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DEPARTMENT OF FOOD SCIENCE AND TECHNOLOGY

INFLUENCE OF PROCESSING METHODS ON THE GLYCAEMIC INDEX OF CASSAVA-BASED TRADITIONAL FOODS

BY

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(BSc. Food Science and Technology)

A THESIS SUBMITTED TO THE **DEPARTMENT OF FOOD SCIENCE AND TECHNOLOGY**, COLLEGE OF SCIENCE, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF

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DECLARATION

I declare that I have wholly undertaken the study reported herein under the supervision of Prof. (Mrs.) Ibok Oduro and Dr. (Mrs.) Faustina Dufie Wireko-Manu, and that except portions where references have been duly cited, this thesis is the outcome of my research.

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ABSTRACT

Processing operations affect starch hydrolysis, digestibility, absorption and glycaemic index (GI) of food. Although some studies have reported on the effect of boiling, frying, roasting and baking on glycaemic index of traditional staples. There is limited information on the contribution of drying, fermentation, boiling and steaming on starch bioavailability and glycaemic index. This research work aimed at determining the effect of fermentation, steaming, boiling and drying on starch bioavailability and predicted GI of some cassava-based traditional foods consumed in Ghana. The total starch, amylose, amylopectin, dietary fibre and predicted glycaemic index of the intermediate and finished products were determined according to standard protocols. This research has revealed the predicted GI of cassava (47.75%), *ampesi* (77.30%), *akyeke* (79.05%), cooked *kokonte* with sun dried flour (40.20%) and cooked *kokonte* with solar dried flour (61.11%). The dietary fibre content of *Capevars bankye* flour was found to be 1.631% and 1.214% for sun and solar drying processes respectively. The analysis established that steaming and boiling increase GI of foods, fermentation has no significant influence on predicted GI of fermented steamed products, and drying has no substantial effect on predicted GI of cassava flour. However, staples or products prepared from solar dried cassava flour would have higher predicted GIs than those of sun dried cassava flour. This work has also provided evidence in support of the fact that starch, amylose, amylopectin and dietary fibre content of a food affect the glycaemic index of the food.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Cassava utilization and cassava-based traditional foods consumption in Ghana is on the increase. However, there are growing concerns about its effect on the health of consumers and diabetic patients due to the high carbohydrate content (Oppong-Apane, 2013). This has necessitated research into processing methods and glycaemic index of cassava-based traditional staples.

Most traditional foods are processed in one form or the other prior to consumption or storage and cassava-based traditional staples are not an exception. This processing activity enhances the eating characteristics, sensory and organoleptic properties, toxic removal, preservation, marketing and distribution of the food. It also increases food consistency, diversity, shelf-life and value addition (FAO, 2011). Processing of cassava involves methods such as cleaning, size reduction, drying, fermentation, cooking methods, heat treatment (pasteurization and sterilization) and many others (FAO, 2011; Granfeldt *et al*., 2000) which improves its palatability, and reduces cyanogen concentration and its toxicity (FAO and IFAD, 2005).

Studies have shown that these processing methods play a significant role in starch digestibility, nutrient metabolism and absorption, as well as the glycaemic index of the food. Further research has revealed that, there is greater variation in digestion, metabolism and absorption of food (carbohydrate) which emanates from the source of the carbohydrate, its composition and the processing methods, the foods go through during preparation or formulation (Granfeldt *et al*., 2000; Omoregie and Osagie, 2008). The glycaemic index (GI) of foods is the measure of the rate of absorption of carbohydrate into the blood after consumption of a meal and is significantly affected by the processing operations (Omoregie and Osagie, 2008). This is because these operations are suggested to cause cell wall

disruption, depolymerization, retrogradation, gelatinization and hydrolysis of the carbohydrate to facilitate enzymatic reaction or digestion, for the release of glucose into the blood after consumption or eating (Bahado-Singh *et al.*, 2011; Chung *et al*., 2008).

A study conducted by Granfeldt *et al*. (2000) on oat and barley flakes revealed that minimal processing operation like size reduction (product thickness) had no significant influence on GI. A research by Bahado-singh *et al*. (2011) on sweet potato cultivars, established a substantial impact of roasting, baking, frying and boiling on the GI of these cultivars. A cohort study carried-out on the glycaemic indices of *fufuo, kenkey, banku and tuo-zaafi* also indicated that the differences in GIs of the foods may be due to different processing methods that were used in their preparations (Eli-Cophie *et al*., 2017) but did not account for the extent of the impact of the individual unit operations resulting in the overall GI of the foods. Therefore, the effects of individual unit operations need to be evaluated separately to actually ascertain the contribution of each operation towards GI reduction or increment.

1.2 Research problem

Many processed and traditional foods go through succession of processing operations which may affect their digestibility and glycaemic index. A lot of works have looked at the effect of some of these operations on starch digestibility and GI. However, very limited information is reported on the contribution of drying, fermentation, boiling and steaming on GI of cassava-based traditional foods.

1.3 Justification

This work would establish and document the effect of fermentation, steaming, boiling and drying on the GI of some cassava-based traditional foods, which will contribute to scientific knowledge and effectively enable the use of glycemic index in conjunction with other dietary recommendations for proper treatment, management and prevention of diseases. Moreover,

the GI data of local foods such as *akyeke*, *ampesi* and *kokonte* considered under this research would assist consumers in making informed food choices.

1.4 Main objective

The principal objective of this research is to determine the influence of processing methods on the glycaemic index of cassava-based traditional foods in Ghana.

1.4.1 Specific objectives

- To determine total starch, amylose, amylopectin and dietary fiber content of fresh cassava, *ampesi*, *akyeke* and *kokonte* samples
- To determine predicted glycaemic index of fresh cassava, *ampesi*, *akyeke* and *kokonte* samples using in-vitro assay
- To determine the effects of fermentation, boiling, steaming and drying on the glycaemic index of intermediate and final products

CHAPTER TWO

LITERATURE REVIEW

2.1 Traditional foods

The existence, health and survival of the human race is undoubtedly dependent on the nutrients obtained from food intake (Ma, 2015). Traditional foods are distinct in nature, composition, preparation methods and have diversity of beliefs or ancestral history and eating habits associated with them, from one geographical area to another (Weichselaum *et al*., 2005; Ivanova and Trifonova, 2014; Laryea *et al*., 2016).

Traditional foods are very rich in nutrient, energy and other phytochemicals significant for nourishment, human health, disease management, growth and development (Soto-Méndez *et al*., 2011). They have found great importance in human endeavor, not because of the nutrients they offer but the role they play as medium for cultural expression, projection and transmission (Ma, 2015). Ghana has *fufuo, eto, apranpransa, kokonte, akyeke, apiti,* etc whereas *eba, abacha, obe, ewedu, amala and ila* are associated with Nigerians (Stajcic, 2013; Laryea *et al.*, 2016). Traditional foods form integral element of tourism and should be prioritized in the tourism industry for national development and international recognition, since these sumptuous delicacies attract and sustain the interest of tourists (Amuquandoh and Asafo-Adjei, 2013).

This clearly indicates that traditional foods play significant socio-economic roles in a country and provide the nutritional needs of its people. Therefore, it is very important to tailor research towards preservation and conservation of these foods, and investigate the possible factors that affect their consumption.

2.2 Cassava production and utilization

Cassava (*Manihot esculentun crantz*) is a perennial shrub, starchy tuberous root crop or plant belonging to the family euphorbiaeceae and genus manihot (Augusto and Alves, 2002). It grows and performs well in many tropical countries owing to its ability to tolerate or withstand poor soil and harsh climatic environmental conditions. Due to its high yield, low production cost, minimal disease occurrences and pest infestation, and its role as soil fertility management crop (Nweke, 2004; Saïdou *et al.*, 2004; Oppong-Apane, 2013), it is cultivated by small-scale farmers for subsistence and used in other agricultural products and food systems (Augusto and Alves, 2002).

Cassava is an important crop embraced and cultivated by most African countries to address the problem of food insecurity and poverty (Augusto and Alves, 2002; Yidana and Amadu, 2013). It is considered as the second most important crop in Africa following maize per amount of calories consumed (Nweke, 2004). Cassava has been ranked the fourth and sixth most important supply of calories in many human diets or staples in Africa and worldwide respectively (Augusto and Alves, 2002).

Nigeria is the world's leading producer of cassava and Ghana is second amongst the first five leading producers of cassava in Africa (Buhari, 2017; Koyama *et al*., 2015; Bedford *et al.*, 2017)). Ghana has increased its economic growth and export rate through production and export of cassava to neighbouring West African countries (Chauvin *et al*., 2012). Cassava is therefore of so much significance to Ghanaians and it has received progressive increment in production from 16,524,000 to 19,139,000 metric tonnes since 2014 to 2017 with per capita consumption standing at 32,500 kg/annum (Bedford *et al.*, 2017)

Science and technology has gone the greatest extent to reduce the cost of cassava production and processing through the introduction of high yielding varieties, labour-saving harvesting methods and improved processing technologies. These improved or high yielding varieties

are pest and disease tolerant, early bulking and have in-ground storage stability, excellent processing qualities, large canopy and low cyanogen levels (Newke, 2004; Nweke, 2005). Ghana was introduced to these varieties in 1993 and has received so much credit in Eastern, Greater Accra and Volta regions (FAO and IFAD, 2005). *Capevars banye* is one of the improved cassava varieties developed by University of Cape Coast (UCC) and is best for all manner of cassava-based traditional foods. It is for this reason that, *Capevars bankye* was used in the preparation of the various food samples for this study.

