*., 2013)

3.4 Results and Discussion

3.4.1 Effect of Pre-Treatment on the Drying Characteristics

The changes in the moisture content of pre-treated cassava samples with time for the samples from *Ampong*, *Broni* and *Otuhia* cassava varieties harvested at various ages of maturity are shown in Figures 3.5 to 3.7. The plots in these figures are relatively similar to each other as they follow typical drying trends of moisture content decreasing exponentially with time. For each of the graphs, the five pre-treatment methods can be grouped into two categories.

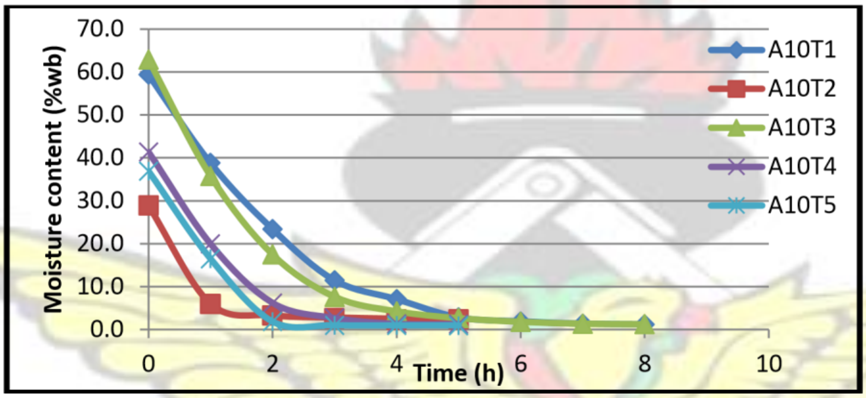
In the first category, which comprises the grated cassava samples (T_4) and the toasted samples (T_2 and T_5), the moisture content of the samples decreased very rapidly during the first 1 h after which it decreased more slowly with further drying and attained equilibrium level within two to four hours. The second category which comprises of chipped samples ($T_1$and T_3) lost moisture very rapidly within the first one hour and then much more slowly for the next seven to nine hours before it attained equilibrium moisture content.

As can be observed from the graphs, there was no constant drying rate period in all the pre-treated cassava samples and all the drying processes were seen to have occurred within the falling rate period. In the falling rate period, the surface of the material is not saturated with water and drying is controlled by moisture diffusion from the interior of the material to the surface (Khazaei and Daneshmandi, 2007; Diamante and Munro, 1993). This observation was in agreement with the results reported by other researchers on root crops and other agricultural products (Addo *et al.*, 2009; Khazaei and Daneshmandi, 2007; Doymaz, 2006; Ayim, 2011; Olawale and Omole, 2012; Koua *et al*., 2013).

The beginning of the drying process was characterized by very fast drying which was enhanced by available free water and the initial high moisture content of the material. As the moisture content reduced, the drying rate progressively reduced until the moisture content attained equilibrium level.

The very short drying time (2 to 4 h) of the grated samples (T_4) and the toasted sample (T_2 and T_5) could have resulted from the very low initial moisture content of the sample which was accomplished by the initial moisture removal during the pretreatment. The mechanical grating of the samples also reduced the materials into smaller particle sizes with large surface areas exposed to the drying air which enhanced faster moisture removal. This was reflected in the values of the drying rate constant (k) as presented in Table 3.3 for grated samples (T_4) and toasted samples (T_2 and T_5) which ranged from 1.0 to 2.23 h^{-1} while the k values of chipped samples (T1 and T3) ranged from 0.67 to 1.13 h^{-1}

This agrees with the observation of other researchers that the smaller and more porous the agricultural material, the shorter the time required to move the moisture to the surface of the particles where ultimate moisture evaporation into the hot air occurs (Tunde- Akitunde and Ayala, 2010; Falade and Solademic, 2010; Akpinar and Bicer, 2008; Olawale and Omole, 2012).



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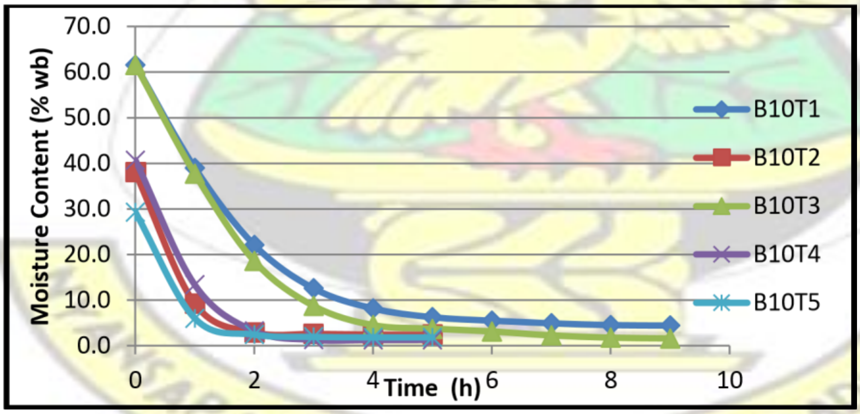

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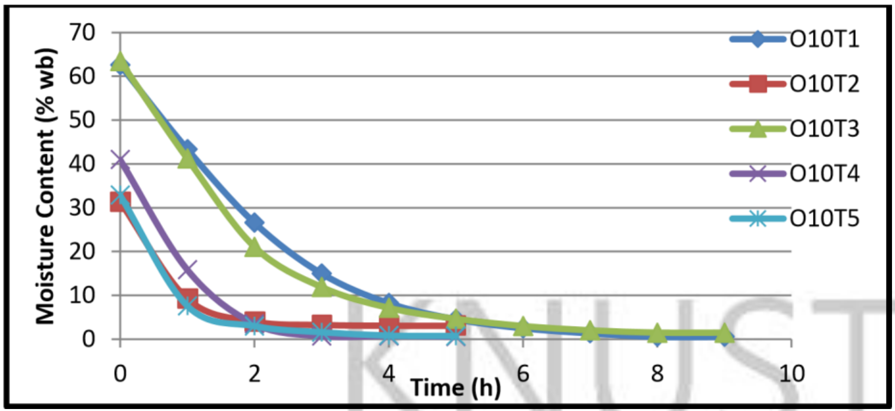
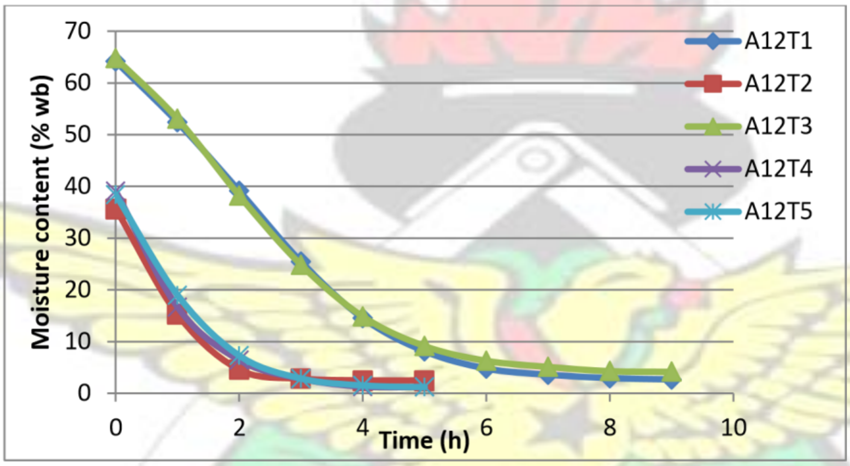
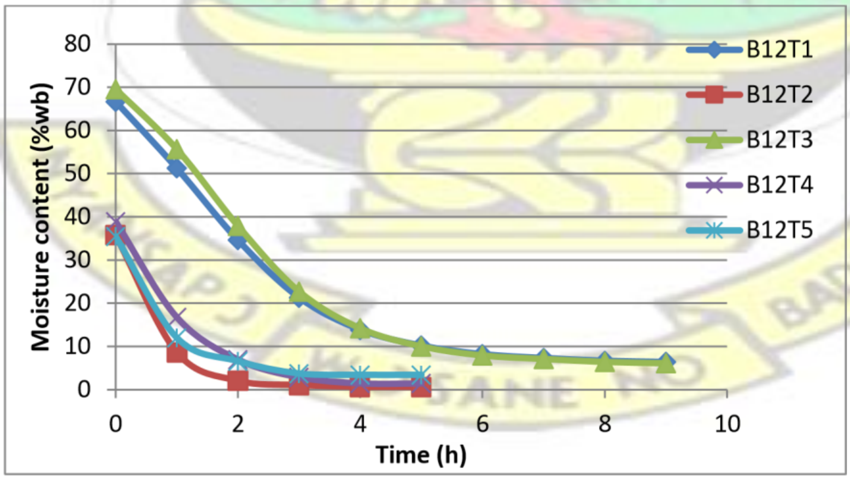


(c)

Figure 3. 5 Effects of different pre-treatment methods on the drying characteristics of three cassava varieties at 10 months harvest age: (a) *Ampong* variety (b) *Broni* variety (c) *Otuhia* variety; Chipping (T1) , toasting pre-treatment (T2), chipping with citric acid pre-treatments (T3), grating pre-treatment (T4) and toasting with citric acid pretreatment (T5).



(a)



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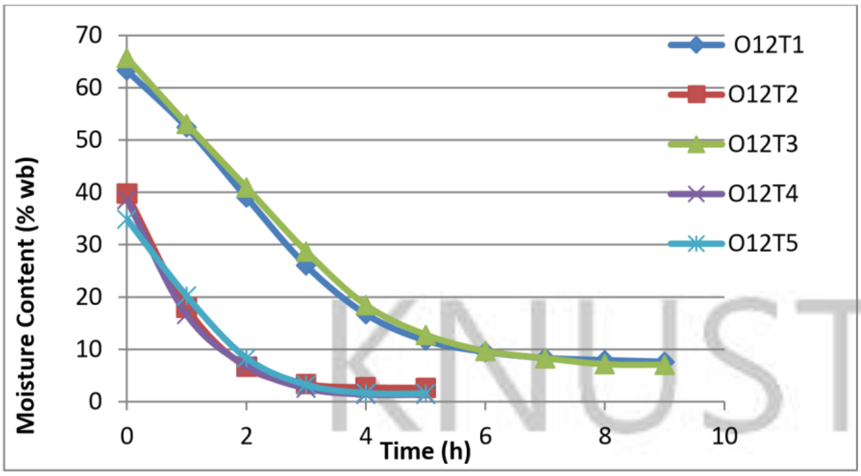
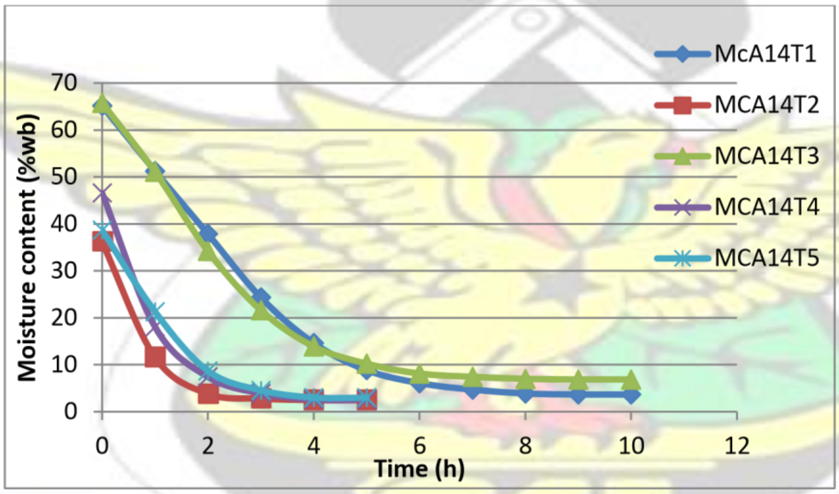
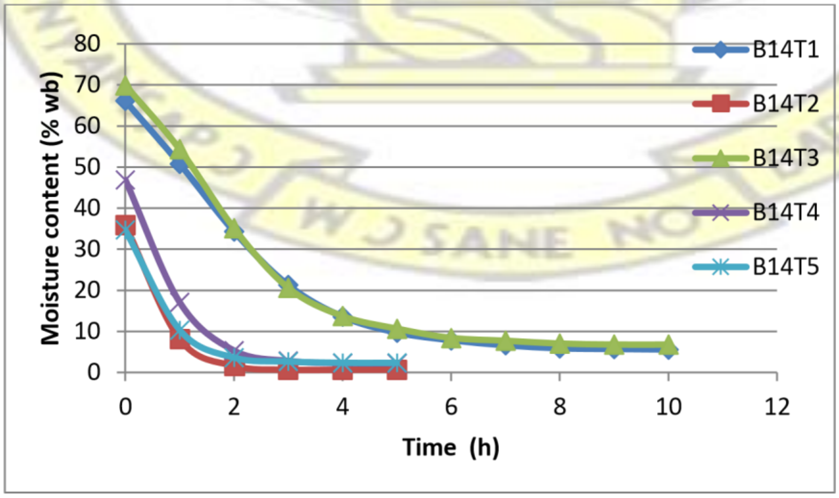


(c)

Figure 3. 6 Effect of pre-treatment methods on drying characteristics of three cassava varieties at 12 months harvest age: (a) *Ampong* variety (b) *Broni* variety (c) *Otuhia* variety; Chipping (T1) , toasting pre-treatment (T2), chipping with citric acid pre-treatments (T3), grating pre-treatment (T4) and toasting with citric acid pre-treatment (T5).



(a)



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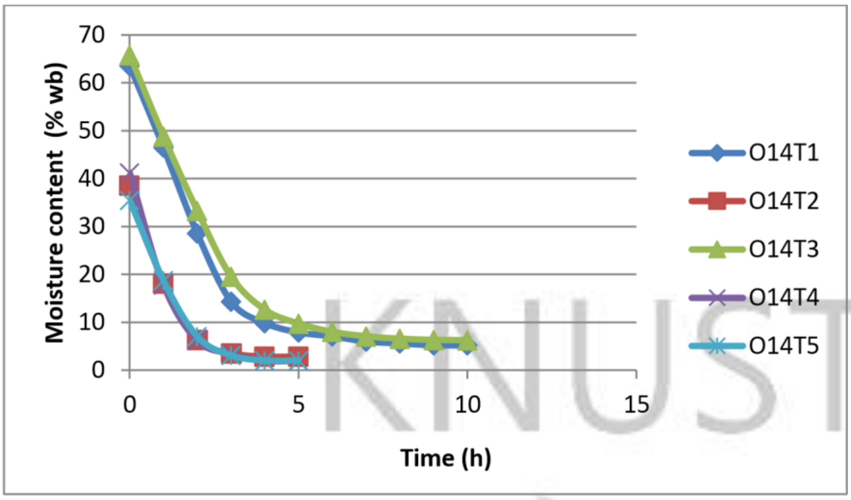


(c)

Figure 3. 7 Effect of pretreatment methods on drying characteristics of three cassava varieties at 14 months harvest age: (a) *Ampong* variety (b) *Broni* variety (c) *Otuhia* variety; Chipping (T1) , toasting pre-treatment (T2), chipping with citric acid pre-treatments (T3), grating pre-treatment (T4) and toasting with citric acid pre-treatment (T5).

The short total drying time of these samples gave them economic advantage over the chipped samples with long drying duration of 7 to 10 h total drying time. The pretreatment method which involved grating and dewatering or grating dewatering and toasting could therefore reduce the total energy cost for drying by more than 50%.

3.4.2 Drying Models

The constants from the statistical analysis of the linearized models are presented in Table 3.3. The calculated values of the constants for each of the 45 samples were substituted into the model equations in Table 3.2 to obtain the predicted values of moisture ratio. The results obtained from the predicted moisture ratio were further substituted into Equations 3.7 and 3.8 with the calculated moisture ratio data from the drying experiment to obtain the parameters for the evaluation of goodness of fit of the models. The results of the calculated goodness of fit parameters are as presented in Table 3.4 below. As can be observed from the table, all the three models assessed were appropriate at varying degrees for grated, toasted and chipped cassava samples of the three cassava varieties harvested at different ages of maturity. However, Page's model was found to be the most appropriate using the coefficient of determination (R^2), root mean square error (RMSE) and reduced chi-square or mean square deviation (χ^2) as assessment criteria. This was based on the principle that the nearer the R^2 value to 1.00, and χ^2 and RMSE to zero, the better the predictive ability of the model (Olawale and Omale, 2012; Radhika *et al.*, 2011; Mohsen *et al*., 2012). Some other researchers who studied thin layer drying of some root crops and other agricultural products indicated that Page's model is accurate in predicting the drying processes (Diamante and Munro, 1993; Koua *et al.,* 2013).

Table 3. 3 Values of model constants for pre-treated cassava samples

Age (months)	Variety	Pre-treatment	Sample code	Thin-layer drying models and the model constants				
				Newton	Henderson and Pabis		Page's model	
				k	a	k	n	k
10	*Ampong*	T1	A10T1	0.627	0.725	0.627	0.842	0.920
10	*Ampong*	T2	A10T2	0.482	0.413	0.482	0.478	1.456
10	*Ampong*	T3	A10T3	0.612	0.503	0.612	0.771	1.135
10	*Ampong*	T4	A10T4	0.845	0.726	0.845	0.909	1.083
10	*Ampong*	T5	A10T5	0.865	0.529	0.865	0.927	1.202
10	*Broni*	T1	B10T1	0.373	0.443	0.373	0.624	1.054
10	*Broni*	T2	B10T2	0.584	0.392	0.584	0.586	1.481
10	*Broni*	T3	B10T3	0.490	0.442	0.490	0.718	1.094
10	*Broni*	T4	B10T4	0.803	0.488	0.803	0.799	1.349
10	*Broni*	T5	B10T5	0.550	0.395	0.550	0.547	1.487
10	*Otuhia*	T1	O10T1	0.659	0.836	0.659	0.875	0.870
10	*Otuhia*	T2	O10T2	0.490	0.470	0.490	0.526	1.326
10	*Otuhia*	T3	O10T3	0.530	0.539	0.530	0.756	1.021

10	*Otuhia*	T4	O10T4	1.003	0.601	1.003	0.961	1.249
10	*Otuhia*	T5	O10T5	0.808	0.509	0.808	0.749	0.845
12	*Ampong*	T1	A12T1	0.506	0.862	0.506	0.883	0.666
12	*Ampong*	T2	A12T2	0.624	0.571	0.624	0.721	1.164
12	*Ampong*	T3	A12T3	0.447	0.761	0.447	0.826	0.694
12	*Ampong*	T4	A12T4	0.815	0.710	0.815	0.856	1.125
12	*Ampong*	T5	A12T5	0.821	0.792	0.821	0.905	1.027
12	*Broni*	T1	B12T1	0.378	0.583	0.378	0.698	0.845
12	*Broni*	T2	B12T2	0.884	0.460	0.884	0.808	1.458
12	*Broni*	T3	B12T3	0.406	0.599	0.406	0.742	0.819
12	*Broni*	T4	B12T4	0.794	0.712	0.794	0.845	1.114
12	*Broni*	T5	B12T5	0.526	0.538	0.526	0.575	1.242
12	*Otuhia*	T1	O12T1	0.357	0.710	0.357	0.752	0.673
12	*Otuhia*	T2	O12T2	0.650	0.623	0.650	0.747	1.124
12	*Otuhia*	T3	O12T3	0.379	0.729	0.379	0.741	0.708
12	*Otuhia*	T4	O12T4	0.797	0.708	0.797	0.850	1.114
12	*Otuhia*	T5	O12T5	0.762	0.871	0.762	0.935	1.120
14	*Ampong*	T1	A14T1	0.416	0.657	0.416	0.779	0.754
14	*Ampong*	T2	A14T2	0.592	0.480	0.592	0.633	1.323
14	*Ampong*	T3	A14T3	0.326	0.516	0.326	0.668	0.844
14	*Ampong*	T4	A14T4	0.704	0.578	0.704	0.736	1.242
14	*Ampong*	T5	A14T5	0.639	0.740	0.639	0.799	0.969
14	*Broni*	T1	B14T1	0.350	0.532	0.350	0.686	0.850
14	*Broni*	T2	B14T2	0.878	0.401	0.878	0.416	2.230
14	*Broni*	T3	B14T3	0.339	0.472	0.339	0.663	0.906
14	*Broni*	T4	B14T4	0.734	0.516	0.734	0.271	2.119

14	*Broni*	T5	B14T5	0.587		0.468	0.587	0.619	1.349
14	*Otuhia*	T1	O14T1	0.330		0.446	0.330	0.646	0.936
14	*Otuhia*	T2	O14T2	0.630		0.626	0.630	0.742	1.102
14	*Otuhia*	T3	O14T3	0.328		0.488	0.328	0.645	0.901
14	*Otuhia*	T4	O14T4	0.732		0.640	0.732	0.795	1.153
14	*Otuhia*	T5	O14T5	0.700		0.745	0.700	0.840	1.015

Table 3. 4 Fit statistics of thin layer drying models for pre-treated cassava samples

Age (months)	Variety	Pre-treatment	Sample code	Thin -layer drying models and fit statistics								
				Newton model			Henderson and Pabis			Page's model		
				R^2	RMSE	χ2	R^2	RMSE	χ2	R^2	RMSE	χ2
10	*Ampong*	T1	A10T1	0.9680	0.0490	0.0027	0.9680	0.0935	0.0112	0.9880	0.0138	0.0002
10	*Ampong*	T2	A10T2	0.6970	0.2365	0.0671	0.6970	0.2452	0.0902	0.6720	0.0379	0.0022
10	*Ampong*	T3	A10T3	0.9300	0.1006	0.0114	0.9300	0.1675	0.0361	0.9760	0.0107	0.0001
10	*Ampong*	T4	A10T4	0.9420	0.0514	0.0032	0.9420	0.1146	0.0197	0.9670	0.0176	0.0005
10	*Ampong*	T5	A10T5	0.8090	0.0725	0.0063	0.8090	0.1998	0.0599	0.8650	0.0333	0.0017
10	*Broni*	T1	B10T1	0.8440	0.1663	0.0307	0.8440	0.1806	0.0408	0.9540	0.0229	0.0007
10	*Broni*	T2	B10T2	0.7130	0.2009	0.0485	0.7130	0.2512	0.0946	0.7150	0.0362	0.0020
10	*Broni*	T3	B10T3	0.8950	0.1251	0.0174	0.8950	0.1806	0.0408	0.9630	0.0196	0.0005
10	*Broni*	T4	B10T4	0.8350	0.1141	0.0156	0.8350	0.2102	0.0663	0.8620	0.0254	0.0010
10	*Broni*	T5	B10T5	0.7100	0.2147	0.0553	0.7100	0.2510	0.0945	0.6980	0.0375	0.0021
10	*Otuhia*	T1	O10T1	0.9920	0.0278	0.0009	0.9920	0.0526	0.0035	0.9920	0.0130	0.0002
10	*Otuhia*	T2	O10T2	0.7370	0.2094	0.0526	0.7370	0.2214	0.0735	0.7870	0.0319	0.0015
10	*Otuhia*	T3	O10T3	0.9460	0.0979	0.0106	0.9460	0.1492	0.0278	0.9850	0.0172	.ooo4
10	*Otuhia*	T4	O10T4	0.8920	0.0539	0.0035	0.8920	0.1648	0.0407	0.9200	0.0176	0.0005
10	*Otuhia*	T5	O10T5	0.9050	0.1283	0.0198	0.9050	0.2025	0.0615	0.8610	0.0336	0.0017
12	*Ampong*	T1	A12T1	0.9680	0.0195	0.0004	0.9680	0.0556	0.0039	0.9330	0.0392	0.0019
12	*Ampong*	T2	A12T2	0.8330	0.1274	0.0195	0.8330	0.1791	0.0481	0.8980	0.0287	0.0012

