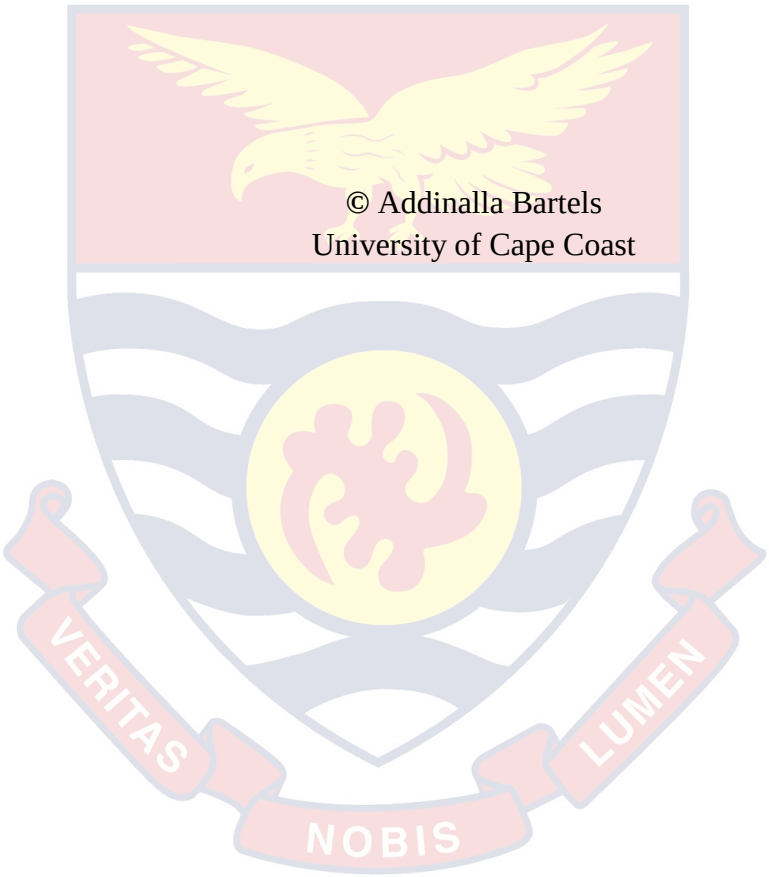
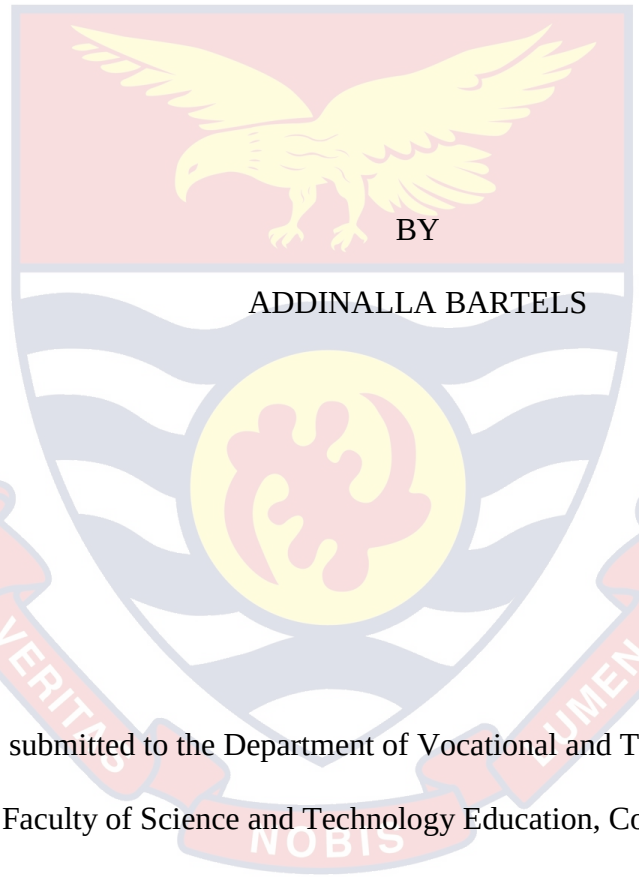


UNIVERSITY OF CAPE COAST

THE GLYCAEMIC INDEX AND LOAD OF THREE GHANAIAN STAPLE FOODS: SWEET POTATO, TARO AND RIPE PLANTAIN



BY

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Thesis submitted to the Department of Vocational and Technical Education of the Faculty of Science and Technology Education, College of Education Studies, University of Cape Coast, in partial fulfilment of the requirements for the award of Master of Philosophy degree in Home Economics

OCTOBER 2021

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:..... Date:.....

Name: Addinalla Bartels

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature: ..... Date: .....

Name: Prof. Mrs. Sarah Darkwa

Co-Supervisor's Signature: ..... Date: .....

Name: Miss Irene Tawiah Ampong

ABSTRACT

Consumption of local staples in Ghana comes with a lot of health-related issues regarding their load. The study therefore sought to assess the glycaemic index and load of sweet potatoes, taro and firm ripe plantain, which are commonly consumed in Ghana. The study was conducted at the Biriwa Baobab Medical Centre in Mfantseman Municipality of the Central Region of Ghana. Nineteen (19) participants (9 males and 10 females) were purposively and randomly selected in accordance with the study protocol for determining glycaemic index and load of the test foods for the study. A crossover experimental design was adopted for the study. The results of the study showed that there was a statistically significant difference in the glycaemic index of sweet potatoes, taro and firm ripe plantain at $p < 0.004$. Additionally, there was a statistically significant difference in the glycaemic load of sweet potatoes, taro and firm ripe plantain at $p < 0.00$. Also, a statistically significant difference in the chemical composition of sweet potatoes, taro and firm ripe plantain was discovered at $p < 0.00$. It was concluded that sweet potatoes had the least GI of 33.92 while firm ripe plantain and taro had medium and high GIs of 58.89 and 98.76 respectively. The GLs of the test foods were 161.85, 62.88 and 43.64 for taro, firm ripe plantain and sweet potatoes respectively. All the test foods had high GLs (GL≥20). The study therefore recommended among others that dieticians help in educating the general public on the consequences of consuming high glycaemic foods.

KEY WORDS

Glycaemic Index

Glycaemic Load

Firm Ripe Plantain

Sweet potatoes

Taro

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DEDICATION

To my parents, my family of procreation and to all working mothers who are aspiring to climb the academic ladder.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADA	American Diabetes Association
AGDP	Agricultural Gross Domestic Product
AOAC	Association of Official Analytical Chemists
BMI	Body Mass Index
CHD	Coronary Heart Diseases
CHO	Carbohydrates
CI	Confidence Interval
CIP	International Sweet Potato Centre
CNCDs	Chronic Non communicable diseases
CRI	Crop Research Institute
CSIR	Council for Scientific and Industrial Research
CV	Coefficient of Variation
CVDs	Cardiovascular diseases
DP	Degree of polymerization
EASD	European Association for the Study of Diabetes
FAOSTAT	Food and Agriculture Organisation Statistical Databases
FBG	Fasting Blood Glucose
GI	Glycaemic Index
GIFSA	Glycaemic Index Foundation of South Africa
GL	Glycaemic Load
HbA1c	Glycated Haemoglobin
HGI	High glycaemic index
HGL	High glycaemic load
IAUC	Incremental area under the curve

IITA	International Institute for Tropical Agriculture
ILSI	International Life Science Institute
ISO/FDIS	International Standards Organisation/Final Draft International Standard
LGI	Low Glycaemic index
LGL	Low glycaemic load
MoFA	Ministry of Food and Agriculture
NCD	Non-communicable diseases
NICUS	Nutrition Information Centre of the University of Stellenbosch
OGTT	Oral glucose Tolerance test
SRID	Statistical Research and Information Directorate
UCC	University of Cape Coast
UK	United Kingdom
USDA	United States Department of Agriculture
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

Background to the Study

Food plays a significant role in human health, providing the body with the necessary nutrients to enable it grow and function. It is usually of plant or animal origin. Foods provide energy (calories), nutrients and other substances desired for growth and health (Brown, Isaacs, Krinke, Lechtenberg, Murtaugh, Sharbaugh, Splett, Stang, & Wooldridge, 2011). According to Adow, Daaku, and Daaku (1993), staple foods in Ghana are grouped into 6 according to their functions, composition and use in meal preparation as:

1. Starchy roots and plantain,
2. Cereals and grains,
3. Fruits and vegetables,
4. Animals and animal products,
5. Legumes and oily seeds,
6. Fats and oils.

Starchy roots and plantain have multifaceted roles to plays in human diet. As a global source of carbohydrates, starchy roots and plantain are second only to cereal. Alexandratos (1995) opined that root and tubers contribute to food source, nutrition and cash income in many developing countries especially most insecure homes. They also add variety to diet and offer numerous desirable nutrition and health benefits.

