KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, GHANA

COLLEGE OF SCIENCE

DEPARTMENT OF BIOCHEMISTRY AND BIOTECHNOLOGY

DETERMINATION OF THE GLYCEMIC INDEX OF LOCAL STAPLES IN GHANA AND THE EFFECT OF PROCESSING ON THEM

BY

DIVINE WORMENOR

MARCH, 2015

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DECLARATION

I Divine Wormenor hereby declare that this thesis titled: "*Determination of the Glycemic Index of Local Staples in Ghana and the Effect of Processing on Them*" is my own work based on primary data collected. To the best of my knowledge, this work contains no material previously published by another person, nor material accepted for the award of any other degree of the university, except where due acknowledgement has been made in the text.

Divine Wormenor	.....	.....
PG 8020012	Signature	Date
Dr. Jacob Agbenorhevi	.....	.....
(Supervisor)	Signature	Date
Dr. Reginald A. Annan	.....	.....
(Co-Supervisor)	Signature	Date
.....	.....	.....
Head of Department	Signature	Date

ABSTRACT

Glycemic index measures the blood glucose raising ability of foods. It is a measure of the quality of a carbohydrate food. Current knowledge on the effect of carbohydrates on diabetes and other metabolic diseases has increased concerns on carbohydrate quality and factors that affect it. The aim of the study was to determine the glycemic index (GI) of some carbohydrate-rich Ghanaian staple foods and to assess the influence of processing on the GI of foods. The study was a crossover trial involving 10 apparently healthy individuals served with 50g portions of pure glucose on two different occasions. They were subsequently given measured amounts of the test foods containing 50g available carbohydrates. The GI values were determined by measuring the capillary blood glucose levels of the subjects at fasting and after ingestion of the glucose and test foods within a 2-hour period. Sampling started 15 min after consumption and subsequent samples taken at the 30, 45, 60, 90 and 120min. A glucose response curve was drawn for each subject for both reference food and test foods. The GI of the test foods were calculated by dividing the incremental area under the glucose response curve of the test food by the incremental area under glucose response curve for the reference food and multiplying the result by 100.The glycemic responses to four major Ghanaian staples, Banku, Tuo Zaafi, Fufu (Pounded and Industry processed), Ga Kenkey were determined in ten apparently healthy individuals (8 males and 2 female) with mean age, Body Mass Index (BMI) and Waist Circumference (WC) of 30.9±6.4 years, 26.94±5.2 kg/m^2 and 88.6±13.8 cm respectively. Fufu prepared from industry processed fufu flour had the least glycemic response followed by Ga Kenkey and locally pounded fufu all falling within the Low GI category. Tuo Zaafi had a medium GI and Banku had a moderately high GI. A multiple comparison of GI of the various foods by ANOVA revealed a significant difference between the GI of locally pounded fufu (LPF) and fufu prepared from industrially-processed fufu flour (IPF) ($p = 0.026$) implying that the processing influenced glycemic quality. In conclusion, the glycemic response of commonly consumed Ghanaian staples Banku, TZ, Kenkey, industrially-processed fufu (Neat® Fufu) and locally pounded Fufu were determined, and should guide health professionals and Ghanaians in their choices of local staples and meal planning. It is recommended that a study to determine the complete nutritional profile of the various local foods be made alongside their serving sizes to aid in the determination of glycemic load of these foods.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BMI	=	Body Mass Index
CHD	=	Chronic Heart Disease
CVD	=	Cerebro Vascular Disease
FAO	=	Food and Agriculture Organization
FBG	=	Fasting Blood Glucose
FDB	=	Food and Drugs Board
GDM	=	Gestational Diabetes Mellitus
GI	=	Glycemic Index
GIT	=	Gastro Intestinal Tract
HBA1c	=	Glycohemoglobin
HDL	=	High Density Lipoprotein
HFCS	=	High Fructose Corn Syrup
IPF	=	Industry Processed Fufu
IAUC	=	Incremental Area Under the Curve
LPF	=	Locally Pounded Fufu
MNT	=	Medical Nutrition Therapy
NVP	=	Novel Viscous Polysaccharide
OGTT	=	Oral Glucose Tolerance Test
PPG	=	Post Prandial Glucose
PUFA	=	Poly Unsaturated Fatty Acid
SD	=	Standard Deviation
SFA	=	Saturated Fatty Acid
WC	=	Waist Circumference
WHO	=	World Health Organization

CHAPTER ONE

1.0 THESIS LAYOUT

CHAPTER ONE: INTRODUCTION, JUSTIFICATION AND OBJECTIVES

Chapter 1 gives a brief summary of carbohydrates food group, its effects on postprandial glucose and the relevance of the concept of glycemic index. The problem statement with a justification or motivation for the study is outlined in this chapter, as well as the general aim of the study with specific objectives.

CHAPTER TWO: LITERATURE REVIEW

Chapter 2 presents a review of carbohydrates and the relevance of glycemic index, a local perspective through a world view.

CHAPTER THREE: MATERIALS AND METHODS

Chapter 3 outlines the methods involved in the determination of the glycemic index of some specific foods, their systematic preparation and analysis of nutrient compositions.

CHAPTER FOUR: RESULTS AND DISCUSSION

In Chapter 4 the results obtained from the study are presented with calculations and appropriate graphical representations. Detailed discussions of the results are also made here.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

The conclusions reached from the study are presented in this chapter. The necessary recommendations for future research are also indicated here.

REFERENCES

This section contains all references used in the research, written in an alphabetical order.

1.1 INTRODUCTION

Food consumption is for the purposes of building the body, providing the body with energy and protection from diseases. Fundamental to healthy living is the need for a balanced consumption of foods that serve the three main purposes of a diet. The main source of energy in the diet of most people is carbohydrates and they play a very significant role in homeostasis and energy metabolism (Mann *et al.*, 2007). The energy contents and digestibility of different carbohydrates, however, differ. Some carbohydrate foods elicit a quicker response from insulin than others. This is due to differences in the rate at which they are metabolized into glucose. A study conducted in the UK concluded that a very good glucose control is paramount in the prevention of complications resulting from diabetes (Salmeron *et al.*, 1997a). Regulation of glucose in the blood is variably dependent on the type of food consumed. This is due to varying effect of different carbohydrates on the blood glucose level. The rate at which particular carbohydrate food substances are converted into sugar in the body is thus an important parameter to consider in glycemic control. The relative ranking of how fast or slow a carbohydrate food is converted to glucose after ingestion is a measure of its glycemic index. Carbohydrate foods that are quickly broken down into glucose after ingestion are considered to be high glycemic index foods whilst those with a relatively slower pace of conversion to glucose and thus elicit a slower insulin response are low glycemic index foods. The GI of foods is ranked on a scale of zero (0) to hundred (100) with zero being the foods with the lowest GI and hundred being the highest. Based on the GI values there are three major categories of carbohydrates. Foods with GI in the ranges of 0 – 55, 56 – 69 and 70 – 100 are considered low, medium and high GI foods, respectively, although they are commonly termed high GI and the low GI foods which often tend to include the medium GI foods. Before the development of the GI concept in 1981 by Jenkins,

the belief that was held for long has been that simple sugars have the highest glucose responses in the body. This has been found not to be entirely true.

Several studies to analytically examine carbohydrates have been undertaken by numerous scientists; however Rubner in 1917 was the first person to provide a report of a detailed study on carbohydrates (Rubner, *et al.,* cited in Nils-George, 1995). McCance and Lawrence in 1929 elucidated the concept of available (glucogenic) and unavailable carbohydrates (McCance, *et al.,* cited in Nils-George, 1995). The concept was a very useful aid in nutritional counselling of diabetics in their choice of carbohydrates. The available carbohydrate concept is however central to the determination of glycemic index since the glucose raising ability of a carbohydrate is by the glucogenic part of the carbohydrates and not the whole carbohydrate food.

Processing, preparation and cooking methods have been found to have an influence on the glycemic index of food (Aston *et al*, 2008). However, as to whether GI would increase or decrease will depend on the type of processing involved.

Although some work has been done to experimentally determine the GI of foods and more specifically carbohydrate foods, the GI of some foods as are known, are extrapolations from published GI values of closely related foods (Aston *et al.*, 2008). A wide range of factors seem to influence the GI values for many foods making it difficult to accurately predict the GI value of a food from a published one with similar characteristics (Aston *et al.*, 2008).

In relation to the relevance of GI, an extensive amount of work has been done on the effect of high blood sugar, measured as fasting (FBG), postprandial (PPG) or HbA1c on the various organs of the body and general wellbeing of individuals. Some prospective study done by Salmeron and his colleagues affirmed the protective effect of low glycemic index on people at risk of diabetes (Salmeron *et al.*, 997; Frost *et al.*, 1998). Various studies have also linked

low glycemic index with improvement in glucose control (Rizkalla *et al.*, 2004), sensitivity to insulin (Salmeron, *et al.,* 997; Frost, *et al.,* 998) and memory (Kaplan *et al.,* 2000). A comparatively older study conducted by Jenkins *et al.,* (1985) is inconsonance with current research findings that suggest the protective role of low GI diet and in this case regulation of blood lipids. In their work they found a significant decline in the total and low density lipoprotein cholesterol as well as triglycerides with the consumption of low GI foods. A systematic review and Meta analysis conducted by Fan *et al.,* (2012) found a slight association between coronary heart disease (CHD) and dietary glycemic index.

The relationships that have been found to exist between GI and various medical conditions have necessitated the standardization of GI determining methods to allow for accuracy and precision (Wolever, et al., 2003)

1.2 PROBLEM STATEMENT

The glycemic index of foods has become an important tool used by apparently healthy individuals and mostly diabetics in their food choices to maintain good glycemic control. Food choices from intercontinental food list using GI are easier because it has been determined. However, the same cannot be said about most of our staple foods in Ghana. With the increased consumption of some of the processed forms of local staples comes a need to understand the rate of converting these foods to sugar in the body which is a measure of their GI.

A report of a joint FAO/WHO Expert consultation stressed the need to determine the GI of local staples locally due to differences that could arise from various cooking and processing methods (Aston *et al.,* 2008). Also a 2010 GI news article quotes Dr Alan Barclay (Chief Scientific Officer at the GI foundation) as saying: ‘Consumers looking for healthy foods need to be confident the claims made by food manufacturers on their labelling and in

advertisements are accurate and reliable,' he adds that. 'Historically, not all GI claims have been reliable with some based on extrapolation or inappropriate methodology. A food's GI value cannot be predicted from its appearance, composition, carbohydrate content, or even the GI values of related foods. The only way to know a food's GI value is to test it, following the international standardized methodology' (Sandall, 2010).

A database of the GI of locally consumed foods determined through ISO certified method is thus critical for diabetics to make quick comparison and easy choices. Since GI does not address the problem of diabetics alone, healthy individuals would also be helped with the data in healthy food choices and meal planning.

1.3 RESEARCH PROBLEM

Does processing methods affect the glycemic index of locally consumed staples?

1.4 AIM

To determine the glycemic response and the glycemic index of some local staples

1.5 SPECIFIC OBJECTIVES

1. To study the body's response to ingested carbohydrates.
2. To determine the glycemic index of a local staple and its processed form.
3. To assess the effect of processing on the glycemic index of foods.

1.6 JUSTIFICATION

The research when completed will provide data on the glycemic index of some local staples which will help diabetics in their choice of local foods based on their glycemic index.

The data provided from the study will give an understanding into the effect of some processing methods on the GI of foods.

The study will provide a platform to ascertain the differences if any, between the GI of foods extrapolated from tables and that which is determined *in vivo*.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Carbohydrates are a group of compounds made up of monosaccharide building units. They range from simple monosaccharide, disaccharides, and oligosaccharides to the more complex forms such as starch and non starch polysaccharides. The traditional classification of carbohydrate foods has been based on the structural conformation or degree of polymeriation of the major carbohydrate that is present in it (FAO/WHO, 1998). Subsequently, the convention has been to classify as 'simple' if it contains mostly mono or disaccharides, and 'complex' cabohydrates if it contains polysaccharides or starches. The complex carboydrate idea was first introduced in a report by the US Senate Select Committee on Nutrition and Human needs in 1977 to denote various fruits, whole grains and vegetables (Stylianopoulos, 2005).

These classifications are, however, based on the chemistry of the carbohydrates and do not necessarily reflect their exact physiological properties, nutritional or health effects ((Cummings & Stephen, 2007). The chemical classification into simple and complex carbohydrates was a basis of the erroneous assumption that all 'simple' carbohydrates (simple sugars) would cause a rapid glucose response in the body whilst the complex carbohydrates would rather elicit a slower response to blood glucose concentrations and thus the suitable option of carbohydrates for persons with glucose intolerances and various insulin disorders.

Carbohydrates contain important mineral and micro nutrients necessary for healthy living, and have also been found to play an important role in the maintenance of gastrointestinal health and glycemic homeostasis (Stylianopoulos, 2005). Studies by Conn and Newburgh (1939) showed how different carbohydrates with comparable micronutrient content yielded

different glycemic responses. In 1980, Otto and Niklas cited in (Wolever, 1991) pioneered the systemic classification of foods according to their glycemic responses.

In 1981 Jenkins *et al*, reported that the carbohydrate exchange list that had been used over the years for controlling diabetes was not a true reflection of the actual physiologic effect of the foods consumed (Jenkins *et al.,* 1981). It was also observed that the health effects of carbohydrate can be better described with their physiological properties (such as its ability to raise blood glucose). The physiological properties are also influenced by the constituent monosaccharide units and physical conformation which enclaves particle size and extent of hydration (Augustin, 2002).