The roots of cassava especially the sweet varieties are consumed raw, roasted, fried or boiled. They are used in the preparation of *fufu, banku, gari, konkonte, yakeyake, tuozaafi ampesi, agbelima, akyeke or attieke, chickwangue, kpokpo gari, mapanga, kanyanga, attoupkou* (Nweke, 2005; Amenu, 2015; Oduro, 2016) and others as staple food for people in the tropical and sub-tropical regions. It has also found usage in food product supplementation, ethanol and starch production in some countries (Aliyu and Aliyu, 2014; Guy *et al*., 1998; Oppong-Apane, 2013; FAO and IFAD, 2005).

2.3 Consumers' misconceptions about cassava staples

A lot of concerns about cassava as a crop and its food staples have been upstretched by consumers all over the world. The low content of protein, some minerals and vitamins in cassava have contributed extensively to the limiting utilization and consumption potential of cassava by many people (Oppong-Apane, 2013). A study by FAO and IFAD (2005) disclosed that food policy analysts place less importance on cassava food and regard it as inferior food since its per capita consumption decreases with increasing per capita income of consumers. It is therefore considered as poor man's food. Again the consumption of cassava leaves (nutritious in protein, minerals and vitamins) by some communities in Congo and Tanzania is regarded as an indicator of low economic status by Ugandans (Nweke, 2004).

The leaves and roots of cassava (consumable parts) are found to contain some level of cyanogens and hence consumption of these parts poses a lot of threat to consumers. However, research has established that these poisonous cyanides are reduced to tolerable or appreciated level during processing for human consumption (Oduro, 2016; Amenu, 2015). This therefore calls for more research into processing methods and their effects on glycaemic index of cassava-based traditional foods.

2.4 Glycaemic index of foods

2.4.1 Definition and relevance of glycaemic index

Glycaemic index (GI) is the measure of blood glucose response after consumption of a food sample (Hettiaratchi *et al*., 2012). It gives an idea or information about the impact of food on the blood glucose rise and subsequent effect on the body of the consumer (Foster-Powell *et al*., 2002; Arvidsson-Lenner *et al.*, 2004). It is also an indicator of how fast or slow foods digest and postprandial blood glucose following food consumption (Omoregie and Osagie, 2008). GI is an important tool for managing diseases (like obesity, diabetes & coronary heart disease) (Siller, 2006) and health, and its legislation is underway in certain advanced countries (Foster-Powell *et al*., 2002). World Health Organization (WHO) and, Food and Agriculture Organization (FAO) have endorsed the application of GI values in collaboration with food composition tables to make food choices in order to promote human nutrition and healthy living (Foster-Powell *et al*., 2002).

GI has been found to be a very useful nutritional phenomenon for the classification of carbohydrates and provides authentic predictions of high density lipoprotein (HDL) concentration in healthy individuals (Nnadi and Keshinro, 2016). Over the years, GI of about 800 foods have been determined and documented since the insertion of GI by Jenkins *et al*. (1981) cited in (Omoregie and Osagie, 2008). Glycaemic index classifies foods on the scale

of hundred (100) based on the impact of the food on postprandial blood glucose (Nnadi and Keshinro, 2016; Omoregie and osagie, 2008). The index ranges from zero (0) to hundred per cent (100%) with 0-55% representing low GI foods, 56-69% and 70-100% designating medium and high GI diets (Eleazu, 2016), respectively.

Low GI foods elicit diminutive amount of glucose into the blood upon consumption. These foods improve or maintain the blood glucose level, LDL- cholesterol and a risk factor for thrombosis in diabetic patients (Nnadi and Keshinro, 2016). Consumption of low GI foods assists healthy individuals to reduce hypoglycaemia and excessive insulin response between meals (Egba *et al.*, 2017; Omoregie and Osagie, 2008). On the contrary, high GI diets produce greater quantities of glucose into the blood and high insulin response which may results in obesity, blindness, heart disease, erectile dysfunction, strokes, mortality, kidney disease, amputations and cancer (Arvidsson-Lenner *et al*., 2004; Egba *et al*., 2017; Nnadi and Keshinro, 2016).

2.4.2 Principle of glycaemic index determination and methods

GI of foods is mainly determined by two methods: in-vivo or in-vitro assay (Hettiaratchi *et al*., 2012). In-vivo GI assay involves the use of human subjects to estimate the rate of glucose response following the consumption of a particular diet. It is usually undertaken by providing subjects with 50 or 25 g of available carbohydrate portion of test foods and glucose or bread as standard (Brouns *et al*., 2005; Hettiaratchi *et al*., 2012; Wolver *et al*., 1994). In-vivo assay produces reliable and reproducible results for grouping foods based on glycaemic response and effect (Foster-Powell *et al*., 2002). Even with that, capillary blood samples are more preferable to venous blood samples owing to the fact that glucose concentration increase in capillary blood than venous. Notwithstanding, there is a direct correlation between the two (Brouns *et al*., 2005; Foster-Powell *et al*., 2002).

In as much as, the GI results from in-vivo assay are reliable, they are actually expensive, laborious, time consuming and need the cooperation of individuals that makes it very difficult (Hettiaratchi *et al*., 2012).

In-vitro GI assay employs digestive enzymes to hydrolyze the carbohydrates in foods to glucose (Englyst *et al*., 2003; Hettiaratchi *et al*., 2012). It mimics the physiological breakdown of carbohydrates in humans using amylase, amyloglucosidase and other proteolytic enzymes (Englyst *et al*., 2003). It is simple, cost effective, less tedious and produces results that correlate well with that of in-vivo GI results (Brouns *et al*., 2005).

2.5 Factors affecting glycaemic index of foods

Glycaemic index reflects the glycaemic response of different foods to the same amount of carbohydrate; thus the quality of the carbohydrates in the foods (Onimawo *et al*., 2007). The glycaemic index of any food is affected by nutritional and physiological factors. These factors may encompass the interactions of starch with proteins, digestibility of the starch, amounts and kinds of fat, fibre and sugar, and the type and level of processing and particle size (Egba *et al.*, 2017). The factors above affect glycaemic index of foods in the following perspectives:

2.5.1 Cooking methods

Cooking methods change the structure of starchy foods and affect their digestibility. Carbohydrate meals may differ in glycaemic responses due to the cooking methods being used in the food preparation. Depending on the cooking method employed in the food preparation, glycaemic index may either increase or decrease (Eleazu, 2016). Bahado-Singh *et al*. (2011) stated that dry food processing methods such as baking and roasting have a higher glycaemic index relative to moist processing methods like boiling and frying if the GI

is not reduced by other factors. High temperature and presence of water during wet processing causes an increase in starch granule disintegration and gelatinization which contributes to high GI of such foods (Eleazu, 2016).

Conventional cooking methods such as boiling, frying, steaming, etc, and industrial processes affect the structure, the digestibility and physicochemical properties of food and its glycaemic index (Bahado-Singh *et al*., 2011) as discussed below.

a. Boiling

Boiling, a common food processing method has been reported to alter the glycaemic index of starch-rich foods. Work done by Kouassi *et al*. (2009) reported that water-cooked (boiled) yam recorded a higher glycaemic index than oven-cooked yam and suggested that the reason may be as a result of the association of temperature and humidity that modify the physical and chemical states of starch and therefore its digestibility. During boiling, starch granules absorb water and swell (gelatinization) which disrupts the crystalline structure of starch irreversibly, making it susceptible to hydrolysis by amylase (Englyst and Cummings, 1987; Soh and Brand-miller, 1999). Glycaemic response as well as glycaemic index increases with increasing starch digestibility by enzymes. Nayak *et al*. (2014) reported that the presence of enough water during boiling enables complete starch gelatinization which decreases the resistant starch content thereby increasing the digestibility.

Bahado-Singh *et al*., (2011) recorded a lower glycaemic index for boiled sweet potatoes compared with roasted, baked and fried sweet potatoes. In a research conducted by Itam *et al*. (2012), boiled sweet potato recorded the least glycaemic index in comparison with fried and baked sweet potato. This was due to the fact that, the degree of cell wall disruption, starch gelatinization and digestibility is lowest in moist heat (boiling) than dry heat (baking and roasting) and hence, the observed results (Jimoh *et al.*, 2008). Also, during frying, baking and

roasting, amylose-lipid formation is high, resulting in decreased starch digestibility and glycaemic index (Holm *et al*., 1983; Leeman *et al*., 2008)

According to Allen *et al*. (2012) and Holm *et al*. (1988), boiling at 60-90˚C leads to starch gelatinization, which increases starch availability to alpha and beta amylases. However on cooling, gelatinized starch retrograde or recrystallize owning to intermolecular hydrogen bonds formation making amylose portions less accessible or resistant to amylases. This reduces the rate of starch digestion, slows glycaemic response and subsequently lowers glycaemic index (Eleazu, 2016). Boiling could also leach some simple sugars in the cooking process and the presence of resistant starches would reduce glycaemic response due to their indigestibility.

b. Steaming

A study done on steamed cakes by Onimawo *et al*. (2007) reported that the steamed cakes reduced the blood glucose response and lowered the glycaemic index in both diabetic and non-diabetic subjects. In parboiling of rice, steaming is found to cause complete gelatinization of starch. In a work done by Kale *et al*. (2017) on the effects of variable steaming on chemical composition, starch characteristics, and glycaemic index of basmati rice (Pusa Basmati 1121), it was reported that the severity of steaming (increased steaming pressure/steaming time) lowered the glycaemic index of basmati rice.

c. Extrusion

Most foods are exposed to extreme temperatures and pressure in processes such as extrusion cooking, explosion puffing, instantization and many others. In extrusion processes, starch and protein are transformed into restructured and texturized convenience foods in which shearing together with high temperatures and low water content, causes some of the starch molecules

to be dextrinised, broken into shorter chains exhibiting greater solubility in water (Leoro *et al.*, 2010). This therefore leads to partial gelatinization of the starch causing high glycaemic responses, hence high glycaemic index.

d. Baking, roasting and frying

Bahado-Singh *et al*. (2011), observed lower glycaemic indices for fried sweet potatoes compared with baked and roasted ones and attributed it to increased fat content (during frying) resulting in retardation in starch degradation, consequently delaying gastric emptying and glycaemic response. A study by Bjorck *et al*. (2000), revealed that minimal roasting prior to flaking maintained high crystallinity in finished products where the glycaemic response of roasted flaked product was similar to the glycaemic response of raw wheat flakes. The degree of crystallinity within starch granules may be increased by minimizing the extent of starch gelatinization.