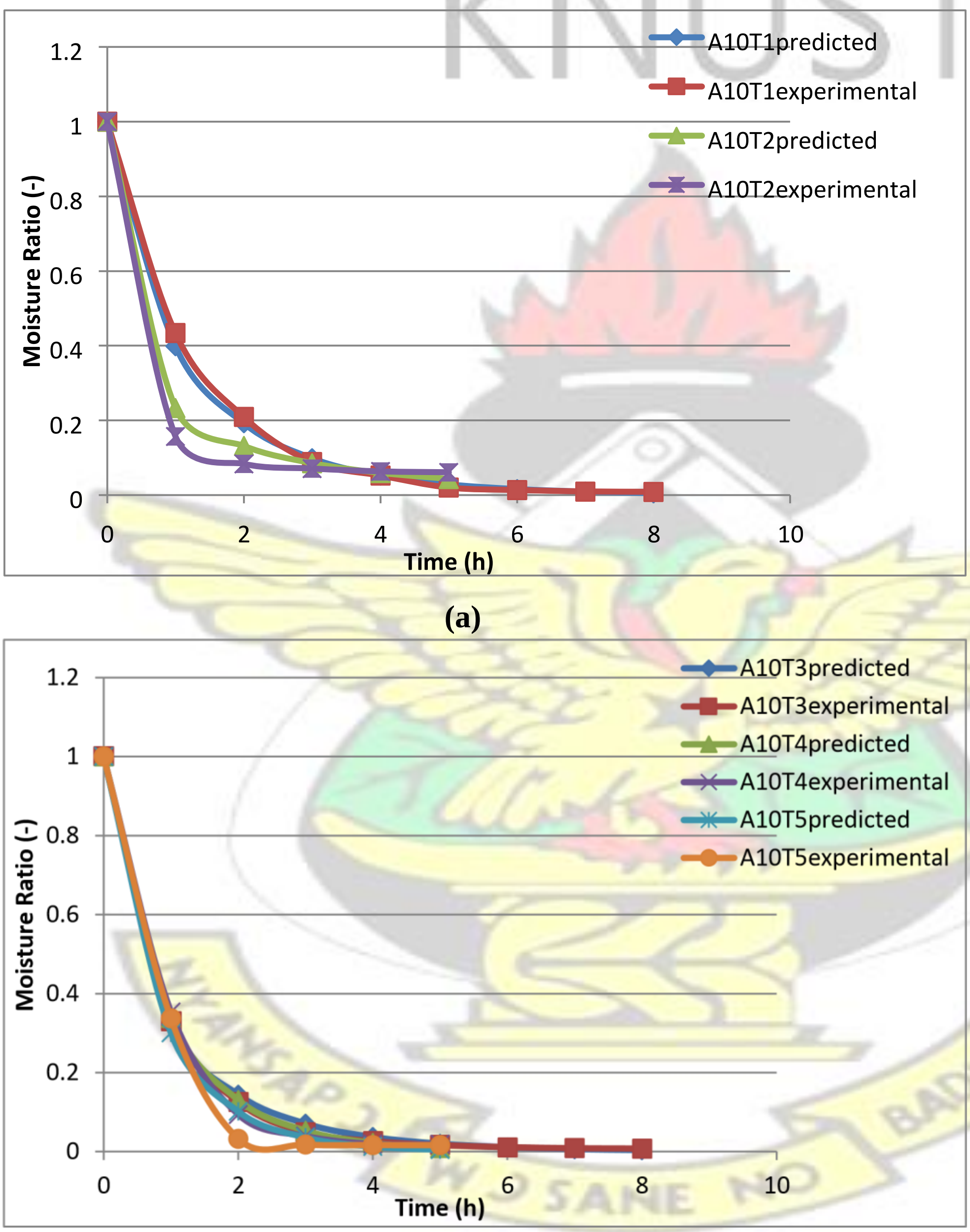
12	*Ampong*	T3	A12T3	0.9510	0.0467	0.0024	0.9510	0.0875	0.0096	0.9280	0.0400	0.0020
12	*Ampong*	T4	A12T4	0.9480	0.0672	0.0054	0.9480	0.1195	0.0214	0.9720	0.0124	0.0002
12	*Ampong*	T5	A12T5	0.9650	0.0414	0.0021	0.9650	0.0868	0.0113	0.9840	0.0130	0.0003
12	*Broni*	T1	B12T1	0.8970	0.1164	0.0151	0.8970	0.1402	0.0246	0.9450	0.0339	0.0014
12	*Broni*	T2	B12T2	0.8710	0.1155	0.0160	0.8710	0.2214	0.0735	0.8420	0.0310	0.0014
12	*Broni*	T3	B12T3	0.9020	0.0994	0.0110	0.9020	0.1377	0.0237	0.9380	0.0377	0.0018
12	*Broni*	T4	B12T4	0.9450	0.0690	0.0057	0.9450	0.1186	0.0211	0.9730	0.0113	0.0002
12	*Broni*	T5	B12T5	0.8200	0.1775	0.0378	0.8200	0.1934	0.0561	0.8810	0.0248	0.0009
12	*Otuhia*	T1	O12T1	0.9160	0.0803	0.0072	0.9160	0.1060	0.0141	0.8930	0.0465	0.0027
12	*Otuhia*	T2	O12T2	0.8810	0.1096	0.0144	0.8810	0.1571	0.0370	0.9380	0.0221	0.0007
12	*Otuhia*	T3	O12T3	0.9420	0.0715	0.0057	0.9420	0.0929	0.0108	0.9250	0.0374	0.0017
12	*Otuhia*	T4	O12T4	0.9410	0.0681	0.0056	0.9410	0.1203	0.0217	0.9740	0.0114	0.0002
12	*Otuhia*	T5	O12T5	0.9580	0.0263	0.0008	0.9580	0.0609	0.0057	0.9640	0.0648	0.0063
14	*Ampong*	T1	A14T1	0.9310	0.0694	0.0053	0.9310	0.1123	0.0154	0.9470	0.0332	0.0013
14	*Ampong*	T2	A14T2	0.7850	0.1709	0.0350	0.7850	0.2157	0.0698	0.8280	0.0299	0.0013
14	*Ampong*	T3	A14T3	0.8510	0.1404	0.0217	0.8510	0.1574	0.0303	0.9260	0.0387	0.0018
14	*Ampong*	T4	A14T4	0.8970	0.1213	0.0177	0.8970	0.1745	0.0457	0.9220	0.0219	0.0007
14	*Ampong*	T5	A14T5	0.9240	0.0736	0.0065	0.9240	0.1108	0.0184	0.9580	0.0274	0.0011
14	*Broni*	T1	B14T1	0.8810	0.1275	0.0179	0.8810	0.1509	0.0278	0.9430	0.0345	0.0015
14	*Broni*	T2	B14T2	0.8120	0.1230	0.0182	0.8120	0.2451	0.0901	0.8000	0.0238	0.0008
14	*Broni*	T3	B14T3	0.8430	0.1490	0.0244	0.8430	0.1702	0.0354	0.9310	0.0380	0.0017
14	*Broni*	T4	B14T4	0.8570	0.1261	0.0191	0.8570	0.1991	0.0595	0.8800	0.0487	0.0036
14	*Broni*	T5	B14T5	0.7810	0.1776	0.0379	0.7810	0.2206	0.0730	0.8160	0.0307	0.0014
14	*Otuhia*	T1	O14T1	0.8240	0.1609	0.0285	0.8240	0.1779	0.0387	0.9240	0.0386	0.0018
14	*Otuhia*	T2	O14T2	0.8720	0.1107	0.0147	0.8720	0.1566	0.0368	0.9320	0.0260	0.0010
14	*Otuhia*	T3	O14T3	0.8510	0.1508	0.0250	0.8510	0.1628	0.0324	0.9410	0.0326	0.0013
14	*Otuhia*	T4	O14T4	0.9160	0.0937	0.0105	0.9160	0.1491	0.0334	0.9500	0.0187	0.0005

14	*Otuhia*	T5	O14T5	0.9260	0.0615	0.0045		0.9260	0.1086	0.0177		0.9600	0.0274	0.0011

R^2 =coefficient of determination; RMSE = Root mean square error; $\chi 2$ = meam square deviation

3.4.3. Model Validation

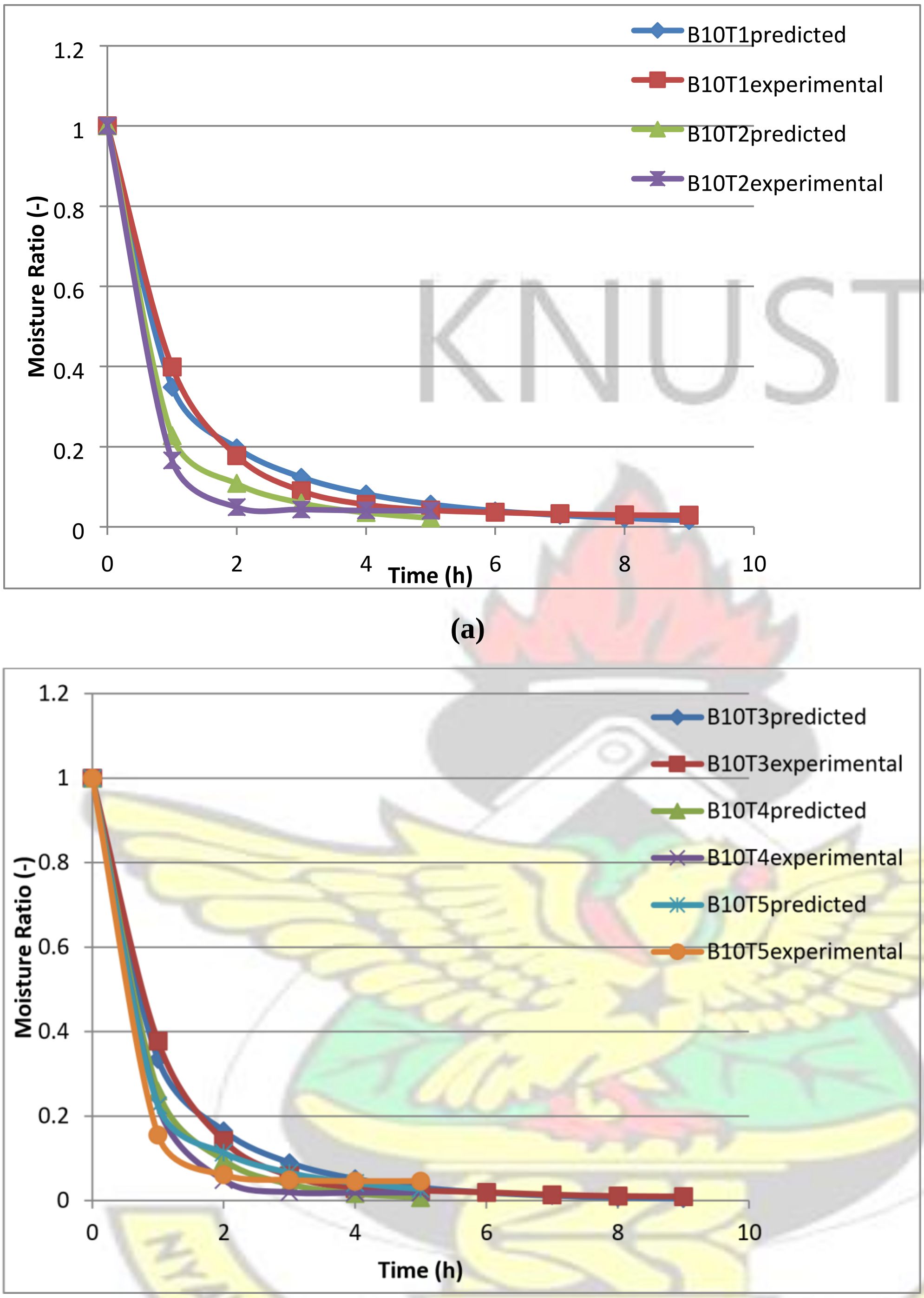
The moisture ratio-time graphs of the experimental and predicated data from the Page's model are presented in Fig 3.8 to 3.16.



(a)

(b)

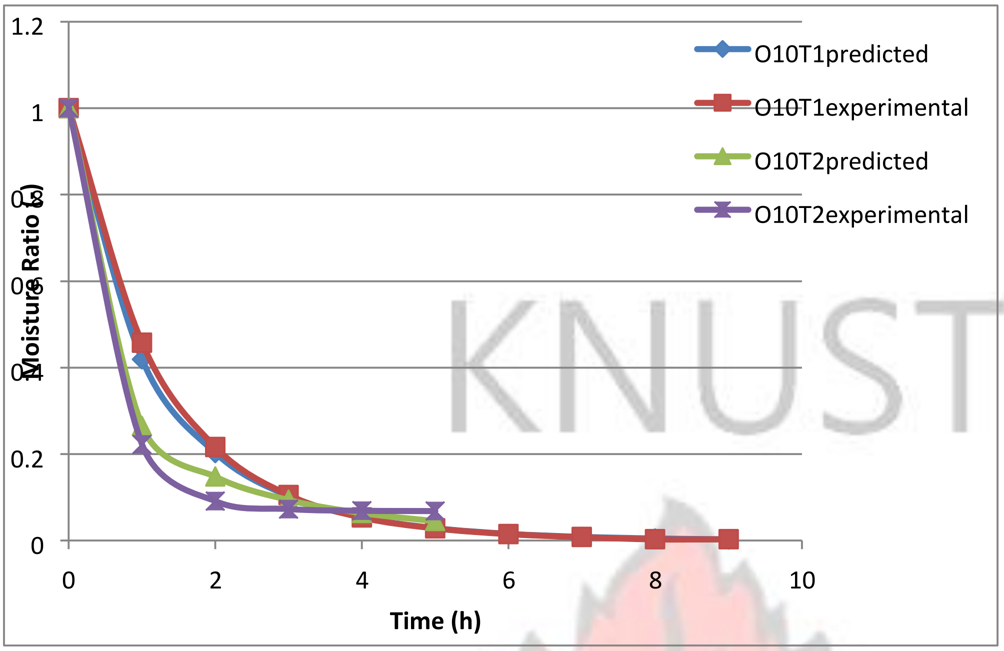
Figure 3.8 Predicted and experimental moisture ratio of *Ampong* cassava Variety at 10 months harvest age; (a) Chipping (T1) and toasting pre-treatment (T2); (b) chipping with citric acid pre-treatments (T3), grating pre-treatment (T4) and toasting with citric acid pre-treatment (T5).



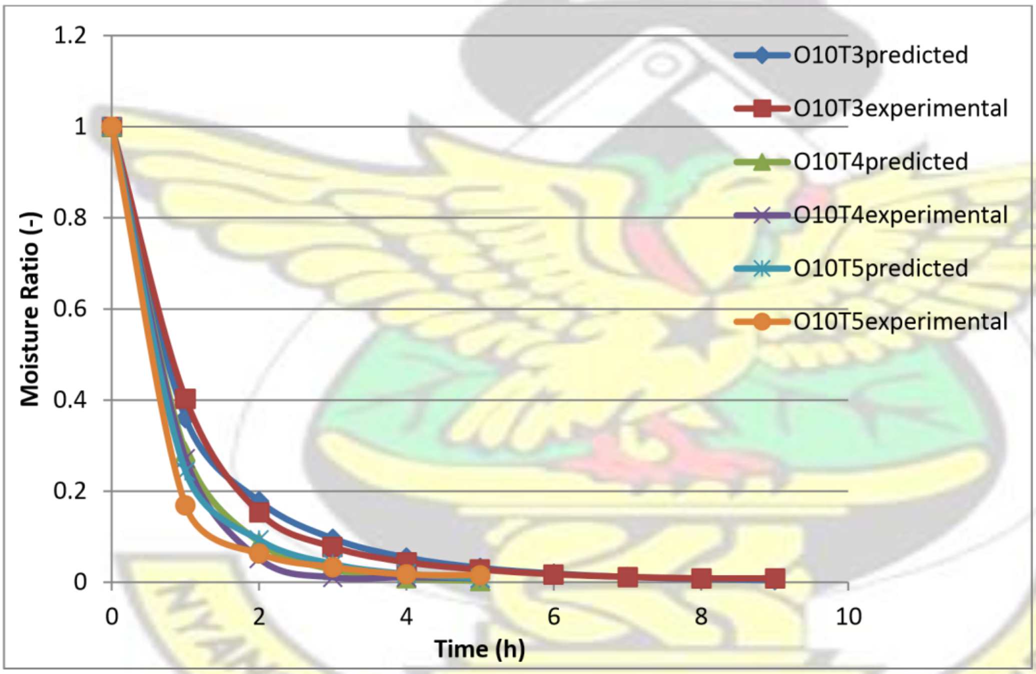
(a)

(b)

Figure 3.9 Predicted and experimental moisture ratio *of Broni* cassava Variety at 10 months harvest age; (a) Chipping (T1) and toasting pre-treatment (T2); (b) chipping with citric acid pre-treatments (T3), grating pre-treatment (T4) and toasting with citric acid pre-treatment (T5).

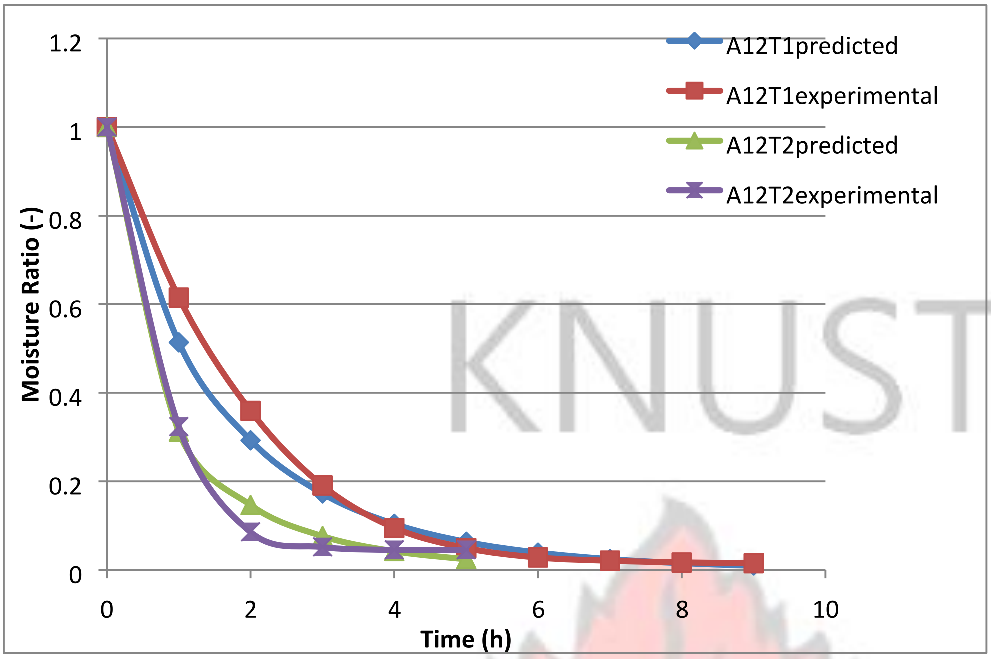


(a)

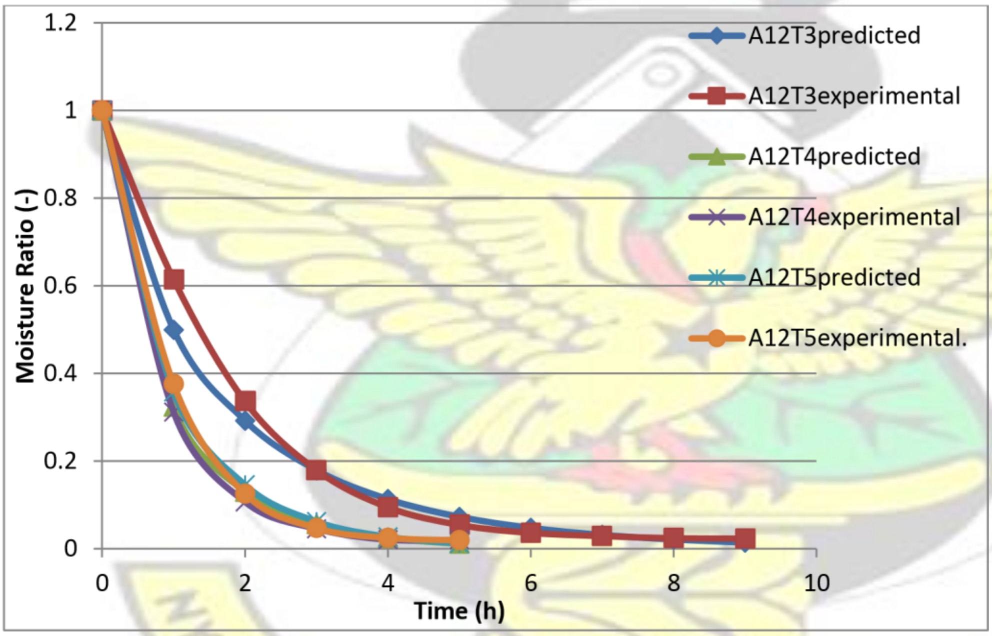


(b)

Figure 3.10 Predicted and experimental moisture ratio of *Otuhia* cassava Variety at 10 months harvest age; (a) Chipping (T1) and toasting pre-treatment (T2); (b) chipping with citric acid pre-treatments (T3), grating pre-treatment (T4) and toasting with citric acid pre-treatment (T5).

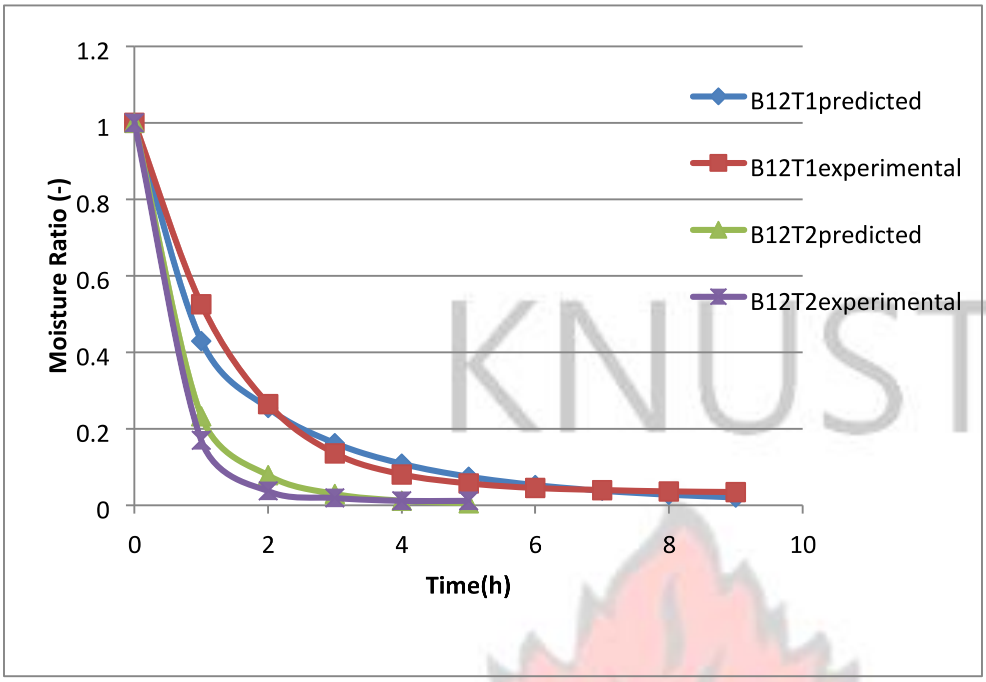


(a)

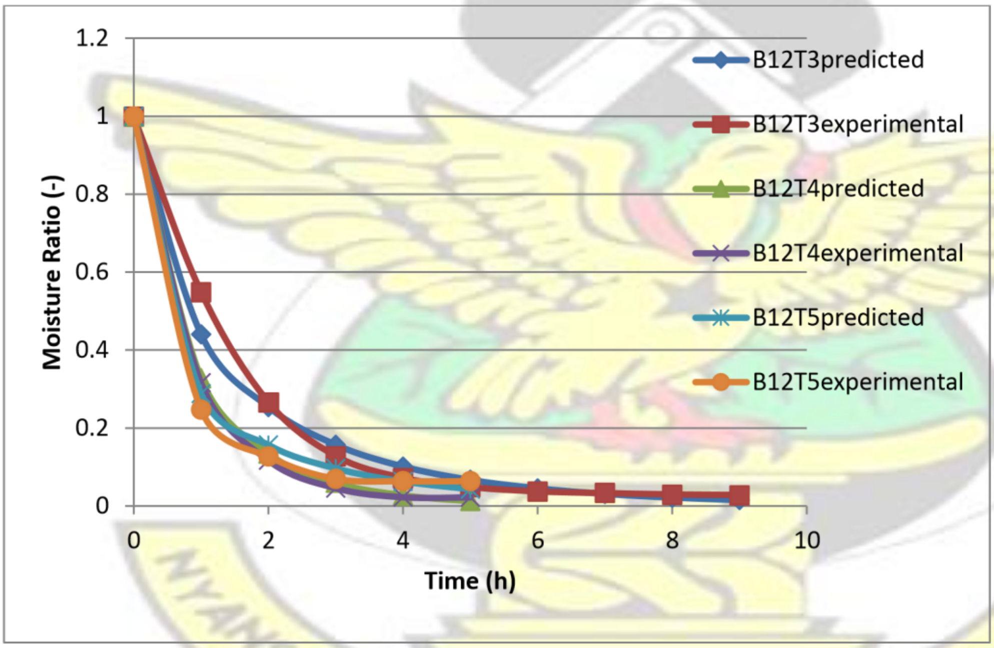


(b)

Figure 3. 11 Predicted and experimental moisture ratio of *Ampong* cassava Variety at 12 months harvest age; (a) Chipping (T1) and toasting pre-treatment (T2); (b) chipping with citric acid pre-treatments (T3), grating pre-treatment (T4) and toasting with citric acid pre-treatment (T5).

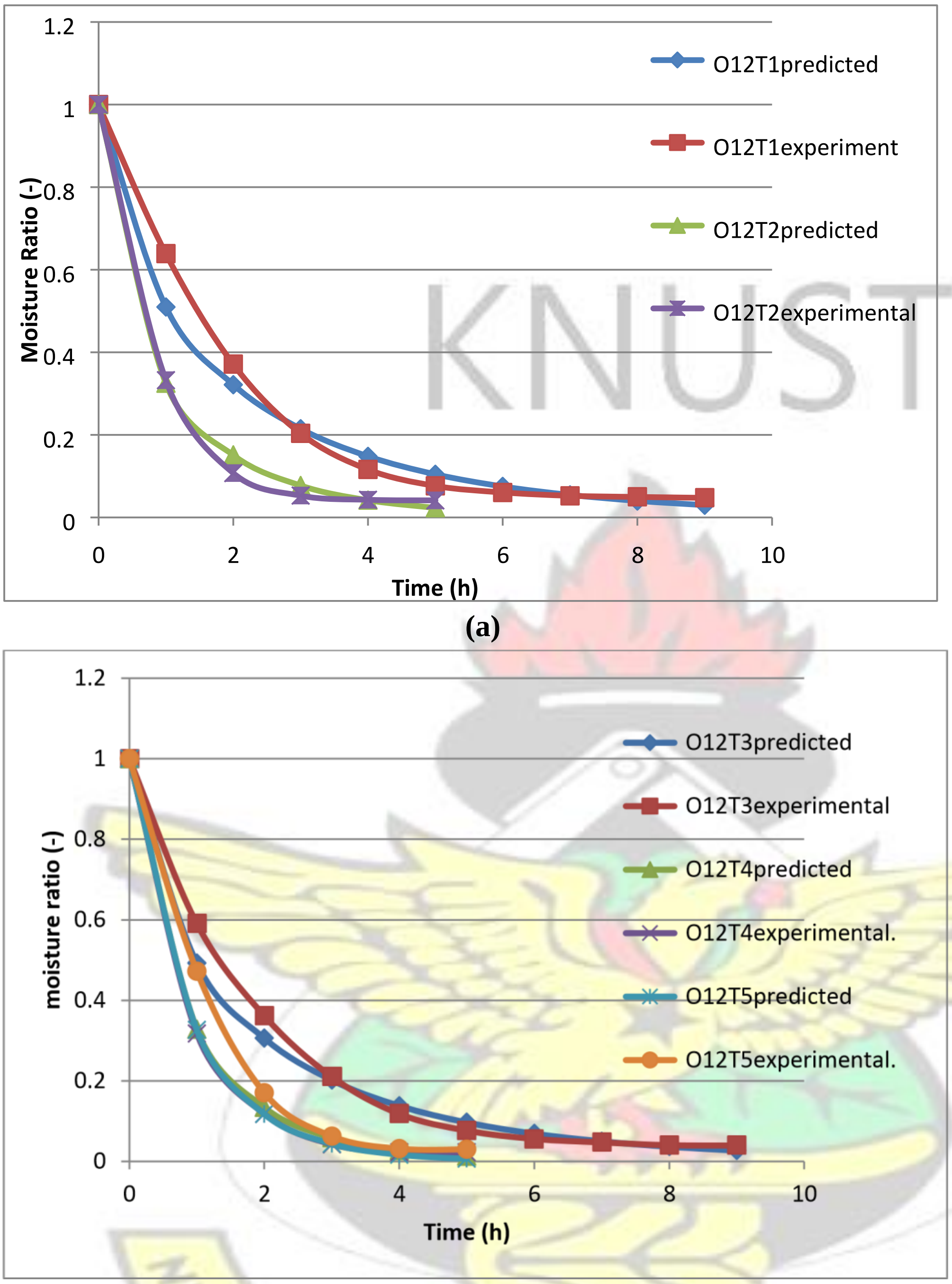


(a)



(b)

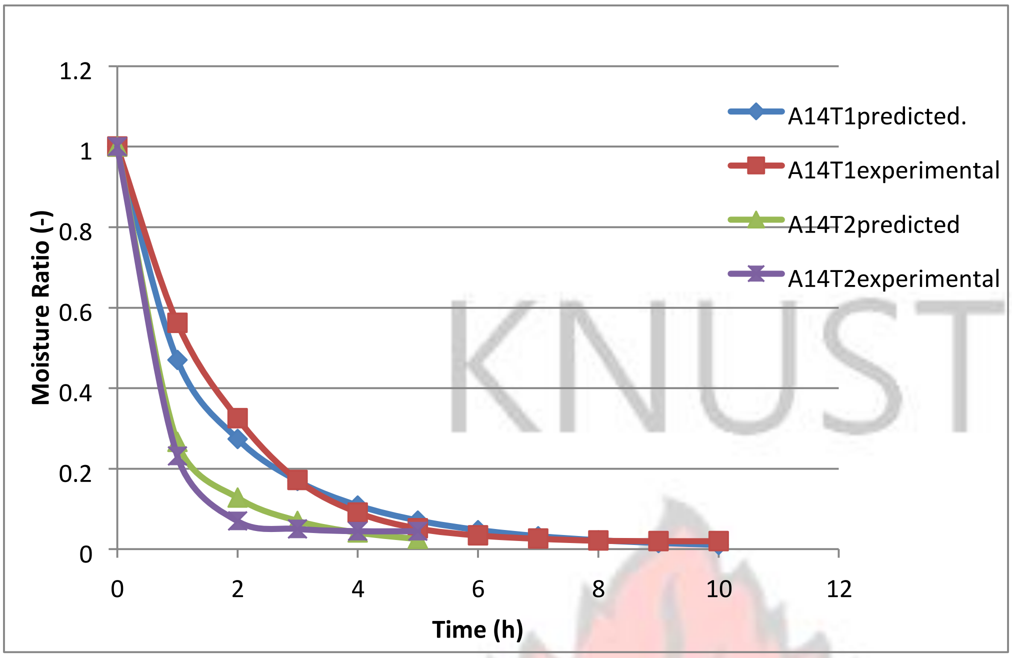
Figure 3. 12 Predicted and experimental moisture ratio of *Broni* cassava Variety at 12 months harvest age; (a) Chipping (T1) and toasting pre-treatment (T2); (b) chipping with citric acid pre-treatments (T3), grating pre-treatment (T4) and toasting with citric acid pre-treatment (T5).