The importance of carbohydrates to health and yet the complexity associated with its classification informed the need for a simple index based on the glycemic effect of foods, to complement information provided in food tables derived from calculations using their chemical composition (Wolever, 1991). The Glycemic index was thus developed. Glycemic index is an empirical system of classification that measures how glucose rises in the blood after ingestion of a carbohydrate food. It is a measure of the quality of the carbohydrate and not the quantity ingested (Mendosa, 2009).

2.2 THE GLYCEMIC INDEX (GI) CONCEPT

Glycemic index is defined as classification of foods according to their glucose raising potential (Wolever, *et al.,* 2003) and measured by determining the incremental area under the blood glucose response curve after the ingestion of a test meal containing 50g available carbohydrate as a percentage of that elicited by a reference food (mainly glucose or white bread) taken by the same individual (FAO/WHO, 1998). Glycemic index measurement is thus equicarbohydrate (because equal quantities of available cabohydrate are involved) (Monro & Shaw, 2008) as compared to Glycemic impact which is a measure of "the weight

of glucose that would induce a glycemic response equivalent to that induced by a given amount of food" (Miller-Jones 2007).

According to a report of the Joint FAO/WHO Expert Committee in 1998, GI is a more established concept though it appears to be a simple index (FAO/WHO, 1998). A number of factors influence the postprandial glycemic response of a food when ingested. These factors range from extrinsic components such as composition of the whole meal and variations in the overall diet, to intrinsic properties such as the amylose to amylopectin ratio, presence or absence of viscous fibre and the length of the monosaccharide units (Bjorck, 1994). Such factors as particle size, processing methods, nature of starch and antinutrients present which are not commonly available in food tables and yet have very significant effects on physiological properties of food highlight the importance of GI determination and use. Research has demonstrated that when the botanical structure of legumes (Golay *et al.*, 1986), apples (Haber *et al.*, 1977), and rice (O'Dea *et al.*, 1980) are disrupted, the amount of available carbohydrates in them increases. These factors are also an underlining cause to the unexpected differences in the GI values of different foods (Wolever *et al.*, 1991).

The defining standard of glycemic index determination, glucose has a value of 100. GI is expressed in percentages and commonly represented on an absolute scale where foods with values of 55 or less, 56 to 69, and 70 or more are classified as low GI, medium GI and High GI foods respectively. GI measures postprandial glucose which can be manipulated by varying the amount and type of dietary carbohydrates consumed. Meals which have a low GI tend to slow insulin response and decrease postprandial glucose concentration.

In summary, the GI concept provides us with a numerical representation of the combined effect of digestion and absorption on the rate at which blood sugar rises upon ingestion of a particular carbohydrate containing food or meal.

2.3 DIETARY CARBOHYDRATES

The concept of glycemic index is fundamentally due to the essential role of carbohydrates in human diet. Carbohydrates are the main energy source in most human diets, making up about 40 – 80% of our calorie intake. They are a primary fuel source for body cells especially red blood cells and cells of the central nervous system (Keim, 2006). Carbohydrates also provide muscle cells with the required energy during very intense physical activity. In the blood, carbohydrates are readily available as simple sugar (glucose) whilst available as glycogen (the storage form) in the liver and muscle (Carol *et al.*, 2013).

Carbohydrates play an enormous role in nature and human physiology and their complexity makes their classification also difficult (Mann *et al.*, 2007). Classification of dietary carbohydrates requires a systematic approach that incorporates their functional, chemical and physiological properties (Englyst *et al.*, 2007).

In 1997, the Joint FAO/WHO expert consultation committee on carbohydrates in human nutrition defined carbohydrates primarily as carbon compounds with ketones or aldehydes functional groups and can be found in their acid and alcohol forms as well as other derivatives (FAO/WHO, 1998). They further indicated that carbohydrates can be grouped into a number of classes and subclasses depending on their molecular size or structural composition. All starches contain amylose and amylopectin but in different ratios depending on the particular carbohydrate. For the same carbohydrate food item, the amylose/amylopectin ratios even differ with variety. Digestibility is greatly influenced by the ratio of amylose to amylopectin which is a more branched glucose chain.

A classical representation of the various carbohydrate groups is shown in Table 2-1 below

Table 2-1: Major Carbohydrates

GROUP	Sub-Group	Components
Sugars (1-2 monosaccharide units)	Monosaccharides	Fructose, galactose, glucose
	Disaccharides	Maltose, lactose, sucrose
	Sugar Alcohols	Mannitol, sorbitol
Oligosaccharides (3-9 monosaccharide units)	Malto - Oligosaccharides	Maltodextrins
	Other Oligosaccharides	Fructo-oligosaccharides, raffinose, stachyose
Polysaccharides (>9 monosaccharide units)	Starches	Modified starches, amylose, amylopectin
	Non- Starch Polysaccharides	Cellulose, hemicellulose, hydrocolloids, pectins.

Source: (FAO/WHO, 1998)

In 2007, an FAO/WHO scientific update endorsed the description as given by the Joint expert consultation committee in 1997 but acknowledged the relevance of physiological functions of carbohydrates in classification (Mann *et al.,* 2007).

2.3.1 Total Carbohydrates

The FAO/WHO defines total carbohydrates on two major principles: by direct measurement of all the components that form carbohydrates and by subtracting the sum of ash, fat, protein, and moisture content from the total weight of the food (FAO/WHO, 1998).

2.3.2 Available Carbohydrates

According to the FAO definition which is currently the most widely applied in various countries (Brouns *et al.,* 2005), available carbohydrates which is basically soluble sugars and starch is total carbohydrate minus dietary fibre. In 1934, Widdowson & McCance underscored the value of determining available carbohydrates for dietetic purposes than total carbohydrates (Widdowson & McCance, 1934).

Available carbohydrate is the part of the carbohydrate that is digested to provide the sugar that is metabolised for energy. The portion of the carbohydrate considered 'unavailable' (hemicellulose and true cellulose) passes into the large intestestines and fermented to produce energy for the body. It is thus appropriate to describe the digestible carbohydrates as glycemic and the indigestible ones as non glycemic carbohydrates (FAO/WHO, 1998). Defining available carbohydrate is important because it helps to understand which part of the carbohydrates are considered in the determination of GI of a food. Glycemic index determination measures the glycemic response of subjects to 50g available carbohydrates relative to 50g pure glucose or 50g available carbohydrate portion of white bread.

2.3.3 Dietary Fibre

Dietary fibre often referred to as roughage, are components of carbohydrates that are not digested by enzymes of the gut and they may be either soluble or insoluble. Dietary fibre retains water and has been found to regulate a number of metabolic hormones and thus influence concentrations of insulin in the blood and improve postprandial glycemic response (Vinik & Jenkins, 1988). Though there are still studies on going to ascertain the mechanism of action of dietary fibre (Anderson & Akanji, 1991), certain mechanical influences such as low energy density and the bulky feeling they produce in the GIT lead to increased satiety with a reduced calorie intake (Leeds, 1987). An earlier study on guar reported the useful influence of fibre on glucose tolerance of the next meal (Trinick *et al.,* 1986).

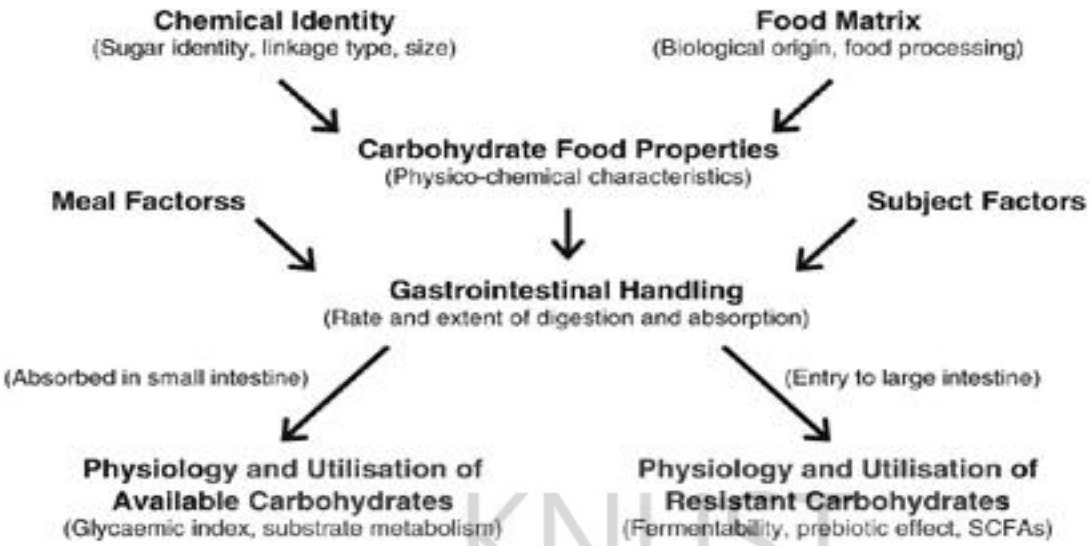

Fig.2.1 Diagrammatic representation of factors that influence Carbohydrate Food Source (Englyst, Liu, & Englyst, 2007)

2.4 CARBOHYDRATE STAPLES IN GHANA

A large number of foods provide the body with carbohydrates; however in Ghana as with other developing countries much of the carbohydrate is obtained from maize, rice, plantain or cassava (FAO/WHO, 1998).

2.4.1 Maize (*Zea mays*)

Maize, also known as corn in most Anglophone countries is the most important cereal in the Ghanaian market and it is known to account for 55% of total grain output. There was also a significant increase in the overall production from 2008 to 2010 (Angelucci, 2012). The immature corn can be eaten raw; it however hardens as it matures. It must thus be processed to be made edible. It could be roasted, boiled or fried for human consumption. Maize is used in the preparation of a number of Ghanaian dishes including Banku, Tuo Zaafi, Kenkey, and 'Apaprensa'. Maize has 74g carbohydrate, 7.3g fibre and 0.64g sugar per 100g of its freshly harvested form.

There are a number of Maize varieties like sweet corn which however, has higher sugar content. With quite different physicochemical properties for different varieties of maize, the physiological effect on the body will vary. As the corn matures, more of the sugar is converted to starch. The physiological effect of corn will be influenced by the maturity of the corn. In some jurisdictions, cornstarch is enzymatically converted to high fructose corn syrup (HFCS) which is used in place of sugar (sucrose). The use of HFCS is however contentious due to its anticipated health effects (Courteau, 2012).

Table 2-2: Some nutrients available in Maize and the roles they play in the human body

NUTRIENT	FUNCTION
Carbohydrates (cellulose, starch, sugar)	Digested and absorbed as glucose used for short-term energy needs or stored
Folate	Enhances cardiovascular health and reduces risk of congenital defects
Vitamin B1 (Thiamin)	Memory improvement
Vitamin B3 (Niacin)	Reduces stress and depression
Vitamin B5 (Pantothenic acid)	Helps in the release of energy from carbohydrates, fats and proteins
Others include:	
Dietary Fibre	Improves bowel function
Manganese	Co factor for the proper function of certain enzymes
Phosphorus	Important for repair of body cells and tissues
Vitamin A	Plays a role in vision, immune function and gene transcription
Vitamin C	Formation of collagen and for healthy teeth and gums

Source: Liu, 2004 (Modified by MacCarthy, 2011, cited in MacCarthy 2014)

Below are pictures of corn on the cob and dried grains of corn

Fig 2.2 (a) Corn on the cob (b) Corn removed from the cob

2.4.2 Cassava (Manihot esculenta)

Cassava is a tropical crop cultivated for its carbohydrate rich tuberous roots. It is considered to be the third most consumed carbohydrate (Food and Agriculture Organization of the United Nations, 2014) and of very great economic importance. Cassava is processed into a number food items including 'tapioca' and 'gari'. Cassava is also boiled and mixed with other carbohydrates crops like cocoyam, plantain and yam into fufu a common Ghanaian delicacy. A 100g of raw cassava contains 38g carbohydrate, 1.8g fibre and 1.7g sugar and could yield about 670 (kJ) of energy. Cassava has an amylose-amylopectin ratio of 30:70 (United States Department of Agriculture, 2002). A high portion of amylopectin which is more branched and more accessible to digestive amylases means cassava is more likely to elicit higher glucose response on consumption. When prepared for human consumption, the nutritional value will vary depending on the cooking method been it frying, roasting, or boiling (United States Department of Agriculture, 2002). Below is a picture of raw cassava root tuber.

Fig 2.3 freshly harvested cassava tubers

2.4.3 Plantain (*Musa Paradisiaca*)

Plantain is a common staple crop consumed mainly in the tropical regions. The major food nutrient in plantain is carbohydrate. The raw unprocessed plantain contains 32g of carbohydrate, 15g sugar and 2.3g fibre per 100g (United States Department of Agriculture, 2002). Plantains unlike banana are often processed before consumption. They are cooked, fried or roasted before consumption. In West African countries like Ghana, plantain could also be boiled and pounded together with boiled cassava into 'fufu'. The boiled plantain could also be mashed into 'eto'.

The nutritional benefits obtained from these plantain dishes besides carbohydrates depend on other food items added in the preparation of the particular plantain dish. The preparation of these foods may alter the nutrient composition. Some nutrients could leach out in the boiling process. Some proteins could also denature at the boiling temperature. The heating and cooling cycles could also increase the amount of retrograded starch (Bahado-Singh, *et al.*, 2011) in the plantain. The health benefits of plantain will thus be influenced ultimately by the processing and what it is consumed with. Below is a picture of a common plantain.