In addition, Leeman *et al*. (2008) also suggested that during frying, amylose is susceptible to react with lipids to form amylose-lipid complexes thus reducing the rate of amylolysis and resulting in lower glycaemic responses and glycaemic index values. In the work of Itam *et al.* (2012), baking of sweet potato recorded the highest glycaemic index in comparison with frying, roasting and boiling. This is because dry air or heat has greater ability in disrupting the organized granular structure and causes high degree of changes in the physical form of the food. This enhances the digestibility and absorption of starch and increase the GI of the food both in-vivo and in-vitro (Jimoh *et al*., 2008).

2.5.2 Preliminary Processing operations

According to Fernandes *et al*. (2005), processing conditions or operations alter postprandial glucose responses of starch by disrupting the cell wall and structure of the starch granule and

causing increased gelatinization which proliferate the glycaemic index. The following preliminary processing methods or operations below affect GI of foods

a. Fermentation

Fermentation in food processing has dual effects on starch digestibility and glycaemic index. It may either contribute to an increase or a decrease in starch digestibility and glycaemic index of foods (Scazzina *et al*., 2009). Ihediohanma (2011) reported a decrease in glycaemic index with decreasing fermentation time and vice versa. A number of studies have been conducted on the effect of organics acids produced during fermentation on postprandial glycaemia where they have been reported to lower blood-glycaemia. Inclusion of either lactic acid (added directly or through fermentation) or the sodium salt of propionic acid in bread products, as well as the presence of lactic acid in mixed meals with vegetables has been reported to lower postprandial glycaemia and insulinaemia(Ostman, 2003). These organic acids inhibit the activity of hydrolytic enzymes during starch hydrolysis and hence reduce the GI of foods (Jin *et al.*, 2014).

However, Batra *et al*. (1994) observed an increase in glycaemic index of green gram cheela and Bengal gram cheela by 2.26% and 2.71% respectively as a result of fermentation process and explained that the increase in glycaemic index was as a result of breakdown of complex carbohydrates like starch and other polysaccharides to simpler forms (disaccharides and monosaccharides). Simpler carbohydrates are known to evoke much increase in blood glucose than complex carbohydrates. Ihekoronye and Ngoody (1985) established that during fermentation, maltose is formed at one stage which is further converted to D-glucose when hydrolyzed in aqueous solutions. Therefore increase in fermentation period may bring about more glucose formation and subsequent increase in the rate of digestion, absorption (glycemic response) and glycaemic index

b. Drying

Drying is known to be one of the simplest methods of food preservation by reducing the moisture content (controlling microbial growth) of a food. Studies have shown that drying alters the glycaemic index of foods (Donlao and Ogawa, 2016). Jaisut *et al*. (2008) conducted a study on the effect of drying temperature on brown fragrant rice, it was found out that during the drying process, the starch granules lost their shape and gelatinization of the rice starch had partially taken place. Also DSC thermogram showed amylase-lipid complex formation for the treated brown rice which lowered starch hydrolysis and consequently decreased the glycaemic index of brown fragrant rice. According to Omolola *et al*. (2015), drying gives rise to low or moderate glycaemic index products with high calorie, vitamin and mineral contents.

Donlao and Ogawa, (2016) observed in one of their works that sun-drying treatment on rice samples showed relatively higher hydrolysis rate when cooked than hot-air drying treatment. The hydrolysis rate of the cooked rice decreased with increasing hot-air drying treatment from 40-90°C. All the cooked rice samples obtained from hot-air drying treatment showed relatively smaller values of hydrolysis index and estimated glycaemic index than samples obtained from sun-drying treatment. Research by Ogbo and Okafor (2015) and Donlao and ogawa (2016) have also revealed that sun drying increases the concentration of resistant starches and hence lowers glycaemic index.

c. Particle size reduction

Starch hydrolysis and digestibility is greatly affected by particle size and surface area to starch ratio (Lanka and Lanka, 2012; Snow and O'Dea, 1981). The particles of food become more uniform in size and results in similar digestion times for the bulk of food ingested. During particle size reduction, the surface area of the food increases and becomes much

larger; allowing the enzymes to get easy access to the food and digest it more quickly. Increase in surface area leads to higher digestibility and faster absorption of foods into the blood stream (Eleazu, 2016).

Milling flours before cooking greatly increases the starch hydrolysis and digestibility due to the increased surface area making it susceptible to enzymes (amylases). Jayasinghe *et al*. (2013) illustrated in their work on two millet flour samples; prepared by a traditional stone grinder and industrial milling machine, the stone ground millet flour (bigger particle size) recorded a lower glycaemic index than the millet flour from industrial milling process (lower particle size). Haber and Heaton (1977) showed that the blood glucose and insulin response to whole apples was increased by blending the apples to a puree or extracting the juice.

d. Temperature changes and Storage of food

Cooling and storage affect the bioavailability of starch in-vivo. Fernandes *et al*. (2005) observed that the consumption of hot red potatoes (GI = 89) released more blood (40%) glucose than that of cold red potatoes (GI = 56) and pre-cooked, frozen and reheated before consumption. Nayak *et al*. (2014) observed reduction in rapidly digested starch compared with slowly digested starch when cooked and refrigerated in comparison with freshly cooked New Zealand potato varieties. Englyst and Cummings (1987) also discovered that intermittent heating and cooling result in more resistant starch that directly affects the glycaemic response by slowing starch digestion and absorption.

2.5.3 Amylose and amylopectin content

The chemical structure of starchy foods, thus amylose and amylopectin ratio also plays a significant role in glucose digestion and absorption. In foods such as rice and pasta, the higher amylose content is accompanied by low metabolic response which may be due to

higher tendency of amylose interaction (Xue *et al*., 1990; Goddard *et al*., 1984). Retrograded amylose fractions that are formed on cooling of gelatinized starch, are poorly digested or less susceptible to amylases (Liljeberg *et al*., 2018; Siljestrom *et al*., 1988). Amylose has a tendency to interact with food components such as lipids, thereby reducing amylose both in-vivo and in-vitro (Holm *et al*., 1983).

Raw starches high in amylopectin have shown to be digested faster than those high in amylose (Arvidsson-Lenner *et al.*, 2004; Eli-Cophie *et al*., 2017). According to Nayak *et al*. (2014) and Foster (1965), amylopectin is a larger molecule (with an average molecular weight of 10^5 to 10^6) than amylose which has average molecular weight of 10^4. Therefore amylopectin has larger surface area per molecule than amylose, hence the difference in starch digestibility of amylopectin and amylose. Tako *et al.* (2014) and Eli-Cophie *et al*. (2017) stated that the glucose chains of amylose starch are more bound to each other by hydrogen bonds which make them less susceptible to amylase attack than amylopectin (more branched glucose chains).

2.5.4 Dietary fibre content

The American Dietetic Association (2008) defines dietary fibre as the primary storage and cell wall polysaccharides of plants that cannot be hydrolyzed by human digestive enzymes. Dietary fibre (both soluble and insoluble) has been shown to increase stomach bulkiness, which increases satiety and slows nutrient absorption. Dietary fibre from cereal has been reported to be more effective than that from fruit and vegetables in relation to diabetes, body weight, insulin sensitivity and small intestinal cancer irrespective of the physiological effect (Scazzina *et al*., 2013).

In a search conducted by Fairchild *et al*. (1996), the low glycaemic responses to food observed in his work resulted from the presence of viscous dietary fibre, which delays gastric

emptying and nutrient absorption in the small intestine. The addition of increasing amounts of fibre to a bread meal (0, 6 and 12g) significantly lowered the postprandial glucose and insulin responses in healthy people in a dose–response manner (Nnadi and Keshinro, 2016; Lu *et al*., 2000). β-D-glucan, another soluble dietary fibre has been shown to be effective in reducing postprandial glycaemic and insulin responses (Scazzina *et al*., 2013).

In a study conducted by Pirasath *et al*. (2015) on Sri Lankan foods, increase in dietary fibre content was reported to decrease the glycaemic index of the various foods. Dietary fibre was also instrumental in lowering the glycaemic index of *pittu* made with millet flour and to a certain extent in legumes. Research by Scazzina *et al*. (2009) disclosed that, high fibre foods have low glycaemic response due to a reduced rate of gastric emptying and small intestinal absorption. Bjorck *et al*. (1994) reported that enrichment of whole-barley bread with viscous dietary fibre such as oat, beta glucan and linseed has been shown to reduce glucose and insulin response.