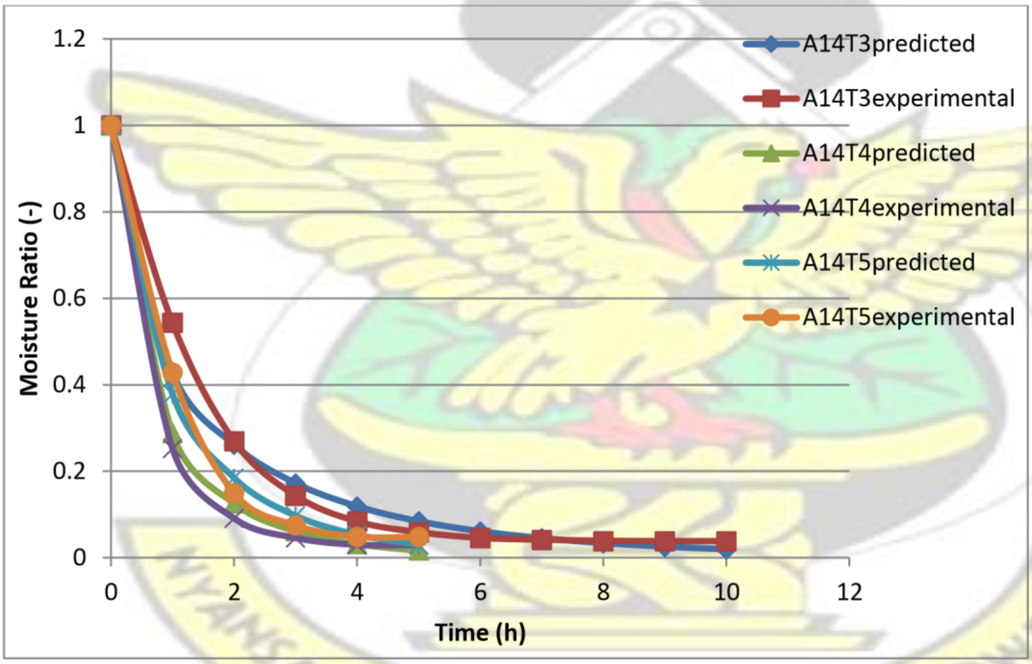
(a)

(b)

Figure 3. 13 Predicted and experimental moisture ratio of *Otuhia* cassava Variety at 12 months harvest age; (a) Chipping (T1) and toasting pre-treatment (T2); (b) chipping with citric acid pre-treatments (T3), grating pre-treatment (T4) and toasting with citric acid pre-treatment (T5).

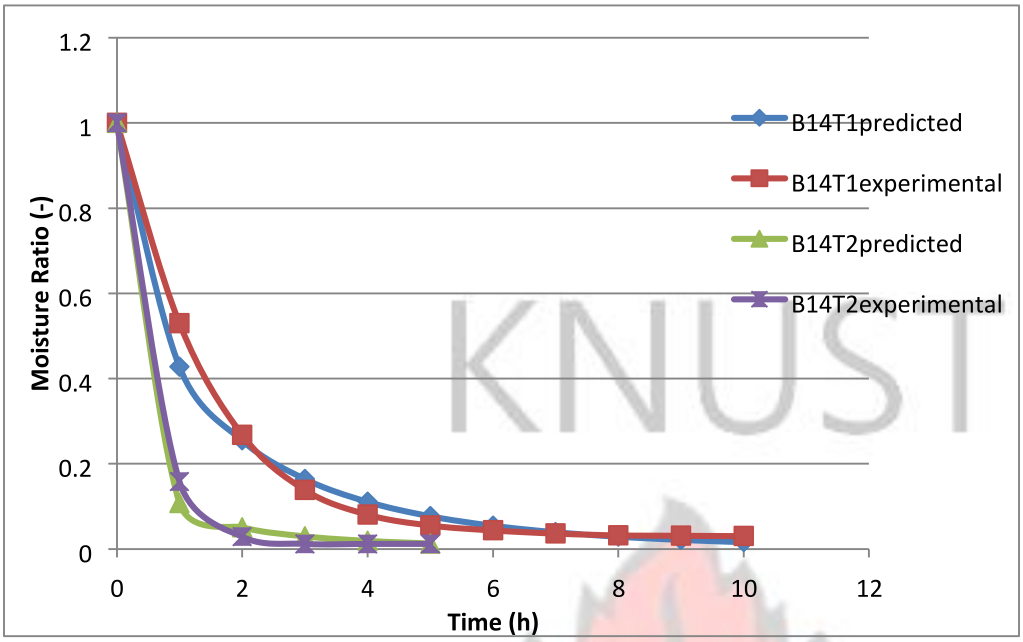


(a)

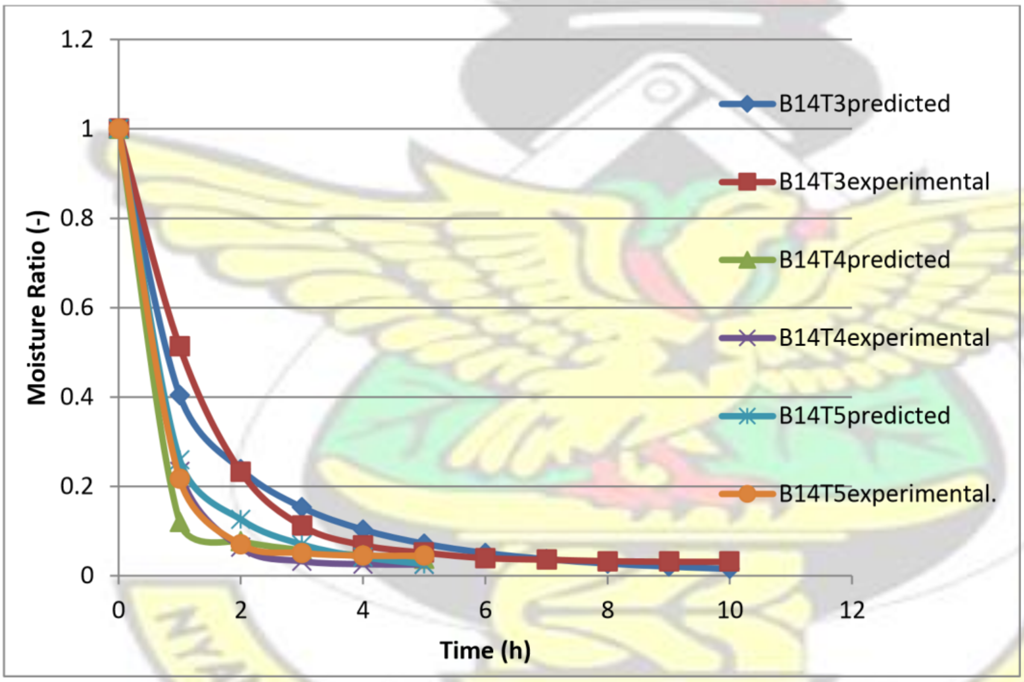


(b)

Figure 3. 14 Predicted and experimental moisture ratio of *Ampong* cassava Variety at 14 months harvest age; (a) Chipping (T1) and toasting pre-treatment (T2); (b) chipping with citric acid pre-treatments (T3), grating pre-treatment (T4) and toasting with citric acid pre-treatment (T5).



(a)



(b)

Figure 3. 15 Predicted and experimental moisture ratio of *Broni* cassava Variety at 14 months harvest age; (a) Chipping (T1) and toasting pre-treatment (T2); (b) chipping with citric acid pre-treatments (T3), grating pre-treatment (T4) and toasting with citric acid pre-treatment (T5).

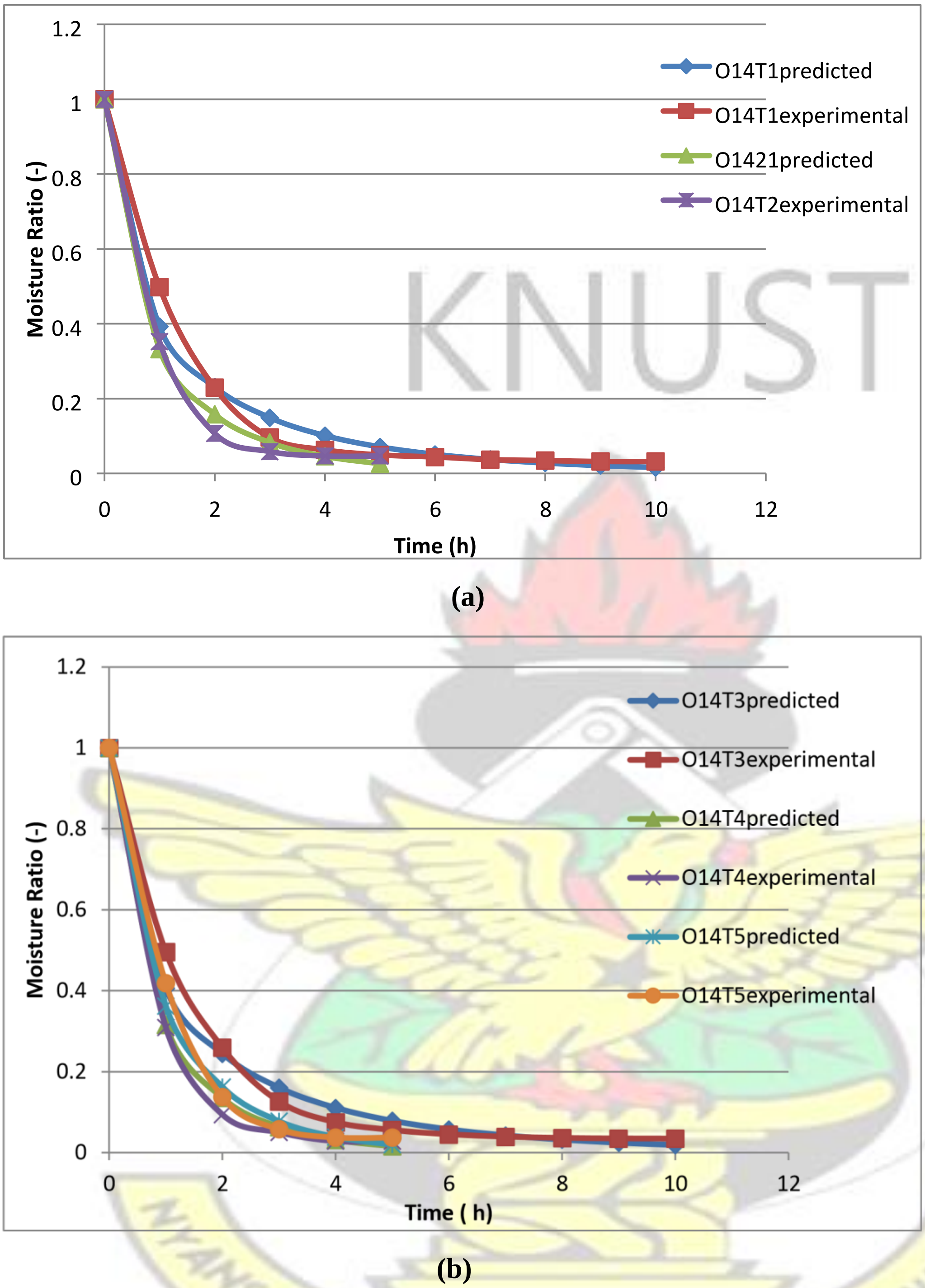


Figure 3. 16 Predicted and experimental moisture ratio of *Otuhia* cassava Variety at 14 months harvest age; (a) Chipping (T1) and toasting pre-treatment (T2); (b) chipping with citric acid pre-treatments (T3), grating pre-treatment (T4) and toasting with citric acid pre-treatment (T5).

It can be observed from the graphs that the predictive ability of the Page's model is evident for thin layer drying data. The drying of the chipped cassava samples (T_1 and

T_3) appears to be better predicted by the equation than the grated sample (T_4) and the toasted samples (T_2 and T_5). This could have resulted from the fact that the moisture loss by diffusion would have played a greater role in the chipped samples than the grated and toasted samples.

3.5 Conclusion

The total time for drying of the chipped cassava samples to the final moisture content of 2–7% (wb) was 8 to 10 h while the grated and toasted cassava samples were dried to the final moisture content of 2 to 4% (wb) within 2 to 5 h. Drying of both chipped and grated samples took place in the falling rate period.

The Page's model described the drying behaviour of all the cassava samples better than the Newton and Henderson and Pabis models. A plot of the experimental moisture ratio and the predicted moisture ratio for the Page model indicates a very minimal deviation from each other. This agreement between the predicted and experimental values of moisture ratio was validated by the high R^2 value and the very low Root Mean Square Error (RMSE) and Mean Square Deviation (χ^2).

CHAPTER FOUR

QUALITY CHARACTERISTICS OF PRE-TREATED CASSAVA FLOUR

4.1 Introduction

The quality of any particular food material is greatly influenced by its nutritional composition. Cassava, which is one of the most important staple foods in most West African countries is a major source of carbohydrate and contains other food nutrients such as fats, proteins, ash, moisture, fibre and some other trace elements in smaller quantities. Proximate composition is a very important criterion that gives an idea of the nutritional composition of food and feed ingredients. The pH values and cyanogenic potentials of the processed flour together with its proximate composition are among the important qualities that affect its use for the production of derived food products. While the pH value of the flour influences the taste of the derived food product, the cyanogenic potential of the cassava flour can be a limiting factor to its use for various food applications. It is therefore necessary that in order to ascertain the suitability of flour from the three cassava varieties under study for use as composite baking material, the proximate composition, pH values and the cyanogenic potentials of the flour be evaluated.

4.2 Materials and Methods

The flour samples obtained from the drying experiment in Section 3.2 were used for this evaluation.

4.2.1 Proximate Analysis

4.2.1.1 Determination of Moisture Content

The moisture content of the cassava flour was determined using the AOAC (1990) method of moisture determination. Five grams (5 g) of each cassava flour sample was weighed in triplicate into previously dried and weighed moisture cans. The cans were placed in a thermostatically controlled oven which was pre-set to a temperature of 105 °C. The samples were left in the oven for 24 h during which they attained constant weight. The moisture content was then determined using Equation (4.1)

$$Moisture\ content = \frac{(\boldsymbol{wt\ of\ can+fresh\ sample})-(\boldsymbol{wt\ of\ can+dry\ sample})}{\boldsymbol{wt\ of\ fresh\ samples}} \times 100 \qquad (4.1)$$

4.2.1.2 Crude Protein Determination

The crude protein content was determined using the Kjeldahl method. This method involves various stages of sample digestion, distillation and titration. One spatula full of catalyst Kjeldahl (potassium sulphate + copper sulphate + selenium powder mixture) together with 20 ml of concentrated sulphuric acid (H_2SO_4) were added to 2.0 g of cassava flour sample which had been weighed and placed in a 500 ml Kjeldahl flask. The flask was thoroughly shaken until the flour became wet.

The flask was then slowly heated in a digestion burner in a Kjeldahl room to digest the sample. Heating was continued until the boiling was complete and the sample became clear green. The flask, together with its content, were cooled to normal room temperature after which the entire content was transferred into a 50 ml volumetric flask and distilled ammonia-free water was added to the 50 ml mark. The Kjeldahl flask was thoroughly rinsed with successive small quantities of distilled water.

The steam generator of the distillation unit was flushed before use by boiling distilled water in it with the connections arranged to circulate the water through the condenser for about 10 min. Two drops of mixed indicator was added to 25 ml of 2 % boric acid pipetted into a 250 ml conical flask. The conical flask and its contents were placed under the condenser such that the condenser tip was totally immersed in the boric acid solution. After the Kjeldahl distillation unit was set up, 10 ml of the digested sample solution was mixed with 20 ml of 40% NaOH solution in a decomposition flask. The distillation process was allowed to continue for about 3 min as the liberated ammonia was collected over the boric acid.

The solution was titrated with 0.01N HCl unit until the first appearance of violet colour was noticed. The same process was used to run a reagent blank with equal volume of distilled water. The nitrogen content of the sample was then calculated for all the samples using Equation (4.2).

$$\boldsymbol{N\ (gkg^{-1}) = \frac{(ml\ HCL - ml\ blank) \times Normaility\ of\ Hcl \times 14.01}{weight\ of\ sample\ (g) \times 10}} \qquad (4.2)$$

The protein content was obtained by multiplying the nitrogen content (N) by a factor of 6.25.

4.2.1.3 Fat determination (Ether extract)

The fatty acid ester of glycerol (fat) content of the sample was obtained by extracting the fat with ether using the AOAC (1990) official method of fat determination. A filter paper was placed in the thimble of a Soxhlet apparatus and 2 g of the dried cassava sample was folded in it. A piece of cotton wool was placed at the top of the condenser to avoid the escape of solvent during extraction. The fat was extracted from the sample with petroleum ether for 2 h by gentle heating without interruption.

The extraction flask was dismantled after cooling and the ether was evaporated on a water bath until no odour of the ether was noticed. The flask was cooled overnight at room temperature after which the flask and its content were weighed to obtain the weight of the extracted fat. The fat content of the sample was then calculated using Equation 4.3.

$$Crude\ fat\ (\%) = \frac{weight\ of\ extracted\ fat}{initial\ sample\ weight} \times 100 \qquad (4.3)$$

4.2.1.4 Determination of Crude Fibre

The weighed residue from the ether extract (fat determination) was transferred into a 500 ml digestion flask and 200 ml of boiling 1.25% H_2SO_4 was added together with 0.5 g of asbestos. The flask was instantly placed on a hot plate and a condenser was connected to the digestion flask. The flask was heated for 30 minutes after which the content was immediately filtered through a linen cloth in a funnel and washed with a large volume of boiling water until the washings were no longer acidic. The acidity was monitored using a pH meter. The residue was washed back together with the asbestos into a flask with 200 ml boiling 1.25% NaOH solution. The flask was then connected to a reflux condenser and boiled for 30 min after which the content was filtered with a linen cloth in a funnel and subsequently washed with large volumes of boiling water. The residue was transferred into a Gooch crucible and washed with hot water from a wash bottle and then washed with 15 ml of 95% alcohol. The crucible and its content was dried at 110 °C to constant weight, cooled in a desiccator and weighed. The crucible with its content was then incinerated in a muffle furnace at 600 °C for 30 min, cooled in a desiccator and reweighed. The crude fibre content was calculated using equation 4.4.

$$Crude\ fibre\ (\%) = \frac{A-B}{C} \times 100 \qquad (4.4)$$

where, A = weight of dry crucible and sample (g)

B = weight of incinerated crucible and ash (g)

C = initial sample weight (weight of residue) (g)

4.2.1.5 Ash Determination

An ash crucible was washed and dried at 105 ^{0}C for one hour, cooled in desiccators and weighed. Two grams of cassava sample was weighed into the porcelain crucible in triplicate and put into a furnace at 600 ˚C for 4 h. The furnace was allowed to cool below 200 ˚C and maintained for 20 min. The crucible was then placed in a desiccator with stopper top, cooled and reweighed (AOAC, 1990). The ash content was calculated as follows

$$Ash(\%) = \frac{(A+C)-A}{(A+B)-A} \times 100 \qquad (4.5)$$

where, A = crucible weight (g)

B = sample weight (g)

C = ash weight (g)

4.2.1.6 Determination of Total Carbohydrate

Total carbohydrate content was determined by summing up the percentage values of moisture, protein, fat, fibre, ash and subtracting them from 100%.

4.2.2 Determination of the pH Values of the Cassava Flour

The pH value of a product is an indicator of the acidity or alkalinity of the product.

The pH values of the cassava flour were determined using pH meter (EUTECH510).

A beaker was washed and 5 g of the cassava flour sample was weighed and put in it. Twenty five millilitre (25 ml) of distilled water was measured and put into the beaker containing the sample and the content was intermittently stirred for about 20 min before allowing the mixture to stand for about 30 min. The sensor of the pH meter was then dipped into the settled mixture in the beaker and the pH value read out on the digital output.

4.2.3 Determination of the Cyanogenic Potential of the Cassava Flour

The cyanide content of the cassava samples was determined using the titration method (AOAC, 1990). Twenty grams of the Cassava sample was weighed into a Kjeldahl distillation flask, 200 ml of distilled water was added to the sample and the mixture was allowed to stand for 3 h. It was then distilled until 150ml of the distillate was obtained. Twenty milliliters of 0.02 M NAOH was added to the distillate and the volume diluted to 250 ml in a volumetric flask using distilled water. Eight milliliters (8 ml) of 6 M ammonia solution and 2 ml of 5% KI were added to 100 ml of the aliquot. This was titrated with a 0.02 M $AgNO_3$ until an end point of faint but permanent turbidity (which is easily recognized especially against a black background) was obtained.

The hydrogen cyanide content of the sample was obtained using Equation 4.6

$$\text{Cyanide content (mg/kg)} \quad = 0.54(v_0 - v_1) \times (\frac{250}{100}) \times (\frac{1000}{m}) - 1350(\frac{v_0 - v_1}{m}) \quad (4.6)$$

where, m = mass of the test sample (g) v_0 = volume of silver nitrate solution used for the titration proper (ml) v_1 = volume of the silver nitrate solution used for the blank test (ml)

4.2.3 Study Design and Statistical Analysis

A 3x3x5 factorial design in CRD was used for the study where the main factors were the three levels of harvest age, three levels of variety and five levels of pre-treatment methods. The data obtained were analysed using GenStat 12th Edition. Analysis of Variance (ANOVA) and mean separation were performed using Fischer’s Least Significant Difference of means to determine significant differences at 5 % probability level.

4.3 Results and Discussion

4.3.1 Proximate Composition of Pre-Treated Cassava Flour

Proximate composition is a very important criterion that gives an idea of the nutritional composition of food and feed ingredients. A sample copy of the ANOVA table generated from the statistical analysis for the proximate composition is as presented in Appendix 4.

4.3.1.1 Effect of Age on Proximate Composition of Cassava Flour

Result of the main effect of harvest age on the proximate composition of the samples indicates that the protein, fat, fiber, ash, moisture and carbohydrate contents of the flour samples are significantly ($p \leq 0.05$) affected by the harvest age of the tubers (Table 4.1).

Table 4. 1 Main effect of age on proximate composition of cassava flour

Age	Protein (%)	Fat (%)	Fibre (%)	Ash (%)	Moisture (%)	C.H. (%)
10 months	2.10	0.46	2.50	0.85	2.74	91.35
12 months	1.71	1.79	2.10	0.83	3.38	90.14
14 months	2.53	0.64	2.35	1.00	2.18	91.30
CV (%)	14.30	23.00	18.00	11.40	12.40	0.70
Lsd	0.13	0.09	0.17	0.04	0.14	0.27

Lsd =Least significant difference, CV = Coefficient of variation, C.H.= Carbohydrate

The mean protein content of the samples harvested at 14 months of age was 2.53% which was significantly higher ($p \leq 0.05$) than those harvested at 10 months with mean values of 2.10% which was in turn significantly higher than the value of 1.71 % for those harvested at 12 months. This is in agreement with the findings of Apea– Bah *et al*. (2011) which indicated that the value of the protein content of flour from four local varieties decreased progressively from 1.10% at 9 months harvest age to

0.37% at 13 months after which it increased to a peak value of 1.42% at 15 months. Sunee *et al.* (2006) also reported a progressive reduction in the protein content of flour from 2.81% at 6 month harvest age to 1.41% at 12 month harvest age. The significant effect of age on protein content is possibly as a result of the differing rate of nitrogen metabolism in the growing plant.