Fig 2.4 Fingers of plantain

A number of dishes are prepared from these and other carbohydrate rich staples. Some dishes are a combination of these staples in different portions. Banku and Fufu are an example of common Ghanaian foods prepared from a mixture of corn and cassava dough and plantain and cassava respectively. The foods prepared from these staples may have physiological effects that may not be the result of only one component of the food. The glycemic response due to banku may be different from that of corn porridge. The influence of other components physiologically can only be determined with the particular food not by extrapolation.

Below are pictures of some Ghanaian dishes prepared from these local carbohydrates rich staples

Fig. 2.5a Balls of Banku wrapped in plastic

Fig. 2.5b Two balls of Fufu in earthenware dish

Fig. 2.5c TZ wrapped in plastic

Fig. 2.5d Ga kenkey

Fig. 2.5e Ampesi with kontomire stew and pear

Fig. 2.5f Konkonte with palm nut soup

2.5 CARBOHYDRATE DIGESTION

The extensive amount of studies conducted on GI is due to the influence of carbohydrates on our hormonal response, and human diseases through their effect on metabolic and physiologic processes (FAO/WHO, 1998). To define the functionality of carbohydrates in metabolism, there is the need to understand the site, extent and rate of digestion in, and absorption from the gastrointestinal tract (Mann *et al.*, 2007). Digestibility and absorption are important components that are also useful in the characterization and functional classification of carbohydrates.

The glycemic index of a carbohydrate food is directly influenced by its rate of digestion and absorption. Carbohydrate digestion begins in the mouth. A research by Aston *et al* showed how the GI of stone ground wholemeal bread differed from more finely ground wholemeal bread (Aston *et al.*, 2008). Accordingly, how well a food is chewed in the mouth before swallowing could affect the rate of digestion in the stomach and small intestines. Chewing would increase the surface area for enzyme activity and thus increase the rate of digestion and absorption.

Digestion and absorption take place in the gastrointestinal tract with the aid of certain fluids and enzymes. From the mouth to the small intestines numerous enzymes work on ingested food. Some carbohydrates and other food substances like fibre may escape digestion into the large intestines where they could undergo fermentation into gases and some other useful by products of metabolism like butyrate and propionates.

2.6 DETERMINATION OF GLYCEMIC INDEX

After the introduction of the glycemic index concept in the 20th century, a number of researches have been done to determine the glycemic index of a number of foods. Although the usefulness of glycemic index has been endorsed by the FAO/WHO expert consultation committee (FAO/WHO, 1998), its application has been difficult because there is still a large number of common foods whose GI is not known. Furthermore, the GI values of some particular food items provided by different laboratories showed some variations (Wolever, *et al.*, 2003). Typical examples being rice (Foster-Powell & Brand-Miller, 1995) and potato (Wolever *et al.*, 1994 ; Soh & Brand - Miller, 1999) cited in a publication by Wolever *et al*, 2003. To allow for harmony and reduced variation of GI values obtained for the same food in different places, a standardized method of determination is used (Brouns *et al.*, 2005).

According to the FAO/WHO recommendation, the approved standard method of determination of the glycemic index of a food is *in vivo,* where a test food containing 50g available carbohydrate is ingested and the rate at which the food is digested and absorbed into the blood stream measured (Brouns *et al.,* 2005). The glycaemic reponse measured by the rate of digestion and absorption is illustrated with *in vitro* digestion models that mimic what happens in human digestive tract. There is strong correlation between the rate at which sugar is released from starchy foods using digestive enzymes *in vitro* to increase in blood glucose levels in humans (Granfeldt *et al.,* 2005). Carbohydrate foods that are digested and absorbed slowly and thus elicit a slow rise in blood sugar levels give a low GI value and thus classified as low GI foods whilst those that are digested and absorbed more rapidly are classified high GI foods.

The measurement of glycaemic reponse is done by taking blood samples for glucose test at timed intervals which start at the first bite of the test food (Wolever *et al.,* 2003). In determining GI of a number of carbohydrate foods, the incremental area under the curve for the reference food is used as a denominator to each test food. According to the standard methodology, the reference food is repeatedly measured to allow for precision. Any variations in the glycemic response from the reference food will have a more profound effect on the GI than variations in the test foods (Brouns *et al.,* 2005). Brouns et al, recommends that the measurement of the reference food be repeated at least one in each participant of a GI determination research.

2.6.1 Reference Food

The determination of GI requires the use of a standardized reference food item against which the test food will be measured. Over the years, a number of foods have been used as reference foods in the determination of GI. An updated database of GI of some 1300 food

measurements involved about 10 different reference foods including: glucose, wheat chapatti, arepa (a Mexican carbohydrate food item) potato, rice, bread, white bread, whole barley bread and wheat. Glucose and white bread were however the major reference foods used (Foster-Powell *et al.,* 2002).

Not much study has been done on the glucose raising effect of commonly used white bread (Brouns *et al.,* 2005). Nonetheless its use has shown an appreciable level of consistency in determination of GI of various test meals. Using white bread as a reference food produces a comparatively higher GI value than using glucose as a reference food. The GI of white bread as determined in some nine studies has yielded a value of 73 consistently (Wolever *et al.,* 1991). White bread composition and preparation may however differ from one experimental setting to another as was supposed in a study where white French bread produced a GI value of 97 (Bornet *et al.,* 1987).

There are concerns about the extreme sweetness of glucose and some persons also complain of a nauseating effect when they take in glucose solution in the morning after a 10 – 14 hr fast (Brouns *et al.,* 2005). Pure glucose is, however, more likely to be the same in most experimental settings. This makes it easier to compare results from other laboratories.

The IUAC value obtained from the reference food is used as the denominator in calculation of the GI of all the test foods. Variations in glycemic response to the glucose or white bread used will thus yield significant variation in the GI of the test foods (Brouns *et al.,* 2005). To reduce these variations, Wolever *et al*. (2003) revealed that the mean of three trial of the reference food used in the determination reduce variations (Wolever *et al.,* 1991) although there was no substantial data to affirm this position. Subsequently, various theoretical assessment and simulation studies have indicated that either three or two trials of the reference food are acceptable (Brouns, et al., 2005).

2.6.2 Blood Sampling

Glucose concentrations can be measured from whole blood or plasma from various parts of the body. Blood samples could be taken from the veins, arteries or capillaries. Arteries are blood vessels that deliver blood from the heart to the tissues and will obviously be richer in nutritional composition. An assessment of the arterial blood could have yielded the truest reflection of the glucose concentration being delivered to the various body tissues. However, the arteries are found deeper within the body than the capillaries and veins as such drawing arterial blood could come with associated risks. This notwithstanding, capillary blood approximates the composition of arterial blood and therefore a better alternative to the more invasive arterial blood (Brouns *et al.,* 2005).

There is a marked effect of ambient temperature on the flow rate of venous blood. Thus venous blood which can be taken from the forearm among other visible parts of the body has been found to be more variable in its glucose concentration than capillary blood (Frayn *et al.,* 1989). Measured glucose concentration in the capillaries is comparatively higher than in venous blood and thus makes it easier to detect very small changes in blood sugar concentrations over time. In the determination of GI, blood from the capillary taken from the fingertip or earlobe is thus more convenient and better for the assessment of glycemic response (Wolever *et al.,* 1991).

2.6.3 Pathophysiology of Study Subjects

GI determination is a measure of postprandial glucose response and this is influenced by an individual's insulin response and glucose tolerance. There were thus concerns on the physiological state of persons participating in GI studies. Numerous studies have however tried to address the issue to give an accurate perspective on the right subject characteristics for GI determination study. Studies by Jenkins *et al.,* (1983) on normal versus diabetic

participants, Walker & Walker (1984) on rural African versus normal Western subjects, Wolever *et al.* (1986) on type II diabetics with good glycemic control as opposed to those with poor glycemic control, Wolever *et al* (1998) on glucose tolerance and BMI and publications by Livessey (2002) on children with type I diabetes as against adult with type I diabetes and individuals with type II diabetes as against individuals with type I diabetes have all indicated that the various subject characteristics have no significant effect on the mean GI of a food (Brouns *et al.*, 2005).

A study by Wolever, *et al*. (1985) on "Prediction of the relative blood glucose response of mixed meals using the white bread glycemic index" confirmed an intra-individual variation in glycemic response to white bread. They observed that normal apparently healthy subjects showed intermediate intra-individual variation in glycemic response, whilst subjects with type II diabetes showed a less significant intra-individual variation as compared to subjects with type I diabetes. Brouns *et al.* (2005) thus recommended the use of apparently healthy individuals in the determination of GI to increase precision.

2.6.4 REVIEWS ON GI DETERMINATION

A review of published researches to determine the glycemic index of some foods was done and summarized in the table below:

Table 2-2 A Summary of findings of studies on the Glycemic index (GI) of foods

Authors	Study Design	Subjects used for study	Foods Studied	Findings
Wolever et al., 2003	Experimental (Inter laboratory study	Non diabetics (10)	Oat biscuits, cheese balls, fruit leather	GI determined by standard operating procedures showed no significant differences between laboratories. Variations that resulted were due analytical or mathematical errors. Like the calculation of IAUC
Fajkusova *et al.*, 2007	Experimental	Healthy persons (10)	Ten food items	GI for ten foods was determined. Significant inter individual differences were found between the GIs of foods that were studied.
(Aston *et al.*, 2008)	Experimental	Forty-two healthy adults	Thirty three (33) foods	GI of 33 foods were determined with an emphasis placed on the need to measure the GI of each food distinctly rather than assuming a previously published value of a food with similar description
Chlup *et al.*, 2008	Observational	Healthy subjects (20)	Chocolate, apple baby food, rice squares yoghurt	Spreadsheet software combined with continuous glucose monitoring (CGM) could be used in routine measurement of GI
Aston *et. al.*, 2008	Experimental	46 healthy adults	Breads, breakfast cereals, pasta, rice	Some intrinsic factors in foods affect their GI. The GI of individual foods should be measured other than making assumptions or extrapolations based on values published for similar foods
Chlup *et al.*, 2008	Experimental (Extended post prandial)	Healthy subjects	Mixed foods Honey, tomato soup, white bread, potatoes and fish, wafers, etc.	120 min GI of some foods vary from their respective GIs at 210 min
(Lin *et al.*, 2010)	Experimental (2hr post prandial	Healthy individuals (10)	Taro, brown rice, yam, mung bean noodles, adlay	GI values determined in decreasing order Brown rice, taro, adlay yam, mung bean noodles
(Alkaabi, (2011)	Experimental	Healthy Participants (13) Type II Diabetics (10)	Five Varieties of dates (Tamer stage)	GI of dates did not vary with variety GI of dates determined in diabetics were not significantly different from healthy individuals

2.6.5 Number of Subjects

Based on the review, we observe that the number of subjects used in various determinations varied. The differences in part can be attributed to the number of foods that were being tested. Although there is a higher cost component, the greater number of subjects used provides us with more precise results. According to the FAO/WHO joint expert committee report, to determine the GI of a food, the test foods should be repeated in six more subjects (FAO/WHO, 1998). However, in a report for the determination of Hand-stretched Pizza, 2011 compiled by Jenkins, using the standard ISO method (ISO/FDIS 26642), ten (10) subjects were studied. According to the report, "using the t-distribution and assuming an average CV of within individual variation of IUAC values of 25%, n=10 subjects has 80% power to detect a 33% difference in IAUC with 2 tailed $p<0.05$" (Wolever *et al.,* 2011). Brouns and his colleagues also recommended the use of ten subjects for an appreciable degree of precision (Brouns *et al.,* 2005).

2.7 PROCESSING EFFECTS ON GLYCEMIC INDEX

The structure of a carbohydrate is of great importance in the light of its metabolic responses. The structure affects enzyme accessibility and interaction. Factors that affect the structure of the structure will affect its metabolic response as well (Bjorck *et al.,* 1994).

Carbohydrates are subjected to quite a number of processing during preparation for consumption. The processing of a particular carbohydrate food plays an important role in determining its overall properties (Englyst *et al.,* 2007), which also has a significant influence on physiological function in the human body. Glycemic index value is also directly influenced when the physiological effect of a carbohydrate is altered. Besides the processing and cooking methods, other factors such as maturity and ripeness, the presence of other anti – nutrients and macronutrients also influence GI values (Aston *et al.,* 2008).

2.7.1 Cooking Methods and GI

Food preparation methods can alter the structure and the physicochemical properties of the food (Bahado-Singh *et al.,* 2011) and thus affect its glycemic response and subsequently its glycemic index.

Boiling, a heat treatment method would lead to gelatinization of the starch increasing its availability to amylases (Holm *et al.,* 1988). When digestibility of an enzyme increases, its glycemic response increases as well as its GI. On cooling, however, starch which has undergone gelatinization will retrograde or recrystallize making amylose portions poorly digestible to amylases (Bjorck *et al.,* 1994). Boiling could also leach some simple sugars in the cooking process and the presence of resistant starches would reduce glycemic response due to their indigestibility. Boiled sweet potatoes have however been found to have a lower GI compared to baked, roasted or fried ones (Bahado-Singh *et al.,*2011).