Fibre from non-cereal sources such as legumes has been reported to be effective in reducing postprandial glycaemic and insulin responses of foods. Adding about 10% of *Detarium senegalense Gmelin* (an African legume) flour to a bread meal was shown to reduce the glycaemic response by more than 60% compared with a white bread (Onyechi *et al*., 1998). Guar gum and galactomannan are high soluble fibres known to decrease the glycaemic response as well as the glycaemic index of bread (Scazzina *et al*., 2013).

2.5.5 Moisture content

Moisture content is also a major factor that determines the portion size, thus the glycaemic load of the food. The moisture content of food ingredients and amount of water incorporated during heat treatment affect the degree of gelatinization, starch digestibility and glycaemic index. An increase in moisture content of food increases starch hydrolysis and glucose

release rate, as well as the glycaemic index of the food (Dhaheri *et al.*, 2015). On the contrary, a study by Pathirannehelage *et al*. (2013) revealed that porridges with high water content have low GI, and this was due to reduction in oral and gastrointestinal starch digesting enzymes activity and delay in the digestion of starch. Quantitative changes in various starches during selected processing conditions depend on the availability of water.

2.5.6 Food structure and nature of the starch

It has been reported that disrupting the botanical structures of foods increases the availability of the carbohydrate moiety to digestion and absorption. In starchy foods, the enzyme activity as well as the glycaemic response is affected by the structure of the food (Bjorck *et al*., 1994). Arvidsson-Lenner *et al*. (2004) reported that, when the gross structure of the food is treated with heat (gelatinized) or destroyed mechanically (ground), it increases the rate of digestion and glycaemic response as well as glycaemic index of the food. Raw potatoes exhibit high resistant starch which decreases with an increase in gelatinization (Nayak *et al*., 2014). Also the ripening of cellular structure of a particular food increases the glycaemic index of the foods. According to Brand *et al*. (1985), much greater blood glucose response occurs after the consumption of cooked compared with raw starch, and pureed compared with whole foods.

2.5.7 Anti-nutrients

Starch digestion in the gastrointestinal tract may be inhibited by anti-nutrients. Anti-nutrients like phytates, enzyme inhibitors and lectins may affect starch digestibility and glucose response (Thompson *et al*., 1987). In a research conducted by Kakade and Evans (1961), enzyme inhibitors and lectins were shown to produce hypoglycaemia and decreased growth rates in rats. According to Puls and Keup (1973), certain amylase inhibitors have been reported to decrease glucose absorption in humans and rats as judged by the peripheral glucose response. Yoon *et al*. (1982) recorded decreased rate of release of starch digestion

products in vitro and decreased glucose response when phytic acid supplements were added to unleavened white bread compared to plain unleavened white bread. The mechanism suggested for lowered glycaemia was that phytic acid may affect starch digestibility through interaction with the amylase protein and/or binding with salivary minerals such as calcium, which is known to catalyse amylase activity (Thompson *et al*., 1987). Although anti-nutrients are introverted by heat treatment, however some survive depending on the method of cooking.

2.5.8 Food components interactions

The presence of other foods or dietary components in a meal can influence the digestibility as well as the glycaemic response of the food. In food systems, starch forms molecular complexes with lipids and proteins which renders it less susceptible to enzymatic (amylase) digestion (Dhaheri *et al.,* 2015). Urooj and Putraj (1999) and Eleazu (2016) reported reduced starch digestion and low digestibility index in protein rich foods and attributed to the presence of protein matrix around the starch granules as seen in the SEM, which reduced the amylase penetration in the starch granules in a study conducted. It has been established that high protein foods/meals such as legumes and mixed rice meal have lowering effect on glycaemic index. This is ascribed to the information that increase in protein content results in higher gastric inhibitory peptide (GIP) and insulin responses which lowers glucose release and glycaemic index (Dhaheri *et al.,* 2015).

Table 2.1: Summary of Literature on Glycaemic Index of Foods and Processing Methods

Title of paper	Food items	Findings	Reference
Glycemic indices of different cassava food products	*Fufu, abacha, gari* and *tapioca*	Glycemic indices of *fufu (84.06), abacha (84.88), gari (92.36)* and *tapioca (78.67)* diets were high	Ogbuji and David-Chukwu (2016)
Determination of the glycemic index of local staples in Ghana and the effect of processing on them	Banku, fufu, kenkey and TZ	Glycemic indices of banku, processed fufu, fufu (pounded), kenkey and TZ were 73, 31, 55, 41 & 68 respectively	Eli-Cophie *et al*. (2015)
Effects of processing methods on amaranth starch digestibility and predicted GI	Amaranth seeds	Popping (101.26), roasting (105.81) and flaking (106.01) processes increase glycemic index of amaranth	Capriles *et al.* (2008)
An examination of the possibility of lowering the glycemic index of oat and barley flakes by minimal processing	Oath and barley flakes	Size reduction (rolling or flaking) has relatively minor effect on GI	Granfeldt *et al*. (2000)
Relationship between Processing method	sweet potatoes	Roasting, baking, frying and boiling	Bahado-Singh *et al*. (2011)

and the glycemic indices of ten sweet potato (Ipomoe abatatas) cultivars commonly consumed in Jamaica		affect GI of sweet potatoes	
Glycaemic Index and Load Values Tested in Normoglycaemic Adults for Five Staple Foodstuffs	Pounded Yam, Pounded Cassava-Plantain, Placali, Attieke and Maize Meal Stiff Porridge	Attieke recorded the lowest G (63), Maize Porridge (74), Yam (85), pounded Cassava-Plantain (91) and Placali (106)	Kouamé *et al.* (2015)
Glycaemic Index of Traditional Foods in Northern Sri Lanka	Different traditional foods (raw and cooked)	The GIs Boiled cassava (78.7), potato (75.20), chick pea (33.30) and green gram (31.40)	Pirasath *et al*. (2015)
Glycaemic Indices of Selected Nigerian Flour Meal Products in Male Type 2 Diabetic Subjects	Flours from yam, cassava, maize and wheat	The GIs of the flours were found to be cassava (40.12/59.34*), yam (35.3/49.81*), maize (26.21/54.34*) and wheat (37.50/70.10*).	Fasanmade *et al*. (2007)

* represents GI of diabetic subjects

CHAPTER THREE

MATERALS AND METHODS

3.1 Source of cassava and chemical reagents

A general purpose cassava variety, *Capevars bankye* was used for the study. Fresh cassava tubers of ten months maturity were obtained from Crop Research institute of Ghana at Fumesua-Kumasi. Glucose oxidase/ peroxidase (GOPOD) reagent was obtained from Megazyme Ireland. Amyloglucosidase, α-amylase, urea dimethyl sulfoxide (UDMSO), trichloroacetic acid and all other reagents used for the analysis were purchased from Sigma-Aldrich.

3.2 Preparation of food staples

The fresh tubers were washed, peeled and washed again immediately upon arrival from farm. They were cut and divided into four (4) groups for the preparation of the various food staples as follows;

All the food staples were prepared at the sensory laboratory of the Department of Food Science and Technology – KNUST following a preliminary standardization process. The standardization was done using the schematic flow diagram for local food preparation by Oduro (2016) in **Figure 3.1** below. The whole process was facilitated by a caterer. *Ampesi*, *kokonte* and *akyeke* were chosen because all the processing operations (drying, fermentation, steaming and boiling) under investigation could be identified from their preparations.

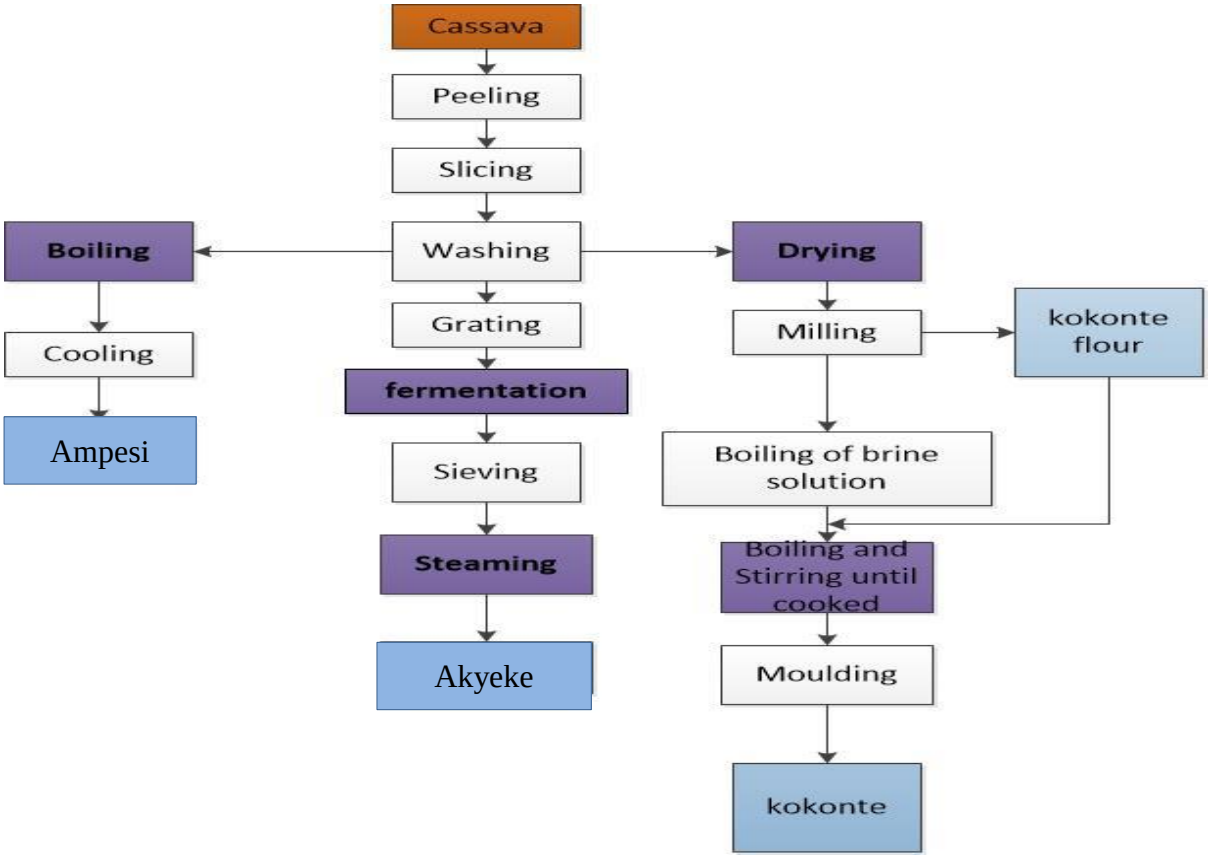

Fig 3. 1: Schematic flow for the preparation of *ampesi*, *akyeke* and cooked *kokonte*