The total production of root and tubers in sub-Saharan Africa was estimated as 254 million/annum (Food and Agriculture Organisation [FAO], STAT, 2012). In Ghana, starchy roots and plantain serve as staples with which

majority of carbohydrate diets are prepared. Examples include sweet potatoes, yams, taros, cocoyams and plantains. Different dishes including "ampesi," "fufu", "mpotompotɔ'' and snack dishes such as grilled plantain, "asanku"," "ɔfam", cakes and biscuits are prepared from this food group. African diets are usually based on carbohydrate staples served with soups, vegetable sauces and relishes.

The end product of carbohydrate digestion is glucose which is an important source of energy to the human body's tissues and cells. The capacity of a carbohydrate diet to increase blood glucose is linked to individuals' consumption pattern of these carbohydrate foods. According to Brown *et al.* (2011) and Mann *et al.* (2007), the energy content and digestibility of different carbohydrates differ. Some carbohydrate diets elicit faster response from insulin than others. This comes about as a result of the differences in the degree to which the body releases glucose to the body. If glucose becomes too much, it becomes harmful to the brain and other organs in the body (Ahmed, 2002). It may lead to diabetes (Type II) which is a disorder associated with metabolism and a leading cause of cardiovascular diseases with a prevalence of 10% globally. The American Diabetes Association (ADA) also affirms that 6.2% of Americans have diabetes with one third of the individuals ignorant of the disease. One out of six individuals in America has diabetes.

When the body is unable to metabolise glucose efficiently, the blood glucose level rises and this causes decrease in energy levels, growth and immune response (Ahmed, 2002). As a result, numerous cells, tissues and organs including the kidneys, nerves, eyes, heart and blood vessels are harmed and eventually die. Diabetes leads to loss of life every eight seconds and a

limb every thirty seconds (Zhang Hu, Zhang, Mayo, & Chen, 2015). Any type of diabetes may cause complications in many parts of the body and significantly raise the overall risk of death (Deshpande, Harris-Hayes & Schootman, 2008). It can cause serious diseases, including heart attacks, blindness, kidney failure, amputations, hypoglycaemia and hyperglycaemia (Hippisley-Cox & Coupland, 2016). This indeed is a major health threat. Diabetes complications represent a risk to the economies of all countries, particularly the developing countries, and account for higher morbidity, disability and mortality.

In most developed countries, obesity has been an epidemic and increasing in developing countries. Obesity and overweight are the fifth leading cause of global deaths with an average of three million adults dying each year (WHO, 2012). It is a major risk factor for many diseases, including type II diabetes and cardiovascular disorders. In the 1980s, the prevalence of obesity and overweight in Ghana was as low as 0.9%. However, from 1998 to 2016, the prevalence of obesity and overweight has astronomically risen to almost 43% (Ofori-Asenso, Agyeman, Laar, & Boateng, 2016; Amoah, 2003). According to Ofori-Asenso *et al.* (2016) and Amoah, (2003), the prevalence nationwide of obesity were estimated as 25.4% (95% CI 22.2–28.7%) and 17.1% (95% CI = 14.7–19.5%) respectively and is predominantly found among women than men. In 2008, Ghana was ranked 100th out of 142 countries in the female category of the global prevalence of obesity rankings (International Association for the study of Obesity, 2012). Brown *et al.* (2011) observed that poor nutrition can impact the development of some diseases. Intake of inadequate and excessive nutrients may contribute to the

development of more than one disease and produce diseases by more than one mechanism. Kris-Etherton (2009) however, observed the efficacy of nutrition practices in curing diseases, slowing down the progression of diseases, and markedly decreasing the risk associated with pharmacological therapy. Medical nutrition therapy (MNT) is critical for managing existing diabetes (type I, type II, and gestational diabetes) and limiting the advancement of impaired glucose tolerance and diabetes-related complications (ADA, 2008; Kalergis, De Grandpre, & Andersons, 2005). Proper dietary consumption can avoid the onset of several diseases and can also reduce the severity of current diseases. According to Ferri (2004), there is no official diabetic diet in principle. Theoretically, a diabetic diet is one that balances calories, exercise and medication with blood glucose levels. Thus, a major focus on the nutritional management of diabetes is the improvement of glycaemic control by balancing food intake with endogenous or exogenous insulin levels (Marsh & Brand-Miller, 2008; Sleeth, Psichas, & Frost, 2012).

The astronomic increase in chronic diseases compelled Jenkins *et al.* (1981) to develop and introduce the glycaemic concept as a ranking system for carbohydrate based on the immediate impact on the level of blood glucose. The Glycaemic Index (GI) is a significant food quality parameter that compares the hyperglycaemic impact of a tested meal with pure glucose (or another defined reference food). Aston, Gambell, Lee, Bryant, and Jebb (2008) report that more scientific and popular attention in the role GI foods play in the management of weight and metabolic disease risk has become important. Carbohydrates which rapidly break down during digestion are considered as having high GIs, because their glucose response is fast and high

whereas slowly digested carbohydrates have low GI values (Jenkins, Kendall, Augustin, & Vuksan 2002).

This termnology (GI) has been expanded considering the effects of the overall carbohydrate consumption. Thus, the glycaemic load (GL) a product of glycaemic index (GI) and the quantity of carbohydrate eaten gives a clue to the quantity of glucose accessible for energy or storage after eating a carbohydrate containg meal. Besides the role in treating diabetes, low (GL) and low (GI) diets have been recommended for the prevention of chronic diseases, including obesity, cancers and heart diseases. Again, Low (GL) and low (GI) diets have been recommended for the treatment of cardiovascular risk factors, particularly dyslipidemia (Jenkins, Kandall, Augustin, Franceschi, Hamid, & Marchie, 2002). Concepts of GI and GL are ways of identifying foods that may protect the body from chronic diseases or are necessary for disease management (Mann, 2007). Bornet *et al*. (1987) reported that increased risk of type II diabetes and coronary heart diseases is linked with the long-term intake of relatively high GL diets. Foods that are low in GI are recommended as healthy diets as these may help keep the euglycaemia and spectrum of lipoprotein in people with diabetes, obesity and insulin resistance normal (Brand-Miller, Holt, Pawlak, & McMillan, 2002). These effects lead to reduced risk of cardiovascular diseases, colon and breast cancers.

It is with this background that the investigation of the glycaemic index and load of sweet potatoes – (*Ipomoea batatas*) CSIR-CRI Ligri, pale yellow variety, taro – (*Colocasia esculenta*) and firm ripe plantain -false horn variety (apantu) consumed in Ghana was carried out. This will help serve as a better parameter to help consumers know their postprandial glucose response and its

implications on their health. Like most Ghanaian local foods, the glycaemic index and load of sweet potatoes – (*Ipomoea batatas*) pale yellow variety, taro – (*Colocasia esculenta*) and firm ripe plantain -false horn variety (apantu) have not been reported. Reporting GI and GL of Ghanaian local foods may help the establishment of optimal recommendations in diet for healthy eating. This data will be useful for health professionals when formulating nutritional guidelines and dietary recommendations.

Statement of the Problem

Globally, chronic non-communicable diseases (CNCDs) are rapidly increasing and resulting in early mortality due to changes in lifestyle and diet (Ameraican Diabetes Association, 2013; Salehi, Yousefinejad, & Pishdad, 2012; Salgado, Bombarde, Mansi, Piedade, & Meletti, 2010). About 60% of global mortality is attributable to chronic diseases such as diabetes, cardiovascular diseases, stroke and cancer and this figure is anticipated to rise to 75 % by 2030 (WHO, 2011; WHO, 2018; WHO/FAO, 2003).

According to the International Diabetes Federation, non-communicable diseases (NCDs) disproportionately affect persons living in low and middle-income countries, accounting for more than three quarters (31 million) of global NCD fatalities. Increased death rates from non-communicable diseases (NCDs) have been correlated with unhealthy diets (ADA, 2013). Numerous researches conducted in the area of health and nutrition has demonstrated a link between dietary carbohydrates, cardiovascular disease, and diabetes (Mann, 2007). Barclay *et al.* (2008) discovered that Low GI and low (GL) diets have the potential to protect against the development of chronic diseases such as obesity, diabetes (type II) and coronary heart disease -CHD. The GI

value of a food value cannot be predicted from its composition, appearance, carbohydrate content or even the GI values of similar foods. It can only be verified using the internationally recognised methodology (Sandall, 2010).

Root tubers and plantains are common traditional staples in Ghana. Products from starchy roots and plantain are frequently consumed daily in Ghana. In recent times, some concerns have been raised over the consumption of these staples. Some are of the opinion that these traditional starch-based staples could be harmful to an individual's health if consumed frequently. Proponents of this perspective are of the opinion that the high starch content in the staples can trigger postprandial glucose response.