Frying significantly influences the rate of digestion. The oil used in frying suppresses starch breakdown and delays gastric emptying and thus reduce glycemic response. In *an in vitro* study conducted by Garcia -Alonso cited in a publication by Bahado-Singh *et al.,* (2011) it was asserted that resistant starch content of potatoes increase with frying. When a starchy food is fried, amylose can react with the lipid to form a complex which is less digestible by amylases and thus reduce glycemic index. All fats do not however behave in the same way with carbohydrates. Studies on omega 3 and 6 fatty acids on glycemic response in healthy individuals have shown that omega 3 enhances the release of insulin quicker than omega 6 when added to food, though long term use of omega 3 could be detrimental to diabetics (Lardinois *et al.,* 1987).

Proteins also influence GI by its effect on insulin secretion due to amino acid interaction. Proteins that are digested quickly, however, elicit a quicker insulin response compared to less rapidly digested proteins (Wolever *et al.*, 1991).

2.7.2 REVIEW OF FACTORS THAT INFLUENCE GI

A review of some published studies to assess the influence of various external and internal factors on the Glycemic index of foods is summarized in the table below.

Table 2-3 Summary of outcome of studies on the influence of processing/modification, ripeness, maturity and other external factors on Glycemic Index (GI) values of foods

Author	Study design	Exposure	Foods studied	Outcome
(Ramdath, 2004)	Experimental	Boiling and Crushing	Caribbean staples (cassava, breadfruit, green banana etc.)	Crushing had no significant effect on the GI of the common Caribbean staples studied
Henry et al., 2005	Experimental (cross over design trial)	Variety	Potatoes	Different varieties of the same potatoes showed wide variation in GI
(Ostman *et al.*, 2005)	Interventional Studies	Acetic acid (Vinegar) Supplementation	Bread meal	The glycemic response to bread meal was decreased with increased vinegar (acetic acid) dose.
(Aston *et al.*, 2008)	Experimental	Grinding, Cooking, Variety	Various breads, breakfast cereals, pasta, potatoes and rice	Porridge meal made with intact jumbo oats was significantly lower than meal made with finely processed oats. The GI of easy cook basmati rice was significantly higher than normal basmati rice. The GI of foods taken with their skins (source of fibre) was comparatively lower than the same foods taken without their skins. For some of these foods the differences were however not significant.
Chung *et al.*, 2008	Experimental	Chemical Modification	Normal Corn	Oxidation, hydroxypropylation, and

		(Oxidation, hydropropylation, acetylation, crosslinking)		acetylation caused a reduction in amount of rapidly digestible starch and thus reduced GI. GI of cross-linked starch was however similar to unmodified starch
(Jenkins, 2010)	Experimental (Open label randomized)	Novel Fibre (PGX) (Novel Viscous Polysaccharide)	Corn flakes, rice, turkey dinner	Foods that were incorporated with NVP had their GIs reduced drastically
(Bahado-Singh *et al.*, 2011)	Experimental (Randomized cross-over) 10 subjects	Roasting, Baking, Frying, Boiling	Sweet potatoes (*Ipomea batatas*)	GI of sweet potatoes varied with methods of preparation. Boiling decreased GI of foods where as roasting and baking increased it significantly Intra variety also showed some little variation in GI
(Su-Que, 2013)	Experimental	Micronutrient	Two varieties of wheat bread	Enrichment with micronutrients reduced GI of wheat variety

In 2004, Arvidsson-Lenner *et al.* (2004) summarized a number of important factors that may influence the rate of digestion and absorption in the gastro intestinal tract and thus affect the GI value that will be obtained when measured.

Table 2-4 Summaries of factors that influence Gl and Glycemic Response

	INFLUENCING FACTOR	FOOD FACTOR	INFLUENCE ON GI AND GLYCEMIC RESPONSE
1.	Heat treatment	Granular starch structure	Higher when gelatinized
2.	Heating-cooling cycles	Resistant starch content	Indifferent when testing equal amounts of available carbohydrates
3.	Grinding	Gross matrix structure	Higher when homogenized
4.	Added acids	Organic acids, e.g. acetic acid	Reduced
5.	Added gelling fibres	Gelling dietary fibre content	Reduced
6.	Added inhibitor	Amylase inhibitor	Reduced
7.	Amylopectin is branched and more quickly digestible than amylose	Amylose and amylopectin content	Lower with higher amylose content and higher with increased amylopectin content
8.	Types of sugar added, e.g. glucose: fructose ratio. Type of raw material, type of monosaccharide bonds in carbohydrate molecule	Monosaccharide composition Molecular composition of carbohydrate	Reduced with increased fructose content. Reduced with increased number of bonds other than α1-4 and α1-6
9.	Degree of ripening	Cell – wall and starch structure	Higher with ripening

2.8 GLYCEMIC INDEX: THE ARGUEMENTS

Though much work has been done and still being done on the role of glycemic index in healthy eating choices, the glycemic index concept generated a number of controversies especially in the late 90's, with various arguments been advanced for (Wolever, 2002) and against its usefulness, especially in the management of diseases such as diabetes. Opponents of the glycemic index intimate that it as a needless burden which complicates dietary restriction in the management of diseases (Coulston, 1997). The alternative view is, however,

that the glycemic index remains only a simple tool to provide alternative carbohydrates foods that consumers may otherwise not have considered (Jenkins *et al.,* 2002).

An inclusion of GI values on food labels have been advocated by proponents of the glycemic index concept. Publication made by Health Canada indicated that GI was not an important concept worth including on food labels, though a number of prominent institutions such as the Canadian Diabetes Association, WHO (Mann *et al.,* 2007), Diabetes UK, and the American Diabetes Association (Sheard *et al.*, 2004) have endorsed its importance and use (Atkinson *et al.*, 2008). A number of countries including Australia, SA, Sweden, UK, and Germany are including GI values on food labels (Brouns *et al.*, 2005).

Concerns about intra and inter individual variations in the glycemic responses to any particular food have also been addressed in the determination of GI by expressing the glycemic response of a particular food as a percentage of 50g glucose or white bread. It has been shown that the variation is reduced to approximately 10% (Wolever *et al.,* 2003; Sheard *et al.,* 2004).

Accuracy and Precision of GI values obtained has also been questioned. The imperfections of GI determination as with other scientific determinations do not invalidate the usefulness of the concept. The determination of GI of a food is based on the calculated portions of the food that is available carbohydrate. This is normally written on food labels by manufacturers or computed by academic institutions. The methods used to determine the carbohydrates and fibre content of foods vary from place to place and may sometimes increase the margins off error in the final analysis. These notwithstanding GI determination allows an acceptable margin of error of less than 15%, whilst the permissible margin of error for nutritional analysis on food lables is less than 20%. This affirms that GI determination is measured to a

higher standard of precision and accuracy than everyday nutritional analysis on food labels (International Carbohydrate Quality Consortium (ICQC), 2014).

The result from a study done by She stanford group led to criticism of the GI concept because according to them, their expected glycemic response from foods were inconsistent in mixed meals (Wolever, 2002). Wolever however, asserts that their method of calculation was inaccurate and that after re-calculating their data using the incremental area under the curve instead of the area under the curve they used, the new values obtained affirm the accuracy of the GI concept (Wolever, 2002).

GI is a very useful concept that is not used in isolation in dietary counselling, just as a single laboratory test is not used for conclusive diagnosis. Arguments that GI does not consider saturated fats and fibre content has lost relevance in the face of the fact that GI is provided as a guide in food choice and not a panacea to all diet related health problems, overriding professional dietetic counselling.

2.8.1 RELEVANCE OF GLYCEMIC INDEX

In 1997, the FAO/WHO Expert Consultation underscored the relevance of GI as guide in making food choices alongside information about food composition (FAO/WHO, 1998). A review done by Jenkins also suggested the potential therapeutic utility of the concept of glycemic index (Jenkins *et al.*, 2002). Jakobsen *et al.*, (2009) showed the effect of replacing saturated fats with carbohydrates in a diet, re-echoed the importance of GI as a dietary tool in carbohydrate food choices. Numerous studies have associated GI and various health conditions affirming its relevance and use.

2.8.2 GLYCEMIC INDEX (GI) AND HEALTH

Glycemic index has been related to a number of health conditions in various epidemiological studies (Sheard *et al.,* 2004). High GI diets have been associated to increased risk of certain chronic diseases whilst low GI diets are thought to be protective (Augustin *et al.,* 2002). The quality of carbohydrates consumed has also been found to be positively associated with ovulatory infertility in women who have never been delivered of live babies (Chavarro *et al.,* 2009).

Meals that are mainly made of low GI components are reported to lengthen the duration of satiety and thus suggestive of a preventative role in the onset and progression of obesity (Leathwood & Pollet, 1988 cited in Bjorck, 1994).

2.8.3 Glycemic Index And Obesity

Consequences of recommendations on fat and protein intake led to the development of western dietary guidelines which seemed to encourage carbohydrate intake (Truswell, 1987). However, a decline in fat intake has not led to that expected decline in obesity. Prevalence of obesity has rather increased in recent years (Aderson & Woodend, 2003) with reported decline in fat consumption (Willet, 1998) and increased carbohydrate intake. There are suggestions that the consumption of high glycemic index foods contribute to the observed prevalence, by causing people to overeat (Ludwig *et al.,* 1999). On the other hand low glycemic index foods have been found to enhance satiety (Leathwood & Pollet, 1988 cited in Bjorck, 1994) and thus reduce the frequency and quantity of foods eaten. Low GI food thus influence total calorie intake and will thus lead to a decline in weight if other indulging lifestyles are put in check.

2.8.4 Glycemic Index and Diabetes

Diabetes represents a group of metabolic disorders that are characterized by hyperglycemias (high blood glucose) or hypoglycaemia (low blood glucose) as well as glucose intolerances, and may be implicated in a number of conditions such as cardiovascular, cerebrovascular, and peripheral vascular diseases (Wang *et al.,* 2013). A review done by Ceriello discovered the involvement of postprandial hyperglycemias in a cascade of events which result in oxidative stress which is associated with a number of diseases including CVDs. This is based on the evidence that certain reactive oxygen species are released in acute hyperglycemias (Ceriello *et al.*, 2000). These complications impact negatively on the general wellbeing of individuals. Hyperglycemic conditions would occur if there is a defect in insulin secretion or its action. Insulin is secreted in the body by the beta cells in the islets of Langerhans in the pancreas in response to blood glucose which results from the intake, digestion and absorption of carbohydrates foods.

Increased intake of high GI foods has been hypothesized to cause type II diabetes with evidence from epidemiological studies (Sheard *et al.,* 2004). Intake of low GI foods has, however, been associated with improvement in glycemic control in persons with Type I diabetes and Type II diabetics patients with well controlled metabolism (Wolever *et al.,* 2009). In the conclusive statements of a research that found a link between consumption of low GI foods and reduced need for insulin in GDM patients for glycemic control, Dr. Robert Moses of Illawarra Diabetes Service in New Wales Australia and his Associates stated that: "the usual practice in our clinic has been to encourage low–glycemic index choices when offering MNT to women with GDM (Moses *et al.,* 2009). However, this recommendation was based on clinical experience and had not been formally examined". In an earlier research, they found an association of low GI intake with better fetal outcomes (Moses *et al.,* 2009).

The consumption of low GI foods have been found to have beneficial effects comparable to pharmacological agents that check elevated postprandial glucose levels. These benefits from the consumption of low GI foods provide an economic gain in the management of diabetes (Brand-Miller *et al.,* 2003).

2.8.5 Glycemic Index and Cardiovascular Health

Concerns about improving cardiovascular health led to numerous studies which have proposed low fat diet especially saturated fats as a means of preventing coronary health diseases (American Heart Association Dietary guidelines for healthy American adults, 1986). The recommendations have led to increased consumption of high carbohydrates, low fat diets. However, further studies have shown an increased cardiovascular health risk to increased intake of refined carbohydrates in place of saturated fats (Jakobsen *et al.,* 2009). In a systematic review by Jakobsen *et al.,* (2009) they indicated that although it is suggested that SFAs be replaced with PUFA other than carbohydrates, the quality of the carbohydrate is of paramount importance if it must be substituted. Ludwig (2002) affirmed the role of carbohydrate quality in cardivascular health in a review on GI in prevention and treatment of cardiovascular disease, obesity and diabetes.

There is evidence to the effect that, intake of high GI diet increases CHD risk by increasing plasma TG levels whilst decreasing HDL cholesterol. On the contrary, a cohort study by Jenkin *et al*. (1985) showed a significant reduction in total cholesterol, HDL cholesterol and triglycerides in patients with hyperlipedemia by intake of low GI foods. Low GI foods can be thus protective in cardiovascular health with a concomitant reduction in these cardiovascular risk factors. Mirrahimi *et al.,* 2012 also found a favourable association between the intake of low GI diet and CHD in women in a sytematic review of 473 studies.

2.9 GLYCEMIC INDEX LABELLING

The labelling of foods products is to provide consumers with knowledge on nutritional composition to make informed dietary choices for healthy living (FAO/WHO, 1998). The right of the consumer to know what is likely to be the impact of a food product on his health makes food labelling an important part of food packaging.

Due to numerous researches and articles published since the inception of the GI concept, a lot of attention has been drawn to its relevance and application (Brouns *et al.*, 2005) and including GI of foods on labels is considered one of the most promising items on food labels (Mitchell, 2008). Countries like Australia and the United Kingdom have acknowledged and introduced some form of GI labelling of foods. The knowledge on the GI concept is thus high as well within these settings (Mitchell, 2008).

Currently, a number of countries including New Zealand, Canada and some other European countries have accepted the GI concept which they have integrated into medical nutrition therapy (MNT) for clients. Although not much is published about the GI concept within the African jurisdiction, there is recognized application in MNT within the Ghanaian dietetics setting. South Africa, however, has made significant progress in the development and use of GI although the legislative instrument to propel GI labelling is still in the shadows (Gibson, 2010).