3.2.1 Cassava ampesi

The cassava tubers were cut into uniform sizes (2 cm x 2 cm) using a stainless steel kitchen knife and washed into a sauce pan. One litre (1 L) of water and 3 g of salt was added to 1.5 kg of cassava chunks and the sauce pan was suspended on a gas burner to cook. The water was poured off after boiling at 100 ^{o}C for 25 min.

3.2.2 Cooked kokonte

The cassava tubers were further reduced into smaller sizes using a locally manufactured manual chipper. The chipped samples were evenly spread on four separate stainless steel trays; two for sun drying and the other two for solar drying. The trays were labelled and placed in a solar dryer and in the sun respectively for three (3) days. The sun dried sample was dried from 8:00 am to 5:00 pm each day. The temperature and humidity of the surrounding environment were monitored using data loggers. After the 3 days of drying, the

samples were milled into powder using a locally fabricated hammer mill and packaged in zip-lock bags.

The flour was sieved using a 1 mm mesh to obtain fine flour prior to use. One and half litre (1.5 L) of water was brought to the boil and 650 g of flour was added while stirring for 5 min to form a cohesive paste.

3.2.3 Akyeke

The fresh cassava tubers were grated using a manual grater after peeling and washing. The grated sample was squeezed in a white cloth to reduce the moisture content. The dough obtained was pressed to further reduce moisture content. This was left undisturbed for 42 hrs to ferment. The fermented dough (cake) was disintegrated and sieved using 2.00 mm pore size sieve.

About 200 g of the sample was weighed into a colander suspended over boiling water for the steam to cook the product. The sample was cooked for 8 min to obtain the *akyeke*.

3.3 Sample preparation and storage

All the food samples including fresh cassava and fermented dough were oven dried to moisture content less than 15% at 40 ^{o}C. The drying times were different depending on the nature and initial moisture content of the samples. **Table 2.0** shows the drying times of the samples.

All the samples were milled using the locally fabricated attrition mill and made to pass through a 0.5 mm sieve to obtain uniform and fine flour. The samples were packaged in zip-lock bags and stored at -4^{o}C until further analysis.

Table 3. 1: Drying times of samples

Sample	Drying time / hours
Fresh cassava	98.5
Ampesi	98
Akyeke	19
Fermented dough	72
Kokonte	147

3.4 Chemical analysis

The total starch, amylose, amylopectin, dietary fibre contents and glycaemic index of all the samples were determined in triplicate at the Food Science and Technology laboratory, KNUST according to standard protocols as follows;

3.4.1 Amylose determination

Approximately 0.1 mL of the sample solution composed of 50 mg of flour and 6 mL UDMSO (0.6 M urea in 90% Dimethyl sulfoxide) was mixed with 0.9 mL absolute ethanol. The samples were centrifuged (2000 g, 15 min), washed with 2 mL 95% ethanol and centrifuged again. The solvent was decanted; 0.1 mL UDMSO was added to the pellet and placed in a boiling water bath for 15 min to ensure complete dissolution of the samples. About 5 mL 0.5% trichloroacetic acid (TCA) and 0.05 mL iodine solution (1.27 g I_2 and 3.00 g KI per litre) was added and mixed immediately. The test tubes were allowed to stand undisturbed at room temperature for 30 min, and absorbance for the samples was read at 620 nm with water as reference from a spectrophotometer (UV5, 2017). The amylose contents of

the samples were estimated using a amylose standard curve with the equation, Y = 0.0164X+0.001 (Eriksson *et al.*, 2014).

3.4.2 Total starch determination

About 0.1 g of sample was weighed into centrifuge tubes and 5.0 mL of aqueous ethanol (80%) was added and incubated at 84 ^{o}C in Isotemp205 for 5 min. The mixture was well mixed on a vortex stirrer following addition of 5.0 mL of 80% ethanol. The contents of the tubes were centrifuged at 1800 g for 10 min and the supernatant was discarded. The pellet was stirred again on a vortex stirrer upon the addition of 10 mL ethanol (80% v/v). The tubes were placed in ice/water bath over a magnetic stirrer for 20 min after adding 2 mL of 2 M KOH. Approximately 8 mL of 1.2 M sodium acetate buffer (pH 3.8), 0.1 mL a-amylase and amyloglucosidase solutions were added and mixed thoroughly. The tubes were incubated at 50 ^{o}C for 30 min with an intermittent mixing on a vortex. The contents of the tubes were quantitatively transferred into 100 mL volumetric flasks and adjusted to 100 mL with distilled water. It was well mixed and centrifuged at 1800 g for 10 min. Duplicate aliquots of 0.1 mL of D-glucose and reagent blank solutions were dispensed into glass test tubes and 3.0 mL of glucose oxidase/ peroxidase (GOPOD) reagent was added to each. The absorbance for the sample and the D-glucose was read at 510 nm from spectrophotometer (UV5, 2017) against the reagent blank (Megazyme, 2011).

3.4.3 Amylopectin determination

Amylopectin content of the samples was determined by difference. The difference between total starch and amylose contents of the samples represents the amylopectin content.

3.4.4 In-vitro glycaemic Index assay

The glycaemic indices of the samples were determined according to Goñi *et al.* (1997) protocol. Milled sample (1 g) was weighed into 50 ml tube and 10 glass beads (5 mm diameter) were added. The tube was incubated at 37 °C in a shaking water bath for 30 min after adding 2 mL of 0.05 M hydrochloric acid and 0.001 g of pepsin. Four millilitres (4 mL) of 0.5 M sodium acetate buffer (pH 5.2) was added to the test tube followed by the addition of 1 m of freshly prepared amyloglucosidase solution after 1 min interval. The mixture was incubated at 37 °C in a shaking water bath. Aliquots of 0.1 mL were taken at 0, 10, 20, 30, 60, 90, 120, and 180 min intervals and mixed with 1 mL of 50% ethanol. The samples were centrifuged at 800 g for 10 min. In order to determine the amount of glucose released, 0.1 mL of sample solution, D-glucose and blank were dispensed into glass test tubes and 3.0 mL of glucose oxidase/ peroxidase (GOPOD) reagent was added to each. The test tubes were incubated at 50 ^{o}C for 20 min and absorbance was read at 510 nm from spectrophotometer (UV5, 2017).

3.4.5 Dietary fibre determination

The dietary fibre contents of the samples were analyzed following the protocol by Prosky *et al*. (1988). About 1 g of each sample was weighed in quadruplicates into tall form beakers and 50 mL of phosphate buffer pH 6.0 was added. Then 0.10 mL α-Amylase was added to each beaker, well mixed and covered with aluminium foil. The beakers were placed in a boiling water bath and incubated for 15 mins with gentle agitation at 5 min intervals after the internal temperature of the beakers had reached 95 °C. The solutions were allowed to cool to room temperature and the pH of the solutions was adjusted to 7.5 ± 0.2 by adding 10 mL of 0.275 N NaOH to each beaker. About 0.1 mL of freshly prepared protease solution (0.15 g in 3 mL of phosphate buffer) was pipetted into each beaker. The beakers were covered with aluminium foil and incubated for 30 mins in a water bath with continuous agitation after the

internal temperature of the beakers had reached 60 ^{o}C. The solutions were cooled to room temperature and pH was adjusted to between 4.0 and 4.6 by adding 10 mL of 0.325 M HCl to each beaker. Then 0.1 mL of Amyloglucosidase solution was dispensed into each beaker and covered with aluminium foil. The beakers were incubated with a continuous agitation in a 60 °C water bath for 30 mins after the internal temperature had reached 60 °C. About 4 mL of 95% ethanol was added to each beaker and allowed to set overnight at room temperature. The contents (precipitate and suspension) of the beakers were quantitatively transferred to their respective crucibles and filtered by gentle suction. The residue was washed with three 20 mL portions of 78% ethanol, two 10 mL portions of 95% ethanol, and two 10 mL portions of acetone. Crucibles containing residues were dried overnight in a 105 °C air oven, cooled in a desiccator and weighed. The residues from two samples and two blanks were analysed for protein by Kjeldahl nitrogen analysis as specified in the AOAC procedure.5. The protein content was estimated by multiplying nitrogen content by 6.25. The residues in the crucibles from two samples and two blanks were ashed for 5 hours at 525 °C, cooled in a desiccator and weighed to obtain the ash weight. The fibre content was calculated from;

$$Dietary\ fibre\ (\%) = \frac{\frac{R1 + R2}{2} - p - A - B}{\frac{m1 + m2}{2}} \times 100$$

Where:
R1 = residue weight 1 from m1; R2 = residue weight 2 from m2
m1 = sample weight 1; m2 = sample weight 2
A = ash weight from R1; p = protein weight from R2 and
B = blank

$$B = \frac{BR1 + BR2}{2} - BP - BA$$

Where:

BR = blank residue; BP = blank protein from BR1
BA = blank ash from BR2

3.5 Statistical analysis

The predicted glycaemic index of each test food and the control was calculated as the mean GI using glycaemic index estimation module. Mean values, standard deviations and significant difference between test samples at 95% confidence level were determined using Microsoft Excel (2010) and Statistical Package for Social Sciences (SPSS) software version 20, respectively. The component and contribution of starch, amylose, amylopectin and dietary fibre contents to the glycaemic indices of the samples was assessed using principal component analysis (PCA).