The fiber content of the flour at 10 months harvest age was 2.50% and higher ($p \leq 0.05$) than the 2.10% value of those harvested at 12 month but not statistically different from that of 14 months.

The higher fibre content at 10 months could be attributed to the fact that at this stage the plant is within the end of bulking of its fibrous roots and the associated translocation and conversion of sugar into starch in the roots as it advances to the dormancy stage which ends at 12 months for the start of another cycle (Nassar, 2005).

The fat, ash and moisture content of the samples were significantly ($p \leq 0.05$) affected by harvest age. The fat content of the samples harvested at 12 months was 1.79% and higher than 0.64 % value at 14 months which was in turn significantly higher ($p \leq 0.05$) than the 0.46% value obtained at 10 months. The ash content

(1.00%) was higher ($p \leq 0.05$) at 14months harvest age while the values obtained at 10 months (0.85%) and 12 months (0.83%) did not differ from each other. The values of carbohydrate content at 10months and 14 month harvest age (91.35 and 91.3% respectively) were not significantly different from each other but higher ($p \leq 0.05$) than the 90.14% obtained at 12 months.

4.3.1.2 Effect of Variety on the Proximate Composition of Cassava Flour

The main effect of variety on the proximate composition of cassava flour is presented in Table 4.2. The result of the analysis indicates that the protein content of the cassava flour from *Ampong, Broni* and *Otuhia* cassava varieties were 2.17%, 2.09% and 2.09% respectively which were not significantly different ($p > 0.05$) from each other. They are however within the range of values reported by some researchers on the protein content of some local and cassava mosaic disease (CMD) resistant varieties. Ooye *et al*. (2014) reported a protein content range of 0.35% to 1.43% for some cassava varieties from Nigeria while Afoakwa *et al.* (2012) reported protein content range of 1.17% to 3.48% for six varieties of both local and improved CMD resistant varieties in Ghana.

Table 4. 2 Main effect of Variety on proximate composition of cassava flour

Variety	Protein (%)	Fat (%)	Fibre (%)	Ash (%)	Moisture (%)	CHO (%)
Ampong	2.17	0.95	2.49	0.81	2.27	91.32
Broni	2.09	1.08	2.40	0.87	3.25	90.32
Otuhia	2.09	0.87	2.05	1.01	2.79	91.10
cv%	14.30	23.00	18.00	11.40	12.40	0.70
L.s.d.	0.13	0.09	0.17	0.04	0.14	0.27

Lsd =Least significant difference, CV= Coefficient of variation, CHO=Carbohydrate

The fat content of the flour ranged from 0.85% for *Otuhia* variety to 1.08% for *Broni* variety. The fat content of *Ampong* variety (0.95%) did not differ from that of *Otuhia* (0.87%) but was lower ($p \leq 0.05$) than that of *Broni* Variety. The Crude fibre content of *Ampong* (2.49%) did not differ from the value obtained for *Broni* (2.40%) but significant difference ($p \leq 0.05$) existed between the two varieties and *Otuhia* (2.05%) as can be observed in Table 4.2. The carbohydrate content of *Ampong* (91.32%) and *Otuhia* (91.10%) did not differ from each other but they were significantly higher ($p \leq 0.05$) than the value obtained for *Broni* (90.32%) variety. The high carbohydrate content and desirable nutritional contents like protein obtained in this study suggests that the three cassava varieties could be effectively used as a reliable food security crop as proposed by FAO (2008).

4.3.1.3 Effect of Pretreatment on Proximate Composition of Cassava Flour

The main effect of pre-treatment on the proximate composition of cassava flour is as presented in Table 4.3.

Table 4.3 Main effect of pre-treatment on proximate composition of cassava flour

PT	Protein (%)	Fat (%)	Fibre (%)	Ash (%)	Moisture (%)	CHO (%)
T1	2.59	1.11	2.32	1.36	2.71	89.83
T2	1.87	0.71	2.50	0.74	2.84	91.34
T3	2.45	1.01	2.01	0.94	3.04	90.56
T4	1.81	1.07	2.39	0.77	2.43	91.53
T5	1.85	0.92	2.35	0.66	2.82	91.30
cv%	14.30	23.00	18.00	11.40	12.40	0.70
L.s.d.	0.16	0.12	0.22	0.06	0.18	0.35

Lsd = Least significant difference, CV = Coefficient of variation, CHO = Carbohydrate, PT = Pre-treatment, T1 toT5 represents pre-treatment methods as described in section 3.2.5

The protein content of cassava flour produced from chipping pre-treatment (T_1) and chipping with steeping in citric acid pretreatment (T_3) were significantly higher ($p \leq 0.05$) than those for toasting pretreatment (T_2), grating pre-treatment (T_4) and steeping in citric acid with toasting pre–treatment (T_5). The protein content of T_2 (1.87%), T_4 (1.81%) and T_5 (1.85%) did not significantly differ from each other even though they were lower ($p \leq 0.05$) than the 2.59% and 2.45% obtained from the two chipping pre-treatment methods (T_1 and T_3). It is important to note that the lower values of protein content of T_2, T_4 and T_5 pre–treatment could have arisen from the loss of protein alongside the discharged waste-water during the pre–drying dewatering processes of the mash associated with the three pre-treatment methods. The fat contents of T_1

(1.11%), T_3 (1.01%), and T_4 pre-treatment are significantly higher ($P \leq 0.05$) than those of T2 (0.71%) and T_5 (0.92%) pre-treatment. The fiber content of T_3 (2.01%) was significantly lower ($p \leq 0.05$) than those of T_1 (2.32%), T_2, (2.50%) T_4 (2.39%) and T_5 (2.35%) while the ash content of T_1 (1.36%) was higher ($p \leq 0.05$) than those of T_3 (0. 94%) which was in turn higher than those for T_2 (0.74%), T_4 (0.77%) and T_5 (0.66%). The carbohydrate content of T_1 (89.83) and T_3 (90.5%) were lower than those of T_2 (91.34), T_4 (91.53) and T_5 (91.30).

4.3.1.4 Effects of Variety, Harvest Age and Pretreatment Interaction on Proximate Composited of Cassava Flour

The result of the effects of variety, harvest age and pre–treatment interaction on proximate composition of cassava flour are presented in Table 4.4

The protein content of $A_{14}T_3$ (3.06%) and $O_{14}T_3$ (3.01%) which are respectively flour samples from chips of *Ampong* and *Otuhia* varieties harvested at 14 months and pretreated with citric acid were significantly higher ($p \leq 0.05$) than the rest of the flour samples with the exception of $A_{10}T_1$ (2.68%), $A_{14}T_4$ (2.70%), $B_{10}T_1$ (2.63%), $B_{14}T_1$ (2.90%), $A_{14}T_3$(2.82%), $O_{10}T_1$(2.79%), and $O_{14}T_1$ (2.91%), which did not significantly differ from the two samples.

Table 4.

4 Effects of variety, harvest age and pretreatment interaction on proximate composition of cassava flour

Variety	Harvest.Age (months)	Pre-treatment	Sample code	Protein (%)	Fat (%)	Fibre (%)	Ash (%)	Moisture (%)	CHO (%)
Ampong	10	T1	$A_{10}T1$	2.68	0.38	2.92	1.44	1.44	91.14
Ampong	10	T2	$A_{10}T2$	1.93	0.43	2.94	0.96	1.19	92.55
Ampong	10	T3	$A_{10}T3$	2.11	0.75	3.16	0.26	1.04	92.68
Ampong	10	T4	$A_{10}T4$	2.00	0.55	2.85	0.76	0.28	93.56
Ampong	10	T5	$A_{10}T5$	1.79	0.27	2.50	1.06	0.97	93.41
Ampong	12	T1	$A_{12}T1$	2.34	2.67	2.34	1.01	4.07	87.57
Ampong	12	T2	$A_{12}T2$	1.40	0.67	3.04	0.57	2.40	91.93
Ampong	12	T3	$A_{12}T3$	2.08	1.50	2.31	0.77	3.93	89.41
Ampong	12	T4	$A_{12}T4$	1.30	2.17	2.47	0.50	3.00	90.57
Ampong	12	T5	$A_{12}T5$	1.38	1.17	2.60	0.30	3.80	90.76
Ampong	14	T1	$A_{14}T1$	2.82	0.83	1.49	1.53	2.14	91.19
Ampong	14	T2	$A_{14}T2$	2.44	0.83	1.91	0.76	2.48	91.58
Ampong	14	T3	$A_{14}T3$	3.06	1.00	1.90	0.83	2.43	90.78
Ampong	14	T4	$A_{14}T4$	2.70	0.50	2.05	0.72	2.22	91.81
Ampong	14	T5	$A_{14}T5$	2.44	0.50	2.89	0.65	2.66	90.86
Broni	10	T1	$B_{10}T1$	2.63	0.21	2.73	1.34	0.72	92.36
Broni	10	T2	$B_{10}T2$	1.71	0.36	2.36	0.47	4.86	90.24
Broni	10	T3	$B_{10}T3$	2.34	0.56	0.68	1.02	5.12	90.28
Broni	10	T4	$B_{10}T4$	1.74	0.48	2.43	0.84	4.23	90.28
Broni	10	T5	$B_{10}T5$	1.77	0.44	1.99	0.33	4.26	91.21
Broni	12	T1	$B_{12}T1$	2.20	3.17	1.82	0.72	3.87	88.23
Broni	12	T2	$B_{12}T2$	1.46	2.17	2.39	0.61	3.00	90.38
Broni	12	T3	$B_{12}T3$	2.24	1.33	1.86	1.14	4.20	89.24
Broni	12	T4	$B_{12}T4$	1.62	2.50	2.24	0.73	3.40	89.52
Broni	12	T5	$B_{12}T5$	1.38	2.33	2.07	0.80	4.60	88.81
Broni	14	T1	$B_{14}T1$	2.90	0.50	3.47	1.27	2.66	89.19
Broni	14	T2	$B_{14}T2$	2.44	0.50	3.42	1.01	3.01	89.62
Broni	14	T3	$B_{14}T3$	2.60	0.67	2.41	1.08	1.16	92.09
Broni	14	T4	$B_{14}T4$	1.98	0.50	2.60	0.85	1.38	92.68
Broni	14	T5	$B_{14}T5$	2.29	0.50	3.53	0.78	2.24	90.66
Otuhia	10	T1	$O_{10}T1$	2.79	0.44	2.68	1.55	4.01	88.53
Otuhia	10	T2	$O_{10}T2$	1.82	0.24	2.48	0.53	2.86	92.07
Otuhia	10	T3	$O_{10}T3$	2.54	0.29	2.38	0.89	3.98	89.93
Otuhia	10	T4	$O_{10}T4$	1.76	0.93	2.59	0.76	2.91	91.05
Otuhia	10	T5	$O_{10}T5$	1.93	0.57	2.74	0.60	3.25	90.91
Otuhia	12	T1	$O_{12}T1$	2.02	1.33	1.67	1.79	3.80	89.38
Otuhia	12	T2	$O_{12}T2$	1.35	0.67	1.60	0.92	3.07	92.40
Otuhia	12	T3	$O_{12}T3$	1.99	2.50	1.72	1.22	3.53	89.03
Otuhia	12	T4	$O_{12}T4$	1.37	1.33	2.08	0.85	2.53	91.84
Otuhia	12	T5	$O_{12}T5$	1.50	1.33	1.29	0.48	1.50	92.99
Otuhia	14	T1	$O_{14}T1$	2.90	0.50	1.76	1.61	1.69	91.54
Otuhia	14	T2	$O_{14}T2$	2.29	0.50	2.33	0.83	2.73	91.32
Otuhia	14	T3	$O_{14}T3$	3.06	0.50	1.64	1.28	1.93	91.59
Otuhia	14	T4	$O_{14}T4$	1.83	0.67	2.22	0.90	1.95	92.42
Otuhia	14	T5	$O_{14}T5$	2.14	1.17	1.57	0.94	2.08	92.09

cv (%)				14.30	23.00	18.00	11.40	12.40	0.70
L.s.d.				0.49	0.36	0.67	0.17	0.55	1.06

CHO=carbohydrate,CV=Coefficience of variation,L.s.d.=Least significant difference.A,B ,O=Ampog,Broni and otuhia varieties respectively while subscript 10,12 and 14 = harvest ages in months, and T1 to T5 represents pretreatment methods as presented in section3.2.5

The fat content of B_{12} T_1 (3.17%) was higher than the rest of the flour samples while the fiber content of $B_{14}T_5$ (3.53%) was higher ($P \leq 0.05$) than the other samples with the exception of $A_{10}T_1$ (2.92%), $A_{10}T_2$ (2.94%), $A_{10}T_3$ (3.16), $A_{14}T_5$ (2.89%), $B_{14}T_1$ (3.47%) and $B_{14}T_2$ (3.42%) which did not differ from each other.

Generally, the fibre content of all the samples were observed to range from 1.29% to 3.53% which falls within the range of 1.38% to 3.20% reported by Afoakwa *et al.* (2012) but much higher than the range (0.01 to 0.8%) reported by by Etudaiye *et al.* (2008). The ash content of A_{12} T_1 (1.79%) was also observed to be higher ($p \leq 0.05$) than the rest of the samples which ranged from 0.26% to 1.53%.

The moisture content of all the samples were observed to be generally low ranging from 0.28% for $A_{10}T_4$ to 5.12% for $B_{10}T_3$.

The generally low moisture content recorded by the samples emanates from the fact that the samples were dried to a constant weight using a mechanically ventilating oven dryer. This moisture content range was below the 13% Codex Standard of FAO (1995) for maximum moisture content of cassava flour for effective storage.

The carbohydrate content was observed to range from 87.57% for $A_{12}T_1$ sample to 93.56% for $A_{10}T_4$ sample. However, the $A_{10}T_4$ sample with 93.56% of carbohydrate which was at the upper limit of the range was significantly higher ($p \leq 0.05$) than the rest of the samples with the exception of $A_{10}T_5$ (93.41) $B_{14}T_4$ (92.68%) and $O_{12}T_5$ (92.99%) which were not significantly different.

Table 4.

4.3.2 The Effects of Varietal Differences, Harvest Age and Pretreatment On pH Values of Cassava Flour

The main effect of harvest age on the pH values of cassava flour is presented in table 4.5 below

5 Main effect of harvest age the on pH values of cassava flour

	Harvest age (months)				
	10	12	14	CV (%)	Lsd
pH	6.088	6.214	6.198	0.300	0.008

The pH values of the cassava flour samples produced from tubers harvested at 10 months, 12 months and 14 months were 6.088, 6.214 and 6.198 respectively and they differed significantly ($p \leq 0.05$) from one another with the flour samples from tubers harvested at 12 months of age being higher than the rest.

The table of the main effect of variety on pH values of cassava flour (Table 4.6) indicates that the pH was significantly ($p \leq 0.05$) affected by variety with that of *Ampong* variety having the highest value of 6.326 while the values were 6.131 and 6.043 for *Broni* and *Otuhia* varieties respectively.

Table 4. 6 Main effect of Variety on pH values of cassava flour

	Variety			CV (%)	Lsd
	Ampong	*Broni*	*Otuhia*		
pH	6.326	6.131	6.043	0.300	0.008

The results obtained from the main effect of harvest age and variety imply that products developed from *Ampong* cassava variety and the cassava products harvested at 12 months of age are less acidic and hence less sour in taste since the sourness of food product can be associated with their level of acidity.

The pH values of the cassava flour was also significantly ($p \leq 0.05$) affected by pre-treatment as can be observed from the table of means of the main effect of pre–treated presentment in Table 4.7

Table 4. 7 Main effect of Pre-treatment on pH values of cassava flour pretreatment

	Pre-treatment					CV (%)	Lsd
	T1	T2	T3	T4	T5		
pH	6.844	6.105	5.839	6.197	5.850	5.850	0.011

The pH values of the cassava flour significantly varied ($p \leq 0.05$) among treatment with the T_1 pre-treatment (chipping) which has a value of 6.844, being higher ($p \leq 0.05$) than the rest. The pH values of T_3 (5.839) and T_5 (5.850) were not significantly different from each other even though they were lower ($p \leq 0.05$) than the other three samples. The high acidity (low pH) of T_3 and T_5 could be associated with the use of citric acid solution during the pre-treatment while the low acidity (high pH) of T_1 was as a result of the fact that drying started immediately after chipping without exposure to any form of fermentation as experienced by the other samples.

The interactive effect of harvest age, variety and pre-treatment on pH values of cassava flour is presented in Table 4.8.

8 The interactive effect of variety, harvest age and pre-treatment on pH values of cassava flour

Table 4.

Sample code	Variety	Age (months)	Pre-treatment	pH
$A_{10}T1$	*Ampong*	10	T1	6.683
$A_{10}T2$	*Ampong*	10	T2	6.443
$A_{10}T3$	*Ampong*	10	T3	5.473
$A_{10}T4$	*Ampong*	10	T4	6.417
$A_{10}T5$	*Ampong*	10	T5	5.693
$A_{12}T1$	*Ampong*	12	T1	6.713
$A_{12}T2$	*Ampong*	12	T2	6.533
$A_{12}T3$	*Ampong*	12	T3	6.643
$A_{12}T4$	*Ampong*	12	T4	6.540
$A_{12}T5$	*Ampong*	12	T5	5.893
$A_{14}T1$	*Ampong*	14	T1	6.887
$A_{14}T2$	*Ampong*	14	T2	6.593
$A_{14}T3$	*Ampong*	14	T3	5.770
$A_{14}T4$	*Ampong*	14	T4	6.687
$A_{14}T5$	*Ampong*	14	T5	5.923
$B_{10}T1$	*Broni*	10	T1	6.960
$B_{10}T2$	*Broni*	10	T2	5.920
$B_{10}T3$	*Broni*	10	T3	5.953
$B_{10}T4$	*Broni*	10	T4	6.090
$B_{10}T5$	*Broni*	10	T5	5.837
$B_{12}T1$	*Broni*	12	T1	6.847
$B_{12}T2$	*Broni*	12	T2	5.953
$B_{12}T3$	*Broni*	12	T3	5.990
$B_{12}T4$	*Broni*	12	T4	5.987
$B_{12}T5$	*Broni*	12	T5	5.803
$B_{14}T1$	*Broni*	14	T1	6.720
$B_{14}T2$	*Broni*	14	T2	5.973
$B_{14}T3$	*Broni*	14	T3	6.000
$B_{14}T4$	*Broni*	14	T4	6.027
$B_{14}T5$	*Broni*	14	T5	5.903
$O_{10}T1$	*Otuhia*	10	T1	6.903
$O_{10}T2$	*Otuhia*	10	T2	5.800
$O_{10}T3$	*Otuhia*	10	T3	5.500
$O_{10}T4$	*Otuhia*	10	T4	5.950
$O_{10}T5$	*Otuhia*	10	T5	5.703
$O_{12}T1$	*Otuhia*	12	T1	6.910
$O_{12}T2$	*Otuhia*	12	T2	5.863
$O_{12}T3$	*Otuhia*	12	T3	5.597
$O_{12}T4$	*Otuhia*	12	T4	6.023
$O_{12}T5$	*Otuhia*	12	T5	5.910
$O_{14}T1$	*Otuhia*	14	T1	6.970
$O_{14}T2$	*Otuhia*	14	T2	5.863
$O_{14}T3$	*Otuhia*	14	T3	5.620
$O_{14}T4$	*Otuhia*	14	T4	6.050
$O_{14}T5$	*Otuhia*	14	T5	5.980
cv (%)				0.300
L.s.d				0.032

CV=Coefficience of variation,L.s.d.=Least significant difference.A,B ,O=Ampog,Broni and otuhi varieties,respectively,subscript 10,12 and 14 = harvest ages , and T1 to T5 represents pretreatment methods as presented in section3.2.5

a

The cassava flour samples from *Broni* variety harvested at 10 months and *Otuhia* variety harvested at 14 months with chipping pre-treatment ($B_{10}T1$ and $O_{14}T1$ respectively) had pH values of 6.960 and 6.970 which were significantly higher ($p \leq 0.05$) than the pH values of other samples. The flour samples from *Ampong* (5.473) and *Otuhia* varieties harvested at 10 months and pre-treated by steeping chipped roots in citric acid ($A_{10}T_3$ and $O_{10}T_3$) had pH values of (5.473 and 5.500 respectively) which were lower ($P \leq 0.05$) than the pH values of all other samples.

4.3.3 The Hydrogen Cyanide Content of Cassava Products

The hydrogen cyanide content of cassava is a measure of the amount of cyanogenic glucoside present in the roots. When the cassava product is eaten by an animal or a human being, the cyanogenic glucoside contained in it is released in the form of hydrogen cyanide which is toxic when present in a sufficient quantity in the body (Moller and Seigler, 1999; Ermans *et al*., 1980; Nahrstedt, 1993).

4.3.3.1 The Hydrogen Cyanide Content of the Fresh Cassava Roots

The cyanogenic potential of any particular cassava variety will partly determine the type of pre-treatment and processing the roots will need to undergo to make it safe for consumption. Fresh cassava roots with very high cyanogenic potential are expected to go through more elaborate processing than those with low cyanogenic potential. The main effect of harvest age on the hydrogen cyanide concentration of fresh cassava roots are as presented in Table 4.9

The result of the main effect of harvest age on the HCN concentration of fresh cassava roots reveals that the cyanide concentration was significantly affected ($p \leq 0.05$) by harvest age.

Table 4.

9 Main effect of harvest age on cyanide content of fresh cassava tubers

	Age (months)			CV (%)	Lsd
	10	12	14		
Cyanide content ($mgHCN_{eqv}/kg$)	84.97	55.55	42.22	4.00	2.38

The HCN of the roots harvested at 10 months was 84.97 mg HCN_{eqv}/kg which was significantly higher ($p \leq 0.05$) than the mean values of those harvested at 12 months (55.5 mg HCN_{eqv}/kg) and 14 months (42.22 mg HCN_{eqv}/kg). This result agrees with that of Sunne *et al.* (2006) which indicates that the cyanide content of the roots of a cassava variety in Thailand was significantly higher ($p \leq 0.05$) at 6 months (1427.2 mg HCN_{eqv}/kg) and 8 months (1259 mg HCN_{eqv}/kg) than the values obtained at 10 month (799.9 mg HCN_{eqv}/kg) and 12month harvest age (533.7 mg HCN_{eqv}/kg).

The table of means of the main effect of variety on cyanogenic potentials of fresh roots presented in Table 4.10 indicates that significantly differences ($p \leq 0.05$) existed between the cassava varieties studied. The cyanide concentration range of 55.39 mg HCN_{eqv}/kg to 65.43 mg HCN_{eqv}/kg for the roots from the three cassava varieties indicate that they can be classified as "average toxic" varieties in line with the classification methods of Jansz and Uluwaduge (1997). Nhassico *et al.* (2008) and Jansz and Uluwaduge (1997) categorized cassava into sweet (non-toxic), average toxic and bitter (toxic) with cyanide content ranges of less than 50, 50 to 100 and more 100 mg HCN_{eqv}/kg fresh weight basis respectively. Since these varieties fall within the "average toxic" category, they only require moderate processing to bring their cyanide contents to safe levels.

The cyanide content of fresh roots of *Otuhia* cassava variety which was recorded as

65.43 mg HCN_{eqv}/kg significantly differed ($P \leq 0.05$) from *Ampong* variety which had 61.91 mgHCN_{eqv}/kg and *Broni* variety with 55.39 mgHCN_{eqv}/kg

Table 4. 10 Main effect of variety on cyanide content of fresh cassava tubers

	Variety			CV (%)	Lsd
	Ampong	*Broni*	*Otuhia*		
Cyanide content (mgHCN_{eqv}/kg)	61.91	55.39	65.43	4.00	2.38

The effects of the harvest age and variety interaction on the cyanide concentration presented in Table 4.11 indicate significant differences ($p \leq 0.05$) between the samples. The cyanide content of *Broni* variety harvested at 14 months of age (38.34 mg HCN_{eqv}/kg) significantly differed ($p \leq 0.05$) from the rest of the samples with the exception of *Ampong* variety harvested at 14 months with cyanide content of 42.17 mg HCN_{eqv}/kg.

The cyanide content of *Otuhia* variety harvested at 10 months which had a value of 91.45 mg HCN_{eqv}/kg was significantly higher ($p \leq 0.05$) than the rest of the samples. The harvest age and variety interaction also showed that cyanide content of *Ampong*, *Broni* and *Otuhia* varieties when harvested at 14 months were less than 50 mg HCN_{eqv}/kg hence making them fall within the sweet or non-toxic class.

11 The interactive effects of harvest age and variety on cyanide content of fresh cassava roots

Sample code	Age (months)	Variety	HCN (mg/kg)
A_{10}	10	*Ampong*	87.22
B_{10}	10	*Broni*	76.24
O_{10}	10	*Otuhia*	91.45

Table 4.

A_{12}	12	*Ampong*	56.34
B_{12}	12	*Broni*	51.61
O_{12}	12	*Otuhia*	58.69
A_{14}	14	*Ampong*	42.17
B_{14}	14	*Broni*	38.34
O_{14}	14	*Otuhia*	46.16
cv %			4.00
Lsd			4.13

A, B, O=*Ampong*,*Broni* and *Otuhia* respectively, subscripts 10,12,14 are harvest ages in months

4.3.3.2 Hydrogen Cyanide Content of Pre-Treated Cassava Flour

The main effect of harvest age on the cyanide content of pre-treated cassava flour is as presented in Table 4.12

Table 4. 12 Main effect of harvest age on cyanide content of pre-treated cassava flour

	Age (months)			CV (%)	Lsd
	10	12	14		
Cyanide content ($mgHCN_{eqv}/kg$)	4.15	3.99	3.92	2.20	0.04

The cyanide content of the pre-treated cassava flour was significantly ($p \leq 0.05$) affected by harvest age. The cyanide content was higher ($p \leq 0.05$) at 10 months harvest age (4.15 mg HCN_{eqv}/kg) than the values obtained at 12 months (3.99 mg HCN_{eqv}/kg) and 14 months (3.92 mg HCN_{eqv}/kg). All these values were lower than the ARSO (2012) and the FAO (1995) Codex Standard of 10 mg HCN_{eqv}/kg dry matter in cassava flour recommended as maximum allowable cyanide content of cassava flour for human consumption.

The table of means of the main effect of variety on cyanide concentration (Table4.13 indicates that the cyanide content of *Otuhia* variety was higher ($p \leq 0.05$) than those of *Ampong* (4.09 mg HCN_{eqv}/kg) and *Broni* (3.67 mg HCN_{eqv}/kg).