2.9.1 GI Labelling in Ghana

Most Ghanaian staples are home cooked and their packaging for sale and consumption do not give room for any form of labelling. The nutritional content of food labels does not seem to form the basis of the food choices made by most consumers in Ghana because virtually all Ghanaian staples are sold without labels.

Packaged foods which are hermetically sealed require labelling according to the regulation by the regulatory body; the Food and Drugs Board (FDB). The major items required by the FDB before product registration in Ghana does not include GI. Although dietitians in Ghana are employing the GI concept in MNT in various hospitals, much is not known on the concept by the average Ghanaian.

Education is necessary to create the needed awareness on the GI concept. A lot more research is also required to determine the GI of most Ghanaian staples. This would go a long way in supporting the provision of knowledge based on nutritional counselling using the local staples. A strong awareness and popular knowledge of use of the concept will initiate discussions that can set the tone for legislative consideration.

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

This chapter details the materials and specific methods that were used in preparation and determination of the glycemic index of the various food items. The chapter also introduces us to the study design used and the subjects that were used in the study.

3.2 STUDY DESIGN

The determination of Glycemic index was carried out experimentally and the design was a crossover trial. It was necessary to use a crossover trial because the subjects who were given the test foods had to be the same subjects to be given the reference food. The standard protocol required the test being carried out *in- vivo* because a number of factors affect the metabolism of food in the human body. An *in-vivo* approach was thus the best means of determination if the outcome could be used as reference data. Extrapolation from tables has been found not to be exactly accurate. Every food item is somehow different from the other even when they are of the same species.

3.3 STUDY SUBJECTS

The research was approved by the Committee on Human Research, Publication and Ethics of the Kwame Nkrumah University of Science and Technology School of Medical Sciences/Komfo Anokye Teaching Hospital. Following the approval, ten (10) apparently healthy human subjects were recruited for the clinical trial, eight (8) males and two (2) females. All ten (10) people gave their informed consent. The ten subjects recruited are in line with the FAO/WHO (1998) recommended method for the determination of Glycemic Index.

3.3.1 Inclusion Criteria

1. Healthy people with no complain of ill health or uneasiness.
2. Both males and females who were not morbidly obese based on their calculated BMI.
3. Subjects aged 20 to 50.

3.3.2 Exclusion criteria

1. Subjects aged 20 to 50 but with a history of hepatitis or any known metabolic disorder.
2. Morbidly obese individuals with or without diabetes.
3. Persons with any known cardiovascular disease to whom such a work might pose a health risk or stress as well as individuals on medications that could influence the results in any way.
4. Subjects who for one reason or the other could not take any one of the test meals.

All subjects were grouped together a week before the start date of experiment for orientation. All subjects were again informed of the importance of adhering to the rules of engagement in the research. Participants were informed of a strict abstinence from smoking or drinking within the period of the study. They were also not to engage in any strenuous activity prior to testing days

3.4 Data

Some basic information was required from participants. Data such as age, sex, history of diabetes, metabolic disorder or any CVD, last meal eaten the previous night and time eaten were taken from the subjects.

3.5 PROTOCOL

All subjects were made to undergo a 10 to 14 hour fast from the time of taking the last meal of the previous night to the morning of testing. All participants reported to the premises of Medilab Diagnostic Services Ltd at Bantama opposite the Komfo Anokye Teaching hospital at 6:45 to 7:15am. The reporting time and venue was the same for both reference and test foods

The subjects on reporting were weighed without shoes on using a bathroom scale. The heights of participants were measured in an upright position with a stadiometer. The weight and height measurements were taken repeatedly for each subject. The average heights and weights obtained were used for the analysis done.

3.5.1 FASTING BLOOD SUGAR (FBS)

After the measurements were taken, capillary blood was taken from each participant to assay for the FBS using an Ultra 2 glucometer. The time of taking the fasting blood sugar was recorded to confirm that each participant had undergone the 10 -14 hr fast prior to testing.

3.5.2 ORAL GLUCOSE TOLERANCE TEST (OGTT), Modified

Subjects were each given a glucose solution prepared from 50g glucose and 200ml of bottled water. The stop watches were started when subjects started to drink the glucose solution. The glucose solutions were taken within a 5 minute period. The time each participant begins to drink the glucose solution is recorded. Fifteen (15) minutes after the start of consumption of the glucose solution the reference sample, capillary blood was taken from all the participants and assayed for glucose. Subsequently, samples were taken from all participants at the 30^{th}, 45^{th}, 60^{th}, 90^{th} and 120^{th} min as well and assayed for the glucose concentration in mmol/l. Participants were asked to ensure very minimal activity. They were asked not to leave the lab

premises as a measure to ensure that an extremely low level of physical activity took place within the testing period.

After the 2 h period when all samples had been taken, participants were all informed of the next testing day and were appropriately reminded of the restrictions that accompanied their participation in the research work. After that was done, participants were each given cocoa drink or fresh yoghurt with biscuit and allowed to go about their normal activities.

3.5.3 Test Foods

The first test food (Neat fufu) was administered two days after the glucose had been given. Participants, as with the reference food were required to undergo a 10-14 h fast prior to the day of testing. Subjects were also required to abstain from smoking and drinking alcohol during the whole period. Just as with the reference food, participants reported at 6:45 – 7:15 am at the same venue. The last meal and time of meal of each participant was asked and recorded.

All participants had their thumbs or index fingers cleaned with alcohol and wiped with cotton to disinfect them. They were then pricked with lancet. A rounded drop of blood was obtained by squeezing the fingers gently. A glucometer with an inserted strip was used to pick the drop of rounded blood to determine the fasting blood sugar in mmol/L. The time each participant's FBS was measured was appropriately recorded.

A measured amount (153g) of Neat® fufu (industry processed fufu), with about 110g of light soup and about 30g salmon was given to each participant. The time each participant started the meal was recorded. Participants were made to consume the food in 10 min. The timer was started when each participant commenced eating of the food. The first sample was taken 15 min after the start time. Samples were taken again at the 30^{th}, 45^{th}, 60^{th}, 90^{th}, and 120^{th} min and the glucose concentration recorded in mmol/l.

On specified days, subjects assembled at the same venue and times. Similarly, measured amounts of the other test foods, containing 50g available carbohydrate was given to each subject and eaten within a 10 min period. The timer was started when each participant commenced eating of the food. The first sample was taken 15 min after the start time. Samples were taken again at the 30^{th}, 45^{th}, 60^{th}, 90^{th}, and 120^{th}, min. Before any test food was given, capillary blood was taken and a fasting blood sugar assayed for and appropriately recorded.

Participants were given lunch after the whole exercise and then made to leave.

Five foods including: fufu (normal), kenkey (Ga), Banku, Tuo Zaafi (TZ), Fufu (Processed Powdered) were tested under the same pre conditions and procedure.

3.6 PREPARATION OF TEST MEALS

The processes that were involved in the individual preparation of the test foods are as indicated below.

3.6.1 Fufu Prepared From Industry Processed Fufu Flour (Neat® Fufu)

A 700g pack Neat fufu was purchased from the open market (Silvercrest supermarket). The powdered product was dissolved in about a litre of water into uniform on a gas stove. The product was stirred continuously with a wooden spatula until it began to harden. It was kneaded with some water added until the desired thickness was achieved. The fufu obtained was taken from the fire, allowed to cool and moulded into reasonable sizes, each with an average size of about 250g and wrapped neatly in plastic rubbers.

3.6.2 Locally Pounded Fufu

Fingers of commonly used plantain fingers and cassava were pealed and washed. They were cut into small sizes and boiled. After boiling, the plantain and cassava were pounded together in a ratio of 80 to 20. The final fufu product obtained is divided into sizeable portions

3.6.3 Banku

The banku was prepared from 20% and 80% portions of cassava dough and corn dough. The dough was mixed in the specified portions into a smooth paste. The paste was dissolved in water, mixed thoroughly and placed on fire to boil whilst stirring. The paste was stirred continuously till it was completely cooked and attained the desired hardness. The banku was fashioned into the desired portions of about 300g and wrapped in plastic containers and then allowed to cool.

3.6.4 Kenkey

The Kenkey was prepared with fermented corn dough. The corn dough was dissolved in water into a paste and put on fire to boil whilst stirring. When the paste was partially cooked, it was removed from the fire and mixed with uncooked fermented corn dough. The product was then moulded into sizeable portions of about 200g, wrapped in dry corn leaves and boiled to cook completely.

3.6.5 Tuo Zaafi (TZ)

TZ was prepared from corn powder dissolved in warm water and stirred continuously. As the food hardened, more powdered corn flour was added and stirred till completely cooked. The cooked TZ was moulded into about 250g sizes into plastic rubbers.

After the preparation of the various test meals, they were sent to the research site and the specific quantities that contain 50g available carbohydrate portions were weighed into 10

clean containers and administered to subjects with about 110g of light soup and a serving of salmon on specified days. All test foods were taken with the same amount of light soup and salmon fish.

Below is a table of the nutrient analysis of the various foods that were studied. The calculations made were based on 100g portions.

TABLE 3-1 NUTRIENT CONTENT OF TEST MEALS

TEST MEAL	**AMOUNT (g)**	**PROTEIN (g)**	**FAT (g)**	**TOTAL (CHO). (g)**	**DIETARY FIBRE (g)**	**ENERGY (kcal)**	**AVAILABLE CHO (g)**
BANKU	281	20.23	0.56	50.30	0.28	287.16	50.
TUO ZAAFI (TZ)	229	3.21	0.46	50.61	0.69	219.42	50
KENKEY (GA)	189	5.86	0.76	52.35	2.46	239.68	50
LOCALLY PREPARED FUFU (Plantain)	153	0.92	0.15	50.30	0.15	205.15	50
INDUSTRY PROCESSED NEAT® FUFU	153	5	0.4	81	1	1487	50

Note: Calculation of Available carbohydrates in fufu (normal), kenkey, TZ, and banku was based on proximate analysis done by Eyeson *et al.*,(1975). The nutritional analysis stated for neat fufu was calculated based on nutritional facts on package provided by manufacturer per 100g of raw uncooked flour. The package however did not have data on the nutritional content after preparation for consumption.

The quantity (153g) of locally pounded fufu containing 50g available carbohydrate portion was measured for Neat® fufu and tested. This was done so that their GI could be compared on a weight for weight since they are the same food produced differently. This was done on

the assumption that, being the same kind of food they contain the same amount of available carbohydrate per 100g gram of their prepared form.

TABLE 3-2 NUTRIENT CONTENT OF SOUP WITH FISH

TEST MEAL (g)	AMOUNT (g)	PROTEIN (g)	FAT (g)	TOTAL CHO (g)	DIETARY FIBRE (g)	ENERGY (kcal)
LIGHT SOUP	110	1.98	0.77	2.31	0	24.09
SALMON	30	4.98	1.74	0	0	35.58

Note: Nutrient analysis as done on the soup was based on proximate analysis done by Eyeson *et al.*,(1975).

3.7 DATA ANALYSIS

The incremental area under the glucose response curves (IAUC) were calculated using the trapezoid rule as recommended by FAO/WHO (FAO/WHO, 1998). The area under the fasting baseline was ingnored in the calculation. All GIs that were 2SD above or below the mean GI value for a given given test was ignored as an outlier (Wolever *et al.*, 2011).

The IAUC for each test food was expressed as a percentage of the mean IAUC of the glucose which was the reference food used.

The Glycemic index of each test food was calculated as the mean GI as obtained by each subject in the study that consumed the test food.

The glucose response curves were plotted with the GraphPad Prism software version 5.00.

Data was analysed using Microsoft Excel and Statistical Package for Social Sciences (SPSS) software version 20.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 GENERAL CHARATERISTICS OF SUBJECTS

A total of 10 subjects, all of African descent were recruited for the study of the selected foods. There were 8 males and 2 females with a mean age of 30.9 ± 6.4 years (range: 24 – 46), mean body mass index (BMI) of 26.96±5.2 kg/m^2 (range: 22.2 – 39.1), and mean Waist circumference (WC) 88.6±13.84 cm (range: 77 – 122). The anthropometric characteristics of the subjects are represented in Table 4-1

Table 4-1 Characteristics of subjects that participated in the study

SUBJECTS	ANTHROPOMETRIC CHARACTERISTICS				
	AGE (yrs)	**WEIGHT (Kg)**	**HEIGHT (m)**	**BMI (Kg/m2)**	**WC (Cm)**
VK01	33	56	1.55	23.3	77
JK03	27	71	1.79	22.2	83
IA04	31	78	1.73	26.1	87
EL05	32	85	1.65	31.2	102
AD06	46	82	1.71	28	90
JA07	24	68	1.72	23	77
CP08	27	79	1.65	29	86
PB09	24	59	1.55	24.6	80
BA10	34	66	1.69	23.1	82
PA11	31	117	1.73	39.1	122
All	30.9±6.4	76.1±17.28	1.677±0.08	26.96±5.2	88.6±13.84

All values = mean and standard deviation

4.2 GLYCEMIC INDEX VALUES

The measured GI values of the tested foods are shown in Table 4-2. Glucose, the standard food item against which the foods were measured has a GI of 100%. Only one of the tested foods (banku) had a high glycemic index. The rest were either low or moderate.