CHAPTER FOUR

RESULTS AND DISCUSSION

The content of total starch, amylose, amylopectin, dietary fibre and predicted glycaemic indices of the fresh cassava, boiled cassava (*ampesi),* cooked *kokonte* with either sun or solar dried flour, *akyeke*, fermented cassava dough, sun dried *kokonte* flour and solar dried *kokonte* flour samples are presented in **Table 4.1**.

4.1 Effects of processing methods on total starch content of samples

The total starch content of the fresh cassava was found to be 42.21%. The carbohydrate content of cassava has been reported to be between 26.3 - 39.6 % (Richardson, 2013) and 38.06% (USDA, 2007) cited in Montagnac *et al*. (2009). The starch content reported in this study was higher compared with reported literature. This difference in carbohydrate content may be due to factors such as variety, geographical location, age of plant and environmental conditions (Montagnac *et al*., 2009). However, the intermediate products: sun dried *kokonte* flour sample (38.23%), solar dried *kokonte* flour sample (33.32%) and fermented cassava dough sample (39.81%) had total starch contents lower ($p < 0.05$) than the fresh cassava sample (42.21%). The decrease in total starch content of the samples may be attributed to the differences in processing methods that resulted in such products (Montagnac *et al*., 2009). Processing methods like drying and fermentation convert starches to sugars and other organic acids which contribute to reduction in starch content (Ostman, 2003; Ihekoronye and Ngoody, 1985). It is for this reason that, fermented cassava dough and cassava flour samples had lower starch content than the fresh cassava sample.

Cooked *kokonte* with solar dried flour recorded the highest starch content (47.07%), followed by boiled cassava (*ampesi*) (45.47%), *akyeke* (42.22%) and cooked *kokonte* with sun dried flour (37.185%) had the lowest. There was a significant difference ($p < 0.05$) between all the

finished food samples. Boiled cassava (*ampesi)* (45.47%) and cooked *kokonte* with solar dried flour (47.07%) had a significant ($p < 0.05$) increase in their total starch contents compared with fresh cassava (42.41%). The increase in starch content in boiled cassava (*ampesi)* and cooked *kokonte* with solar dried flour is due to increased degradation of food structure during boiling (Arvidsson-Lenner *et al*., 2004: Bjorck *et al*., 1994). This permits amylase penetration into the starch granules to allow for hydrolysis and estimation of more starch (Urooj and Putraj, 1999: Eleazu, 2016). The total starch content of cooked *kokonte* with sun dried flour (37.19%) was significantly ($p < 0.05$) lower than cooked *kokonte* with solar dried flour (47.07%). The variation may be a result of increased degree of starch gelatinization due to high temperature recorded in solar dried (28 – 62 ^{o}C) kokonte flour than sun dried (23 – 30 ^{o}C) kokonte flour. Studies have discovered that starch hydrolysis and bioavailability increases with increasing drying temperature (Harper, 1995). Cooked *kokonte* with solar dried flour, boiled cassava (*ampesi*) and *akyeke* are high starch yielding foods, and are good for consumers with high energy requirement.

Table 4. 1: Total starch, total dietary fibre, amylose, amylopectin contents and predicted GI for the fresh cassava, fermented cassava dough, cassava flour (sun and solar dried), boiled cassava (*ampesi*), cooked *kokonte* (sun and solar dried flours) and *akyeke* samples.

Sample	Total starch (%)	Amylose (%)	Amylopectin (%)	Dietary fibre (%)	Glycaemic index (%)
Fresh cassava	42.41± .04^{d}	4.23±.09^{bc}	38.18±.52^{d}	1.23±.02^{a}	47.75^{bc}
Fermented cassava dough	39. 81±.24^{c}	3.49±.16^{b}	36.32±.39^{bc}	2.761±.06^{d}	46.47^{b}
Sun dried *kokonte* flour	38.23±.96^{b}	14.74±.33^{g}	23.49±1.07^{a}	1.63±.04^{b}	47.49^{bc}
Solar dried *kokonte* flour	33.32±.09^{a}	8.28±.31^{f}	25.04±.23^{a}	1.21±.01^{a}	48.50^{c}
Cooked *kokonte* (Sun dried flour)	37.19±.24^{b}	2.38± .07^{a}	34. 81±.21^{b}	2.84±.10^{d}	40.20^{a}
Cooked *kokonte* (solar dried flour)	47.07±.80^{f}	4.53±.03^{cd}	42.54±.79^{e}	1.53±.02^{b}	61.11^{d}
Boiled cassava (*Ampesi*)	45.47±.08^{e}	6.91±.33^{e}	38.47±.42^{d}	1.80±.03^{c}	77.30^{e}
Akyeke	42.22±.08^{d}	4.90±.10^{d}	37.21±.29^{cd}	1.19±.05^{a}	79.05^{e}

* Values are means ± standard deviation

* Values with the same superscript in a column are not significantly different ($p > 0.05$)

4.2 Effects of processing methods on amylose content of samples

The amylose contents of the samples were within 2 – 15% and are relatively lower since they are far below 20% on the general amylose standard scale (Chen and Bergman, 2007; Odenigbo *et al.*, 2013). Among the intermediate products; sun dried (23 - 30 ^{o}C) *kokonte* flour recorded the highest amylose content (14.74%), followed by solar dried (28 - 62 ^{o}C) *kokonte* flour (8.28%) whiles fermented cassava dough had the least (3.49%). Both *kokonte* flours (sun and solar dried) went through some sort of heat treatment and hence the conversion and hydrolysis of amylopectin at the amorphous regions of the starch granules to amylose was greatest (Numfor *et al*., 1995). However, there was significant difference ($p < 0.05$) between the amylose contents of the different flours. This variation may be due to different drying temperatures recorded (Jaisut *et al*., 2008). The fermented cassava dough sample recorded significantly ($p < 0.05$) lower amylose content compared to the other intermediate products (sun dried *kokonte* flour and solar dried *kokonte* flour) and fresh cassava sample. The reduction in amylose content of fermented cassava dough as elaborated by Maldonado *et al.* (2013) was owed to an increased oxidative depolymerisation of the amylose during the fermentation process. Oxidative depolymerisation involves the use of enzyme system (glucosidase, amylase, cellulase, chitinase, inulinase, phytase, xylanase, tannase, esterase, invertase or lipase) to hydrolyse glucosides, cell wall or starch and high molecular components of food (Jin *et al.*, 2014). These enzymes produced in the course of the fermentation are able to hydrolyse amylose, thereby, reducing its content in the fermented product (Maldonado *et al.*, 2013). This makes fermented products more digestible for consumers and creates market opportunity for food products that involve fermentation.

The amylose contents of the finished products: *akyeke*, boiled cassava (*ampesi*), cooked *kokonte* with sun dried flour and cooked *kokonte* with solar dried flour samples were found to be 4.90%, 6.91%, 2.36% and 4.53% respectively. There were significant differences among

the finished products except between *akyeke* and cooked *kokonte* from solar dried flour at 5% confidence level. Boiled cassava (*ampesi)* recorded slight increase in amylose content, and this increase may be due to the conversion of amylopectin to amylose and leaching of amylose that occurs during boiling (Holm *et al*., 1988; Vesterinen *et al*., 2001). The low amylose recorded for *akyeke* could be attributed to formation of amylose–lipid complex that occurs during steaming, making amylose less extractable as explained by Holm *et al*. (1983) and Leeman *et al*. (2008). The higher amount of amylose recorded in cooked *kokonte* with solar dried flour (4.53%) compared with that of cooked *kokonte* with sun dried flour (2.38%) can be ascribed to leaching of amylose that transpired predominantly in solar drying than sun drying (Englyst and Cummings, 1987; Nayak *et al*., 2014; Vesterinen *et al*., 2001).

4.3 Effects of processing methods on amylopectin content of samples

The amylopectin content of the samples ranged between 23.49 – 42.54%. Fresh cassava had amylopectin content of 38.18% which was lower than the value of 77.05% reported by Aliyu and Aliyu (2014). This variation in amylopectin content might have resulted from physiological factors such as variety used, age and native structure of the tubers and the method of determination of total starch and amylose since amylopectin was determined by difference (Bjorck *et al*., 1994; Bahado-Singh *et al*., 2006). The amylopectin contents of sun dried *kokonte* flour and solar dried *kokonte* flour were 23.49% and 25.04% respectively. The heat generated during the course of drying causes conversion of amylopectin to amylose (Vesterinen *et al*., 2001) and starch to other simple sugars (Batra *et al*., 1994). The difference in the amylopectin contents of the two *kokonte* or cassava flours was not significant ($p > 0.05$), implying that the different drying methods (sun or solar drying) have almost equal effects on amylopectin contents of the intermediate products. However, there was high disparities between the amylopectin content of fermented cassava dough (36.32%), *kokonte*

flour; sun dried (23.49%) and *kokonte* flour; solar dried (25.04%) at 5% significance level. This is because during drying more of amylopectin is converted to amylose as stated by Vesterinen *et al*. (2001) than in the case of fermentation and hence the observed variation.