Table 4. 13 Main effect of variety on cyanide content of pre-treated cassava flour

	Variety			CV (%)	Lsd
	Ampong	*Broni*	*Otuhia*		
Cyanide content (mg HCN_{eqv}/kg)	4.09	3.67	4.30	2.20	0.04

The cyanide concentration in the cassava flour was also significantly ($P \leq 0.05$) affected by pre-treatment as can be observed in Table 4.14. Chipping pre-treatment (T1) yielded higher ($p \leq 0.05$) cyanide concentration of 6.10 mg HCN_{eqv}/kg relative to the other pre-treatment methods which had cyanide concentrations of 4.03 mg HCN_{eqv}/kg for toasting (T_2), 4.27 mg HCN_{eqv}/kg for chipping and steeping in citric acid (T_3), 2.90 mg HCN_{eqv}/kg for grating pre-treatment (T_4) and 2.8 mg HCN_{eqv}/kg for steeping in citric acid and toasting (T_5).

Table 4. 14 Main effect of pre-treatment on cyanide content of pre-treated cassava flour

	Pre-treatment					CV (%)	Lsd
	T1	T2	T3	T4	T5		
Cyanide content (mgHCN_{eqv}/kg)	6.10	4.03	4.27	2.90	2.80	2.20	0.05

The relatively higher values of cyanide concentration in T_1 pre-treatment can be attributed to the fact that there was not maceration or fermentation of the chips to accelerate cyanide reduction (White *et al*, 1994). The very low value of T_4 and T_5 can be attributed to the disruption of the cell structure of the cyanogenic glucoside (during grating) which lead to the release and spontaneous decomposition of compartmentalized cyanogens (by the enzyme linamarase) into volatile hydrogen cyanide which was lost by leaching and evaporation (White *et al*., 1994, Moller and Seigler, 1999).

From this results T_1 pre-treatment is not recommended for use as a processing method for cassava varieties with very high cyanogenic potential since this pretreatment method will not likely reduce the cyanide content of the final product to the safe level of 10 $mgHCN_{eqv}$/kg.

The harvest age, variety and pre-treatment interaction presented in Table 4.15 below indicate that the cyanide content of flour produced from *Otuhia* variety harvested at 10 months with chipping pre-treatment (O_{10} T_1) had a value of 6.99 $mgHCN_{eqv}$/kg. This was higher ($p \leq 0.05$) than the value for all other samples while the flour from *Broni* Variety harvested at 14 months with citric acid and toasting pre–treatment ($B_{14}T_5$) had lower ($p \leq 0.05$) cyanide content (2.48 $mgHCN_{eqv}$/kg) than other samples. The three factor combinations generally produced cassava flour with cyanide content in the range of 2.48 $mgHCN_{eqv}$/kg - 6.99 $mgHCN_{eqv}$/kg which is below the maximum cyanide content of 10 $mgHCN_{eqv}$/kg dry matter in cassava flour for safe consumption as recommended by FAO/WHO (2013).

Table 4. 15 The interactive effect of variety, harvest age, and pre-treatment on cyanide content of cassava flour

Sample code	Variety	Pre-treatment	Age (months)	HCN(mg/kg)
$A_{10}T1$	*Ampong*	T1	10	6.40
$A_{10}T2$	*Ampong*	T2	10	4.10

$A_{10}T3$	*Ampong*	T3	10	4.56
$A_{10}T4$	*Ampong*	T4	10	3.14
$A_{10}T5$	*Ampong*	T5	10	3.00
$A_{12}T1$	*Ampong*	T1	12	6.14
$A_{12}T2$	*Ampong*	T2	12	3.98
$A_{12}T3$	*Ampong*	T3	12	4.38
$A_{12}T4$	*Ampong*	T4	12	2.97
$A_{12}T5$	*Ampong*	T5	12	2.91
$A_{14}T1$	*Ampong*	T1	14	5.97
$A_{14}T2$	*Ampong*	T2	14	3.93
$A_{14}T3$	*Ampong*	T3	14	4.32
$A_{14}T4$	*Ampong*	T4	14	2.82
$A_{14}T5$	*Ampong*	T5	14	2.77
$B_{10}T1$	*Broni*	T1	10	5.34
$B_{10}T2$	*Broni*	T2	10	3.92
$B_{10}T3$	*Broni*	T3	10	3.98
$B_{10}T4$	*Broni*	T4	10	2.97
$B_{10}T5$	*Broni*	T5	10	2.70
$B_{12}T1$	*Broni*	T1	12	5.18
$B_{12}T2$	*Broni*	T2	12	3.86
$B_{12}T3$	*Broni*	T3	12	3.92
$B_{12}T4$	*Broni*	T4	12	2.67
$B_{12}T5$	*Broni*	T5	12	2.58
$B_{14}T1$	*Broni*	T1	14	5.14
$B_{14}T2$	*Broni*	T2	14	3.83
$B_{14}T3$	*Broni*	T3	14	3.88
$B_{14}T4$	*Broni*	T4	14	2.61
$B_{14}T5$	*Broni*	T5	14	2.48
$O_{10}T1$	*Otuhia*	T1	10	6.99
$O_{10}T2$	*Otuhia*	T2	10	4.52
$O_{10}T3$	*Otuhia*	T3	10	4.61
$O_{10}T4$	*Otuhia*	T4	10	3.07
$O_{10}T5$	*Otuhia*	T5	10	2.97
$O_{12}T1$	*Otuhia*	T1	12	6.90
$O_{12}T2$	*Otuhia*	T2	12	4.13
$O_{12}T3$	*Otuhia*	T3	12	4.40
$O_{12}T4$	*Otuhia*	T4	12	2.97
$O_{12}T5$	*Otuhia*	T5	12	2.91
$O_{14}T1$	*Otuhia*	T1	14	6.81
$O_{14}T2$	*Otuhia*	T2	14	4.02
$O_{14}T3$	*Otuhia*	T3	14	4.38
$O_{14}T4$	*Otuhia*	T4	14	2.93
$O_{14}T5$	*Otuhia*	T5	14	2.88
cv (%)				2.20
Lsd				0.14

CV=Coefficience of variation,Lsd=Least significant difference

A,B ,O=Ampong,Broni andOtuhia cassava varieties respectively

subscript 10,12 and 14 = ages in months; T1 to T5=pre-treatments

4.4 Conclusion

The proximate composition of cassava flour was significantly ($p \leq 0.05$) affected by harvest age, variety and pre-drying treatments. The protein and ash contents of flour for 14 months harvest were higher ($p \leq 0.05$) than those for 12 and 10 months harvest while the fat content of the flour for 12 months harvest was higher ($P \leq 0.05$) than those for 10 and 14 months. The fibre and carbohydrate contents of those for 10 and 14 months harvest age did not differ from each other but were higher ($p \leq 0.05$) than those for 12 months harvest age. The protein and carbohydrate contents of *Ampong*, *Broni* and *Otuhia* cassava varieties did not differ from each other while the fat content of *Broni* and the ash content of *Otuhia* were higher ($p \leq 0.05$) than the others. Chipping pre-treatment produced cassava flour with higher protein and ash content while toasting produced flour with higher fibre.

The *Broni* and *Otuhia* cassava varieties harvested at 10 months and 14 months, respectively produced flour with higher ($p \leq 0.05$) pH values than those from other factor combinations.

The results generally showed that the processing of *Ampong*, *Broni* and *Otuhia* cassava varieties into flour using chipping, toasting, grating and citric acid pretreatment resulted in acceptable flour yield. The flours obtained had satisfactory quality attributes in terms of protein, fat, fibre, ash, carbohydrate, moisture content, pH and cyanogenic potentials.

The cyanide content of fresh *Ampong*, *Broni* and *Otuhia* cassava tubers harvested at 14 months were lower ($p \leq 0.05$) than those harvested at 10 months and 12 months and can be classified as sweet or non-toxic since the values were lower than 50

$mgHCN_{eqv}/kg$ fresh weight identified as the threshold for non-toxic fresh cassava tubers.

The three cassava varieties produced flour with low cyanide content in the range of 2.48 to 6.99 $mgHCN_{eqv}/kg$. These values are below the WHO/FAO (2013) recommendation (of cyanide content not greater than 10 $mgHCN_{eqv}/kg$ dry matter of cassava flour) and hence could be safely consumed by humans and animals without any fear of cyanide toxicity.

CHAPTER FIVE FUNCTIONAL AND VISCO-ELASTIC PROPERTIES OF PRE-TREATED

CASSAVA FLOUR

5.1 Introduction

Functional and visco-elastic properties of flours present useful information on the potential utilization of different types of flour for various purposes in the food and other related industries (Abioye, 2012). Some of the functional properties relevant in the use of flour for baking purposes are water absorption capacity, water binding capacity, swelling power and solubility. Water absorption capacity measures the extent of water retention in flours and hence affects the ability of the flour to form paste. In bread baking, flour with high water absorption capacity has greater potential for producing dough that gives a high yield of bread (Freeland-Graves and Peckham, 1987; Baidoo, 2010). Swelling power and solubility provide evidence of the magnitude of interaction between starch chains with the amorphous and crystallize domains and also evidence of association of bonding within the granules (Jimoh *et al*., 2010). Water binding capacity is an indicator to the usefulness of particular flour in the food system that requires hydration to improve handling characteristics. Giami and Alu (1994) reported that water binding capacity of 125% and above is an indication of a good baking material.

Visco-elastic properties of flour and starch materials are among the most vital parameters used in determining their suitability for particular end uses as they influence the texture, stability and digestibility of starch foods and hence determine the application and use of flour in various food products (Oke *et al*., 2013; Afoakwa *et al*., 2012). They are important indices vital in determining the cooking and baking qualities of flours from various crops and their use for other industrial purposes (Adeniji *et al*., 2010).

The visco–elastic properties of flour and starch materials also assists the industrialists and food producers in selecting the type of flour or starch for use as thickeners and binders. Some components of the visco-elastic properties considered in this report are peak time, gelatinization temperature, peak viscosity, breakdown, setback and final viscosities of the cassava flour. Gelatinization temperature is the temperature at which irreversible swelling of starch granules is obtained leading to formation of a viscous paste in an aqueous solution (Afoakwa *et al*., 2012). It is an indicator of the minimum temperature required to cook the sample (Adeniji *et al*., 2010; Otegbayo *et al.*, 2006). Low pasting temperature and paste stability implies that fewer associative forces and cross-links are present within the starch granule (Afoakwa and SefaDedeh, 2002; Oduro *et al*., 2000). Peak viscosity of flour mixtures is a measure of the highest value of viscosity attained by the slurry during the heating cycle and is an indicator of the strengths of paste formed during processing (Niba *et al*., 2002). It reflects the ability of cooked starch to freely swell before their physical breakdown (Adeniji *et al.*, 2010; Singh *et al*., 2003). Various researchers have positively linked high peak viscosity with baking qualities of flour (Eduardo *et al*., 2013; Lazaridou *et al.*, 2007).

Breakdown viscosity is an indicator of resistance to heating and shear-thinning and the cohesiveness of cooked starch has been attributed to the resistance to breakdown viscosities of its molecules during heating and stirring (Adeniji *et al.*, 2010; Mahasukhonthachat *et al*., 2010; Moorthy, 2002). Setback viscosity is a measure of the retrogradative potential of food products. High setback viscosity is associated with the ability of the product to harden after cooling. Final viscosity indicates the ability of a flour sample to form gel or paste on cooling and also indicates the strength of cooked paste (Adeniji *et al*., 2010; Otegbayo *et al.*, 2006 Niba *et al.,* 2002).

5.2 Materials and Methods

The flour samples obtained from the drying experiment in section 3.2 were used for this evaluation.

5.2.1 Determination of the Functional Properties of Cassava Flour

5.2.1.1 Swelling Power (SP) and Solubility

The solubility and SP of the cassava flour were determined using the method of Leach *et al*. (1959). One gram of the sample was weighed into a 50 ml centrifuge tube and water added to give a total volume of 40 ml. The tube and its contents were heated for 30 min in a water bath at a temperature of 85 ^{o}C with constant stirring. The sample was then centrifuged for 15 min using Hermle 2206A centrifuge of 5 cm radius at a speed of 2200 rpm (271 x g) after cooling to room temperature. The supernatant was poured into a glass crucible and the weight of the sediment noted. The supernatant in the glass crucible was evaporated in an oven at 105 ^{o}C for 24 h and the residue weighed. The solubility and swelling power were calculated using equations (5.1) and (5.2) respectively:

$$\text{Solubilty}(\%) = \frac{\text{weight of residue}}{\text{weight of sample}} \text{ x } 100 \qquad (5.1)$$

$$\text{Swelling power } (\%) = \frac{\text{weight of sediment}}{\text{weight of sample x } (100-\text{ solubility})} \times 100 \qquad (5.2)$$

5.2.1.2 Water Binding Capacity (WBC)

The water binding capacity (WBC) of the flour was determined by dissolving 2.0 g sample of cassava flour in 40ml of distilled water (Sathe and Salunkle, 1981). The aqueous suspension formed was agitated for about 1 h in a water bath (OLS 200, UK) after which it was centrifuged for 10 min using Hermle 2206A centrifuge of 5 cm radius at 2200 rpm (271 x g). The free water was decanted from the wet sample and drained for 10 min. The WBC was then calculated using equation (3):

$$\text{WBC (\%)} = \frac{\text{bound water}}{\text{weight of sample}} \times 100 \qquad (5.3)$$

5.2.1.3 Water Absorption Capacity (WAC)

The water absorption capacity (WAC) of the flour was determined by measuring 10 ml of distilled water into a 50 ml centrifuge tube containing 1.0 g of the cassava flour sample and then mixed for 3 min in the Rota Mixer 7023. The resulting suspension was centrifuged for 30 min at 500 rpm (14 x g) using a centrifuge (Hermle, Z206A) of 5 cm radius. The water density was taken as 1.0 g.ml^{-1}. The water absorbed was then calculated as the difference between the initial volume of water added to the sample and the volume of the supernatant.

The procedure was repeated for oil absorption capacity except that oil was used instead of water. The density of the oil used (frytol) was 0.882 g/ml

WAC (g/g) = Initial volume of water added – volume of the supernatant.

OAC (g/g) = (Initial volume of oil added – volume of the supernatant) x oil density

5.2.2 Determination of the Visco-elastic Properties

The Visco-elastic properties of the cassava flour were determined using the Brabender Viscogrpah (Brabender Instrument Inc. model 80256 Germany). The moisture contents of the samples were first determined and the values obtained entered into the software which gave the required sample weight and the volume of distilled water to be added. The required volume of distilled water was thoroughly mixed with the flour sample in a beaker and the solution dispensed into a canister well fitted in the equipment as recommended in the operating manual. The slurry was then heated from 50 °C to 95 ^{o}C and held at 95 ^{o}C for 15 min after which it was cooled to 50 ^{o}C and again held for 15 min. The heating and cooling was at a constant rate of 1.5 ^{o}C/min. The gelatinization temperature, peak time, peak viscosity, breakdown, set-back and final viscosity values were read from the pasting profile (Fig 5.1) using the software Thermocline for Windows. The viscosity was expressed in Brabender Units (BU).

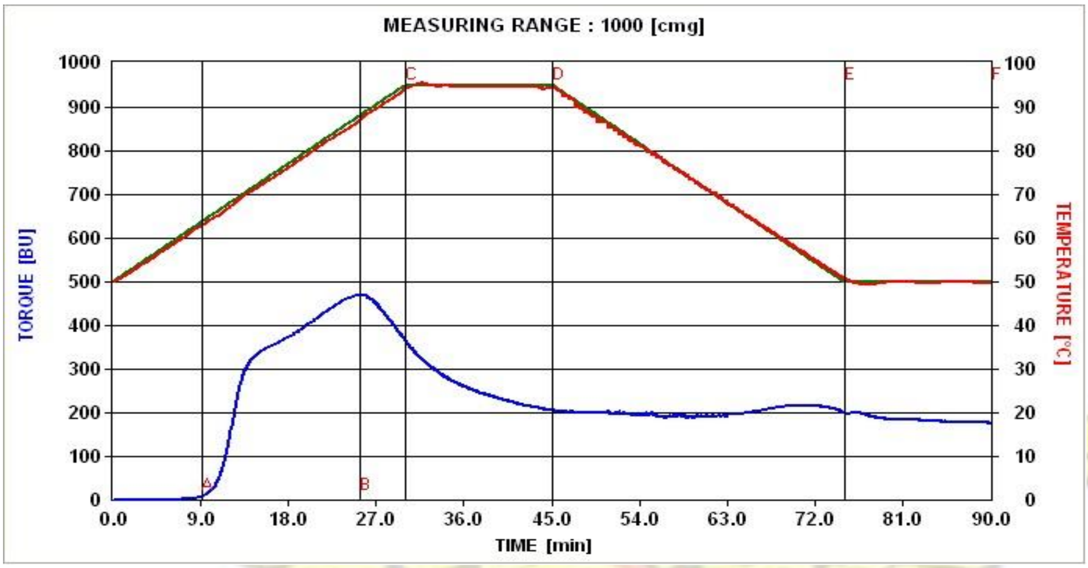


Figure 5. 1 A sample of the pasting profile of cassava flour toasted for 6min. ABeginning of gelatinization; B-maximum viscosity; C- starting of holding period; D-start of cooling period; E-end of cooling period; F-end of final holding; (B-D)—breakdown viscosity; (E-D)- setback viscosity.

5.2.3 Study Design and Statistical Analysis

A 3x3x5 factorial design in CRD was used for the study where the main factors were the three levels of harvest age, 3 levels of variety and 5 levels of pre-treatment methods. The data obtained were analysed using Genstat 12th edition. General

Analysis of Variance (ANOVA) and mean separation were performed using

Fischer’s Least Significant Difference of means to determine significant differences at 5 % probability level.

5.4 Results and Discussion 5.4.1. Effect of Toasting Time on Functional and Visco-Elastic Properties of Toasted Cassava Flour.

5.4.1.1 Effect of Toasting Time on Functional Properties of Toasted Cassava Flour.

The results of the functional properties of the flour are presented in Table 5.1

The water absorption capacity of the flour samples produced for 4 min and 6 min toasting was significantly higher ($p \leq 0.05$) than the values obtained for all other samples. Low water absorption capacity as reported by Lorenz (1990) is attributed to a close association of polymers in the native starch granules. Freeland-Graves *et al*. (1987) and Baidoo *et al*. (2010) also reported that in the baking industry, flour with high water absorption capacity have greater potentials for producing dough that will give a high bread yield .

Table 5. 1 Mean values of functional properties of toasted cassava flour at different toasting durations

Toast time (minutes)	Solubility (%)	SP (%)	WAC (g/g)	WBC (g/g)
2	4.33^{a}	9.60^{b}	4.233^{c}	213.3^{e}
4	4.07^{ab}	9.87^{ab}	4.900^{a}	389.7^{c}
6	4.27^{a}	10.13^{ab}	4.600^{b}	487.3^{a}
8	4.50^{a}	10.37^{a}	4.300^{c}	415.3^{b}
10	3.30^{b}	10.20^{ab}	4.233^{c}	353.3^{d}
LSD	0.681	0.934	0.29	14.52

Means with different letters in the same column are significantly different at $p \leq 0.05$; SP = Swelling power, WAC = Water absorption capacity, WBC = Water binding capacity

Cassava flour produced for 6 min and 8 min toasting time had higher values of swelling power and solubility than the other flour samples. Soni *et al.* (1993) attributed the high solubility indices in starches to easy solubility of the linear fraction (amylose) which is loosely linked to the rest of the macro molecular structure, and released during the swelling process.

The value of WBC of the flour for 6 min toasting time is significantly higher than those obtained for the other flour samples. Giami and Alu (1994) reported that WBC of 125% and above is an indication of a good baking material. The WBC of all the (5) samples were however higher than the benchmark value reported by Giami and Alu (1994).

5.4.1.2 Effect of toasting time on the visco –elastic properties of toasted cassava flour

The results of relevant components of visco-elastic properties of toasted cassava flour at different toasting durations are as presented in Table 5.2.

Table 5. 2 Mean values of the visco-elastic properties of toasted cassava flour at different toasting durations

Toast Time (min)	Gelatinization Temp. (°C)	Peak viscosity (BU)	Breakdown Viscosity (BU)	Setback viscosity (BU)	Final Viscosity (BU)
2	87.17^{cd}	481.0^{a}	248.0^{b}	$(-75.0)^{c}$	169.0^{c}
4	87.20^{c}	458.0^{b}	230.0^{c}	$(-2.0)^{a}$	244.0^{a}
6	87.00^{d}	483.3^{a}	267.3^{a}	$(-5.0)^{a}$	206.7^{b}
8	88.20^{a}	423.0^{c}	217.0^{d}	$(-55.0)^{b}$	146.0^{d}
10	87.60^{b}	378.0^{d}	179.0^{e}	3.0^{a}	201.0^{b}
Lsd	0.1879	13.15	7.34	17.85	18.13

Means with different letters in the same column are significantly different from each other

The cassava flour samples obtained for 6 min toasting time had the lowest gelatinization temperature which was significantly lower ($p \leq 0.05$) than the gelatinization temperature of the other four samples as shown in Table 5.2. This implies that fewer associative forces and cross-links are present within the starch granule of this sample and hence has a faster cooking quality.

The peak viscosity values of the flour samples produced for 2 min and 6 min toasting periods were significantly higher ($p \leq 0.05$) than the values from the other samples while those produced from 10min toasting time had the least value. This implies that pre-drying toasting of cassava for 6 min will result in the production of flour with better baking quality than those toasted for other time durations. Breakdown viscosity was significantly affected by the toasting time. The cassava flour that was toasted for 6 min had the highest value of breakdown viscosity while those toasted for 10 min had the least value. This is associated with the low gelatinization temperature which disposed it to a longer period of shear and hence a higher breakdown value.

The flour samples obtained for 4 min, 6 min and 10 min toasting time gave higher ($p \leq 0.05$) setback viscosity relative to those obtained for 2 min and 8 min toasting time as indicated in Table 5.2. A high setback viscosity is associated with the ability of the product to harden after cooling.

The highest value of the final viscosity observed in this study was 244 BU for 4 min toasting time followed by 206.7 BU for 6 min toasting time while the least value was 146 BU for 8 min toasting time as given in Table 5.2. Cooked products from flour toasted for 4 min and 6 min will therefore have greater gel or paste strength.

5.4.2 Functional and Visco-Elastic Properties of Pre-Treated Cassava Flour

5.4.2.1 Effect of Harvest Age on Functional Properties of Cassava Flour.

The main effect of harvest age on the functional properties of pre-treated cassava flour is as presented in Table 5.3.

Table 5. 3 Main effect of harvest age on functional properties of cassava flour

Age (Months)	WBC (%)	Sol (%)	SWP (%)	WAC (g/g)	OAC (g/g)
10	291.4	9.97	10.60	3.40	0.67
12	240.4	6.91	9.14	1.78	0.64
14	238.7	5.46	6.23	3.39	0.32
CV%	5.3	12.90	4.20	5.00	21.90
Lsd	5.74	0.40	0.15	0.06	0.05

WBC=Water binding capacity; SOL=Solubility; SWP=swelling power; WAC = Water absorption capacity, OAC = Oil absorption capacity, CV=Coefficient of variation, Lsd = least significant difference ($p \leq 0.05$)

The results of the main effect of harvest age on the WBC of the cassava flour indicate that the value of the WBC progressively decreased from 291.4% at 10 months to 238.7% at 14 months even though the value obtained at 14 months was not statistically different from the value for 12 months (240.4%) but differed ($p \leq 0.05$) from the value for 10 months. The least mean value of 238.7% recorded for 14 months harvest age was however, higher than 125% minimum the WBC value recommended by Gianmi and Alu (1994) for good baking quality of a flour.

The solubility of the flour was equally higher ($p \leq 0.05$) at 10 months harvest age (9.97%) than the values of those for 12 months and 14 months harvest age (6.91% and 5.46% respectively). Significant differences ($p \leq 0.05$) existed between the solubility of the flour from roots harvested at 10 months (9.97%) and those at 12 months (6.91%) and 14 months (5.46%). Solubility which is a measure of the ease of dissolution of flour particles in water permits rapid and extensive dispersion of flour particles in solutions (Abiodun and Akinoso, 2014). High solubility of flour products leads to a finely dispersed colloidal system which results in the production of derived foods with homogenous macrostructure and smooth texture. Chelftel *et al.* (1986) reported that data from solubility properties of flour can be effectively utilized in determining the optimum conditions for flour extraction while Appea–Bah *et al*. (2011) and Eriksson (2014) in their work separately emphasized the importance of solubility in the study of the baking characteristics of flour. They reported that a flour with high solubility value tend to produce soggy and less cohesive dough.

Cassava flour produced from fresh roots at different harvest ages also differed significantly ($p \leq 0.05$) from each other in their swelling power. Swelling power which is the maximum increase in volume and weight starch when allowed to swell freely in water, appreciably affects the behavior of starch in food systems. The highest value of SWP (10.60%) was obtained from flour samples of roots harvested at 10 months of age while the lowest value of 4.20% was obtained from those harvested at 14 months. The higher swelling power of the flour sample from the roots harvested at 10 months of age suggests that they have relatively weaker bonding forces between their granules (Safo-Kantanka and Acquistucci, 1996).

The WAC of the flour samples for 10 months (3.40 g/g) and 14 months (3.39 g/g) harvest ages were significantly higher ($p \leq 0.05$) than the WAC values of samples from 12 months (1.78 g/g) harvest age. WAC is a very important functional property in the development of ready to eat food since it assures product cohesiveness (Kulkani *et al*., 1996). It is also essential in bulking of food products especially in baking application (Niba *et al*., 2002).

The Oil absorption capacity (OAC) of the flour samples from roots harvested at 10 months (0.67 g/g) and 12 months (0.64 g/g) were significantly higher ($p \leq 0.05$) than the mean values of the samples for roots harvested at 14 months (0.32 g/g). OAC is vital in food products since oil acts as flavor retainer and affects the mouth feel as well as improvement of the palatability and shelf life extension of food products particularly meat and bakery products where fat absorption is desired (Aremu *et al*., 2007)

5.4.2.2 Effect of Variety on Functional Properties of Cassava Flour

Mean values of the main effect of variety on functional properties of pre-treated cassava flour is presented in Table 5.4.