Again, some individuals, especially diabetic patients, often exclude root tubers and ripe plantain from their diets. They believe such staples increase their blood glucose level. However, knowledge of the concept of glycaemic index and load values for Ghanaian local staples could have prevented this from happening. Due to a paucity of knowledge regarding various African traditional foods' GI and GL values, observational and interventional investigations on them are hampered (Omoregie & Osagie, 2008). Although there is an International Tables of Glycaemic Index and Glycaemic Load Values (Foster-Powell, Holt, & Brand-Miller, 2002), these do not represent meals commonly consumed in Ghana. Very little can be said about the GI and GL of sweet potatoes - (*Impomea batatas*) pale yellow variety, taro - (*Colocasia esculenta*) and firm ripe plantain consumed in Ghana. In addition, very little data on the GI and GL of our local foods are reported. This limits the use to which GI and GL data can be put. A database of the GI and GL of locally consumed foods is thus critical for individuals to

make quick comparison and easy choices from the list of local foods. This is particularly important for diabetic and pre-diabetic individuals. In the absence of data on the blood glucose response of these foods, dieticians and physicians are handicapped in suggesting diets for patients who show symptoms of hyperglycaemia.

There was therefore a need to assess the glycaemic index and load of key "staple" carbohydrate-rich Ghanaian foods, sweet potato – (*Ipomoea batatas*) pale yellow variety, taro (*Colocasia esculenta*) and firm ripe plantain – false horn variety (apantu). Also, the extent to which each of these foods affected the blood glucose level of consumers was presented. This could serve as nutritional guidelines for the general public to make informed food choices, which will eventually help reduce the overwhelming growth of chronic NCDs in Ghana.

Purpose of the Study

The study sought to investigate the glycaemic index and load of three common staple foods in Ghana. They were sweet potatoes - pale yellow variety (*Ipomoea batatas*), taro (*Colocasia esculenta*) and firm ripe plantain - false horn variety (apantu). The proximate analysis of these foods was also identified and compared.

Specific Objectives

Specifically, the study sought to:

i. determine the glycaemic index and load of sweet potatoes, taro and firm ripe plantain.

ii. examine the impact of sweet potatoes, taro and firm ripe plantain on blood glucose levels.

iii. identify and compare the chemical composition of sweet potatoes, taro and firm ripe plantain.

iv. analyse possible health implications of the glycaemic index and load of sweet potatoes, taro and firm ripe plantain.

Hypothesis

The following three (3) hypotheses were tested:

1. H_o: There is no statistically significant difference in the glycaemic indices of sweet potatoes, taro and firm ripe plantain.

   H_1: There is statistically significant difference in the glycaemic indices of sweet potatoes taro and firm ripe plantain.

2. H_o: There is no statistically significant difference in the glycaemic loads of sweet potatoes, taro and firm ripe plantain.

   H_1: There is statistically significant difference in the glycaemic loads of sweet potatoes, taro and firm ripe plantain.

3. H_o. There is no statistically significant difference in the chemical composition of sweet potatoes, taro and firm ripe plantain.

   H_1. There is statistically significant difference in the chemical composition of sweet potatoes, taro and firm ripe plantain.

Research Questions

1. To what extent does 50 g of available carbohydrate of sweet potatoes, taro and firm ripe plantain impact on consumers' blood glucose level?
2. What health implications do glycaemic index and load of sweet potatoes, taro and firm ripe plantain have on consumers?

Significance of the Study

It is anticipated that the findings from this study will guide consumers of the foods studied in terms of consumption levels. It will educate people with special health conditions such as cardiovascular diseases, diabetes and obesity in their choice of food, especially carbohydrate based foods. It may help health practitioners, especially nutritionists, dieticians and diet therapists, to recommend interventive diets for their clients. It may also serve as a tool for counseling their clients. Obtaining the glycaemic indices and loads of these local foods could add onto the list of foods with documented glycaemic index. In addition, it could be a good resource to guide consumers in how they use staple foods in their diets.

Delimitation of the Study

There are many varieties of tuber crops as well as plantains in Ghana but the study specifically considered sweet potatoes (*Ipomoea batatas*) – CSIR-CRI Ligri, pale yellow variety, taro and firm ripe plantain (apantu) - false horn variety.

In addition, although a variety of dishes can be prepared from the staples, for the purpose of this study, the staples were only boiled as 'Ampesi' for the participants to consume as well as for the proximate analysis.

The proximate analysis determined moisture, ash, dry matter, protein, fat, fibre and carbohydrate. There are other reference foods but for this study, glucose was used with glucose purification subjected to visual examination, solubility, and pH tests.

Participants used for the study were limited to only non-diabetic individuals within the normal range of BMI (18.5kg/m^2 – 24.9kg/m^2) and in the age range of 20 – 50 years.

Limitations

Lateness on the part of the health personnel who helped with taking blood samples and determining the glucose level and on the part of one of the participants extended unduly the time for one of the sessions. Fifty three percent of the participants included in the study complained about the number of times they were finger- pricked in a day.

Operational Definition of Terms for the Study

Available carbohydrate: Total carbohydrate content minus the non-glycaemic carbohydrate content.

Blood glucose response: Change in blood glucose concentration over 2 hrs after ingesting test or referenced food.

Carbohydrate portion: Weighed food containing 50 g of available carbohydrate.

Coefficient of variation CV: Positive random variable- standard deviation divided by the mean.

Firm ripe plantain: Matured plantain stored at room temperature to ripe for 6-7 days.

Glycaemic carbohydrate: The amount of carbohydrate absorbed into the bloodstream which is able to increase blood glucose levels.

Glycaemic index (GI): A characteristics of the carbohydrate in different foods. Specifically, the blood glucose-raising ability of digestible carbohydrates in a given food.

Healthy individuals: Males and females within the age range of 20-50 years who are non-diabetic.

Incremental Area Under the Curve (IAUC): Area under the curve is calculated as the incremental area under the blood glucose response curve, ignoring the area beneath the fasting concentration.

In vivo GI testing: Glycaemic index testing carried out by the determination of blood glucose responses in human volunteers**.**

Non-glycaemic carbohydrate: Non-digestible carbohydrate including fibre. Carbohydrate largely escaping digestion in the small intestine and not directly providing carbohydrate for metabolism

Obese: An individual whose BMI is above 25 kg/m^2.

Postprandial: Blood glucose response after eating a meal containing carbohydrate.

Proximate analysis: Determination of moisture, ash, dry matter contents as well as carbohydrate, protein, fibre and fat.

Reference food: Glucose, having by definition a GI of 100.

Test food: Food whose GI value is being determined.

Treatments: Food samples for the clinical trial test (sweet potato, taro and firm ripe plantain)

Young adults: Males and females in the age range of 20-31 years.

Organisation of the Study

The study has been organised into five chapters. Chapter one gives a background to the study, the problem statement with a motivation for the study as well as the purpose of the study and specific objectives. Chapter Two presents a review of carbohydrates, sweet potatoes, taros, plantains, concepts

of glycaemic index and load, the clinical significance of glycaemic index and load, GI/GL and health, and empirical literature on the study food samples.

Chapter three outlines the research design, methods involved in the determination of the glycaemic index and load of test foods, their systematic preparation and analysis of nutrient compositions (Proximate analysis), data collection, processes and management, and analysis. In Chapter four, the results obtained from the study are presented in tables and appropriate graphical representation. Detailed discussions of the results are also made there. The conclusions reached from the study are presented in Chapter five. The necessary recommendations for future research are also indicated there.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews literature relevant to the study. It covers carbohydrate, classification of carbohydrates, total carbohydrate and available carbohydrate, dietary fibre as well as digestion and absorption of carbohydrate. It also presents a review on etiology, nutritional value and health benefits of sweet potatoes, taro and plantain. This chapter also expounds the concept of glycaemic index and load, determination of glycaemic index and load, factors affecting glycaemic index/load, clinical significance of glycaemic index and load, contrasting opinions on the use of glycaemic index and load, and glycaemic index/load and health. Finally, trends on diabetes, hypertension and obesity in Central Region and empirical studies related to this study are reviewed.

Dietary Carbohydrates

Carbohydrates are the world's leading energy food source. Depending on social and cultural considerations or economic position, they provide about 40 to 80% of overall food energy intake. Their most essential nutritional property is their digestibility in the small intestine (Southgate, 1995). The primary source of energy consumed by the human body is carbohydrates (Caffall & Mohnen, 2009; Dutta, 2015). Glucose is the body's primary energy source (Dutta, 2015) whereas glycogen is the excess glucose stored in skeletal muscles and liver (Carol, Gaile, Donna, & Jacqueline, 2013).

Hou and Lowary (2009) hypothesised that when glucose consumption outweighs what is utilised in the body, the excess is converted into fat.

Carbohydrates are polyhydroxy aldehydes, ketones, alcohols and acids, with their simple derivatives and their polymers having linkages of the acetal type. These are the primary source of energy for the body's cells, particularly 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 sugars (glucose).