The amylopectin contents of boiled cassava (*ampesi),* cooked *kokonte* with solar dried flour, cooked *kokonte* with sun dried flour and *akyeke* samples were 38.47%, 42.54%, 34.81% and 37.21% respectively. There was a significant difference ($p < 0.05$) among the amylopectin contents of boiled cassava (*ampesi),* cooked *kokonte*; sun dried flour and cooked *kokonte* with solar dried flour. The difference might have resulted from the reduced particle size of the flours and stirring whiles boiling that occurred in the cooking process of *kokonte.* Studies have discovered that reduced particle size, stirring and boiling facilitate starch hydrolysis and conversion of amylopectin to amylose (Ogbo and Okafo 2015; Donlao and Ogawa, 2016). Cooked *kokonte* with solar dried flour sample recorded the highest amount of amylopectin content (42.54%) relative to cooked *kokonte* with sun dried flour sample (34.81%) due to the degree of amylopectin leaching from starch granules. Leaching of amylopectin from starch granules is optimal at 40-50 ^{o}C as reported by Tester and Morrison (1990), implying that solar dried flour (28 – 62 ^{o}C) is more susceptible to starch gelatinization and amylopectin leaching during boiling than sun dried flour (23 – 30 ^{o}C) and this could account for the differences in amylopectin contents of cooked *kokonte* with solar dried flour and cooked *kokonte* with sun dried flour. Starch gelatinization and amylopectin leaching is high at high temperature (Harper, 1995: Tester and Morrison, 1990) and solar dried kokonte flour recorded the highest temperature compared with the sun dried sample. *Akyeke* had moderate amount of amylopectin (37.21%) relative to the other finished products. This is because during steaming, there is increased starch hydrolysis as compared to boiling (Daomukda *et al.*, 2011).

4.4 Effects of processing methods on dietary fibre content of samples

The dietary fibre contents of the samples ranged between the values of 1.19 – 2.84%. The dietary fibre content of fresh cassava (1.22%) was within the values 0.1 – 3.7% reported by Montagnac *et al*. (2009) and varied slightly from the work (1.8%) of Onyenwoke and Simonyan (2014). This variability could be due to the variety and age of cassava used (Sarkiyayi and Agar, 2010; Onyenwoke and Simonyan, 2014). The intermediate products: solar dried *kokonte* flour, sun dried *kokonte* flour and fermented cassava dough recorded dietary fibre contents of 1.21%, 1.63% and 2.76%, respectively. There were significant ($p < 0.05$) differences in the dietary fibre contents of the intermediate products, and this may be due to differences in unit operations undertaken in each sample. Drying causes leaching of amylose from starch granules giving rise to the potential subsequent formation of retrograded starches (Vesterinen *et al*., 2001). These starches are resistant to enzyme hydrolysis and therefore contribute to an increase in dietary fibre content of the flours, but is predominant in sun drying (lower temperature transitions) than solar drying. The fermented cassava dough had highest dietary fibre content amongst all the intermediate products because of the inhibitory activity of the organic acids (produced during the fermentation process) on hydrolytic enzymes (Ostman, 2003).

Cooked *kokonte* with sun dried flour, boiled cassava (*ampesi)* and cooked *kokonte* with solar dried flour samples recorded considerable amounts of dietary fibre 2.84%, 1.80% and 1.53% respectively. This increase is due to leaching of amylose from the starch granules during the heat application. Boiling has been reported to cause amylose leaching and the potential subsequent formation of retrograded or resistant starches; which form part of the indigestible component of the food (dietary fibre) (Nayak *et al*., 2014; Eleazu, 2016). However, *akyeke* recorded a decrease in dietary fibre content compared with the other finished products, though the intermediate product (fermented cassava dough) used for its preparation had a

high dietary fibre content (2.76%). This is because during steaming, there is complete starch gelatinization and destruction of intermolecular hydrogen bonds thereby reducing the resistant ability of retrograded starches to hydrolytic enzymes (Daomukda *et al.*, 2011).

4.5 Combined effects of total starch, amylose, amylopectin and dietary fibre contents on predicted glycaemic index of samples

Principal component analysis (PCA) was conducted on the data sets to reduce the dimension of the data, to visualize the similarities and differences between the samples and to describe which category variable is responsible for the variation in the data sets. This will assist in analysing the contribution of starch, amylose, amylopectin and dietary fibre to the glycaemic indices of the samples. The scores and loadings of a PCA plot help to explain the interrelationships and impacts of variables on the trend or behaviour of a phenomenon (Tharwat, 2017). **Figure 4.1** and **4.2** shows the PCA scores and loading plots of samples and their determined parameters, respectively.

It can be deduced from the two PCA plots that total starch and amylopectin contents correlated well with an increase in glycaemic index than dietary fibre and amylose contents. This substantiates why samples with high dietary fibre and amylose contents recorded lower glycaemic index values whereas samples with higher total starch and amylopectin contents had higher glycaemic index values except other factors contributed to GI reduction.

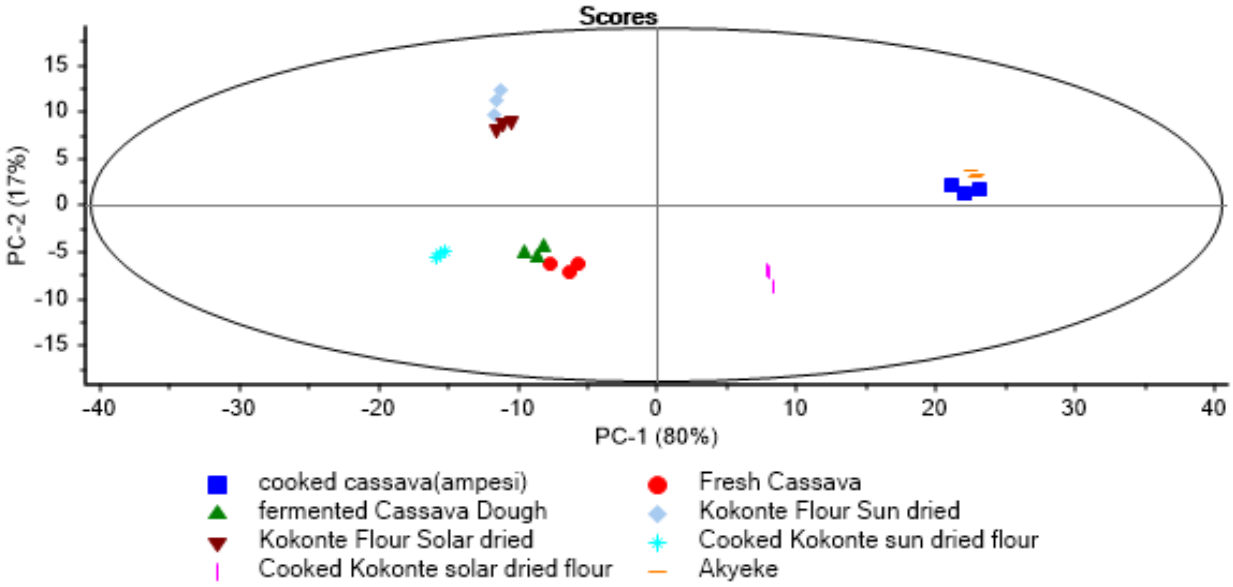

Fig 4. 1: PCA scores of Glycaemic index of samples

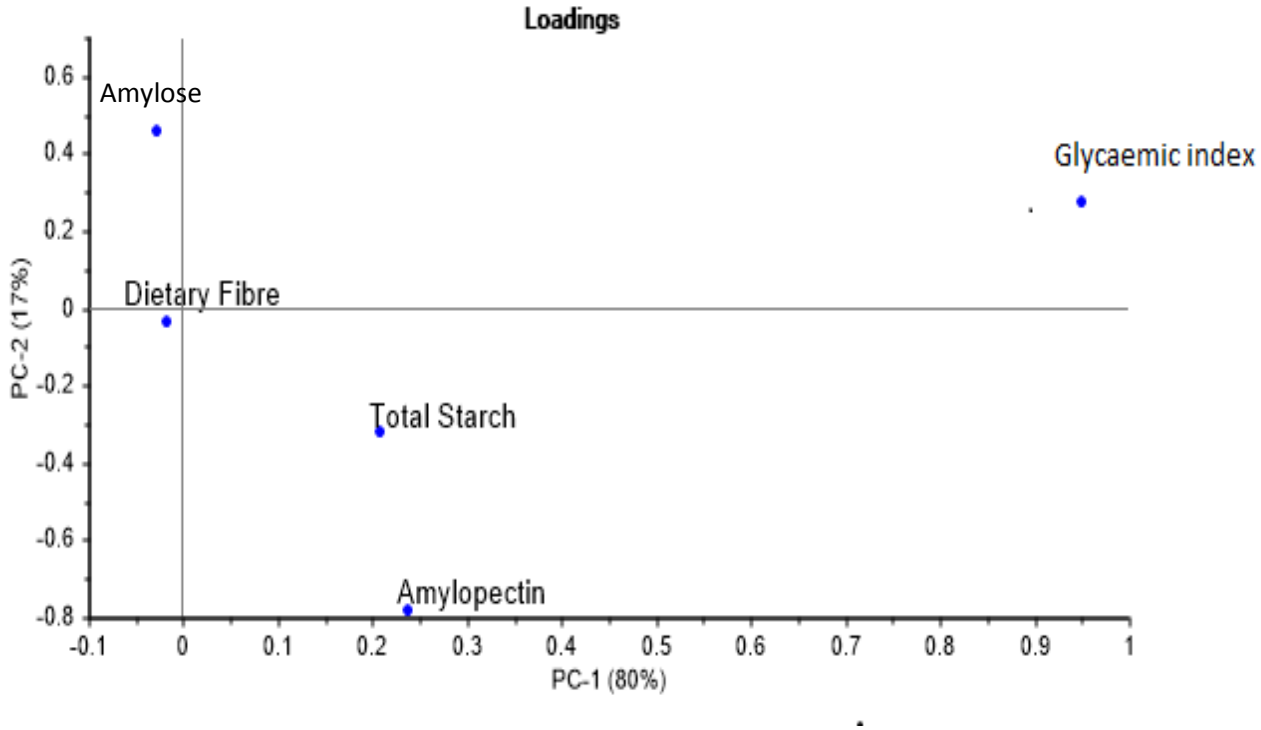

Fig 4. 2: PCA loadings of total starch, amylose, amylopectin, dietary fibre and GI of samples