Table 4-2 Glycemic Index of Selected Staples GI groups: Low (L), Medium (M), High (H)

	FOOD ITEM	AT 95% CI			SE	GI CLASS
No.		GI_{min} (%)	GI_{max} (%)	GI (%)		
1	GLUCOSE	100	100	**100**	0.0	H
2	BANKU	61	85	**73^{A}**	5.0	H
3	KENKEY	25	55	**41^{BC}**	6.8	L
4	TUO ZAAFI (TZ)	50	84	**67^{AC}**	7.5	M
5	POUNDED FUFU	30	76	**55^{AC}**	8.7	L
6	PROCESSED FUFU	17	48	**31^{B}**	6.6	L

^{ABC}Values in the same column with different superscripts differ significantly ($p<0.05$)

Glycemic Index Classes: Foods were classified as low medium or high GI according to the following:

GI values ≤55; Low GI, 56 – 69; Medium GI and ≥ 70; High GI

The GI of all the foods tested, their standard error and GI group are represented in Table 4-2 with their minimum and maximum values at a 95% confidence interval. This means that there is a 95% certainty that the GI value of the tested food would be in the minimum and maximum range of values stated.

The measured GI of the various staples and their classes are shown in Table 4-2. Glycemic index of the foods ranged from low (≤ 55) through medium (56-69) to high (≥ 70). The three corn based foods, Banku, TZ, and Kenkey had a high GI, Medium and low GI, respectively. There were no significant differences between the GI of Banku and TZ or Banku and Locally pounded fufu (LPF); however, the GI of Banku differed significantly from kenkey ($p<0.05$) which is also corn based. There was a significant difference between the GI of LPF and fufu

made from industry processed fufu flour (*p = 0.026*) both of which are processed quite differently.

4.3 GLUCOSE RESPONSES AND INCREAMENTAL AREAS UNDER THE CURVE (IAUC)

Table 4-3 Incremental Area under the curve of the test and reference foods by the study subjects

SUBJECTS	INCREMENTAL AREA UNDER THE GLUCOSE RESPONSE CURVE (IAUC)					
	GLUCOSE MEAN	BANKU	KENKEY	TZ	POUNDED FUFU	PROCESSD FUFU
VK01	156.08	125.25	63.75	154.5	124.5	105
JK03	112.13	74.14	26.59	54	32.4	11.36
IA04	92.57	58.61	49.2	84.75	92.25	16.05
EL05	112.88	-	-	-	-	48.75
AD06	292.88	152.25	18.94	119.25	104.25	43.75
JA07	104.4	102.75	46.5	60.19	64.5	26.25
CP08	152.38	92.25	44.63	66.75	56.67	77.25
PB09	206.45	180.75	153.75	195	82.38	83.25
BA10	131.49	109.5	46.5	84	-	20.25
PA11	226.87	145.5	136.5	157.15	123.75	-
MEAN	**158.8±64.4**	**115.7±39.2^{X}**	**65.2±47.4^{XY}**	**108.4±47.5^{X}**	**85.1±32.7^{XY}**	**47.9±33.5^{Y}**

^{XY}Values in the same row having different superscripts differ significantly ($p<0.05$)

The GI of both normal pounded fufu and Industry processed fufu are low, and there is no significant difference between the incremental areas under the curve (AUC) for both (*p>0.05*). An example of the calculation of the incremental AUC is however shown in the Appendix.

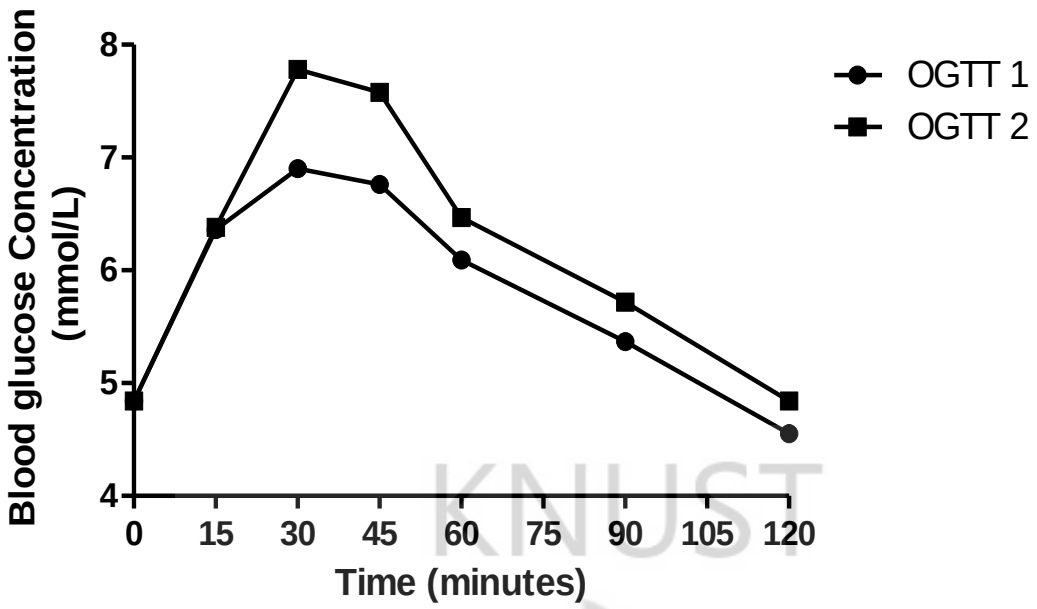

Figure 4.1 Mean Glycemic response elicited by 50g glucose in duplicate.

The average fasting blood sugar levels before the ingestion of the glucose was the same in both tests. There was, however, some difference in the AUC of glucose administered on two different occasion though the difference was not significant ($p>0.05$). The average peak of postprandial glucose in all subjects after consumption of the reference food (glucose solution) was observed at the 30th minute from glucose ingestion.

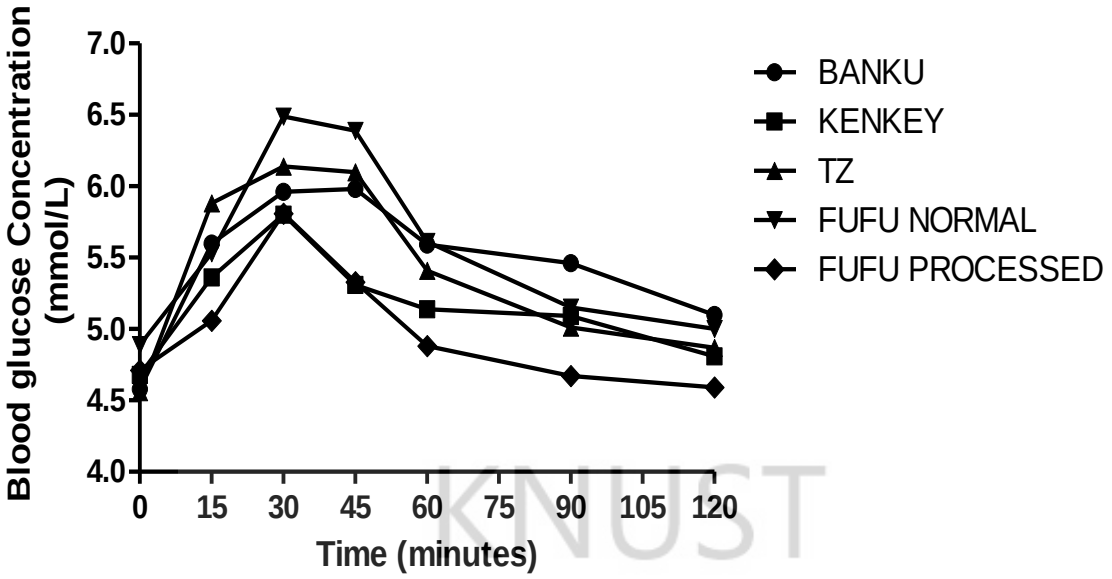

Figure 4.2 Mean Glycemic responses elicited by study subjects after consumption of 50g available carbohydrates portions of different samples

From Fig 4.1& 4.2 the average fasting blood glucose levels before the consumption of the various test foods and reference food are similar. For an apparently healthy individual, the body maintains a fairly constant normal blood sugar level even after an overnight fast.

The average peak of postprandial glucose in all subjects after consumption of test food was observed at the 30th minute from ingestion of food as was observed with the pure glucose solution.

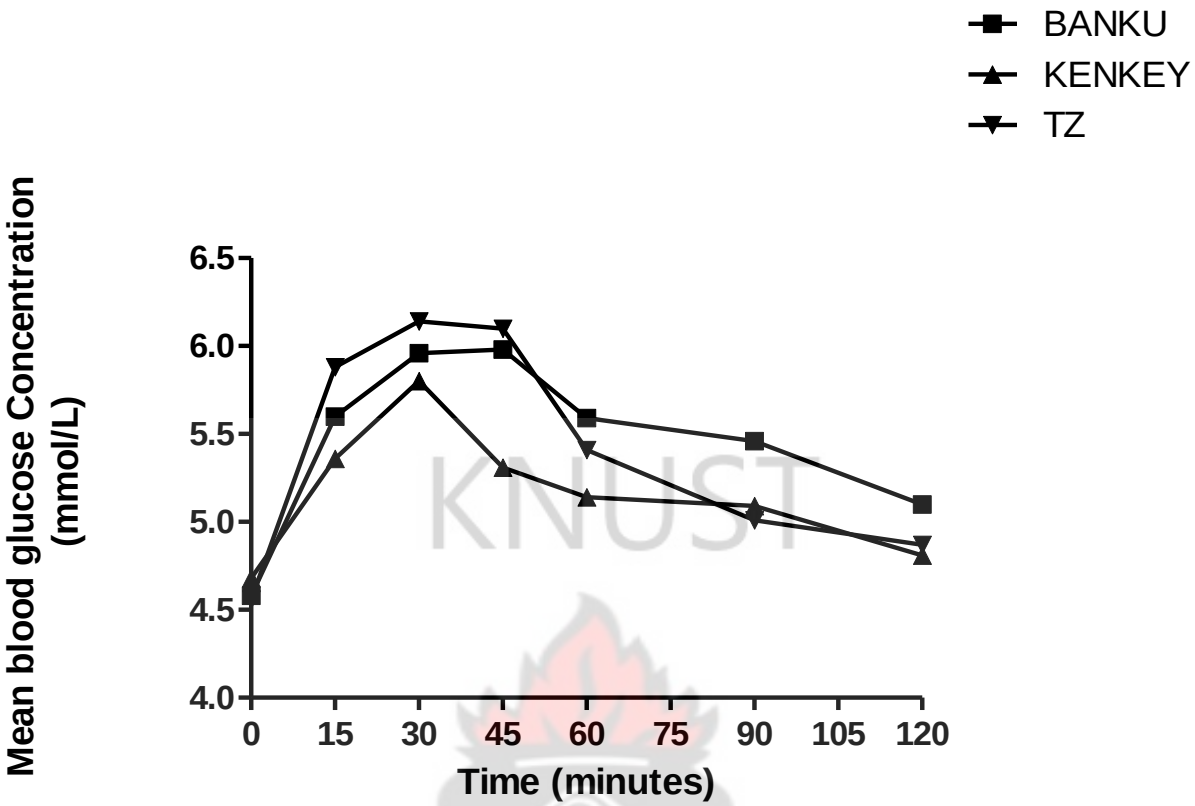

Figure 4.3 Mean blood glucose responses of subjects elicited by the consumption of 50g available carbohydrate portions of the corn-based foods.

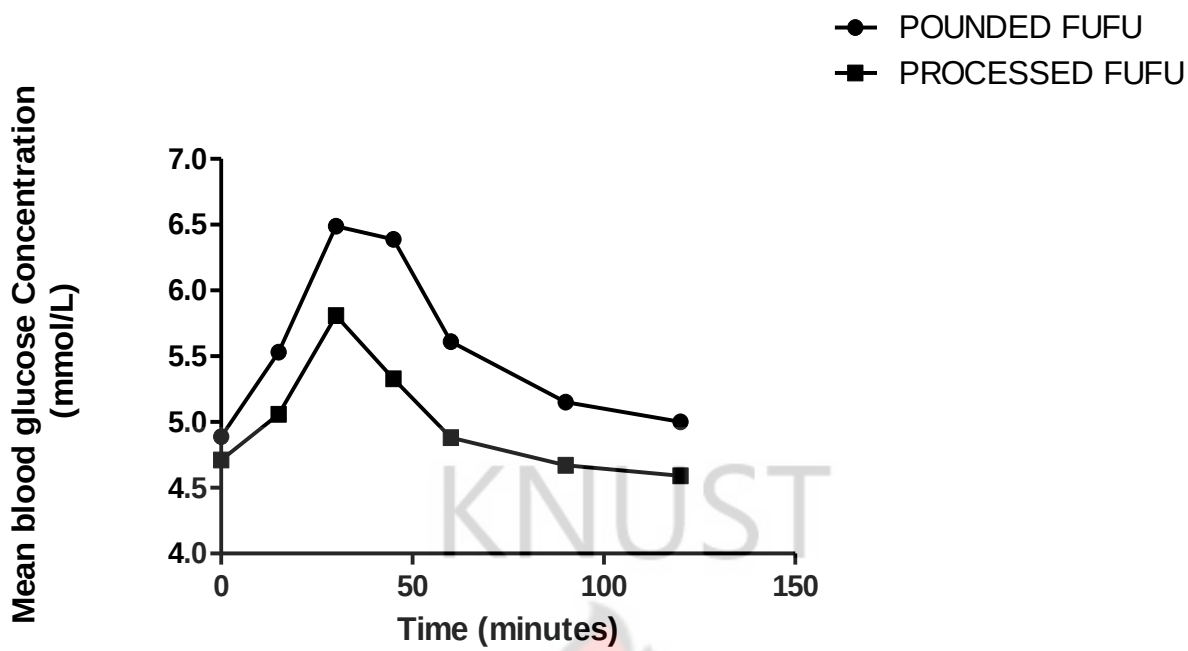

Figure 4.4 Mean blood glucose responses of subjects elicited by the consumption of 153g (50g available carbohydrate portions) of locally pounded fufu (LPF) and industry processed fufu (IPF).