Carbohydrates play an enormous role in nature and human physiology and their complexity makes their classification also difficult (Mann *et al.*, 2007). While carbohydrate containing foods provide readily available energy for oxidative metabolism, they are also vehicles for important micronutrients and phytochemicals. Carbohydrates are required for glycaemic control and gastrointestinal integrity and function. Carbahydrates possess a plethora of positive physiological properties, such as energy supply; satiety or gastric emptying; blood glucose and insulin metabolism control; glycosylation of proteins; cholesterol and triglyceride metabolism; bile acid dehydroxylation; fermentation (hydrogen or methane production; short-chain fatty acids, colonic epithelial manufacturing control, bowel habit/laxation/motor activity) and effects on large bowel microflora. Cereals, root crops, sugar crops, pulses, vegetables, fruit and milk products are the most important carbohydrate sources in human diet (Adow *et al.*, 1993).

Classification of Dietary Carbohydrates

Classification of dietary carbohydrates requires a systematic approach that incorporates their functional, chemical and physiological properties (Englyst, Liu, & Englyst, 2007). The primary categorisation of dietary

carbohydrates, recommended at the Joint Food and Agriculture Organisation (FAO)/World Health Organisation (WHO) Expert Consultation on carbohydrates in human nutrition convened in Rome in 1997, is by molecular size, as determined by degree of polymerization (DP), character of individual monomers and the type of linkage (α or non-α) (FAO, 1998). This categorisation is comparable to dietary fat, which is based on carbon chain length, number and position of double bonds and the arrangement of the double bonds.

The chemical approach suggested by Cummings and Stephan (2007) is a coherent and enforceable approach to the measurement and labeling of macronutrients which forms the basis of terminology and understanding of the physiological and health effects of carbohydrates. Carbohydrates are chemically classified into three classes, namely sugars (1 to 2 polymers), oligosaccharides (3 to 9 polymers), and polysaccharides (10 or more polymers) (McWilliams, 2009). Numerous techniques exist for determing a food's carbohydrate content. According to Cummings and Stephan (2007), the fundamental issue in grouping carbohydrates chemically is by reconciling the numerous chemical divides with their physiological and health effects. A purely chemical classification does not adequately define the nutritional benefits of carbohydrates, as each of the three classifications listed above has multiple overlapping physiological impacts.

Besides the chemical analyses, terminology based on physiological qualities, such as a glycaemic response, reflects on the possible health consequences of these macronutrients and helps select foods within the group that are more likely to be included in a well-balanced diet. The concept of

glycaemic index (GI) is based on the distinction whether or not the carbohydrate source does or does not directly supply carbohydrates as an energy source into the blood stream following digestion and absorption in the small intestine (Cummings & Stephan, 2007). Carbohydrate's physiological and health benefits depend not only on its primary chemical form, but also on the physical properties, including water solubility, gel forming, crystallisation status, relation to other molecules and its aggregation into a complex structure of plant cell walls (Cummings & Stephan, 2007). In classifying carbohydrate-rich foods, the GI mechanism integrates all these factors when basing glycaemic release of energy into the body. Table 1 gives a summary of the classification of carbohydrate.

Table 1: Classification of Carbohydrate

CLASS (DP)	SUB GROUP	PRINCIPAL COMPONENTS
Sugars (1-2)	Monosaccharaides	Glucose, galactose, fructose
	Disaccharides	Sucrose, lactose, Maltose, Trehalose
	Polyols	Sorbitol, mannitol
Oligosaccharides (3-9)	Malto-oligosaccharides	Maltodextrins
	Other oligosaccharides	Raffinose, stachyose, fructo-oligosaccharides
Polysaccharides (>9)	Starch	Amylose, amylopectin, modified starches
	Non-starch polysaccharides	Cellulose, hemicellulose, pectins, hydrocolloids

Source: McWilliams, (2009); Based on Food and Agriculture Organisation/World Health Organisation 'Carbohydrates in Human Nutrition' report (1998), and Cummings *et al.*, (1997).

The monosaccharide structure of human carbohydrates can be classified into one of these three classes. Sugars include monosaccharides, disaccharides and polyols (sugar alcohols); oligosaccharides including malto-oligosaccharides (primarily those induced by hydrolysis of starch), and other

oligosaccharides (raffinose, stachyose and fructo-oligosaccharides). The final group is the polysaccharides classified into the polysaccharides of starch (glucans) and non-starch polysaccharides mostly cellulose, hemicellulose, and pectin.

Total Carbohydrate

Total carbohydrate is defined by the FAO/WHO based on two major premises: 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, 1998). For many years, total carbohydrates have been calculated by difference rather than direct measurement. Using this approach, other nutritional components (protein, fat, water, alcohol and ash) are analysed separately, summed and subtracted from the total weight of the food. This is referred to as total carbohydrate by difference. It is calculatd by the formula 100 – (weight in grammes [protein + fat + water + ash + alcohol] in 100 g food). Carbohydrate estimated in this fashion includes fibre, as well as some components that are not strictly speaking carbohydrate (e.g. organic acids). Total carbohydrate can also be calculated from the sum of the weights of individual carbohydrates and fibre after each has been directly analysed: weight in grammes - (mono + disaccharides + oligsaccharides + polysaccharides, including fibre).

Available and Unavailable Carbohydrate

In 1929, McCance and Lawrence established the distinction between available and unavailable dietary carbohydrates as a critical phase in defining carbohydrates. They discovered that not all carbohydrates could be "useful and metabolised" (i.e. provide the body with "carbohydrates for metabolism"), in

attempt to prepare food tables for diabetic diets. Available carbohydrate has been defined as 'starch and soluble sugars' and unavailable carbohydrates as 'hemicellulose and fibre (cellulose). Available carbohydrate can be determined by adding the amount of available sugar, starch, oligosaccharides and maltodextrins (Barclay, Brand-Miller, & Wolever, 2005).

This concept proved useful because it drew attention to the fact that some carbohydrates are not digested and absorbed in the small intestine but rather reach the large bowel where they are fermented. An FAO technical workshop in Rome in 2002 on 'Food energy – methods of analysis and conversion factors' defined available carbohydrate as 'that portion of carbohydrate that can be digested by human enzymes, is absorbed and enters into intermediary metabolism' (FAO, 2003). Dietary fibre is excluded because it does not become an energy source until fermentation has occurred. It suggests that the site of digestion or fermentation of carbohydrate (in the gut) is of overriding importance. However, the phrase "unavailable carbohydrate" is misleading because some indigestible carbohydrates can be fermented to provide energy to the body. Carbohydrates possess a range of properties, among which are digestibility and fermentability. A more realistic substitute for the terms "available" and "unavailable" would be to describe carbohydrates as either glycaemic (i.e. providing carbohydrate for metabolism) or non-glycaemic, which is closer to the original concept of (McCance & Lawrence, 1929). They are frequently classified as available and unavailable carbohydrates based on their physiological or nutritional function. Available carbohydrates are those that are hydrolysed by enzymes of the human gastrointestinal system to monosaccharides that are absorbed in the small

intestine and enter the pathways of carbohydrate metabolism. Unavailable carbohydrates are not hydrolysed by human enzymes, although they may be fermented in the large intestine to varying extents. To calculate available carbohydrate by difference, the amount of dietary fibre is analysed and subtracted from total carbohydrate, thus:

100 - (Weight grammes [protein and fat + water and ash + alcohol + food fibre] per 100 grammes of food). This yields the estimated weight of available carbohydrate, but gives no indication of the composition of the various saccharides comprising available carbohydrate. Alternatively, available carbohydrate can be derived by summing the analysed weights of individual available carbohydrates. When reporting the number of available carbohydrates, either the weight or the equivalent monosaccharides might be used.

Dietary Fibre

Dietary fibre is a physiological and nutritional solution for foods not digested in the small intestine which contain carbohydrates. The American Association of Cereal Chemist, AAAC (2010) described dietary fibre as carbohydrate polymers with a polymerization in excess of three degree which is neither digested nor absorbed into the small intestine. In addition, the British Nutrition Foundation (2015) defined dietary fibre as a group of substances in plant foods that cannot be fully broken down by the human digestive enzymes. This includes waxes, lignin and polysaccharides such as cellulose and pectin.

According to the American Association of Cereal Chemists (2010) as described by James and Mark (2010), dietary fibre is subdivided into 3 constituents: non-starch polysaccharides (NSP) and oligosaccharides (celletic

cellulose, hemicellulose, inculin, pectin, gums, mucilages, polufructoses, arabinogalactans and other), analogous carbohydrates (indigestible dextrins, polydextrose), and lignin substances associated with NSP and lignin complex (waxes, phytate, cutin, saponin, tannins, and suberins). Dietary fibre has an important role in maintaining human health. It affects glucose absorption and lowers blood cholesterol.

Research has shown that certain plant fibres retard carbohydrate absorption and contribute to less postprandial hyperglycaemia. Increased fibre in the diet is linked to decreased resistance to insulin. For example fibre from whole grains, legumes and vegetables is beneficial for diabetics (Sardesai, 2003). Dietary fibre aids in the prevention of a variety of ailments, notably those affecting the digestive tract (Eckel, 2003). Root tubers such as sweet potatoes are high in dietry fibre. The dietary fibre reduces glycaemic response because it is slowly digested. Dietary fibres coinciding with resistant starch enter the colon and are fermented by anaerobic bacteria. These polysaccharides are then broken down into simple saccharides by several reactions yielding lactic acid, gases such as carbon dioxide, hydrogen and methane and short chain fatty acids (acetic, propionate, and butyric acids). The short-chain fatty acids supply significant direct energy to the intestinal mucosa; they are also absorbed and enter into intermediary metabolism (Cummings & Macfarlane, 1991).