4.6 Effects of processing methods, total starch, amylose, amylopectin and dietary fibre contents on starch digestibility and predicted glycaemic index of samples

From the **table 4.1** of results, fresh cassava, sun dried *kokonte* flour, cooked *kokonte* with sun dried flour, solar dried *kokonte* flour and fermented cassava dough had predicted glycaemic index values of 47.75%, 47.49%, 40.20%, 48.50% and 46.47%, respectively. Their GI values are described as low because they fall within the low (0 – 55%) glycaemic index chart (Eleazu, 2016). The analysis revealed that, fresh cassava has high amount of starch and amylopectin than amylose and dietary fibre, and was therefore, expected to have a GI value more than what was reported. This deviation may be due to the fact that, the fresh cassava was raw, unprocessed and the botanical or gross structure of cassava was intact, making starch and amylopectin unavailable for hydrolysis into glucose by the hydrolytic enzymes (Nayak *et al*., 2014). The lower and slower the release of glucose from uncooked and unprocessed starch, the lower glycaemic response and the estimated glycaemic index (Brand *et al*., 1985). Consumers and patients with diabetic conditions can resort to consumption of foods with minimal processing. Processors may consider limiting the level of processing operations in order to produce low glycaemic index products.

Sun *dried Kokonte* flour and solar dried kokonte flour recorded a lower glycaemic index. They all had considerable amounts of amylose and dietary fibre and therefore expected to have a lower glycaemic index values (Scazzina *et al*., 2013; Lu *et al*., 2000). Sun dried *Kokonte* flour recorded significant ($p < 0.05$) amount of amylose and dietary fibre than solar dried *kokonte* flour. However, the difference in the glycaemic indices of *kokonte* flour (sun dried) and *kokonte* flour (solar dried) was insignificant ($p > 0.05$). This implies that producers of cassava flour can employ sun or solar drying in their operations and still have the desired results or outcome, in terms of glycaemic index value.

Fermented cassava dough; an intermediate product used in preparation of *akyeke* also recorded a lower glycaemic index value of 46.47% and shown a slight decrease from the fresh cassava (47.75%), yet there was no significant difference ($p > 0.05$) between them. The fermented cassava dough has higher quantities of amylopectin and starch, and was therefore expected to elicit good amount of glucose upon hydrolysis (Arvidsson-Lenner *et al*., 2004; Eli-Cophie *et al*., 2017) but differed. This observed variation might have resulted from the high dietary fibre content (Scazzina *et al*., 2013) and the production of organic acids during the course of the fermentation (Ostman, 2003). These organic acids are postulated to inhibit the activity of hydrolytic enzymes during starch hydrolysis and hence the reduced GI recorded (Ostman, 2003). Consumers and diabetic patients should cultivate the habit of consuming fermented and high dietary fibre foods to augment their health and medical conditions. Processors may also look at incorporating more fibre into food products, in order to reduce their GIs.

This study revealed *akyeke* (79.05%) and boiled cassava; *ampesi* (77.03%) to be high (70 – 100%) glycaemc index foods (Eleazu, 2016) and having high concentrations of total starch and amylopectin which are major contributing factors to high glycaemic index foods. The value recorded for *akyeke* varied slightly from the work (63.0%) done by Kouame *et al*. (2015) who used in-vivo method of GI determination. The difference in this case is due to the method of analysis and preparation of food. The GI of *akyeke* was significantly higher than that of *ampesi* though they all went through some form of heat treatment operation. Studies have revealed that dry heat (steaming) causes high degree of gelatinization than moist heat (boiling) (Kale *et al*., 2016). The *akyeke* was prepared by steaming fermented cassava dough, and this contributed to an increase in the GI. Steaming has been reported to cause complete gelatinization of starch and destroy the intermolecular hydrogen bonds between organic acids produced in the course of the fermentation process (Daomukda *et al.*, 2011). Batra *et al*.

(1994) and Ihediohanma (2011) revealed that fermentation causes the breakdown of complex carbohydrates like starch and other polysaccharides to simpler forms (disaccharides and monosaccharides) which elicit more glucose upon hydrolysis and therefore such high glycaemic index recorded.

Boiled cassava (*ampesi)* also had a high glycaemic index value of 77.30% and is well correlated with 78.70% reported by Pirasath *et al*. (2015). Boiled cassava (*ampesi*) has high amounts of total starch and amylopectin, and therefore expected to produce more glucose into blood and compound the adverse effect of glucose on diabetic patients and regular consumers (Jenkins *et al*., 1988). Boiling of food stuff in water has been suggested to modify the physical and chemical states of starch and therefore improve its digestibility by hydrolytic enzymes (Kouassi *et al*., 2009). It has been established that, starch granules absorb water and swell (gelatinization) during boiling which disrupts the crystalline structure of starch irreversibly, making it susceptible to hydrolysis by amylase and hereafter an increase in glycaemic index of such foods (Englyst and Cummings, 1987; Soh and Brand-Miller, 1999). It has also been appreciated that the cooking method, amount of water and duration of boiling (cooking) significantly affect the level of gelatinization and digestibility of the starch, and this also account for differences in glycaemic index of some boiled staples (Nayak *et al*., 2014; Daomukda *et al*., 2011). Boiled cassava (*ampesi)* can be consumed with other food ingredients with lower glycaemic index or consumers may minimize its consumption to reduce effects on their health.

The predicted glycaemic indices of cooked kokonte with sun dried flour and cooked kokonte with solar dried flour were 40.20% and 61.11% correspondingly. Cooked *kokonte* with solar dried flour contains higher amounts of total starch and amylopectin, and less of dietary fibre compared with cooked *kokonte* with sun dried flour. It is therefore expectant of cooked kokonte with solar dried flour to elicit more glucose, glycaemic response and glycaemic

index. The GI of the cooked *kokonte* with sun dried flour was significantly ($p < 0.05$) lower than that of solar dried, and this variation could be accounted for by the differences in their total starch, amylopectin and dietary fibre contents as well as drying temperature. Studies have shown that drying reduces the moisture content; which causes partial starch gelatinization, loss of starch granules and low digestibility (Jaisut *et al*., 2008) , giving rise to low or moderate glycaemic index products (Omolola *et al*., 2015). The heating and cooling regimes or transitions involved in drying has been reported to facilitate formation of high resistant starches concentration (Ogbo and Okafo 2015; Donlao and Ogawa, 2016) and amylose-lipid complex thereby reducing starch hydrolysis (Holm *et al*., 1983). This may be responsible for the low and moderate glycaemic index recorded in cooked *kokonte* with sun dried flour (23 – 30 ^{o}C) and cooked *kokonte* with solar dried flour (28 – 62 ^{o}C), respectively. The higher temperature of the solar dried kokonte flour might have contributed to an increased starch hydrolysis, glucose response and moderate glycaemic index value. Consumption of cooked *kokonte* may decrease the risk of postprandial blood glucose rise, and prove to be more efficacious in the management of type 2 diabetes mellitus and cardiovascular diseases.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This study has affirmed that processing methods or operations affect starch digestibility and glycaemic index of food samples. It has established that steaming and boiling increase the GI of foods, fermentation (period of 42 hrs) has no significant effect on GI of fermented steamed cassava products, and drying of cassava has no substantial effect on GI of cassava flour. However, staples or products prepared from solar dried cassava flour would have higher GIs than those of sun dried cassava flour. This work has provided evidence in support of the fact that total starch and amylopectin give rise to an increase in GI whereas amylose and dietary fibre contents contribute to a decrease in GI of foods.

The predicted GIs of cassava (47.75%), boiled cassava (*ampesi)* (77.30%), *akyeke* (79.05%), cooked *kokonte* with sun dried flour (40.20%) and cooked *kokonte* with solar dried flour (61.11%) have been made known. The dietary fibre content of *Capevars bankye* flour was found to be 1.631% and 1.214% for sun and solar drying processes, respectively.

5.2 RECOMMENDATION

More research is required to investigate the structure of starch granules in cassava-based traditional staples, to account for differences in their starch hydrolysis rate, digestibility and glycaemic index. Further research is also needed to explain the effect of cooking methods (boiling, roasting, baking) on the glycaemic index of fermented traditional staples, to determine whether changes in GI of these staples is due to the fermentation process.

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