4.4 POSSIBLE FACTORS THAT AFFECTED GLUCOSE RESPONSE

The glucose response as obtained for the various test and reference foods might have been influenced by a number of intrinsic and extrinsic factors. From the results the following were observed:

4.4.1 EFFECT OF PORTION SIZE

The GI of Banku which had the largest available carbohydrate portion was the highest among the foods. However, the same could not be said for Kenkey and fufu. Kenkey had a larger available carbohydrate portion size (189g) than fufu (153g) but elicited a lower glycemic response than locally pounded fufu. Also, the amount of LPF and IPF ingested by subjects were the same (153g) but the AUC of the LPF was about 33% higher than that of IPF. Though a larger available carbohydrate portion would elicit a higher glucose response,

comparing the glucose response of equal available carbohydrate portions the quality and processing factors are of significant influence.

4.4.2 EFFECT OF FIBRE

The fibre content of freshly harvested 100g cassava, plantain and maize are 1.8g, 2.3g and 7.3g respectively, all of which are higher than in their processed form as banku, TZ, Kenkey or fufu. Comparing the fibre contents, weight for weight, there is a noticeable difference in the fibre content before and after processing into various dishes. Processing obviously affects the total fibre content.

The fibre content of banku, TZ and Kenkey were 0.1, 0.3 and 1.3 g per 100g respectively. The GI of kenkey which had the highest fibre content was significantly lower than that of banku (p = 0.024). The fibre content of fufu was 0.1g as with banku but had a lower glycemic response than banku of similar fibre content and TZ of comparatively higher fibre content. GI is influenced by other factors that will include but not restricted to amount of fibre of the food item.

4.5 DISCUSSION

Most staple foods of the various regions in Ghana are carbohydrate rich. Classification of foods based on their respective glycemic responses has helped to clear the erroneous perception that carbohydrate-rich foods are the bane of most persons with metabolic disorders. The increasing number of evidence-based researches affirms the assertion that not all carbohydrates are of the same quality.

All test foods in the study provided an average of 231kcal (per 50g available carbohydrate quantity) which was not significantly different ($p > 0.05$) from the calorie content of glucose, the reference food (200kcal).

Most of the participants complained of a nauseating feeling after consumption of glucose solution which was the reference food. The response from the participants was as Brouns *et al.*, (2005) indicated when they studied the use of white bread and glucose as reference materials in GI determination. Despite the observed effect, glucose happens to be the reference material of choice because of potential variations that could result in the preparation of white bread in different research areas (Bornet *et al.,* 1987).

The foods tested Banku, Ga Kenkey, Tuo Zaafi and Fufu are the main staple foods consumed by the people of the Volta, Greater Accra, Northern and Ashanti Regions respectively. However the consumption of these foods are now not limited to persons of these regions alone.

Of all the foods tested, Banku had the highest GI value (73), followed by TZ (68), and locally prepared fufu (55), Kenkey (41) and the least being fufu (31) prepared from industry processed fufu flour (Table 4-2). All these foods were prepared by going through boiling of one form or the other.

Generally and for most foods, boiling is considered to increase GI due to increased gelatinization which improves starch digestibility and increased glucose response (Lin *et al.,* 2010; Bahado-Singh *et al.,* 2011). This could explain the high GI obtained with Banku which also had low fibre and a comparatively larger 50g available carbohydrate portion. Also banku was prepared from corn dough and cassava dough. The 20% part of the banku from cassava dough could have influenced the higher GI obtained than TZ of relatively similar preparation process. Cassava has a higher amylopectin to amylose ratio (United States Department of Agriculture, 2002). Amylopectin is more branched and more susceptible to digestive amylases and would thus increase glucose response (Arvidsson-Lenner *et al.,* 2004). The influence of the cassava could have increased the glycemic response of the banku further beyond TZ whose cooking method is not much different from banku.

Of all the corn based foods, however, Kenkey had the least glycemic response (Table 4-2). The low GI value obtained for Ga Kenkey was in agreement with a study done by Brakohiapa on the glucose response to some mixed Ghanaian diet, in which he reported that Kenkey induced a low glucose response on consumption by healthy individuals (Brakohiapa *et al.,* 1997). The low GI obtained for Kenkey was not surprising considering that it had the highest fibre content as well as a lower available carbohydrate portion per 100g of test food compared to the other corn based foods tested besides other underlining influencing factors. TZ had a dietary fibre of 0.3 per 100g and Banku had the least amount of dietary fibre of 0.1g per 100g. In the preparation of TZ, however, the milled corn was winnowed after milling. The winnowing of the corn powder could thus have been a major factor to the further decreased amount of fibre as compared to kenkey both of which were made of corn only.

The role of fibre in digestibility and gastric empting has been extensively evaluated in a number of studies showing its ability to delay gastric emptying. A delayed gastric emptying also has an influence on glucose response by the body (Lin *et al.,* 2010). Fibre is classified as

a non digestible starch and together with some other non starch polysaccharides enters the large intestines to undergo fermentation into short chain fatty acid products such as a butyrate, propionate, and acetate. Butyrate has also been found to be protective against colon cancer (Silvester *et al.,* 1995). Thus high amounts of fibre may not only reduce glycemic response but may protect against cancer. Accordingly it could be inferred that low GI diets which are rich in fibre could have a potentially beneficial effect in the protection against colon cancer.

Furthermore, in the preparation of Kenkey, the corn was soaked for some days in water to ferment. Some organic acids could probably be produced as by-products of the fermentation. Acetic acid which is considered part of normal diet and forms during sourdough fermentation (Ostman *et al.,* 2005) could have been produced during the fermentation of corn for kenkey preparation The acids (which contributes to its characteristic taste and flavour) from the fermentation of Kenkey during preparation could also have influenced the glycemic response of kenkey. There have been reports of the improvement in glycemic control to starch following fermentation of vegetables (Ostman *et al.,* 2001) and other foods. Earlier studies by Hunt and Knox in the 70's had hinted the increased potential of weak acids with lower molecular weight (eg. acetic acid, M_w = 60g/mol) to delay gastric emptying and thus reduce glycemic response (Ostman *et al.,* 2005). Liljeberg and Bjorck (1998) underscored the influence of acetic acid on glycemic response and even sugested the inclusion of fermented foods in meals to improve glycemic control. They further affirmed that acetic acids reduced glycemic response by delaying gasteric emptying. The acids from the fermentation of corn in kenkey preparation could have decreased the glycemic response by same mechanism of delayed gasteric emptying

Kenkey preparation process required a partial cooking of the fermented dough, followed by cooling to mix with uncooked dough as well as molding and then final boiling. In TZ

preparation, cool corn powder was added as cooking continued. These heating and cooling cycles which are critical in kenkey preparation but less pronounced in TZ preparation have the likelihood of leading to the formation of retrograded starches (Bahado-Singh *et al.*, 2011). Retrograded starches are recrystallization product of starches that have formed due to strong intermolecular hydrogen bonding and are thus less susceptible to enzymatic breakdown. Increased amounts of retrograded starch increase the value of resistant starches in the boiled food and could have reduced glucose response and led to a lower GI.

Although TZ is wholly corn based like kenkey but unlike banku, the GI value of TZ was classified medium. The less pronounced heating and cooling cycles in the preparation of the TZ could have introduced retrograded starches to reduce glycemic response to the TZ. Also gelatinization due to boiling could have influenced the glycemic response. These contrasting factors could have been a major contributor to the medium GI value obtained for TZ.

The values obtained and differences observed in the GI values of the corn based foods are similar to what is observed in the Revised International Table of Glycemic Index and Glycemic load where Corn granules consumed commonly in China had a GI of 52±3, Maize (*Zea mays*) flour made into Chapatti in India had GI of 59 and Corn meal porridge in china which is similar to local corn porridge or very soft banku reported a GI of 68±3 (Atkinson *et al.*, 2008).

Although Banku and locally pounded fufu (LPF) had 0.1 g fibre per 100g, their glycemic responses differed, banku having a higher GI than LPF (Table 4-2). The Banku was prepared from corn and cassava dough whilst the LPF from plantain and cassava. The two foods could not be unbiasly compared on the basis of their fibre content alone because difference in the amylose-amylopectin ratios of their starch structure and different processing methods are

important factors in the rate of starch digestion and important influence on their glycemic responses.

The GI value of fufu prepared from industry processed flour was the least (GI =17-48 at 95% CI) (Table 4-2). Although both industry processed fufu and locally pounded fufu had low GI, the IAUC of locally pounded fufu was about 33% higher than the IAUC of industry processed fufu (Table 4-3). The differences between the GIs of fufu prepared from Industry processed fufu flour and locally pounded fufu reached statistical significance *($p<0.05$)*. A number of factors could have influenced the observed differences in glycemic response. Though the major component in the preparation of both LPF and IPF is plantain, the quantity differed per 100g of each. The LPF was 80% plantain and 20% cassava whilst the IPF was 60% plantain, 10% cassava and 30% granular potatoes (which were added to protect flavour). The influence of fibre on the different glycemic responses cannot be fully examined and compared. This is because the amount of fibre anticipated in fufu prepared from industry processed fufu flour (Neat® fufu) was not stated on the package and was not determined in this study.

However the different processing methods and the variation in composition of raw materials of both fufu types could have significantly influenced the glycemic responses. From the summary of the production of fufu flour shown in the Appendix, and subsequent cooking of the flour to produce the finished fufu product, a number of wetting, heating and cooling cycles are involved (blanching, hot air drying and cooking) (Johnson *et al.*, 2006). These temperature induced processes affect starch digestibility and influence glycemic response (Brand *et al.,* 1985). Higher processing temperatures lead to a disruption of the starch structure and increase digestibility, however the processing of the fufu flour involves blanching which does not expose the raw materials (plantain, cassava, potato) to extreme temperatures to completely disrupt the starch structure. The drying temperature is also not

beyond 60^0C. Conversely, the heating and drying cycles during the production of the flour and the cooking of the flour to fufu could have rather increased the amount of retrograded starch (R3-resistant starch) present in the flour which are less susceptible to enzymatic breakdown (Bahado-Singh *et al.,* 2011) and thus lower glycemic response. To add to, the 30% granular potatoes fraction added to protect the flavour could have significantly influenced the low GI of processed fufu flour. Studies by Elmståhl in 2002 revealed a high resistant starch content of processed potatoes. The contribution of R2- resistant starch (Liljeberg, 2002) from the 30% processed potato fraction of the fufu flour could have significantly influenced the lowered glycemic response of the IPF as compared to locally pounded fufu.

In summary, although not much could be said on the influence of fibre on the GI of IPF, the role R2 and R3 resistant starches in reducing the glycemic response of fufu from industry processed flour cannot be overemphasized.

4.5.1 EFFECT OF PREVIOUS MEAL

In the study there were no restrictions on evening meals prior to testing days. According to a study by Thorburn (1993), low GI foods especially fermentable high fibre evening meals like barley improved glucose tolerance to a breakfast meal the following morning compared to rice. Wolever in 1988 studied the second meal effect on GI and concluded that high fibre in an evening meal without recourse to the GI of the meal necessarily, could influence the glucose response of the morning meal. A similar finding was observed in a study by Granfeld *et al.* (2005) on the effect of high fibre evening meal on GI. A critical assesment of the previous evening meals of subjects in this study revealed one subject (IA 04) who had taken a high fibre diet, oats the evening prior to testing of banku. Though subject IA 04 did not exclusively have the least glucose response for all the foods tested, the IUAC of banku for

that subject was observed to be the least compared to the other subjects. Although it was an isolated case, it agrees with the findings of earlier studies that high fibre evening meal improves glycemic response of breakfast meals.

From Fig. 4.1, 4.2 & 4.3, there were not much difference in the fasting blood sugar levels before any of the test or reference foods were consumed though the subjects consumed different meals the evenings prior to testing days. The inter-individual variations in glycemic responses are in agreement with studies by Brouns, et al., 2005. Since the previous evening meals were not controlled the interindividual variations in GI of foods could not be attributed wholly to previous evening meals though the possibility could not be ruled out.

4.5.2 EFFECT OF SOUP TAKEN WITH TESTED FOODS

Fundamentally the foods tested could not be taken alone even for the sake of testing. All the test foods were taken with the same quantity and quality of light soup and about a 30g size of salmon fish. This was to ensure that there were no differences that could be attributed to the soup taken with a particular food item. Light soup was used instead of any other soup that could be taken with these foods because light soup added very little variation to the fibre and available carbohydrate portions that are important components to the GI measurements. The light soup together with the fish provided a total of 6.96g of protein, 2.52g of fat and 2.31g of available carbohydrate with no fibre.