Carbohydrate Digestion in the Human Body

Waasdorp Hurtado (n.d.), defined digestion as the physical and chemical break down of food into small organic molecules. Macronutrients such as starches, sugars, fats and proteins are the main energy carrying

components in the human diet. These components must be synthesized into smaller molecules in the human Gastrointestinal Tract (GIT) before they can be absorbed and further metabolised in the rest of the human body (Bender, 1997). According to Waasdorp Hurtado (n.d.), the aim of carbohydrate digestion is to break down all disaccharides and complex carbohydrates into monosaccharides for absorption, although not all are completely absorbed in the small intestine e.g., fibre.

Specific roles are played by different organs in the digestive process. The main regions in GIT are the mouth, stomach, small intestine, large intestine and rectum.

In the mouth

Carbohydrate digestion begins in the mouth. The main functions of the mouth, in terms of digestion and absorption of carbohydrates, are chewing to increase the surface area of the molecules, and the initiation of starch hydrolysis catalysed by amylase enzymes in saliva. The salivary amylase secreted by salivary glands begins the breakdown of food starches into a disaccharide called maltose. Amylase is sensitive to pH. No significant digestion of carbohydrates takes place as bolus of food travels through the esophagus to the stomach since it does not secrete any digestive enzyme. The esophagus thus produces mucous for lubrication.

In the stomach

The enzyme pepsin secreted by the gastric glands in the stomach hydrolyses proteins. According to Bender (1997), the pH in the stomach is acidic, this condition denatures the proteins, increases the surface area which

proteolitic enzymes can hydrolyse as well as denaturing the amylase enzymes which are introduced in the mouth and rendering them inactive.

In the pancreas and small intestine

The chyme from the stomach enters the duodenum and mixes with the digestive secretion from the pancreas, liver, and gallbladder. Pancreatic juices also contain amylase, which continues the breakdown of starch and glycogen into maltose, a disaccharide. The enzymes maltase, sucrases, and lactases which are also present in the brush border of the small intestinal wall break down disaccharides into two monosaccharides during the process of digestion. According to Amy, Davidson, Sean, Laghaeian, and Daynene (1996); Fox, Cummins, and Cummins (2002) when maltose is hydrolysed, it yields two molecules of glucose. Maltase breaks down maltose into glucose. Other disaccharides, such as lactose and sucrose are broken down by the enzymes lactase and sucrase, respectively. Lactase breaks down lactose (or "milk sugar") into glucose and galactose and sucrase breaks down sucrose (or "table sugar") into glucose and fructose. The monosaccharides (glucose) thus produced are absorbed and then can be used in metabolic pathways to harness energy. The most important carbohydrate in human biochemistry is glucose because nearly all carbohydrate in food is converted to glucose for metabolism (Mayes & Bender, 2000). The monosaccharides are transported across the intestinal epithelium into the bloodstream to be transported to the different cells in the body. As a result of the lack of cellulase enzyme, humans cannot break down cellulose (Brown, Malcom, & Inder, 2007). Generally, foods that are broken down easily during digestion will immediately increase the blood glucose levels. Quick rise of blood glucose levels pushes the pancreas to

produce and release more insulin. As a consequence, high blood glucose levels will increase the insulin response (Ostman, Elmstahl, & Bjorck, 2001). The type of carbohydrates that strongly influence blood glucose concentrations and other metabolic parameters more are those rapidly absorbed from the small intestine.

In the large intestine (colon)

Dietary fibre reaches the colon undigested and where they undergo bacterial degradation. The presence of dietary fibre in legumes, vegetables, and fruit, as well as in whole-meal cereals, acts on intermediate metabolism by slowing the absorption rate of glucose and fat from the small intestine. Short-chain fatty acids that can contribute to the modulation of glucose and lipid metabolism in the liver are produced when dietary fibre ferments in the gut (Giacco *et al.*, 1998). The undigested gut contents are stored in the rectum prior to ejection as faeces (Bender, 1997).

The steps in carbohydrate digestion are summarized in Figure 1, 2, and Table 2

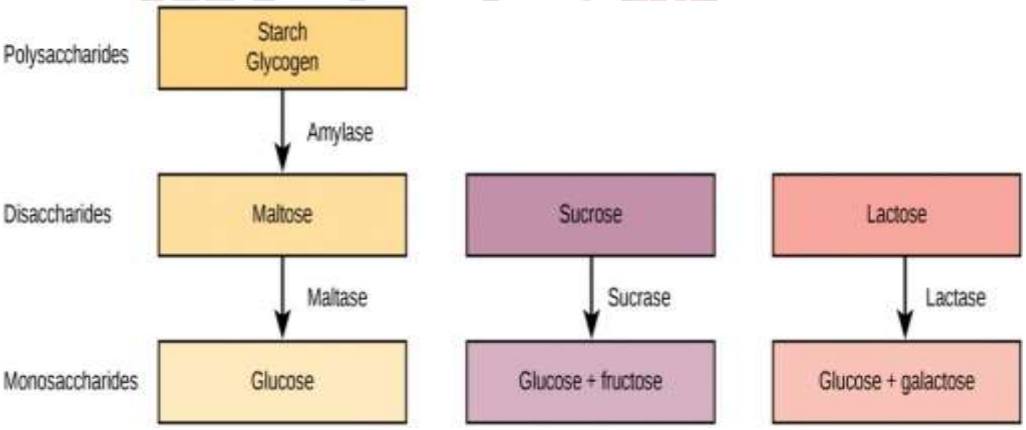

Figure 1: Digestion of carbohydrates.
Source: Molnar and Gair (2015)

Several enzymes help in the digestion of carbohydrates. Amylase and maltase break down starch and glycogen into glucose. Sucrose (table sugar) and lactose (milk sugar) are broken down by sucrase and lactase respectively.

Table 2: Digestion of Carbohydrates

Enzyme	Tissue/Organ	Action Site	Substrate	End Products
Salivary amylase	Salivary glands	Mouth	Polysaccharides (Starch)	Disaccharides (maltose), oligosaccharides
Pancreatic amylase	Pancreas	Small intestine	Polysaccharides (starch)	Disaccharides (maltose), monosaccharides
Oligosaccharidases	Lining of the intestine; brush border membrane	Small intestine	Disaccharides	Monosaccharides (e.g., glucose, fructose, galactose)

Source: Molnar and Gair (2015)