Table 5. 4 Main effect of variety on functional properties of cassava flour

Variety	WBC (%)	Sol (%)	SWP (%)	WAC (g/g)	OAC (g/g)
Ampong	242.80	7.38	8.98	2.97	0.53
Broni	252.80	7.48	8.28	2.66	0.58
Otuhia	274.90	7.49	8.71	2.94	0.51
CV (%)	5.30	12.90	4.20	5.00	21.90
L.s.d	5.74	0.40	0.15	0.06	0.05

WBC=Water binding capacity; SOL = Solubility; SWP = swelling power; WAC = Water absorption capacity, OAC = Oil absorption capacity, CV = Coefficient of variation, Lsd = least significant difference

The WBC of the flour from the three cassava varieties are significantly differed ($p \leq 0.05$) from each other. Flour from *Ampong* variety had the lowest WBC value of 274.9%. The WBC value of flour from *Broni* variety was 252.8% which significantly differed ($p \leq 0.05$) from those of the other two varieties. The WBC values generally obtained from these varieties were either within the range or higher than the values reported by previous researchers on various cassava varieties. Afoakwa *et al.* (2012) in their work on six cassava varieties in Ghana reported a WBC range of 234.53% to 276.63% while Aryee *et al.* (2006) in their work on 31 cassava varieties reported a range of WBC values of 113.66% to 201.99%. Shittu *et al*. (2007) in their study on the bread making properties of some cassava varieties reported a WBC range of 136.03% to 213.02%. The high water binding capacity recorded in the three varieties used in this study indicates that weak associative forces exists between the cassava starch granules resulting in the availability of more molecular surfaces for binding with water molecules (Sonni *et al.* 1993). This may have positive implications in the use of flour from these varieties in bakery products since higher WBC values increase the unit product yield as greater amount of water is required to make batter or dough of pre-determined consistency and this is used as baking guide (Pomeranz, 1971).

Solubility of the flour was however not significantly affected ($p > 0.05$) by the genotypic differences of the three varieties studied. The mean solubility values obtained for the three varieties ranged from 7.38% for *Ampong* variety to 7.49% for *Otuhia* variety. These values are within the range of 3.0% to 9.0% reported by Aviara *et al*. (2009) but lower than the solubility range of 11.0% to 20.8% reported by Eriksson (2013). Apea-Bah *et al*. (2011) also reported a range of higher solubility value of 7.81 to 18.8% for flour from four different cassava varieties. The low solubility values of flour from the three study varieties is therefore an important indicator for the production of more homogeneous dough.

The swelling power of flour from the three varieties significantly differed ($P \leq 0.05$) from each other. Flour from *Ampong* variety had the highest value of 8.98% while those from Broni variety had the lowest value of 8.28. The values obtained were within the range of 5.87% to 13.48% reported by Aryee *et al*. (2006) but lower than the range of 13.16% to 16.17% reported by Shittu et al. (2007) for different cassava varireties.

The WAC of flour samples from *Ampong* (2.97 g/g) and *Otuhia* (2.94 g/g) were significantly higher ($P \leq 0.05$) than the sample from *Broni* (2.66 g/g) variety while the

OAC of *Broni* variety was significantly higher than reported values of *Ampong* and *Otuhia* varieties respectively.

5.4.2.3 Effect of Pre-Treatment on Functinal Properties Cassava Flour

The effect of pretreatment on functinal properties of the cassava flour presented in Table 5.5 indicates that the WBC of the flour samples ranged from 175.70% for chipping with citric acid pre-treatment (T_3) to 387.70% for toasting with citric acid pre-treatment (T_5).

Table 5. 5 Main effect of pre-treatment on functional properties of cassava flour

P.T	WBC (%)	Sol (%)	SWP (%)	WAC (g/g)	OAC (g/g)
T1	177.80	10.16	7.89	2.27	0.44
T2	350.30	6.13	9.53	3.94	0.59
T3	175.70	9.16	7.71	2.12	0.61
T4	192.70	6.37	8.18	2.11	0.54
T5	387.70	5.42	9.98	5.00	0.53
CV%	5.30	12.90	4.20	0.08	21.90
Lsd.	7.40	0.52	0.20	0.08	0.06

WBC=Water binding capacity; SOL=Solubility; SWP=swelling power WAC = Water absorption capacity, OAC = Oil absorption capacity, P.T = Pre-treatment, T1 toT5 = Pre-treatment method as described in section3.2.5

Beside the chipping (T_1) and chipping with citric acid (T_3) pre-treatment which had WBC values of 177.8% and 175.7% respectively and were not signifficantly different from each other, all the pre-treatment methods differed ($p \leq 0.05$) from one another. Toasting (T_2) and toasting with citric acid pretreatment (T_5) had the highest WBC values of 350.3% and 387.7% respectively. The unusually high water binding capacity values of T_2 and T_5 could have arisen from the pre-gelatinisation action of the toasting pre-treatment which greatly weakened the associative forces between the starch granules that resulted in the exposure of more molecular surfaces of the granules for binding with water molecules. The WBC values of each of the five pre-treatment methods were however, above the 125% minimum WBC value recommended by Gianmi and Alu (1994) for good baking quality of flour.

The solubility values of the flour samples were significantly ($p \leq 0.05$) affected by pretreatment. The chipping pre-treatment had the highest level of solubility values of 10.6% and 9.16% for T_1 and T_3 respectively while the toasting pre-treatment recorded the lowest values of 6.13% for T_2 and 5.42% for T_5. The grating pretreatment (T_4) which had solubility value of 6.37% was not significantly different ($p \leq 0.05$) from the 6.13% value recorded for toasting (T_2) pre-treatment. The values recorded in this study for all the pree-treatment methods were within the solubility value range of 3.00% to 9.00% reported by Aviara *et al.* (2010) for cassava starch dried at different temperatures.

The SWP of the flour samples were significantly affected by pre-tretment. The SWP of the flour from T_2 (9.53%) and T_5 (9.98%) pre-treatment were significantly higher ($p \leq 0.05$) than the values obtained for T_1 (7.89%), T_3 (7.71%) and T_4 (8.18%) pretreatment methods.

The WAC of the flour ranged from 2.11 g/g for T_4 to 5.00 g/g for T_5 pre-treatment methods. With the exception of WAC of T_3 (2.12 g/g) and T_4 (2.11 g/g) which did not significantly differ from each other, all the flour samples were significantly affected by pre-treatment.

The oil absorption capacity (OAC) of the flour from the five pre-tretment methods ranged from 0.44 g/g for T_1 to 0.61 g/g for T_3 pre-treatment. The OAC of samples produced from T_2 (0.59 g/g), T_4 (0.54 g/g) and T_5 (0.53 g/g) were not significantly different ($p \leq 0.05$) while flour from T_3 (0.61 g/g) was higher ($p \leq 0.05$) and T_1 (0.44 g/g) was lower ($p \leq 0.05$) than the rest.

5.4.2.4 Interaction of Variety, Harvest Age and Pre-Treatment on Functional Properties of Cassava Flour

The results of the variety, harvest age and pretreatment interaction on the functional properties of cassava flour are presented in Table 5.6. The results indicate that the interactive effect was significant ($p \leq 0.05$) on the water binding capacity of the flour. The results show that the WBC values of $B_{IO}T_5$ (*Broni* variety harvested at 10 months with citric acid and toasting pre-treatment), O10T5 (*Otuhia* variety harvested at 10 months with citric acid and toasting pre-treatment) and O10T2 (*Otuhia* variety harvested at 10 months with toasting pre-treatment) were 473.30%, 490.00% and 491.70% respectively. The WBC of these three flour samples did not significantly differ from each other but were higher ($p \leq 0.05$) than the WBC values of samples from other factor combinations.

From Table 5.6, it can be deduced that all the flour samples with toasting pretreatment as part of their factor combination had very high WBC values. This is in agreement with what was earlier observed from the main effect of pre-treatment on the functional properties of cassava flour reported in Section 5.4.2.3.

The WBC values of the flour samples from A14T1 (145.0%) and O12T3 (146.0%) were significantly lower than the flour samples from the other factor combinations with the exception of A14T1 (156.7%), B12T4 (164.7%), O10T4 (165%) and O14T4 (160.7%) which were not significantly ($p \leq 0.05$) different from each other.

The solubility values of $A_{10}T_1$ (14.05%), $A_{10}T_3$ (13.68%), $O_{10}T_1$ (13.43%) and $O_{10}T_3$ (14.03%) were significantly higher ($p \leq 0.05$) than the values of the flour from other factor combinations with the exception of $O_{10}T_4$ (12.70%). The high solubility values of the flour samples with these factor combinations imply that the use of the flour in baking will result in products with homogenous macroscopic structures and smooth texture. Conversely, the solubility values of $A_{14}T_4$ (3.08%) were lower than the rest of the samples from other factor combinations with the exception of $A_{10}T_2$ (3.279%), $A_{14}T_5$ (3.67%) and $B_{14}T_2$ (3.90%) which were not significantly different from each other.

The SWP of the flour produced from *Otuhia* and *Ampong* varieties harvested at 10 months and subjected to toasting with citric acid pre-treatment were 13.20% and 12.95% respectively. These values were significantly higher ($p \leq 0.05$) than the values obtained from the other factor combinations. The swelling power of $O_{14}T_4$ (4.94%), $O_{14}T_3$ (4.83%), $B_{14}T_4$ (4.90%) and $B_{14}T_1$ (5.31%) were however lower ($p \leq 0.05$) than the values obtained from the other factor combinations with the exception of $A_{14}T_1$ (5.31%) which was not significantly different from the four samples.

The water absorption capacity of $A_{14}T_2$ (5.17 g/g) and $O_{14}T_5$ (5.17 g/g) were significantly higher ($p \leq 0.05$) than the values from other samples with the exception of $A_{10}T_2$ (5.00 g/g) which did not differ from the two samples.

The flour samples from $A_{10}T_2$, $A_{10}T_3$, $A_{10}T_5$, $B_{10}T_3$, $B_{10}T_5$, $O_{10}T_4$ and $O_{12}T_3$ had the same value of OAC (0.88 g/g) which was not different from the OAC value obtained from O10T2 (1.03 g/g) but was higher ($p \leq 0.05$) than the values obtained from samples with the other factor combinations.

Table 5. 6 Interaction of variety Age and pre-treatment on the functional properties of cassava flour

Variety	Age	P.T	sample code	WBC (%)	Sol (%)	SWP (%)	WAC (g/g)	OAC (g/g)
Ampong	10	T1	$A_{10}T1$	173.30	14.05	10.09	3.00	0.74
Ampong	10	T2	$A_{10}T2$	405.00	8.89	11.31	5.00	0.88
Ampong	10	T3	$A_{10}T3$	171.70	13.68	10.12	2.77	0.88
Ampong	10	T4	$A_{10}T4$	223.30	9.46	11.44	2.63	0.59
Ampong	10	T5	$A_{10}T5$	430.00	6.62	12.95	4.53	0.88
Ampong	12	T1	$A_{12}T1$	175.30	10.53	8.21	1.27	0.21
Ampong	12	T2	$A_{12}T2$	221.00	6.10	9.99	2.60	0.31
Ampong	12	T3	$A_{12}T3$	187.00	9.43	8.22	1.13	0.50
Ampong	12	T4	$A_{12}T4$	256.70	4.96	10.34	2.00	0.71
Ampong	12	T5	$A_{12}T5$	343.70	4.71	10.96	3.00	0.38
Ampong	14	T1	$A_{14}T1$	156.70	7.38	5.31	2.50	0.42
Ampong	14	T2	$A_{14}T2$	214.30	3.27	7.73	5.17	0.44
Ampong	14	T3	$A_{14}T3$	181.70	4.83	5.82	2.10	0.23
Ampong	14	T4	$A_{14}T4$	156.70	3.08	5.63	2.00	0.41
Ampong	14	T5	$A_{14}T5$	345.00	3.67	6.62	4.87	0.44
Broni	10	T1	$B_{10}T1$	173.30	11.80	9.11	2.50	0.44
Broni	10	T2	$B_{10}T2$	423.30	9.70	10.16	4.00	0.44
Broni	10	T3	$B_{10}T3$	175.00	9.51	8.35	2.50	0.88
Broni	10	T4	$B_{10}T4$	171.70	7.18	8.28	2.00	0.44
Broni	10	T5	$B_{10}T5$	473.30	5.73	10.73	4.50	0.88
Broni	12	T1	$B_{12}T1$	170.00	10.46	7.74	1.07	0.74
Broni	12	T2	$B_{12}T2$	273.70	6.29	9.92	2.50	0.62
Broni	12	T3	$B_{12}T3$	174.70	10.17	7.87	1.00	1.18
Broni	12	T4	$B_{12}T4$	164.70	5.20	9.03	1.43	0.79
Broni	12	T5	$B_{12}T5$	256.30	5.35	10.92	2.07	0.82
Broni	14	T1	$B_{14}T1$	145.00	9.23	5.10	2.17	0.39
Broni	14	T2	$B_{14}T2$	393.30	3.90	8.49	4.83	0.39
Broni	14	T3	$B_{14}T3$	181.70	7.51	5.71	2.43	0.27
Broni	14	T4	$B_{14}T4$	180.00	4.35	4.90	2.17	0.24
Broni	14	T5	$B_{14}T5$	436.70	5.75	7.88	4.67	0.21
Otuhia	10	T1	$O_{10}T1$	210.00	13.43	11.16	3.00	0.26
Otuhia	10	T2	$O_{10}T2$	491.70	7.10	11.92	4.50	1.03
Otuhia	10	T3	$O_{10}T3$	195.00	14.03	10.17	3.00	0.59
Otuhia	10	T4	$O_{10}T4$	165.00	12.70	10.09	2.50	0.88
Otuhia	10	T5	$O_{10}T5$	490.00	5.72	13.20	4.50	0.18
Otuhia	12	T1	$O_{12}T1$	288.30	6.95	7.57	2.40	0.47
Otuhia	12	T2	$O_{12}T2$	364.00	5.28	9.32	2.07	0.80
Otuhia	12	T3	$O_{12}T3$	146.00	6.66	8.26	1.60	0.88
Otuhia	12	T4	$O_{12}T4$	256.00	5.40	8.97	1.23	0.56
Otuhia	12	T5	$O_{12}T5$	328.00	6.12	9.82	1.30	0.62
Otuhia	14	T1	$O_{14}T1$	108.30	7.57	6.71	2.50	0.32
Otuhia	14	T2	$O_{14}T2$	366.70	4.66	6.95	4.83	0.38
Otuhia	14	T3	$O_{14}T3$	168.30	6.60	4.83	2.50	0.09
Otuhia	14	T4	$O_{14}T4$	160.00	4.99	4.94	3.00	0.27
Otuhia	14	T5	$O_{14}T5$	386.70	5.08	6.76	5.17	0.35
			cv (%)	5.30	12.90	4.20	5.00	21.90
			L.s.d.	22.21	1.56	0.59	0.23	0.19

WBC=Water binding capacity; SOL=Solubility; SWP=swelling power; WAC=Water absorption capacity, OAC=Oil absorption capacity, P.T =Pre-treatment, A, B, O=Ampong,Broni and Otuhia respectively, subscripts 10,12,14 are harvest ages in months,T1 toT5 represent pre-treatment methods as presented in section 3.3

5.4.2.5 Effect of Age at Harvest on Visco-Elastic Properties of Pre-Treated Cassava Flour

The main effect of age at harvest on the visco-elastic properties of pre-treated cassava flour from the three study varieties are summarized in Table 5.7. The results presented in the table indicate that the gelatinization temperature was significantly ($p \leq 0.05$) affected by harvest age.

Gelatinization temperature which is the temperature at which the starch granules swells irreversibly to form viscous paste in aqueous solution is an indicator of the minimum temperature required to cook a given sample.

Table 5. 7 Main effect of harvest age on Visco-elastic properties of cassava flour

Harvest age (Months)	Gelatinisation temp. (°C)	Peak time (minutes)	Peak. Viscosity (BU)	Breakdown Viscosity (BU)	Setback Viscosity (BU)	Final Viscosity (BU)
10	81.42	10.766	1269.4	755.5	154.8	693.9
12	83.15	11.234	1017.3	513	131.5	608.7
14	80.42	10.411	1278.6	758.2	135.9	686.9
CV%	0.30	2.8	3.4	4.4	17.1	3.6
L.s.d.	0.09	0.125	16.68	12.58	10.06	10.01

CV=Coefficient of variation, Lsd=least significant difference

The flour samples for 14 months harvest age recorded a lower ($P \leq 0.05$) gelatinization temperature of 80.42 °C relative to samples for 10 and 12 months harvest age which recorded 81.42 °C and 83.15 °C respectively. Similar trend was also observed in the value of the peak time with samples for 14 months harvest age recording a lower ($p \leq 0.05$) peak time of 10.41 minutes relative to the peak time values of samples for 10 and 12 months harvest ages which were 10.77 min and 11.23 min respectively. Similar trend was observed by Apea-Bah *et al*. (2011) also observed similar trend in their work on some cassava varieties from the Brong Ahafo region of Ghana where the gelatinization temperature of flour from four different cassava varieties were lower at

14 months harvest age than they were at 12 and 13 month of age. Sunne *et al. (*2006) also reported a significant variation ($p \leq 0.05$) in gelatinization temperature of cassava flour produced in Thailand from 69.94 °C at 6 month harvest age to 71.58 °C at 12 month harvest age.

The lower pasting temperature and peak time of samples for 14 months harvest age suggest that derived products from this flour will cook faster than those for 10 and 12 months harvest age. This will likely be preferred by end users for economic reasons if all other factors are favourable.

Peak viscosity which is the maximum viscosity attained by the cassava flour as a result of swelling of the starch granules during the heating cycle from 50 °C to 95 °C is an indicator of the ability of the starch granules to freely swell to form a strong paste before they physically breakdown during processing in food applications (Niba *et al.*, 2002; Afoakwa *et al*., 2012). The flour samples obtained at 14 months harvest age had the highest peak viscosity value of 1278.6 BU, even though this value was not significantly different from 1269.4 BU value obtained at 10 months. The peak viscosity of 1017.3 BU at 12 months harvest age was lower ($p \leq 0.05$) than the peak viscosity values at 14 months and 10 months. Kin *et al*. (1995) reported that high viscosity values are desirable by industrialists for uses in products requiring high thickening power to form strong paste at high temperature. Barcenas *et al.* (2009) also reported that measures that improve gel network and peak viscosity of flour paste during heating, strengthens the gas holding properties of expanding cells in baking dough and subsequently results in high loaf volume. Eduardo *et al*. (2013) further reported that improvement of dough development and gas retention by increasing dough viscosity and stability resulted in increased bread volume. Kulkani *et al.* (1996) also reported that flour with high peak viscosity are suitable for making products such as food binders while those having low viscosities are more suitable for preparing weaning foods.

Breakdown viscosity (BDV) is a measure of the stability of the hot paste of starch based products. The BDV of flour which is its ability to withstand heating under shear stress is a vital factor for many food processors and it is used in describing the starch gel quality (Madsen and Christian, 1996). Bainbridge *et al*. (1996) explained that industrial users of starch and flour products desire high paste stability because serious changes in paste viscosity during and after processing usually result in undesirable textural changes. The result of the main effect of harvest age on the BDV is reported in Table 5.7. This shows that the breakdown viscosity (BDV) values of the samples for 14 months harvest age (758.2 BU) and 10 months harvest age (755.5 BU) were not significantly different from each other but were higher ($p \leq 0.05$) than those of the samples for 12 months harvest age.

Setback viscosity (SBV) which is the difference between the final and trough viscosities is a measure of the re-association of the starch molecules during cooling. Aryee *et al*. (2006) reported that flour with a low setback viscosity will be unsuitable for products that require starch stability at low temperatures. ANOVA result from the data obtained from this study indicate that SBV of the flour for 12 and 14 month harvest age were not significantly different from each other but were lower ($p \leq 0.05$) than the 154.8 BU obtained at 10 month harvest age. The final viscosity of samples for 10 months and 14 months harvest age (693.9 and 686.9 BU respectively) were also not significantly different from each other but were higher ($p \leq 0.05$) than the final viscosity value of the flour for 12 months harvest age.

From the foregoing discussion, it can be deduced that harvesting cassava tubers at 14 months maturity age resulted in production of flour with relatively lower gelatinization temperature and peak time, higher peak viscosity, setback and final viscosity values which make such samples better for use as composite flour in baking.

5.4.2.6 Effect of Variety on Visco-Elastic Properties of Pre-Treated Cassava Flour

The result of the main effect of variety on the vicso-elastic properties of pre-treated cassava flour presented in Table 5.8 indicates that the gelatinization temperature was significantly ($p \leq 0.05$) affected by variety.

Table 5. 8 Main Effect of Variety on Visco-Elastic Properties of Pre-Treated Cassava Flour

Variety	G.T. (°C)	P.T. (minutes)	PV (BU)	BDV (BU)	SBV (BU)	FV (BU)
Ampong	82.591	11.194	1205.8	686.8	140.2	681.7
Broni	81.607	10.769	1146.3	639	136	631.2
Otuhia	80.793	10.447	1213.1	700.8	146	676.5
CV (%)	0.3	2.8	3.4	4.4	17.1	3.6
Lsd	0.0881	0.125	16.68	12.58	10.06	10.01

Lsd = Least significant difference, G.T.= Gelatinisation temp ; P.T.= Peak time, PV = Peak viscosity, BDV = Breakdown viscosity; SBV = Setback viscosity; FV = Final viscosity.

The gelatinization temperature of 80.79°C for *Otuhia* variety was lower ($p \leq 0.05$) than 81.61 °C and 82.59 °C for *Broni* and *Ampong* varieties respectively. The peak time of

10.45 min for *Otuhia* variety was equally lower ($P \leq 0.05$) than that of *Broni* and *Ampong* varieties which were 10.77 and 11.19 min respectively. This implies that products derived from *Otuhia* variety will most likely cook faster than those from *Broni* and *Ampong* varieties. The peak viscosity was also affected by the varietal differences of the cassava flour. The peak viscosity value of the flour from *Otuhia* variety was 1213.1 BU which was significantly higher than those from *Broni* and *Ampong* varieties with peak viscosity values of 1146.3BU and 1205.8BU respectively. The flour from *Otuhia* cassava variety will therefore be more suitable for use in composite flour for baking purposes while the flour samples from *Ampong* variety will be more suitable for products like light gruels and baby foods.

The breakdown viscosities of the three cassava varieties were generally high. The BDV of 639 BU for *Broni* variety was however lower ($p \leq 0.05$) than those from *Ampong* (686.8 BU) and *Otuhia* (700.8 BU) varieties. The flour from *Broni* variety therefore has greater potential of maintaining paste stability during heating.

The setback viscosity of the flour from the three varieties ranges from 136 to 146 BU and were not significantly different from each other. The final viscosity value of 631.2 BU from *Broni* variety was equally lower ($p \leq 0.05$) than 676.5 BU from *Otuhia* variety which did not significantly differ ($p \geq 0.05$) from the 681.7 BU of *Ampong* variety. Products from *Broni* variety therefore have greater tendency to form more solid paste on cooling. The mean final viscosity range of 631 BU to 681.7 BU obtained from the three varieties were higher than the final viscosity values reported by some previous researchers on different cassava varieties. Afoakwe *et al*. (2012) reported a final viscosity range of 37.17-260 BU for six cassava varieties while Niba *et al*., 2002 reported a final viscosity range of 19.3 to 232.7 RVU for 11 different cassava varieties in Ghana.

5.4.2.7 Effect of Pre-Treatment on Visco-Elastic Properties of Cassava Flour

The main effects of pre-treatment on the cassava flour from the studied varieties are presented in Table 5.9. The gelatinization (gel) temperature was significantly affected ($p \leq 0.05$) by pre-treatment except for T_1 (chipping) and T_3 (chipping with citric acid) pre-treatments which did not differ from each other but were lower ($p \leq 0.05$) than the other pre-treatment methods. The gel temperature of T4 (grating pre-treatment) was also lower ($p \leq 0.05$) than T_2 (toasting) and T_5 (toasting with citric acid).

The peak time of T1 (9.53) and T3(9.55) were also not different from each other but were lower than T4 which was in turn lower than T2 and T5 pre-treatment methods. The flour from T2 and T5 pretreatment will therefore require higher temperature and longer time to cook relative to flour from T4 and T3.

The peak viscosity values of the flour samples were also significantly ($p \leq 0.05$) affected by pre-treatment methods with the exception of T2 (1021.6 BU) and T5 (1038.8 BU) which did not differ from each other but were lower ($p \leq 0.05$) than 1215.4 BU and 1279.7 BU for T1 and T3 respectively. The peak viscosity of flour samples from T4 pre-treatment (1386.4 Bu) was higher ($p \leq 0.05$) than the values for all the other four samples.

The BDV of samples for T_2 and T_5 pre-treatments were 4511.2 BU and 458.8 BU respectively. These values were not significantly different ($p \leq 0.05$) from each other but were lower than the breakdown values of 811.6 BU, 8229.4 BU and 826.6 BU for T1, T3 and T4 respectively. The breakdown value of T_3 and T_4 were however not different ($p \leq 0.05$) from each other. The SBV of the flour for T_1 and T_3 which were 92 BU and 103BU respectively did not differ from each other but were lower ($p \leq$

0.05) than the values from the other three pretreatment methods. The values for T_5 (198.7 BU) and T_4 (136.6 BU) pretreatment methods were significantly different from each other and also higher ($p \leq 0.05$) than the values from T_1 and T_3.

The final viscosity values of the flour samples were significantly ($p \leq 0.05$) affected by pre-treatment methods. Final viscosity values of 793.7 BU and 716.3 BU for T_5 and T_4 pre-treatment methods were higher ($p \leq 0.05$) than the values obtained for the other pretreatment methods while the values from T_1 (524.9 BU) and T_3 (579.7 BU) were lower ($P \leq 0.05$) than the rest of the samples. Derived products from T5 and T4 pretreatment will therefore have more solid paste or gels after cooking and cooling.