Studies on protein hydrolysates in meals showed significant effect in insulin and glucagon responses. The effect was, however, dependent on the type of protein at significant quantities given per body weight (Claessens *et al.,* 2009). Earlier researches into co-ingestion of carbohydrates with protein however showed increases in response of plasma insulin (Rabinowitz *et al.,* 1966: Newsholme *et al.,* 2005). The effect of proteins on the glucose raising abilty of foods were not however elucidated in these studies though insulin secretion

would influence the AUC of glucose response curve. In a study conducted in type II diabetics where participants were given each 50g glucose plus 25g of different proteins including egg white, the highest glucose response was found in glucose ingestion alone or glucose ingested with egg white (Gannon *et al.,* 2001). This informs the position that the egg white did not counter influence glucose response and that for a protein to influence glucose response, the quality and quantity of the protein is critical as indicated by Newsholme *et al.,* 2005. The total amount of protein from the salmon fish and soup in this study being 6.96g was similar to the total protein content of kenkey but significantly lower than the total protein content of banku. With the same amount of soup and salmon taken with all the foods and the responses observed, it was not likely there was any significant effect of the very low protein value on the IAUCs of the various foods tested. Furthermore studies that demonstrated significant effect of protein on glucose response or even insulin response required significant quantities of defined proteins (Lavigne, *et al.*, 2000; Claessens *et al.*,, 2009).

The soup and fish provided a total of 2.51g fat to the tested foods. This was the same throughout all the tested foods and could not have influenced the glucose response significantly. The amount of fat that could influence glycemic response should be enough to influence the physicochemical properties of the food as with frying demonstrated by Bahado-Singh, Riley, Wheatly, & Lowe, 2011 in studying the effect of various processing methods on sweet potatoes (*Ipomoea batatas*). This was not likely with the amount of fat from the soup and fish because it was almost of the same value as that present in the various tested foods.

The salmon added had no available carbohydrate portion. The light soup however had approximately 2g available carbohydrate which could be considered within an acceptable standard deviation for the measured amount of available carbohydrate portion of the food tested and thus provide no significant increase in the glucose response of the tested foods. To add to, the soup and fish was the same for all the foods and considering the different

responses obtained it would be difficult to assume any significant influence to glucose response (either increasing or decreasing the AUC values obtained) for the different foods especially those from the same maize source. These notwithstanding, any potential influence of the soup or fish could be further studied.

CHAPTER SIX

CONCLUSION

This study has made available the GI values of four carbohydrate-rich staples commonly consumed in Ghana. The GI value of industry processed fufu (Brand: Neat® Fufu) which is marketed in European and Asian markets has also been determined. A low GI was found for cooked Industry processed fufu, kenkey, and locally pounded fufu. Tuo Zaafi had a medium GI and Banku had a high GI.

Important and useful information on the factors that influence the GI value of foods have been evaluated, cooking methods being an important factor assessed in the study. A multiple comparison of the GI of the various foods by ANOVA revealed a significant difference between the GI of locally pounded fufu (LPF) and fufu prepared from industry processed fufu flour (IPF) ($p = 0.026$) affirming the influence of processing on the GI of foods. Furthermore, a comparison of means of GI of the various foods showed a significant difference between Banku and Kenkey both of which are made mainly from corn but contain different quantities of fibre and have significant differences in their processing methods with kenkey involving a repeated heating and cooling cycle as well as fermentation. The results showed no statistically significant difference between the GI of locally pounded fufu and TZ though they had nothing in common with respect to their food composition.

The study has revealed that although boiling increases glycemic response of foods, repeated boiling and cooling cycles in the cooking process tend to reduce glycemic response. Fermentation of foods also decreases glycemic responses which tend to decrease the Gl. The results from this study also affirm the position that the GI of individual foods should be tested and not extrapolated from foods that have similar descriptions. The GI values obtained can be used as a guide by professionals who have a duty to advise persons on their diet and provide

Medical Nutrition Therapy. The general populace could also use the data provided in their choice of food for healthy living.

RECCOMENDATIONS

A current nutrient analysis of all our local dishes should be done because calculations of available carbohydrates are based on nutrient analysis done on the food.

Further studies that focus on other meals should be done to provide a more comprehensive database of GI of Ghanaian foods.

The effect of various soups and condiment on foods could be studied to clear all potential doubt on their influence on GI.

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APPENDIX

CALCULATING INCREMENTAL AREA UNDER A GLUCOSE RESPONSE CURVE (According to FAO/WHO, 1998 method)

The values used for the calculation are those obtained for study subject VK01 after administration of first glucose test

t	FBS	15min	30min	45min	60min	90min	120min	IUAC
Glucose Concentration (mmol/L)	4.7	5.9	7.6	7.3	6.8	6.1	4.6	**188.35**
	a	b	C	d	e	f	g	

The IUAC for the data above equals the sum of the traingles and trapezoids: A +B +C +D +E +F

Area of Triangle A = t/2 * height(b-a)

= 15/2 * (5.9 - 4.7)

= 7.5 * 1.2

= **9**

Area of Trapeziod B = ½ (a+b) * height (t)

= ½ {(b-a) + (c-a)} *t

= ½ {(5.9-4.7) + (7.6-4.7)} * 15

= ½ (4.1) *15

= **30.75**

Area of Trapezoid C = ½ (a+b) * height (t)

= ½ {(c-a) + (d-a)} *t

= ½ {(7.6-4.7) + (7.3-4.7)} * 15

= ½ (5.5)*15

= **41.25**

Area of Trapezoid D = ½ (a+b) * height (t)

=½ {(d-a) + (e-a)} *t

= ½ {(7.3-4.7) + (6.8-4.7)} * 15

= ½ (4.7)*15

= **35.25**

Area of Trapezoid E=½ (a+b) * height (t)

=½ {(e-a) + (f-a)} *t

= ½ {(6.8-4.7) + (6.1-4.7)} * 30

= ½ (3.5)*30

= **52.5**

Area of Triangle F= $t^{\#}/2$ * height (f-a)

$t^{\#}$ = ?

$t^{\#}/t$ = h/H

$t^{\#}/30$ = (f-a)/{(f-a) + (a- g)}

$t^{\#}/30$ = 1.4/1.5

$t^{\#}$ = 30* 0.9333333

$t^{\#}$ = 27.9999

Area of Triangle F = 27.999/2 * 1.4

= **19.6**

Thus IUAC of glucose response elicited by VKO1 to 50g glucose solution = A+B+C+D+E+F

= **188.35**

ONEWAY GI BY FOOD

/MISSING ANALYSIS

/POSTHOC=TUKEY ALPHA (0.05).

Oneway

ANOVA

GI

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	9569.650	4	2392.413	7.683	.000
Within Groups	10898.125	35	311.375		
Total	20467.775	39			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: GI

Tukey HSD

(I) FOOD	(J) FOOD	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
BANKU	TZ	5.50000	8.82291	.970	-19.8664	30.8664
	KENKEY	28.00000*	8.82291	.024	2.6336	53.3664
	LPF	14.87500	8.82291	.455	-10.4914	40.2414
	IPF	42.62500*	8.82291	.000	17.2586	67.9914

(I) FOOD	(J) FOOD	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
TZ	BANKU	-5.50000	8.82291	.970	-30.8664	19.8664
	KENKEY	22.50000	8.82291	.102	-2.8664	47.8664
	LPF	9.37500	8.82291	.824	-15.9914	34.7414
	IPF	37.12500*	8.82291	.002	11.7586	62.4914
KENKEY	BANKU	-28.00000*	8.82291	.024	-53.3664	-2.6336
	TZ	-22.50000	8.82291	.102	-47.8664	2.8664
	LPF	-13.12500	8.82291	.577	-38.4914	12.2414
	IPF	14.62500	8.82291	.472	-10.7414	39.9914
LPF	BANKU	-14.87500	8.82291	.455	-40.2414	10.4914
	TZ	-9.37500	8.82291	.824	-34.7414	15.9914
	KENKEY	13.12500	8.82291	.577	-12.2414	38.4914
	IPF	27.75000*	8.82291	.026	2.3836	53.1164
IPF	BANKU	-42.62500*	8.82291	.000	-67.9914	-17.2586
	TZ	-37.12500*	8.82291	.002	-62.4914	-11.7586
	KENKEY	-14.62500	8.82291	.472	-39.9914	10.7414
	LPF	-27.75000*	8.82291	.026	-53.1164	-2.3836

*. The mean difference is significant at the 0.05 level.

Multiple Comparisons

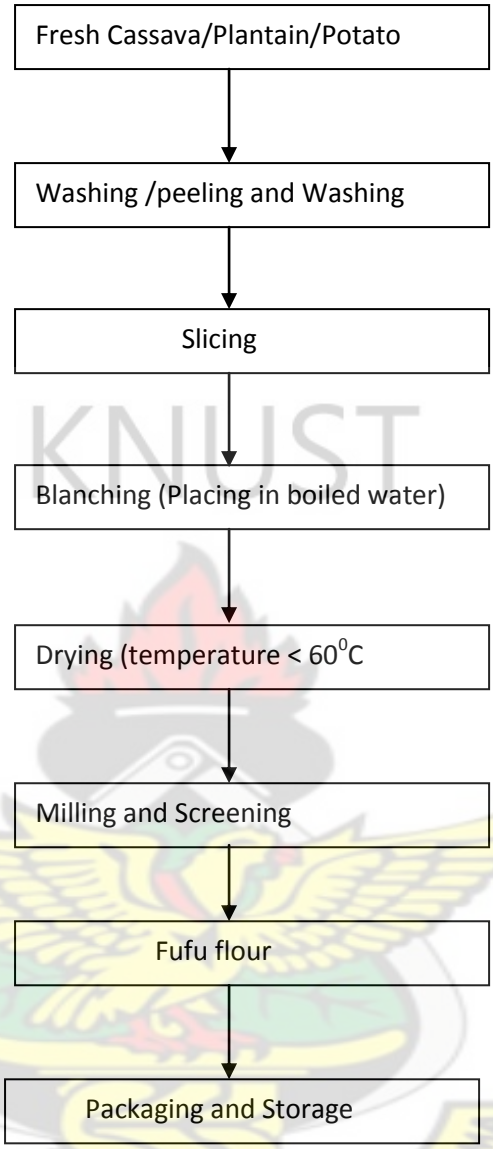
Dependent Variable: AUC

Tukey HSD

(I) FOODS	(J) FOODS	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
BANKU AUC	KENKEY AUC	50.51556	20.19437	.111	-7.1614	108.1925
	TZ AUC	7.26778	20.19437	.996	-50.4092	64.9447
	LPF AUC	40.03333	20.19437	.293	-17.6436	97.7103
	IPF AUC	67.67667*	20.19437	.014	9.9997	125.3536
KENKEY AUC	BANKU AUC	-50.51556	20.19437	.111	-108.1925	7.1614
	TZ AUC	-43.24778	20.19437	.223	-100.9247	14.4292
	LPF AUC	-10.48222	20.19437	.985	-68.1592	47.1947
	IPF AUC	17.16111	20.19437	.913	-40.5159	74.8381
TZ AUC	BANKU AUC	-7.26778	20.19437	.996	-64.9447	50.4092
	KENKEY AUC	43.24778	20.19437	.223	-14.4292	100.9247
	LPF AUC	32.76556	20.19437	.492	-24.9114	90.4425
	IPF AUC	60.40889*	20.19437	.036	2.7319	118.0859
LPF AUC	BANKU AUC	-40.03333	20.19437	.293	-97.7103	17.6436
	KENKEY AUC	10.48222	20.19437	.985	-47.1947	68.1592
	TZ AUC	-32.76556	20.19437	.492	-90.4425	24.9114
	IPF AUC	27.64333	20.19437	.651	-30.0336	85.3203
IPF AUC	BANKU AUC	-67.67667*	20.19437	.014	-125.3536	-9.9997
	KENKEY AUC	-17.16111	20.19437	.913	-74.8381	40.5159
	TZ AUC	-60.40889*	20.19437	.036	-118.0859	-2.7319
	LPF AUC	-27.64333	20.19437	.651	-85.3203	30.0336

*. The mean difference is significant at the 0.05 level.

A systematic Process flow Diagram for the Production of fufu flour



Source: Johnson, P. N-T., Oduro-Yeboah C., & Tortoe C. (2006). Manual on *fufu* Flour Production.

Below is a sample data collection sheet for the study. Each participant was allocated one with defined codes for identification.

GLYCEMIC INDEX RESEARCH

Researcher: Mr Divine Wormenor Mphil Human Nutrition and Dietetics

SUGAR PROFILE SHEET

Participant's Code:..... WC:.....

AGE:..... WEIGHT:.....

HEIGHT:..... BMI:.....

DAY 1 Date:

Last Meal:.....

Time of Last Meal:

OGTT 1

Time (min)	FBS	15	30	45	60	90	120
Concentration (mmol/L)							

DAY 2 Date:

Last Meal:.....

Time of Last Meal:

KENKEY

Time (min)	FBS	15	30	45	60	90	120
Concentration (mmol/L)							

DAY 3 Date:

Last Meal:.....

Time of Last Meal:

BANKU

Time (min)	FBS	15	30	45	60	90	120
Concentration (mmol/L)							

DAY 4 Date:

Last Meal:.....

Time of Last Meal:

TUO ZAAFI (TZ)

Time (min)	FBS	15	30	45	60	90	120
Concentration (mmol/L)							

DAY 5 Date:

Last Meal:.....

Time of Last Meal:

OGTT 2

Time (min)	FBS	15	30	45	60	90	120
Concentration (mmol/L)							

DAY 6 Date:

Last Meal:.....

Time of Last Meal:

FUFU (Processed Fufu i.e. Neat)

Time (min)	FBS	15	30	45	60	90	120
Concentration (mmol/L)							

DAY 7 Date:

Last Meal:.....

Time of Last Meal:

FUFU (Locally Pounded)

Time (min)	FBS	15	30	45	60	90	120
Concentration (mmol/L)							