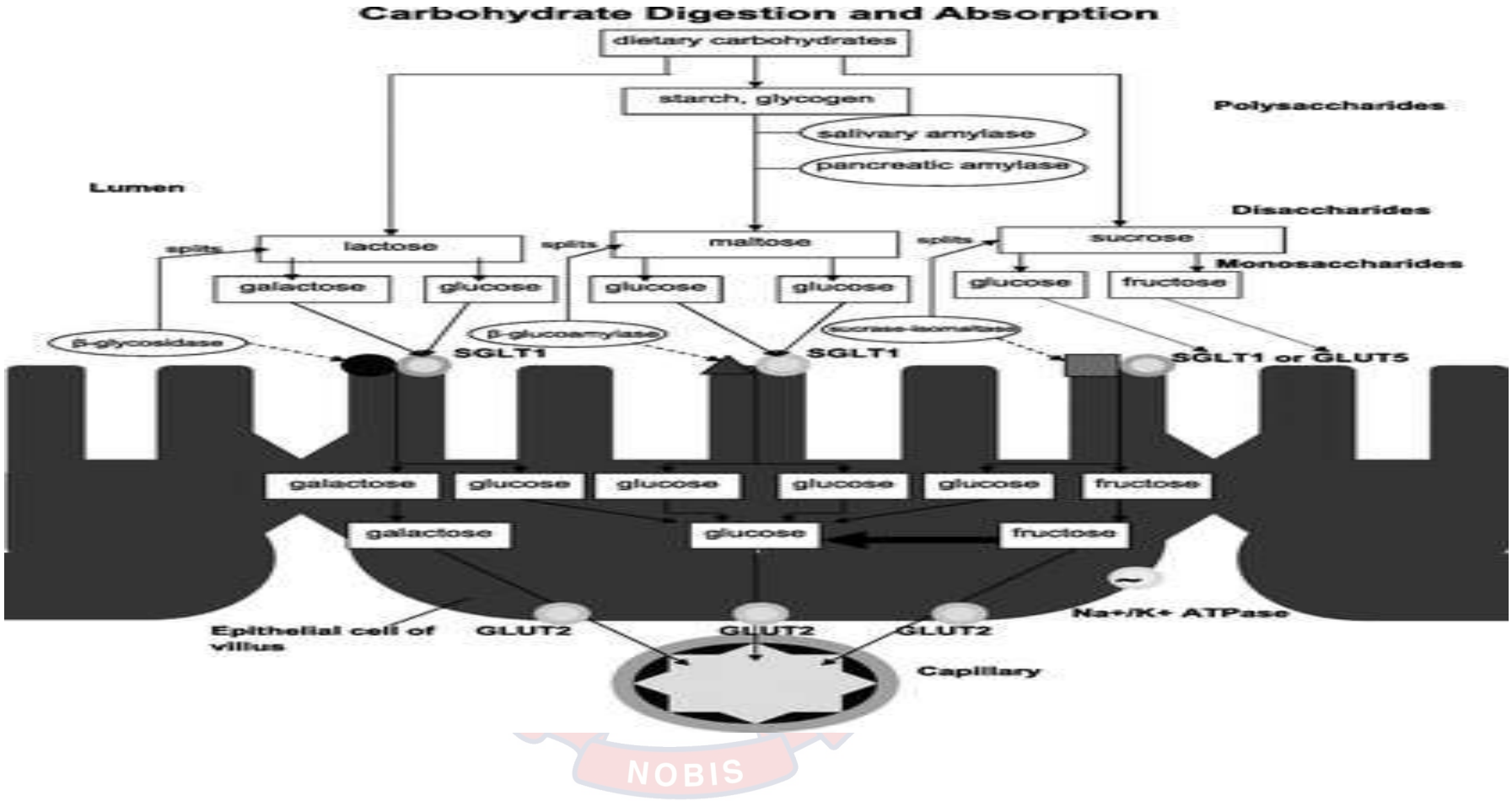

Figure 2: Steps involved in the digestion and absorption of carbohydrates.

Source: Adapted from Goodman 2010

Absorption of Carbohydrates

The carbohydrate digestion is completed in the small intestine and by the time food bolus reaches the end of the small intestine, all the complex carbohydrates would have been converted into simpler monosaccharides. These monosaccharides are almost completely absorbed from the small intestine (Farrell, Feldman, Friedman, & Brandt, 2010).

Some Carbohydrate Staples in Ghana

Sweet potatoes

Sweet potato is a creeping plant and probably the only economically important species of the family Convolvulaceae. As the leaves are a useful source of vegetable greens in some countries, the starchy, tuberous roots also serve as a major source of food. Sweet potato originated from Central America, but today, it is widely cultivated in many tropical and subtropical countries in different ecological regions. In 2013, sweet potato (*Ipomoea batatas* L. Lam) was ranked as the 7th most important crop in the world with a total production of 103 million tonnes (FAOSTAT, 2015). Asia accounts for close to 76% of world's production, followed by Africa (19.5%). According to FAOSTAT (2015), China, Nigeria, Uganda, Indonesia, and the United Republic of Tanzania are the top five producers. China is the highest producer with production figures of approximately 75.6 million tonnes, followed by Tanzania and Nigeria that produced up to 3.57 and 2.73 million tonnes, respectively. Sweet potato is among five most important crops in 40 developing countries beside rice, wheat, maize, and cassava (Elameen, Fjellheim, & Larsen, 2008). Sweet potato has gained popularity over the last two decades, due to its capacity to thrive in different agro ecologies and water

stress soils and short growth cycle (Markos & Loha, 2016; Chagonda, Mapfeka, & Chitata, 2014). As a result of its unique qualities and nutritional benefits, the National Aeronautics and Space Administration (NASA) selected it as an essential crop to be cultivated and included into the menus for astronauts on space missions (Bovell-Benjamin, 2007). Sweet potato is critical for improving food security, health and livelihoods of poor small holder families in sub-Saharan Africa. It is the 3rd most important root and tuber crop after cassava and yam. It is estimated to be cultivated on about 13.37 million hectares of land in sub-Saharan Africa (FAO STAT, 2012).

In Ghana, sweet potato is the 4th most important root crop after cassava (*Manihot esculenta Crantz*), yam (*Dioscorea spp*.) and taro (*Colocasia spp*.). Additionally, Ghana recorded sweet potato production of 135,000 tonnes in 2013 and that was the highest output recorded in the last fifteen years (FAOSTAT, 2015). It is rapidly becoming a critical crop in Ghana's economy, both for food security and as a source of revenue for many actors in the commodity value chain. The crop is widely cultivated by small holder farmers in the Upper West, Central, Northern, Upper East and Volta Regions (Bidzakin, Acheremu, & Carey, 2014; Food and Agriculture Organisation [FAO], 2012). Annual production is estimated at 0.132 million tonnes produced on approximately 9,622ha of arable land **(**SRID, 2013 cited in Sugri, Maalekuu, Gaveh, & Kusi, 2017**)**. In 2014, Ministry of Food and Agriculture reported an increased production on approximately 9,633ha of arable land (Ministry of Food and Agriculture [MoFA], 2014). Low yields of around 8t/ha compared to the yield potential of 24t/ha are recorded. The vast majority were low yielding white-fleshed varieties which have low or no beta carotene.

However, according to Sugri *et al.* (2017), the Root and Tuber Improvement and Marketing Programme (RTIMP) and other partners have made tremendous strides in introducing orange flesh sweet potatoes and other high yielding varieties particularly those that are resistant to the sweet potato viral diseases. There are many vaieties of sweet potatoes each with its own storage life, nutritional content, size, shape, colour and suitability for processing. Onwueme (1978) reported that, a single plant may produce 40 to 50 tubers ranging in length from a few to 30 cm; they may be spindle-shaped or spherical and weigh from 100 g to 1 kg. It may have smooth or irregular surfaces and the skin and flesh may range from almost pure white through cream, yellow, red, brown, orange and pink, to a very deep purple. Phenolic acids and anthocyanins also contribute to the colour of the flesh.

Some improved varieties of sweet potatoes in Ghana are presented in Table 3.

Table 3: Description of some improved varieties of sweet potato in Ghana

Name of variety	Year of release	Original name	Origin	Skin colour	Flesh colour	Dry matter content (%)
CSIR-CRI Ligri	2012	Cemsa74-228	CIP-Kenya	Cream	Pale Yellow	35
Santom Pona	1998	TIS88/0320	IITA	Copper	Yellow	32
Faara	1998	TIS3017	IITA	Dark purple	Pale yellow	34
Okumkom	1998	TIS8277	IITA	Pink	Cream	30
Tech-Santom	2003	TIB2	IITA	Yellow	Light yellow	31
CSIR-CRI Hi starch	2005	Hi-starch	Japan	Brown	Cream	40
CSIR-CRI Ogyefo	2005	Mugande	Rwanda via CIP	Red	White	34
CSIR-CRI Otoo	2005	Mogamba	Burundi via CIP	Cream	Light orange	33
CSIR-CRI Apumuden	2005	Kamala	Bangladesh via CIP	Copper	Orange	22
CSIR-CRI Patron	2012	Mohc	Burundi via CIP	Dark yellow	Dark Yellow	34
CSIR-CRI Bohye	2012	199062.1	CIP-Peru	Purple	Pale Orange	31
Sauti	1998	Tanzania	Malawi	Cream	Dark yellow	35
CSIR-CRI Dadanyuie	2012	Kemb 37	CIP-Kenya	Dark purple	White	35

Source: Adapted from Sugri, Maalekuu, Gaveh, and Kusi (2017)

CSIR-Council for Scientific and Industrial Research

CRI-Crop Research Institute

IITA-International Institute for Tropical Agriculture

CIP-International Sweet potato Centre

The utilisation of sweet potatoes in meal preparation and industry are presented in Table 4.

Table 4: Uses of sweet potatoes

Edible part	Use
Root	1. Can be fried as chips and French fries, boiled, roasted or baked for consumption. 2. Can be used for weaning babies and complementary feed. 3. Can be dehydrated into chips and flour for flour products such as cakes, biscuits and bread. 4. Can be processed industrially into alcohol, starch, glue or bioenergy.
Leaves	5. The green leaves can be used for different vegetable dishes or as salad.

Source: Adapted from Sugri, Maalekuu, Gaveh, and Kusi (2017)

Nutritional value of sweet potatoes

Table 5 gives a clearer picture of the nutritional composition of sweet potatoes as reported by USDA National Nutrient Database for Standard Reference.

Table 5: Nutritional Composition of Sweet Potatoes (Uncooked) per 100 g

Principle Nutrient	Value	Percentage of RDA
Energy	86kcal	4
Protein	1.57g	3
Fat	0.05g	< 0.5
Carbohydrate	20.12g	15.5
Fibre	3.0g	8
Sugar	4.18g	
Vitamins		
Folates	11 µg	3
Niacin	0.557mg	3.5
Pantothenic	0.80mg	16
Pyridoxine	0.209mg	15
Riboflavin	0.061mg	5.5
Thiamin	0.078mg	6.5
Vitamin A	14,187 UI	473
Vitamin C	2.4mg	4
Vitamin E	0.26mg	2
Vitamin k	1.8 µg	1.5
Electrolytes		
Potassium	337mg	7
Sodium	55mg	3.5
Minerals		
Calcium	30mg	3
Iron	0.61mg	7.5
Magnesium	25mg	6
Manganese	0.258mg	11
Phosphorus	47mg	7
Zinc	0.30mg	3

Source: USDA National Nutrient Database for Standard Reference, 2011
* USDA does not specify the sweet potato variety that was analysed.