Table 5. 9 Main effect of pre-treatment on visco-elastic properties of cassava flour

Pre-	Gelatinisation	Peak time	Peak	Breakdown	Setback	Final treatment
	temperature	Time	viscosity	viscosity	viscosity	viscosity
	(°C)	(min)	(BU)	(BU)	(BU)	(BU)
T1	78.063	9.525	1215.4	811.6	92	524.9
T2	84.878	11.83	1021.6	451.2	173	701.1
T3	77.952	9.548	1279.9	829.4	103.4	579.7
T4	80.504	10.637	1386.4	826.6	136.6	716.3
T5	86.922	12.477	1038.7	458.8	198.7	793.7
cv%	0.3	2.8	3.4	4.4	17.1	3.6
Lsd	0.1137	0.161	21.53	16.24	12.99	12.92

T1 toT5 =Pre-treatment method as described in section 3.2.5

5.4.2.8 Effect of Variety, Harvest Age, and Pre-Treatment Interaction on ViscoElastic Properties of Cassava Flour

The results of the variety, harvest age and pre-treatment interaction presented in Table 5.10 indicates that the gelatinization temperature of the flour samples for *Otuhia* variety harvested at 10 months with chipping pre-treatment ($O_{10}T_1$) had a value of

76.27 °C which was significantly lower ($p \leq 0.05$) than the gel temperature of samples from all the other factor combinations. The gel temperature of the flour samples for A_{10} T_3 (76.80 °C), $B_{10}T_4$ (76.97 ℃), $B_{12}T_4$ (76.97 °C) and $B_{14}T_1$ (77.07 °C) were not significantly different from each other. They were however lower

($p \leq 0.05$) than the values from other factor combinations with the exception of $O_{10}T_1$.

The peak time of the flour samples from $O_{10}T_1$ (9.00 min) and $O_{12}T_4$ (9.08 min) did not differ from each other but were significantly lower than the rest of the other samples except for $A_{10}T_3$ (9.29 min), $A_{14}T_1$ (9.42 min), $B_{10}T_3$ (9.46 min), $B_{12}T_4$ (9.33 min), $B_{14}T_1$ (9.17 min), B_{14} T_3 (9.46 min) and $O_{10}T_3$ (9.33 min). The low peak time of the flour for these factor contributions implies that the derived products for these flour samples will cook faster than the ones for the rest of the samples.

Peak viscosity which is one of the most important viscoelastic properties of flour products with respect to baking was significantly affected by age, variety and pretreatment interaction. The peak viscosity values of 1631.71 BU and 1631.00 BU for A14T4 and O_{14} T_1 respectively were significantly higher than the peak values for other factor combinations. Conversely, the peak viscosity values of 678.2 BU and

667.7 BU for $B_{12}T_5$ and $B_{14}T_2$ were significantly lower ($p \leq 0.05$) than those of the flour samples for all the other factor combinations. Products from the identified three factor combinations with the highest peak viscosity values are therefore potentially suitable for use as composite flour with wheat in the baking industry. The peak viscosity values from all the factor combinations were relatively high when compared with the peak viscosity values of 270 BU to 380.67 BU reported by Afoakwa *et al*., (2012). Sakyi-Dawson *et al.* (2006) also reported peak viscosity range of 298 BU to 914 BU for cassava varieties subjected to different pre-treatment methods.

Table 5. 10 Effect of variety, harvest age and pre-treatment interaction on viscoelastic properties of cassava flour

Variety	Age (Months)	P.T	sample code	Gelatinisation temp (ºC)	Peak time (min)	Peak viscosity. (BU)	BDV (BU)	SBV (BU)	Final viscosity (BU)
Ampong	10	T1	A_{10}T1	77.47	9.42	1244.00	834.70	111.30	550.70
Ampong	10	T2	A_{10}T2	87.10	12.54	1265.30	640.70	182.00	829.70
Ampong	10	T3	A_{10}T3	76.80	9.29	1279.00	831.70	131.70	610.30
Ampong	10	T4	A_{10}T4	81.37	11.73	1458.70	921.30	151.30	708.70
Ampong	10	T5	A_{10}T5	84.13	11.62	1147.00	574.70	190.00	794.70
Ampong	12	T1	A_{12}T1	79.27	9.96	1153.30	747.30	80.70	519.00
Ampong	12	T2	A_{12}T2	92.50	14.41	970.00	335.30	190.70	824.70
Ampong	12	T3	A_{12}T3	79.20	9.92	1321.00	847.00	98.70	596.00
Ampong	12	T4	A_{12}T4	90.93	14.17	1050.30	483.30	163.70	726.30
Ampong	12	T5	A_{12}T5	91.57	14.00	882.70	314.00	211.00	783.70
Ampong	14	T1	A_{14}T1	77.97	9.42	1279.00	873.30	75.30	519.00
Ampong	14	T2	A_{14}T2	80.93	10.50	970.30	461.70	171.30	697.70
Ampong	14	T3	A_{14}T3	77.80	9.64	1445.00	936.30	66.70	609.70
Ampong	14	T4	A_{14}T4	78.10	9.92	1631.70	1050.30	106.70	719.70
Ampong	14	T5	A_{14}T5	83.73	11.38	989.30	451.00	172.30	735.30
Broni	10	T1	B_{10}T1	78.73	9.75	1216.70	784.30	100.00	569.00
Broni	10	T2	B_{10}T2	85.00	11.92	1248.00	643.30	198.00	836.70
Broni	10	T3	B_{10}T3	77.83	9.46	1268.70	847.70	122.70	577.30
Broni	10	T4	B_{10}T4	80.30	10.58	1431.30	863.00	140.30	745.00
Broni	10	T5	B_{10}T5	85.17	11.92	1355.30	754.70	193.30	825.70
Broni	12	T1	B_{12}T1	78.70	9.64	1050.30	689.00	88.00	457.00
Broni	12	T2	B_{12}T2	90.80	13.79	850.00	160.70	121.30	283.70
Broni	12	T3	B_{12}T3	78.47	9.63	1108.70	686.70	89.00	519.70
Broni	12	T4	B_{12}T4	76.97	9.33	1121.30	581.00	146.70	695.30
Broni	12	T5	B_{12}T5	87.70	12.75	678.70	189.70	141.30	629.00
Broni	14	T1	B_{14}T1	77.07	9.17	1280.00	880.30	78.00	510.70
Broni	14	T2	B_{14}T2	81.97	10.81	667.70	261.30	160.70	590.30
Broni	14	T3	B_{14}T3	77.57	9.46	1288.30	843.00	101.70	569.70
Broni	14	T4	B_{14}T4	79.40	10.33	1631.00	1006.70	141.30	813.70
Broni	14	T5	B_{14}T5	88.43	13.00	999.00	393.70	218.30	845.70
Otuhia	10	T1	O_{10}T1	76.27	9.00	1077.30	746.70	93.70	454.70
Otuhia	10	T2	O_{10}T2	85.70	12.08	1159.30	613.00	188.30	754.00
Otuhia	10	T3	O_{10}T3	77.30	9.33	1137.00	705.00	128.30	578.70
Otuhia	10	T4	O_{10}T4	81.97	10.67	1507.00	947.30	165.00	692.70
Otuhia	10	T5	O_{10}T5	86.17	12.17	1245.70	624.00	226.30	880.70
Otuhia	12	T1	O_{12}T1	78.60	9.58	997.00	600.00	89.00	496.70
Otuhia	12	T2	O_{12}T2	77.80	9.46	990.00	415.70	147.70	729.00
Otuhia	12	T3	O_{12}T3	79.10	9.79	1157.00	746.30	85.00	513.30
Otuhia	12	T4	O_{12}T4	77.00	9.08	1087.70	591.70	105.70	631.70
Otuhia	12	T5	O_{12}T5	88.60	13.00	841.00	306.70	214.70	725.00
Otuhia	14	T1	O_{14}T1	78.50	9.79	1641.30	1149.00	112.30	647.00
Otuhia	14	T2	O_{14}T2	82.10	10.96	1073.30	529.30	197.00	764.70
Otuhia	14	T3	O_{14}T3	77.50	9.42	1514.00	1021.30	107.30	642.30
Otuhia	14	T4	O_{14}T4	78.50	9.92	1558.70	994.30	108.30	713.70
Otuhia	14	T5	O_{14}T5	86.80	12.46	1210.00	521.00	221.30	924.00
cv (%)				0.30	2.80	3.40	4.40	17.10	3.60

Lsd				0.34	0.48	64.58	48.71	38.96	38.77

P.T =Pre-treatment, A, B, O=*Ampong*,*Broni* and *Otuhia* respectively, subscripts 10,12,14 are harvest ages in months,
T1-T5= pre-treatment methods presented in section 3.2.5, BDV=Breakdown viscosity,SBV= setback viscosity.

The breakdown viscosity values of the flour for $B_{12}T_2$ (160.7 BU) and $B_{12}T_5$ (189.7 BU) were significantly lower than the value for other factor combination indicating that the flour from these samples have better hot paste stability compared with the rest of the flour samples. Conversely the breakdown viscosity value of the flour from $O_{14}T_1$ was 1149 BU which was significantly higher than the value for all the other factor combination implying that its products are unsuitable for use in circumstances where paste stability is required at high temperature under continuous shearing.

The SBV value of 226.3 BU for *Otuhia* ($O_{10}T_5$) variety harvested at 10 months with steeping in citric acid and toasting pretreatment was significantly higher ($p \leq 0.05$) than the values obtained for all the other factor combinations except for $O_{10}T_2$, $O_{12}T_5$, $O_{14}T_2$, $O_{14}T_5$, $B_{10}T_2$, $B_{10}T_5$, $B_{14}T_5$, $A_{10}T_5$, $A_{12}T_2$ and $A_{12}T_5$ which did not differ from each other. It can be observed that the factor combinations that resulted in the above listed samples included toasting pre-treatment (T2 and T5) in each of them. This validates the result obtained from the statistical analysis of the main effect of pretreatment on viscoelastic properties. The analysis indicated that the setback viscosity values for toasting pre-treatment were higher ($p \leq 0.05$) than the values for the other pretreatment methods.

$A_{14}T_3$ also had lower ($p \leq 0.05$) SBV values than all the other samples with the exception of samples for $A_{12}T_1$, $A_{12}T_3$, $A_{14}T_1$, $B_{12}T_1$, $B_{12}T_3$, $B_{14}T_1$, $B_{14}T_3$, $O_{10}T_1$, $O_{12}T_1$, and $O_{12}T_3$. It was also observed that low set back viscosity was generally associated with chipping pretreatment methods (T_1 and T_3) as was also reported in section 4.7.3 on the main effect of pre-treatment.

The final viscosity value of the flour for $O_{14}T_5$ (924.00 BU) was higher ($p \leq 0.05$) than the value for the other factor combinations while $B_{12}T_2$ had a final viscosity value of 283.7 BU which was lower than the values for the other factor combination.

On the average, the viscoelastic properties of flour from *Otuhia* cassava variety harvested at 14 months of age with grating, toasting and citric acid pre-treatments ($O_{14}T_5$) put it in a vantage position for use as partial substitute for wheat flour in baking.

5.5 Conclusion

Toasting duration of 6 min produced cassava flour with higher water absorption capacity, water binding capacity, peak and setback viscosity, and lower gelatinization temperature thus making it a better raw material for the baking industry compared with those produced for 2, 4, 8 and 10 min toasting time.

The mean values of water binding capacity, solubility, swelling power, water absorption and oil absorption capacity of cassava flour from tubers harvested at 10 months, 12 months and 14 months significantly differed ($p \leq 0.05$) from each other. The water binding capacity of flour from *Otuhia* cassava variety was higher than those for *Broni* and *Ampong* while the water absorption and oil absorption capacities of *Otuhia* and *Ampong* varieties did not differ from each other but were higher ($p \leq 0.05$) than that for *Broni* variety. The solubility of the three varieties did not differ ($p \geq 0.05$) from each other. Processing of cassava using toasting and grating pretreatment produced flour with higher swelling power and water-binding capacity while toasting produced flour with higher water absorption capacity than the others.

Harvesting cassava tubers at 14 months maturity age resulted in the production of flour with relatively lower gelatinization temperature and peak time, higher peak viscosity, set back and final viscosity values which make such flour better for use as composite flour in baking. The gelatinization temperature and peak time values of flour from *Otuhia* cassava variety were lower than those for the other varieties. The setback viscosity values of the flour from the three cassava varieties did not differ from each other while the peak and final viscosity values of the flours from *Otuhia* and *Ampong* varieties were higher than that of *Broni* variety. *Otuhia* therefore stands out as the cassava variety with greater potential for use in the baking industry.

The gelatinization temperature and peak time of the flour from chipping and citric acid pre-treatment had lower values than the other pre-treatment methods studied while grating pre-treatment had the highest peak viscosity value. The setback and final viscosity values of toasted and grated samples were higher than the others. Cassava flour produced from toasting and grating pre-treatments will be potentially useful for the baking industry even though products from chipping and citric acid pre-treatment will cook faster than others.

It was observed that the flour samples studied generally exhibited early gelatinization, high peak viscosity, setback and final viscosities and large paste breakdown. The first four qualities are good indicators of the suitability of the flour for the baking industry.

CHAPTER SIX

PRODUCT DEVELOPMENT AND SENSORY EVALUATION

6.1 Introduction

Bread is an important staple food among the urban dwellers in most West African countries and it is traditionally produced from a mixture of wheat flour, yeast, salt and water. Since wheat does not grow well in the tropical climate the concept of composite flour technology encourages the inclusion of indigenous crops such as cassava, yam, maize and other cereal crops as composite baking material for the production of bread and other baked products where wheat is solely used. One of the potential areas where cassava flour can effectively be utilised in the development of value added products of much relevance to the society is in its use as a composite baking material for the production of composite bread.

Since the introduction of this concept, there have been growing interests in the use of composite flour for bread baking in many developing nations. Eduardo *et al*. (2013) reported that in order to reduce the nation's expenses, the government of Mozambique mandated the use of composite flour in bread making. The government of the federal Republic of Nigeria also gave a policy directive for relevant stake holders to include 10% cassava flour in bread, biscuit and other confectioneries in order to sustain cassava production and reduce fund outflow for import of wheat (RMRDC, 2004).

Bread baked with cassava-wheat composite flour has been evaluated by various researchers and the general observations were reduced loaf volume, crust colour and impaired sensory qualities as the level of substitution with other flours increased (Defloor *et al.*, 1993; Eduardo *et al*., 2013; Eriksson *et al.*, 2014).

Various studies on wheat-cassava composite flour have investigated the influence of baking processes, effect of added hydrocolloids and other viscosity enhancers on bread quality (Eduardo *et al*., 2013; Shittu *et al.*, 2007; Owuamanam, 2007) but very little attention has been paid to the investigation of pre-treatment methods as a vital factor in the production of high quality cassava flour as ingredient in composite flour for bread production. The effect of five different pre-treatment methods on specific volume of wheat-cassava composite bread from three cassava varieties at different harvest ages were studied to identify the treatment combinations that will produce composite bread with the highest specific volume and acceptable sensory qualities.

6.2 Materials and Methods

The materials used for the baking were wheat flour (hard wheat), granulated sugar, refined iodide salt, instant dry yeast, nutmeg, margarine, milk, flavour and cassava flour. All these ingredients were purchased from standard shops that supply baking materials keeping the same specification in all experiments. The cassava flour was produced as described in Section 3.3

6.2.1 Baking Procedure

Bread dough was formed using 20% substitution of wheat flour with the pre-treated cassava flour. The dough samples were therefore prepared according to the following formula: 480 g wheat flour (hard wheat), 120 g pre-treated cassava flour, 100 g margarine, 40 g sugar, 4 g yeast, 3 g salt, 1 g nutmeg, 30 ml milk and 2.5 ml flavour. The amount of water added varied slightly from 320 ml to 360 ml in order to obtain equal consistency of the dough from each of the composite flour samples. All the ingredients were mixed in a dough mixer for 10 min after which it was manually kneaded and formed into parts of 350 g weight for baking and the specific volume evaluation (Figs 6.1 and 6.2).

Figure 6. 1 Dough mixer

The dough was covered with kitchen cloth in a greased pan and proofed for 2 h in a warm chamber at 35 °C. The proofed dough was transferred into a preheated oven at 190 °C where it was baked for 25 min. The baked loaves were cooled for one hour and then wrapped in cellophane bags ready for the specific volume evaluation. A control wheat bread (100% wheat flour) was prepared simultaneously in the same oven under identical conditions with those of composite flour.

6.2.2. Evaluation of Specific Volume of the Bread Samples

The specific volume of the bread samples was determined by a modification of the Rapeseed Displacement Method (AACC, 2000; Abdelghafor *et al*., 2011; Mongi *et al.*, 2011, Eriksson *et al*., 2014). Millet grains were used in this method instead of the conventional rapeseed. The bread loaf was first weighed and the weight of the bread sample was noted as W_b. A metal box of fixed dimension was placed on a tray and filled with millet grains till it was slightly overfilled. A level surface was obtained by pressing across the top of the box with a straight edge. The grains were decanted from the box into a bowl. The weighed loaf was placed in the metal box and the decanted grains were used to refill the box and levelled off as before. The overspill which is the volume displaced by the bread was collected, measured and recorded as $V_{b.}$

The specific volume was then calculated by dividing the volume displaced by the bread V_b by the weight of the bread, W_b as indicated in Equation 4.8.1

$$S_v\,(\text{cm}^3/\text{g}) = \frac{V_b}{W_b} \qquad 4.8.1$$

where S_v = specific volume,

V_b = volume of bread,

W_b = weight of bread

6.2.3. Sensory Evaluation

Cassava flour from the factor combinations that produced bread loaves with acceptable specific volume were further used to produce mini loafs using the same specifications as described in Section 6.2.1 and presented for sensory evaluation to establish their level of acceptability. Samples from five of the factor combinations that did not differ significantly from the control bread sample in their specific volumes were used for this purpose.

The sensory evaluation was carried out using 15 trained panellists who were staff members of Food Research Institute, and were familiar with the sensory attributes of local bread. The bread samples were first coded with 3-digits random numbers before serving them to the panellists. The panellists were independently served with the samples for evaluation (Figs 6.2 and 6.3). Crackers and water were provided for each panellist to rinse the mouth after testing each sample so as to remove the residual taste of the sample before going for the next sample.

Figure 6. 2 One of the panellists being served with the bread samples

Figure 6. 3 A panellists on the bread samples

The bread samples were scored based on appearance, colour, aroma, taste, crust, texture, mouth feel and overall acceptability using a 9 point hedonic scale according to Ihekoronye and Ngoddy (1985) with 9 as the highest score representing extremely liked and 1 as the lowest representing extremely disliked. The detailed interpretation of the scores on the 9 point hedonic scale is as presented in Table 6.1.

Table 6. 1 Interpretation of scores by sensory panellists on 9 point hedonic scale

Scale	Interpretation
9	Likes extremely

8	Likes very much
7	Likes moderately
6	Likes slightly
5	Neither likes nor dislikes
4	Dislikes slightly
3	Dislikes moderately
2	Dislikes very much
1	Dislikes extremely

Source: Ihekoronye and Ngoddy (1985)

6.2.4. Evaluation of the Specific Volumes and Sensory Qualities of Composite Bread Samples at Different Levels of Cassava Flour Substitutions

The wheat flour was further substituted by cassava flour from the factor combinations that produced bread loaves with the highest specific volume at different replacement levels to produce bread samples for evaluation of the effect of substitution level on the specific volume and sensory qualities of the composite bread. Bread loaves were baked with the ingredients listed in section 6.2.1. Part of the hard wheat flour was substituted by flour from the selected treatment combination at 20, 30 and 40% replacement level while the proportions of the remaining ingredients were not changed. Bread baked with 100% wheat flour was used as control. All the composite flour samples were baked in triplicates.

6.2.5. Statistical Analysis

The data obtained were analysed using Genstat 12.1 (2009 version). General Analysis of Variance (ANOVA) was performed to evaluate differences in the specific volume of the bread from the various flour samples and the sensory attributes of bread from the selected flour samples with that of the control sample. The specific volume and sensory attributes of bread baked with increasing amount of flour from the best cassava variety was also evaluated using the same statistical tool. Duncan multiple range test at 95% confidence level was used in mean separation for all the three studies.

6.3 Results and Discussion 6.3.1 Effect of Harvest Age on Specific Volume of Wheat-Cassava Composite

Bread

The main effect of harvest age on specific volume of wheat-cassava composite bread is presented in Table 6.2. The specific volume of the composite bread produced from 20% substitution of wheat flour with cassava flour was significantly ($p \leq 0.05$) affected by the harvest age of the cassava.

Table 6. 2 Main effect of harvest age of cassava flour on Specific Volume of wheat-cassava composite bread

	Control	Age (months)			CV (%)
		10	12	14	
Specific Volume (cm^3/g)	3.243^a	2.956^b	2.999^b	3.201^a	3.9

Means with common letters do not differ significantly from each other

The flour from cassava harvested at 14 months was used to produce composite bread with mean specific volume of 3.201 cm^3/g which was not significantly different from the specific volume of the control sample (100% wheat flour) but higher ($p \leq 0.05$) than the mean values of those produced from 10 months and 12 months harvest age. This agrees with the result of the peak viscosity value of the flour from cassava harvested at 14 months which was significantly higher than those harvested at 10 and 12 months and conforms with the findings reported by Rosell *et al*. (2007) that high peak viscosity values of flour paste during heating, strengthens the gas holding properties of expanding cells in baking dough and subsequently results in high loaf volume.

6.3.2 Effect of Variety on Specific Volume of Wheat-Cassava Composite Bread

The main effect of variety on specific volume of wheat-cassava composite bread is presented in Table 6.3

Table 6. 3 Main effect of variety on Specific Volume of wheat-cassava composite bread

	Control	Variety			CV (%)
		Ampong	*Broni*	*Otuhia*	
Specific Volume (cm^3/g)	3.243^a	2.89^c	3.05^b	3.21^a	3.9

Means with common letters do not differ significantly from each other

As can be observed from Table 6.3 above, *Otuhia* cassava variety is superior to *Ampong* and *Broni* variety for its flour to be used as composite baking material in bread production. The specific volume of composite bread produced from the use of *Otuhia* cassava flour was higher ($p \leq 0.05$) than those from *Broni* and *Ampong* varieties and did not differ significantly from the control sample (100% wheat flour). The 3.21 cm^3/g specific volume obtained for *Otuhia* variety was within the range of values reported by some other researchers. Eriksson (2013) obtained specific volume values of 3.25 cm^3/g, 3.13 cm^3/g and 2.74 cm^3/g by substituting wheat flour with 20% cassava flour from *Afisiafi, Doku duade* and *Bankye henma* cassava varieties in Ghana while Idowu *et al.* (2015) reported specific volume of 3.14 cm^3/g for 10% wheat flour substitution with cassava flour and 3.44 cm^3/g when bread improver was added

6.3.3 Effect of Pre-Treatment on Specific Volume of Wheat-Cassava Composite Bread

The result of the main effect of pre-treatment on the specific volume of wheatcassava composite bread samples indicates that the specific volumes were significantly ($p \leq 0.05$) affected by the flour pre-treatment (Table 6.4.).

Table 6. 4 Main effect of pre-treatment on Specific Volume of wheat-cassava composite bread

	Control	Pre-treatment					CV (%)
		T1	T2	T3	T4	T5	
Sv ((cm^3/g)	3.243^a	3.018^c	2.835^d	3.238^a	3.088^b	2.873^d	3.9

Means with common letters do not differ significantly from each other; Sv= specific volume.

Flour from the cassava samples pre-treated with citric acid (T3) produced composite bread samples with improved specific volume which was significantly higher ($p \leq 0.05$) than those for toasted (T2 and T5) and grated (T4) cassava samples but did not differ from the 100% wheat bread (control sample). The specific volume of the composite bread produced from the grated cassava was however higher than those from the toasted cassava samples (Figure 6.4). This result agrees with what was reported by Owuamanam (2007) that steeping cassava chips in citric acid for 24 h increased the volume of the resulting composite bread from the flour. This is also in consonant with the relatively higher peak viscosity values recorded by the citric acid pre-treated cassava flours in Chapter five of this work.

Figure 6. 4 Composite bread samples produced from five different cassava flour pre-treatments (T1- T5) and the control sample (100% wheat)

6.3.4 Effect of Variety, Harvest Age and Pre-Treatment Interaction on Specific Volume of Wheat-Cassava Composite Bread

The result of the harvest age, variety and pre-treatment interaction presented in Table 6.5 indicates that the composite bread samples from *Otuhia* variety harvested at 14 months with combined chipping and citric acid pre-treatment ($O_{14}T3$) had a value of 3.483 cm^3/g. This was significantly higher ($p \leq 0.05$) than 3.243 cm^3/g for the control sample and composite bread from all the other factor combinations with the exception of B14T3, O12T3, O14T1, B14T4 and A14T3 with values of 3.391 cm^3/g, 3.347 cm^3/g, 3.345 cm^3/g, 3.339 cm^3/g and 3.314 cm^3/g respectively. The result was generally encouraging since the specific volume of the control sample did not significantly vary with the values obtained from the 24 factor combinations. It was also observed from the interaction that the specific volume of all the composite bread from the pre-treatment combinations associated with *Otuhia* variety harvested at 14 months ($O_{14}T1$, $O_{14}T2$, $O_{14}T3$, $O_{14}T4$ and $O_{14}T5$) did not significantly differ from the control samples. The composite bread samples from these factor combinations were therefore selected for sensory evaluation.

Table 6. 5 The interactive effect of variety, harvest age and pre-treatment on specific volume of composite bread

variety	Age (months)	Pre-treatment	Sample code	Specific volume
Ampong	10	T1	$A_{10}T1$	2.753^{qrst}
Ampong	10	T2	$A_{10}T2$	2.554^{u}
Ampong	10	T3	$A_{10}T3$	2.907^{nopq}
Ampong	10	T4	$A_{10}T4$	2.803^{pqrs}
Ampong	10	T5	$A_{10}T5$	2.268^{v}
Ampong	12	T1	$A_{12}T1$	2.788^{pqrst}
Ampong	12	T2	$A_{12}T2$	2.658^{stu}
Ampong	12	T3	$A_{12}T3$	$3.054^{hijklmno}$
Ampong	12	T4	$A_{12}T4$	2.528^{u}
Ampong	12	T5	$A_{12}T5$	2.683^{rstu}
Ampong	14	T1	$A_{14}T1$	2.968^{klmnop}
Ampong	14	T2	$A_{14}T2$	2.933^{mnopq}
Ampong	14	T3	$A_{14}T3$	3.314^{abcde}
Ampong	14	T4	$A_{14}T4$	3.257^{bcdefg}
Ampong	14	T5	$A_{14}T5$	2.863^{opqr}
Broni	10	T1	$B_{10}T1$	2.687^{rstu}
Broni	10	T2	$B_{10}T2$	2.555^{u}
Broni	10	T3	$B_{10}T3$	3.289^{bcdef}
Broni	10	T4	$B_{10}T4$	$3.143^{efghijkl}$
Broni	10	T5	$B_{10}T5$	$3.064^{hijklmn}$
Broni	12	T1	$B_{12}T1$	3.018^{jklmno}
Broni	12	T2	$B_{12}T2$	2.518^{u}
Broni	12	T3	$B_{12}T3$	$3.13^{efghijkl}$
Broni	12	T4	$B_{12}T4$	$3.087^{ghijklmn}$
Broni	12	T5	$B_{12}T5$	2.605^{tu}
Broni	14	T1	$B_{14}T1$	$3.12^{fghijklm}$
Broni	14	T2	$B_{14}T2$	$3.062^{hijklmn}$
Broni	14	T3	$B_{14}T3$	3.391^{ab}
Broni	14	T4	$B_{14}T4$	3.339^{abcd}
Broni	14	T5	$B_{14}T5$	$3.154^{cdefghijk}$
Otuhia	10	T1	$O_{10}T1$	$3.208^{bcdefghij}$
Otuhia	10	T2	$O_{10}T2$	2.901^{nopq}
Otuhia	10	T3	$O_{10}T3$	$3.229^{bcdefghi}$
Otuhia	10	T4	$O_{10}T4$	$3.153^{defghijk}$
Otuhia	10	T5	$O_{10}T5$	$2.96l^{mnop}$
Otuhia	12	T1	$O_{12}T1$	3.272^{bcdefg}
Otuhia	12	T2	$O_{12}T2$	$3.127^{efghijkl}$
Otuhia	12	T3	$O_{12}T3$	3.347^{ab}
Otuhia	12	T4	$O_{12}T4$	$3.24^{bcdefgh}$
Otuhia	12	T5	$O_{12}T5$	$3.04^{ijklmno}$
Otuhia	14	T1	$O_{14}T1$	3.345^{abc}
Otuhia	14	T2	$O_{14}T2$	$3.21^{bcdefghi}$
Otuhia	14	T3	$O_{14}T3$	3.483^{a}
Otuhia	14	T4	$O_{14}T4$	$3.24^{bcdefgh}$
Otuhia	14	T5	$O_{14}T5$	$3.216^{bcdefghi}$

Control				$3.243^{bcdefgh}$
Lsd				0.192
CV (%)				3.9

CV=Coefficient of variation,Lsd.=Least significant difference.A,B ,O,are *Ampong,Broni* and *otuhia* varieties respectively, T1 to T5 represents pretreatment methods as presented in section3.2.5 Means with common letters do not differ significantly from each other

6.3.5. Sensory Qualities of Composite Bread Samples from Selected Factor Combination.

The mean scores given by the sensory evaluation panellists for appearance, aroma, colour, crust, texture, and mouth feel, taste and over all acceptability of wheatcassava bread composite are presented in Table 6.6.

Table 6. 6 Mean score for hedonic sensory attributes of wheat-cassava composite bread samples from pre-treated Otuhia cassava variety harvested at 14 months

Sample code	Appearance	Aroma	Colour	Crust	Texture	Mouth feel	Taste	Over all acceptability
control	6.53^{b}	6.73^{a}	6.93^{a}	6.73^{a}	6.60^{a}	6.67^{a}	7.27^{a}	6.80^{a}
O14T1	7.00^{ab}	7.00^{a}	7.20^{a}	6.47^{a}	6.60^{a}	6.33^{a}	6.13^{b}	6.67^{a}
O14T2	6.93^{ab}	6.87^{a}	7.07^{a}	6.47^{a}	6.67^{a}	6.80^{a}	7.00^{ab}	6.87^{a}
O14T3	7.40^{ab}	7.00^{a}	7.53^{a}	7.07^{a}	6.80^{a}	6.60^{a}	6.47^{ab}	6.60^{a}
O14T4	7.60^{a}	7.07^{a}	7.53^{a}	6.73^{a}	6.80^{a}	7.00^{a}	7.07^{ab}	7.20^{a}
O14T5	6.87^{ab}	6.53^{a}	7.20^{a}	6.73^{a}	7.13^{a}	6.80^{a}	6.40^{ab}	6.67^{a}
Lsd	0.82	0.80	0.81	0.91	0.82	1.07	0.98	0.98
CV (%)	16.00	16.00	15.40	18.80	16.70	21.90	20.10	20.00

Control=control sample (100% wheat flour),O14T1 to O14T5=composite bread samples with 80:20 wheat: cassava ratio, T1, T2, T3, T4 and T5 are Chipping, Toasting, Chipping with citric acid, Grating and Toasting with citric acid pre-treatment respectively used for the cassava flour production. Means with common letters do not differ significantly from each other

Figure 6. 5 A set of the composite bread samples used for sensory evaluation

The mean score values for appearance on a 9-point hedonic scale ranged from 6.5 to 7.6 for all the bread samples. The composite bread sample from grating pre-treatment (O14T4) with a mean score value of 7.6 was significantly higher ($p \leq 0.05$) than that of the control sample with a score value of 6.53 but did not differ from the values for the other composite bread samples. The mean score for aroma, colour, crust, texture and mouth feel of the composite bread from the five pre-treated cassava samples did not significantly differ ($p \geq 0.05$) from each other and also from the control sample.

The score value for taste of the control bread sample was significantly higher ($p \leq 0.05$) than that of the composite bread sample from cassava chipping pretreatment but did not differ from the score values of the other four pre-treatment. The bread samples from grating (T4) and toasting (T5) pre-treatments were scored higher than other composite bread samples for taste and overall acceptability even though their differences were not significant. In general, all the bread samples compared very well with the control sample, and were well accepted. The composite bread prepared from the cassava sample pre-treated by grating (O14T4) and toasting (O14T2) were better than composite bread from other pre-treatment methods in most of the vital sensory attributes. These results are similar to those obtained by Eddy *et al.* (2007), Aboaba and Obakpolor (2010) and Eriksson (2013).

6.3.6 Sensory Qualities of Composite Bread at Different Levels of WheatCassava Flour Ratios

The flour sample from O14T4 and O14T2 factor combination were selected for evaluation of the effect of level of wheat flour substitution with cassava flour on the sensory qualities and specific volume of the composite bread. The choice of these factor combinations was based on the excellent performance of their composite bread on the specific volume and sensory qualities as reported in sections 6.3.4 and 6.3.5.

Results of the sensory evaluation of composite bread produced from 20%, 30% and 40% substitution of wheat flour with cassava flour are presented in Tables 6.7 and 6.8.

Table 6. 7 Qualities of composite bread from grating pre-treatment ($O_{14}T_4$) at different levels of substitution

Percentage of cassava flour	100% wheat		Sensory attributes					
	App.	Aroma	Colour	Crust	Texture	M f	Taste	O/A
Control	7.07^{a}	7.00^{a}	7.07^{a}	6.87^{a}	6.73^{a}	6.667^{a}	7.27^{a}	7.00^{a}
20%	7.33^{a}	7.07^{a}	7.40^{a}	6.80^{a}	6.80^{a}	7.0^{a}	7.00^{a}	7.07^{a}
30%	7.27^{a}	6.73^{ab}	7.47^{a}	6.60^{a}	6.87^{a}	6.60^{a}	6.93^{a}	6.87^{a}
40%	6.00^{b}	6.00^{b}	6.20^{b}	5.47^{b}	4.80^{b}	5.13^{b}	5.53^{b}	5.53^{b}
Lsd	0.80	0.78	0.86	0.83	0.97	1.07	0.79	0.90
CV (%)	15.80	15.90	16.60	17.60	20.90	22.90	16.20	18.60

Control = flour; CV = coefficient of variation; O/A = overall acceptability; App. = appearance: Mf = Mouth feel. Means in a column followed by the same letters do not significantly differ from each other

It can be observed from table 6.7 that all the sensory qualities of the composite bread samples did not significantly differ ($p \geq 0.05$) from the control bread sample at 20% and 30% substitution of wheat with the grated cassava flour but they were all significantly lower ($p \leq 0.05$) at 40%. The results obtained from 40% substitution level were however lower ($p \leq 0.05$) than that of the control although they were still within the acceptable level of 5.00 points and above with the exception of texture which had a mean score of 4.8.

It was observed from Table 6.8 that with the exception of aroma and crust the other six sensory qualities of the composite bread did not significantly differ from the control sample at 20%, 30% and 40% substitution of wheat with toasted cassava flour.

Table 6. 8. Qualities of composite bread from toasting pre-treatment ($O_{14}T_{2}$) at different levels of substitution

Subst. Level	App.	Aroma	Colour	Crust	Text.	Mf	Taste	O/A
Control	7.20^{a}	7.20^{a}	7.13^{a}	7.00^{a}	6.86^{a}	6.867^{a}	7.27^{a}	7.13^{a}
20%	6.93^{a}	6.87^{ab}	7.067^{a}	6.47^{ab}	6.67^{a}	6.80^{a}	6.93^{a}	6.73^{a}
30%	6.27^{a}	6.33^{ab}	6.73^{a}	6.40^{ab}	6.73^{a}	6.87^{a}	6.67^{a}	6.67^{a}
40%	6.33^{a}	6.13^{b}	6.67^{a}	6.13^{b}	6.13^{a}	6.47^{a}	6.60^{a}	6.33^{a}
CV (%)	17.60	17.00	16.80	16.30	15.90	18.70	15.90	16.80
Lsd	0.86	0.83	0.85	0.78	0.77	0.93	0.80	0.83

Control=100% wheat flour; App. = Appearance; Text. = Texture; Mf = Mouth feel; O/A= Overall acceptability; CV=coefficient of variation; mean in a column followed by the same letters do not significantly differ ($p \geq 0.05$) from each other

6.3.7 Specific Volume of Composite Bread at Different Levels of Wheat-Cassava Flour Ratios

The specific volumes of the composite bread produced from toasted cassava and grated cassava at 20%, 30% and 40% substitution levels are presented in Table 6.9.

Table 6. 9 Specific volume of composite bread produced from toasted and grated cassava at different substitution levels

Pre-treatment	Sample	Percentage of	Specific Volume

	Code	cassava flour	(cm^3/g)
Grating	$O_{14}T_4P_{20}$	20%	3.24^{a}
	$O_{14}T_4P_{30}$	30%	2.84^{b}
	$O_{14}T_4P_{40}$	40%	2.38^{d}
Toasting	$O_{14}T_2P_{20}$	20%	3.21^{a}
	$O_{14}T_2P_{30}$	30%	2.55^{c}
	$O_{14}T_2P_{40}$	40%	2.18^{e}
Control	Ctr	0%	3.24^{a}
CV (%)			0.9
Lsd			0.04

CV=coefficient of variation; Means in a column followed by the same letters do not significantly differ from each other.

The specific volume of the composite bread samples did not significantly differ ($p \geq 0.05$) from that of the control bread sample at 20% substitution of wheat with cassava flour for both the toasted and the grated cassava samples but they were all significantly lower ($p \leq 0.05$) at 30% and 40% substitution levels. The specific volume of the composite bread samples generally decreased with increasing percentage of cassava flour in the bread samples. The decrease in specific volume of the composite bread with increasing percentage of cassava in the samples was equally observed by Aboaba and Obakpolor (2010), Eriksson (2013) and Eggleston *et al*. (1993). Eriksson (2013) reported a decrease of specific volume of composite bread loaves from 2.74 cm^3/g at 20% substitution to 2.41 cm^3/g at 30% substitution for bread produced from *Bankye hemmaa* cassava variety while the specific volume of bread loaves produced from *Doku duade* cassava variety decreased from 3.13 cm^3/g at 20% to 2.97 cm^3/g at 30% substitution levels.

It was also observed from Table 6.9 above that at each level of substitution the specific volume of composite bread samples produced from grated cassava flour was significantly higher than those from the toasted cassava flour. Eduardo *et al*. (2013) in their work also observed a lower bread volume of 103 cm^3 for composite bread produced from toasted cassava than 107.5 cm^3 for bread from untoasted ones. They however noted that with the addition of HM pectin bread improver, the toasted cassava produced composite bread with a higher volume of 103.7 cm^3 at 40% substitution level than the untoasted cassava flour whose bread volume was 82.4 cm^3 at the same substitution level. Studies by various researchers show that loaf volume is affected by the quantity and quality of protein in the flour used for baking (Shittu *et al*., 2007; Eriksson *et al*., 2014). Veraverbeke and Delcour (2002); Sciarini *et al.* (2010) and Eggleston *et al*. (1993) reported that cassava flour does not have gluten and therefore cannot form the type of cohesive visco-elastic dough that results in the typical fixed open foam structure of bread when hydrated. Consequently, an increase in the proportion of cassava flour in the composite flour for bread production reduces the gluten content as a percentage of the total flour. Since gluten enhances dough elasticity, an increased substitution of wheat with cassava flour results in a weaker and less elastic dough which reduces the leavening ability and consequently produces bread with lower loaf volume unless a deliberate effort is made in modifying the cassava flour quality.

6.3.8 Proximate Composition of Composite Bread Samples from Grated Cassava at Different Substitution Levels

The proximate compositions of cassava–wheat composite breads at 20 % substitution level were analysed following the procedures earlier stated in Section 4.2.1 and the results are presented in Table 6.10.

Table 6. 10 Proximate compositions of Composite Bread Samples from grated cassava at different substitution levels

Subst.	Protein (%)	Fat (%)	Fibre (%)	Ash (%)	M.C (%)	CHO (%)
Control	9.03^a	8.54^a	0.82^b	0.54^a	20.31^b	60.94^c

20%	8.66^{a}	8.01^{b}	1.1a^{b}	0.48^{b}	20.39^{b}	61.28^{c}
30%	7.42^{b}	7.8^{b}	1.39^{a}	0.47^{b}	20.71^{ab}	62.01^{b}
40%	5.88^{c}	7.69^{b}	1.35^{a}	0.45^{b}	20.99^{a}	63.52^{a}
CV	3.3	3	21.6	6.9	1.1	0.5

Subst. = % of cassava flour in the composite bread, CHO = carbohydrate, Moist. = Moisture content control = 100% wheat flour; CV = coefficient of variation; Means in a column followed by the same letters do not significantly differ from each other

The fat and ash contents of the control bread sample were higher ($p\leq 0.05$) than those of the composite bread at all levels of substitution while the fibre content of the control sample and that of 20% substitution did not differ from each other but were lower ($p\leq 0.05$) than the values for 30% and 40% substitutions. The protein content of the bread samples decreased ($p\leq 0.05$) significantly with increasing level of cassava flour in the bread from 20% to 40% while the carbohydrate content increased with increasing level of cassava flour. The significant ($p<0.05$) decrease in protein and increase in the carbohydrate content of the bread samples with increasing levels of cassava flour substitution can be explained by the fact that cassava is not a good source of protein while it is rich in carbohydrate, predominantly starchy, and it is consumed as an energy yielding food (Kwatia, 1986). The protein and carbohydrate contents of composite bread produced from 20% substitution were however not significantly different from the control sample.

6.4 Conclusions

a. The specific volume of wheat-cassava bread containing 20% *Otuhia* cassava variety harvested at 14 months was higher ($p\leq 0.05$) than those from *Ampong* and *Broni* varieties harvested at 10 and 12 months at the same substitution level but was not different from the specific volume of the control bread sample for 100% wheat flour.

b. The sensory attributes of bread samples containing 20% cassava flour produced from the five different pre-treatments studied compared very well with the control sample, and they were well accepted. The composite bread prepared from the cassava sample pre-treated by grating (O14T4) and toasting (O14T2) were better than the composite bread from the other pretreatment methods in some of the vital sensory attributes.
c. The specific volume of the composite bread samples did not significantly differ from that of the control bread sample at 20% substitution of wheat with cassava flour for both the toasted and the grated cassava samples but generally decreased with increasing percentage of cassava flour in the bread samples.
d. Although the specific volume of composite bread samples produced from grated cassava flour was higher ($p \leq 0.05$) than those from the toasted flour at each level of substitution, they were all significantly lower ($p \leq 0.05$) than the control sample at 30% and 40% substitution levels.
e. Composite bread with acceptable sensory qualities can be produced from flour containing up to 40% toasted and 30% grated cassava which is not significantly different from bread containing 100% wheat flour.

CHAPTER SEVEN

GENERAL CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter is aimed at drawing conclusions based on the research objectives and the significance and impact of the results obtained from the various chapters of this work. Recommendations are also made on areas of the work that need to be studied further for more positive impact on the needs of the society.

7.1 Conclusions

The four principal objectives that were set to be achieved by this thesis are:

1. To find out how the drying characteristics of three new cassava varieties were affected by pre-treatment and to establish a suitable thin layer model that adequately described the drying processes.
2. To evaluate the effects of harvest age and pre-treatment on the quality characteristics of the flour produced from these cassava varieties.
3. To investigate the influence of harvest age, variety and pre-treatment on the production of cassava flour with relevant characteristics that make them suitable for use as composite baking material.
4. To investigate the suitability of pre-treated flour from these cassava varieties for use in the production of composite bread and evaluate the effect of substitution levels on the quality characteristics of the bread.

7.1.1 Effects of Pre-Treatment on Drying Characteristics of the Cassava Varieties and Modeling of the Drying Curves

The cassava samples were dried to a moisture content of 2-7% (wb) within three to four hours for the toasting and grating pre-treatment. For the chipping pretreatment the same moisture content level was attained after eight to ten hours. For all the pretreatment methods, drying took place in the falling rate period and the moisture loss was more rapid during the first 1 h than the rest of the drying period. A plot of the changes in moisture content with time followed a typical drying trend of moisture content decreasing exponentially with time for all the samples. The drying rate constant for the grated samples (T_4) and toasted samples (T_2 and T_5) ranged from 1.0 to 2.23 h^{-1} while those of the chipped samples (T1 and T3) ranged from 0.67 to 1.13 h^{-1} .

The Henderson and Pabis, Page and Newton models were appropriate at varying degrees in predicting the drying processes of grated, toasted and chipped cassava samples for the three cassava varieties harvested at different ages of maturity. The Page model was found to be the most appropriate using the coefficient of determination (R^2), root mean square error (RMSE) and reduced chi-square or mean square deviation.

7.1.2 Effects of Harvest Age and Pre-Treatment on Quality Characteristics of Flour Produced From the Cassava Varieties

The proximate composition of the cassava flour was significantly ($P \leq 0.05$) affected by harvest age, variety and pre-drying treatments. The results generally showed that processing of *Ampong*, *Broni* and *Otuhia* cassava varieties into flour using chipping, toasting, grating and citric acid pre-treatment resulted in acceptable flour yield. The flours obtained had satisfactory quality attributes in terms of protein, fat, fibre ash, carbohydrate, moisture content, pH and cyanogenic potentials.

The three cassava varieties produced flour with low cyanide contents of 2.48 to 6.99 mg HCN_{eqv}/kg. These values are below the FAO /WHO (2013) recommendation (of cyanide content not greater than 10 mg HCN_{eqv}/kg dry matter of cassava flour) and hence could be safely consumed by human beings without any fear of cyanide toxicity.

7.1.3 Influence of Harvest Age, Variety and Pre-Treatment in Production of Cassava Flour with Suitable Characteristics for Use as Composite Baking Material

Flour samples from the three cassava varieties generally exhibited early gelatinization, high peak viscosity, setback and final viscosities and large paste breakdown. The first four qualities are good indicators of baking flour and hence adjudging the flour to be suitable for use as composite baking material.

The flour from *Otuhia* variety had lower gelatinisation temperature, lower peak time and higher water binding capacity, while *Otuhia* and *Ampong* had higher peak, setback and final viscosity, higher swelling power and water absorption capacity. These attributes gave *Otuhia* variety a comparative advantage over the other two varieties in their use as composite baking flour.

Flour samples produced from grating and toasting pre-treatment also had higher water binding capacity, swelling power and water absorption capacity setback and final viscosity values while the grated sample had higher peak viscosity. Toasting pre-treatment however produced flour with lower peak viscosity. Grating was therefore selected as a preferred pre-treatment in terms of the flour quality relevant to baking.

Cassava tubers harvested at 14 months produced flour with lower solubility, peak time and gelatinization temperature and higher peak viscosity and water absorption capacity. Those harvested at 10 months and 14 months produced flour with higher setback and final viscosity values hence making 14 months harvest age more suitable for producing cassava flour for baking purposes.

7.1.4 The Suitability of Pre-treated Flour from the Three Cassava Varieties in Composite Bread Production and the Effect of Substitution Levels on the Bread Qualities

The wheat-cassava composite bread produced from all the three factor combinations of harvest age, variety, and pre-treatment had satisfactory specific volume at 20 % substitution level.

Otuhia cassava variety harvested at 14 months produced composite bread with a specific volume that was not statistically different from that of the control sample for the five pre-treatment methods used in the study. The factor combination was therefore adjudged to be better than other factor combinations.

The specific volume of the composite bread was lower ($p \leq 0.05$) than that of the control sample at 30 % and 40 % substitution levels for both grating and toasting pre-treatment.

The specific volume of composite bread samples produced from grated cassava flour was higher ($p \leq 0.05$) than those from the toasted flour at each level of substitution, but both samples were significantly lower ($p \leq 0.05$) than that of the control sample at 30% and 40% substitution levels.

Composite bread with acceptable sensory qualities can be produced from flour containing up to 40 % toasted and 30 % grated cassava which is not significantly different from bread containing 100% wheat flour.

7.2 Contributions from Research Findings

A detailed study has been conducted on the potentials of using flour from three high yielding cassava mosaic resistant (CMR) varieties in the production of wheat- cassava composite bread.

Based on the research findings, it has been discovered that toasting pre-treatment and grating pre-treatment can reduce the drying time of cassava by more than 50 % and hence reducing the energy cost for drying.

Results from functional and visco-elastic properties of the cassava flour provide a useful guide for effective utilisation of the flour for other industrial and domestic purposes.

The three cassava varieties can be successfully used in the production of wheatcassava composite bread with acceptable sensory qualities at 30 % substitution level for grated cassava flour and 40 % level for toasted cassava flour.

Adoption of 30% substitution of wheat flour with cassava flour will reduce the amount spent on wheat importation hence reducing the foreign exchange out outflow from the country.

Employment opportunities will also be created by greater investment in cassava production and processing since the market for cassava will be guaranteed.

7.3 Recommendations

The following recommendations are made:

1. Further studies should consider the effect of inclusion of some protein-rich crops alongside the cassava and wheat flour on specific volume and sensory properties of composite bread.

2. The use of appropriate hydrocolloids for volume enhancement of the composite bread at higher substitution level of wheat flour with toasted cassava flour should be explored.
3. The potentials of other high yielding CMD resistant cassava varieties in composite bread production should also be investigated.

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APPENDICES

Appendix 1 *Ampong* and *Broni* Cassava Plants at the Growing Stage three (3) Months after Planting.

(a) Ampong

(b) Broni

Appendix 2 *Otuhia* Cassava Plant at the Growing Stage three (3) Months after Planting.

Appendix 3 Cassava tuber harvesting at 14 months

Appendix 4 Motorized cassava grater

Appendix 5 A sample ANOVA table for proximate composition of flour from three cassava varieties at different harvest ages and pre- treatment as generated from GenStat : Variate : Protein

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Harv_age	2	15.06145	7.53073	82.05	<.001
PT	4	15.0629	3.76572	41.03	<.001
Variety	2	0.18268	0.09134	1	0.374
Harv_age.PT	8	0.6434	0.08042	0.88	0.54
Harv_age.Variety	4	0.68555	0.17139	1.87	0.123
P_T.Variety	8	0.53562	0.06695	0.73	0.665
Harv_age.P_T.Variety	16	1.51238	0.09452	1.03	0.434
Residual	90	8.26087	0.09179		
Total	134	41.94484			

Appendix 6 Sample ANOVA table for cyanogenic potentials of flour from three cassava varieties at different harvest ages and pre-treatment

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Age	2	1.291792	0.645896	86.2	<.001
Pr_tmt	4	192.0437	48.01094	6407.29	<.001

Variety	2	9.248966	4.624483	617.16	<.001
Age.Pr_tmt	8	0.049559	0.006195	0.83	0.581
Age.Variety	4	0.031676	0.007919	1.06	0.383
Pr_tmt.Variety	8	6.666372	0.833296	111.21	<.001
Age.Pr_tmt.Variety	16	0.293537	0.018346	2.45	0.004
Residual	90	0.674386	0.007493		
Total	134	210.3			

Appendix 7 Sample ANOVA table for functional and visco-elastic properties of flour from three cassava varieties at different harvest ages and pre- treatment

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Age	2	1978760	989380	624.12	<.001
PT	4	2660492	665123	419.58	<.001
Variety	2	120651	60325	38.05	<.001
Age.PT	8	1572352	196544	123.98	<.001
Age.Variety	4	414305	103576	65.34	<.001
PT.Variety	8	152525	19066	12.03	<.001
Age.PT.Variety	16	428051	26753	16.88	<.001
Residual	90	142671	1585		
Total	134	7469806			

(a) Peak viscosity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Age	2	80867.5	40433.8	215.58	<.001
PT	4	1156365	289091	1541.36	<.001
Variety	2	24376.7	12188.4	64.99	<.001
Age.PT	8	185909	23238.7	123.9	<.001
Age.Variety	4	43220	10805	57.61	<.001
PT.Variety	8	70567.4	8820.9	47.03	<.001
Age.PT.Variety	16	54246.3	3390.4	18.08	<.001
Residual	90	16880	187.6		
Total	134	1632432			

(b) Water binding capacity

Appendix 8 Sample ANOVA table for Specific Volume of composite bread of flour from three cassava varieties at different harvest ages and pre- treatment at 20% substitution level

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Age	2	1.91036	0.95518	67.77	<.001
PT	5	4.1202	0.82404	58.46	<.001
Variety	2	2.6485	1.32425	93.95	<.001

Age.PT	10	0.60757	0.06076	4.31	<.001
Age.Variety	4	0.33715	0.08429	5.98	<.001
PT.Variety	10	1.14932	0.11493	8.15	<.001
Age.PT.Variety	20	1.06795	0.0534	3.79	<.001
Residual	108	1.52228	0.0141		
Total	161	13.3633			

Appendix 9 Sample ANOVA tables for sensory qualities of composite bread from *Otuhia* cassava variety harvested at 14 months at 20% substitution level

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatmt	5	3.556	0.711	0.39	0.856
Residual	84	154	1.833		
Total	89	157.556			

(a) Over-all acceptability

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatmt	5	3.033	0.607	0.48	0.793
Residual	84	107.067	1.275		
Total	89	110.1			

(b) Texture

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatmt	5	3.833	0.767	0.36	0.877
Residual	84	181.067	2.156		
Total	89	184.9			

(c) Mouth-feel

Appendix 10 Components of the baking formulations being measured into a bowl

Appendix 11 Some of the composite bread samples


$O_{12}T_1$
$O_{12}T_2$
$O_{12}T_4$
$O_{12}T_5$


$O_{12}T_2$