Figure 3: A picture showing sweet potatoes (CSIR-CRI Ligri).
Source: Field data, Bartels (2020)

Health benefits of sweet potatoes

Antioxidant Activity

Oxidative stress contributes to the development of different cancers, cardiovascular disease, arthritis, diabetes, autoimmune and neurodegenerative disorders, and aging. Though internal antioxidant defense systems, either enzymes (superoxide dismutase, catalase, and glutathione peroxidase) or other compounds (lipoic acid, uric acid, ascorbic acid, α-tocopherol, and glutathione), are available in the body, external sources of antioxidants are needed, as internal defense system may get overwhelmed by excessive exposure to oxidative stress. The antioxidant activities of roots and tuber crops have reported in a number of studies. The plant's antioxidant activity is associated with its alpha-tocopherol content, which is the most common form of vitamin E, and comprises 25 mg per 100 g of sweet potato shoots. The two storage proteins, sporamins A and B, account for more than 80% of the total proteins isolated from the roots of sweet potato (De Feo, Di Loreto, &

Ranchelli, 2006). The peels of sweet potato have been reported to possess a potent wound healing effect, which appears to be related to the free radical scavenging activity of the phytoconstituents and their ability in lipid oxidation inhibition (Chimkode & Patil, 2009; Panda, & Sonkamble, 2011). The healing effect of sweet potato fibre for burns or decubital wounds in a rat model was demonstrated and the reduction in size and changes in the quality of the wounds were reported (Suzuki, Tada, Sato, & Sagae, 1999). Also, petroleum ether extract of sweet potato had shown significant closure of scar area for complete epithelialization compared to the control (Chimkode & Patil, 2009).

Antiulcerative Activities

Velloso, Baeza, and Tornero (2004) have conducted pharmacological investigations on sweet potato's antidiabetic, antihypertensive, anti-inflammatory, antibacterial, and antioxidant properties. American Indians utilised sweet potatoes to alleviate diabetes-related weight loss and quench thirst (Barnard, Cohen, & Jenkins, 2006; De Feo *et al.* 2006). The root and skin contain the majority of the studied therapeutic components. According to Dutta (2015), sweet potatoes are prefered for diabetics as they are high in fibre and have a low glycaemic index blood.

Taro

According to Chaïr, Traore, Duval, Rivallana, and Mukherjee (2016) and Hancock (2004), taro (*Colocasia esculenta* (L) Schott), is an ancient and erect herbaceous perennial root crop widely cultivated in tropical and subtropical regions of the world, particularly in the Pacific and Caribbean islands and in West Africa. Taro belongs to genus *Colocasia* in the plant family called *Araceae* (Macharia, Nuro, Muchugi, & Palapala, 2014).

Taro (*Colocasia esculenta (L) Schott*) is the 14th most consumed crop worldwide and comprises the diet of 300 million people (Bown, 2000). Cultivated across Africa, taro occupies 9th position among world food crops and it is propagated vegetatively. Taro roots are important energy food source and are used as staple foods in tropical and subtropical countries. It is largely produced for its underground corms which contain 70–80% starch. Taro is cultivated to fill seasonal food gaps when other crops were still in the fields. This is because of its potential in giving higher yields under conditions where other crops may be unable to give produce by various crop production constraints (Tewodros, Getachew, & Kifle, 2013).

The term taro should not be interchanged with its related aroid *Xanthosoma spp*. which is called tannia. According to Aregheore and Perera (2003), the species are cultivated mainly for their edible fleshy roots called corms or cormels, while the leaves are consumed as green vegetables. It has a brown outer skin and white flesh with purple specks throughout. It has a mildly sweet taste and a texture similar to potato when cooked.

It is locally refered to as “brobey”. Taro leaves and root are harmful if consumed fresh so they must be destroyed first through cooking. Taro deteriorates rapidly as a result of its high moisture content and has been estimated to have a shelf-life of up to one month if undamaged and stored in a shady area (Lebot, 2009). In some parts of the world taro is made into drinks and ice cream. Figure 4 depicts the picture of taro roots.

Figure 4: A picture showing roots of taro**.**
Source: Field data, Bartels (2020)

Nutritional value of taro

Taro is rich in micronutrients and easily digestible carbohydrates and contains anti-nutrient factors such as: oxalate, phytate and tannin. Foods prepared from taro are helpful to persons allergic to cereals and can be consumed by children/infants who are sensitive to milk (Vinning, 2003).

According to Wang (1983), taro is known to be a good source of carbohydrate, fibre, minerals particularly potassium and vitamins (especially B-complex) than that found in whole milk. It is rather low in vitamin C and carotene with the amount of carotene being the same as that found in cabbage and twice found in potato. Taro has a small starch grain about a tenth of that of potato (1-6.5 micrometers) making it easily digestible. The corm of taro contains more than twice the carbohydrate content of potatoes and yield 135 k cals per 100 g and 11% crude protein on a dry matter (DM) basis. These reported carbohydrate and protein values are even higher than other root crops like yam, cassava or sweet potato (FAO, 1999). Though, fat and protein

content of taro are low, it is high in carbohydrates, fibre and minerals (Del Rosario & Lorenz, 1999). It contains 85-87% starch on a dry matter basis with small granule size of 3-18 μm and other nutrients such as zinc, vitamin C, thiamine, riboflavin and niacin are higher than other root crops (Jirarart, Sukruedee, & Persuade, 2006). Taro starch is also good for peptic ulcer patients, patients with pancreatic disease, chronic liver problems and inflammatory bowel disease and gall bladder disease (Emmanuel-Ikpeme, Eneji, & Essiet, 2007). The most important sugar in taro is sucrose, but fructose, maltose, glucose and raffinose are also present. Malic acid is the most important organic acid (60%) followed by citric acid (25%) and oxalic acid (15%) (Del Rosario & Lorenz, 1999). The roots (corms) are good sources of energy (Lewu *et al.*, 2010) with easily digestible starch grain (Lee, 1999; Oke, Redhead, & Hussain, 1990). The starch has low amylose with A- type crystalline structure while, the leaves are excellent sources of protein, dietary fibre, vitamin and minerals (Lewu *et al.*, 2009a, b). The high protein content of the leaves favourably complements the high carbohydrate content of the cormels. Taro is one of the few major staples with both the leaf and underground part contributing significantly to human diet (Lee, 1999). The nutritional composition per 100 g as reported by USDA National Nutrient data base is presented in Table 6.

Table 6: Nutritional Composition of Taro per 100 g

Principle Nutrient	Value	Percentage of RDA
Energy	112 kcal	6
Carbohydrate	26.46g	20
Protein	1.5g	3
Total fat	0.20g	<1
Cholesterol	0mg	0
Dietary fibres	4.1g	11
Sugar	0.4g	
Vitamins		
Folates	22 µg	5.5
Niacin	0.600mg	4
Pantothenic acid	0.303 mg	6
Pyridoxine	0.238 mg	23
Riboflavin	0.025 mg	2
Thiamin	0.095 mg	8
Vitamin A	76 IU	2.5
Vitamin C	4.5 mg	7
Vitamin E	2.38 mg	20
Vitamin K	1 µg	1
Electrolytes		
Sodium	11 mg	<1
Potassium	591 mg	12.5
Minerals		
Calcium	43 mg	4
Copper	0.172 mg	19
Iron	0.55 mg	7
Magnesium	33mg	8
Mangenese	0.383 mg	1.5
Zinc	0.23 mg	2
Selenium	0.7 µg	1

Source: USDA National Nutrient data base.

Miller (1971) discovered that babies who were fed poi — a sort of taro-based baby food— had a lower incidence of diarrhoea, pneumonia, enteritis and beriberi than babies fed with rice and bread. The nutritive value of poi as being hypoallergenic, rich in calcium, magnesium, B vitamins, potassium, phosphorus, vitamin A and C, high in fibre and serves as a slow release energy food source. Apart from its culinary uses, taro can be used as an additive to render plastics biodegradable (Linden, 1996).

Health benefits of taro

Phytochemicals

Taro root contains various antioxidants, cryptoxanthin and beta-carotene. These antioxidants can help improve vision, by preventing free radicals from attacking ocular cells and causing macular degeneration or cataracts. Root and tuber phytochemicals have demonstrated anticancer effects in several types of carcinoma cell lines and animal models (Huan, Lin, Chen, & Lin, 2004). Taro root contains polyphenols and antioxidants that may combat cancer growth and protect the body from oxidative stress. The primary polyphenol found in taro root is quercetin. Test-tube and animal studies have found that quercetin can trigger cancer cell death and slow the growth of several types of cancers (Nishiyama, 1984). One test-tube study found that taro extract was able to stop the spread of some types of breast and prostate cancer cells, but no human research has been conducted (Onwueme & Johnston, 1998).

Skin Health

The allure of taro root is that it is nature's best-kept secret for skin health. It contains vitamins A and E and has a great impact on the skin. These vitamins boost the formation of new and healthy skin cells, and improves the life of degenerating skin cells. Regular intake of taro root is reported to reduce the appearance of blemishes and wrinkles on the skin (Staughton, 2019).

Immune Booster

An important role of taro root for health is its ability to boost the immune system. According to Staughton (2019), it has a very high level of vitamin C in each serving, which stimulates the immune system to create

white blood cells, which defend the body from microorganismsand infections. This is in sharp contrast with Wang's (1983) observation regarding the vitamin C content of taro. Furthermore, Staughton (2019) reported that, the vitamin C content acts as an antioxidant, which partially inhibits the development of serious health conditions.

Phenolic acids

Taro roots contain anthocyanins, cyanidin 3-glucoside and are rich in starch. The anthocyanin concentration enhances vision by increasing blood circulation and decreasing capillary fragility. Additionally, anthocyanins operate as potent antioxidants, anti-inflammatory agents, and inhibitors of cancer cell growth in humans (Wagner, 1985). According to Del Rosario and Lorenz (1999), flour from taro corms, dried and milled contains easily digestible starch and thus utilised for infants' food preparation.

Blood Glucose Control

Fibre and resistant starch in taro are the two types of carbohydrates that are beneficial for blood glucose control. The combination of resistant starch and fibre makes taro root a good carbohydrate option especially for diabetics (Gunua & Kokoa, 1995). Roughly 12% of the starch in cooked taro root is resistant starch, making it one of the better sources of this nutrient. Taro root is a fibre-rich food. Dietary fibre has the potential to maintain the blood sugar level by controlling the insulin production in the body. Hence, Dimyati (1994) recommends that individuals suffering from type II diabetes should regularly consume it. Studies have found that high-fibre diets—containing up to 42 g per day—can reduce blood glucose levels by roughly 10 mg/dl in people with type II diabetes (FAO, 1997).

Oxalic Acid / Oxalates

Oxalates are a significant inhibitor of taro utilisation. When raw or uncooked taro roots are consumed, the existence of oxalates imparts an acrid taste or induces irritation. This acridity is induced by threadlike calcium oxalate crystals, raphides that can penetrate soft skin (Bradbury & Nixon, 1998). High oxalate concentrations in the taro leaves and corms consumed daily are of concern because of the negative health effects associated with its excessive consumption (Savage & Catherwood, 2007). Large quantities of oxalic acid are poisonous to humans and can also reduce the nutritional value of a food by binding with calcium to form calcium oxalate. As a result, prolonged boiling of the roots is recommended.

Weight Reduction

Research has established that people who eat more fibre tend to have lower body weight and less body fat (Onwueme, 1994). As a result of its high fibre and resistant starch content, taro root may increase feelings of fullness or satiety, reduce overall calorie intake and increase fat burning, potentially leading to weight loss and reduced body fat. One study found that men who took a supplement containing 24 g of resistant starch before meals consumed roughly 6% fewer calories and had lower insulin levels after the meal, compared to the control group (Pancho, 1984).

Protection of the Gut

According to Rochani (1994), gut bacteria ferment the fibre and resistant starch in taro root to produce short-chain fatty acids, protecting persons against colon cancer and inflammatory bowel disease. When taro roots reach the colon, they become food for the microbes in the gut and

promote the growth of good bacteria which ferment these fibres, create short-chain fatty acids that nourish the cells that line the intestines and keep them healthy and strong. Interestingly, patients with inflammatory bowel diseases, such as ulcerative colitis, have decreased short-chain fatty acid levels in their guts (Ratananuku, 1992).

Blood Circulation Improvement

The presence of iron and copper in taro root improve individual's blood's health markedly. Iron helps to prevent anaemia, and promotes blood circulation. Further, the root helps to fight the consequences of anaemia like fatigue, headaches and lack of concentration (Staughton, 2019).

Fatigue Reduction

Taro root is beneficial to the athletes in keeping their energy level high for a longer time. It also has the right amount of carbohydrate that boosts energy and reduces fatigue (Firdous, 2020).

Ageing Delay

Taro root is one food rich in antioxidants which helps in slowing down the ageing process of the cells. It plays a role in revitalising the old and damaged cells, which keeps the body youthful for a longer duration (Firdous, 2020). This root is also cholesterol-free, gluten free, low in sodium and contains protein.

Plantain

Plantain (*Musa paradisiaca*) is a large perennial herbaceous plant, which belongs to the musacace family and is an important staple food. Plantain is a significant carbohydrate source in diets of people from Latin America, through most of Africa and countries of South-east Asia (Marriott &

Lancaster, 1983). Many authors have indicated that plantains provide more than 25% of the carbohydrate and 10% of the calorie intake for approximately 70 million people in the sub-Sahara African region (Kayode, *et al.*, 2013; Adejoro, Odubanjo, & Fagbola, 2010; and Oritz & Vuylsteke, 1996). Plantian has been identified to be of great socio-economic and nutritional significance in developing countries (Dzomeku, Dankyi, & Darkey, 2011). Plantain provides an important source of rural income in addition to being a staple food for rural and urban consumers. The crop is mainly produced by families in compound or home gardens as well as in large fields (Ortiz & Vuylsteke, 1994; Swennen, 1990).

The plant is intercropped with certain cash crops such as cocoa trees, and many food crops such as root tubers and legumes. Ghana is the largest producer of plantain in West Africa and the third in Africa after Uganda and Rwanda (FAO, 2010). Plantain provides approximately 13.1% to Ghana's agricultural GDP, ranking third behind yam and cassava (FAO, 2010). According to Lescot (2000), its per capita annual consumption is higher than maize and yam. Estimated annual consumption in Ghana is 85 kg per capita (MOFA-SRID, 2011). A total of 359,865 ha of land area in Ghana is used to cultivate plantain producing an annual average of 3.7 million tonnes of fruits, of which more than 95% is sold on the domestic market and only 0.5 tonnes is exported (SRID-MOFA, 2010; Lescot, 2000).

In West Africa, several cultivars of plantain are grown. These are classified as French Horn Plantain, False Horn Plantain, or the True Horn Plantain. The major plantain varieties grown in Ghana are Borodewuo, Apantu pa, Borode sebo and Osoboaso "apantu" (false horn) and Apempa, Oniaba and

Nyeretia apem" (French horn plantain) and in isolated cases Asamienu or Asamiensa and Aowin (true horn). The different types of plantain are distinguish by their colour, stem, fruits, skin and pulp as well as the number of fingers in the bunches (Makanjuola, Ajayi, & Makanjuola 2013; Hemeng, Oduro, Ofori, & Banful, 1995).

Plantain can be consumed either riped or unriped. At any stage of ripeness, it can be prepared into a variety of cuisines for human consumption. Ripe plantains are boiled, fried or roasted and eaten alone or with vegetable stew. In West African countries like Ghana, the unripe plantain is boiled and pounded together with boiled cassava into "fufu". The boiled plantain could be eaten as 'ampesi' which goes with vegetable stew–"Abɔm"–and also mashed into "Ɔtɔ".

The crop develops with firm starchy fruits which ripen usually after harvest to soft sweet fruits of high sugar and low acid content of characteristic flavour and texture (Giami & Alu, 1994; Nwaichi, Peters, & Onome, 2014). Ndubuizu (1978) explained ripening as a process composed of complex interrelated but separate physiological events resulting from biochemical and biophysical changes occurring at cellular, subcellular, and molecular levels. Once the fruit matures, ripening in plantain occurs. During ripening, enzyme chlorophyllase degrades chlorophyll to a colourless product, thus, exposing the carotenoids. The changes in colour and texture of plantain fruit during ripening is as a result of the changes in the proximate composition and functional properties. Studies by Kassim (1977) and Ogazi (1982) have shown that the carbohydrate content decreases while the moisture, sugar, protein, lipid, and fibre contents of unripe plantain increase during ripening. Mattil

(1971) defined functional property as those characteristics that govern the behaviour of nutrients in food during processing, storage, and preparation as they affect food quality and acceptability. Some of the important functional properties that influence the utility of most starchy staples, such as plantain, include the drying characteristics, oil absorption capacity, whipability, foam stability, water absorption capacity, emulsion capacity, viscosity, and swelling capacity. In every plantain market, bunches of plantain at various stages of maturation are sold to consumers with little or no scientific method to assist them determine what they are buying. All these native varieties are categorised as triploids with AAB as the genomic group.

Figure 5: A picture of matured unriped and ripe plantatain.
Source: Field data, Bartels (2020)

Nutritional value of plantain

Carbohydrate is the major food nutrient in plantain. The raw unprocessed plantain contains 32 g of carbohydrate, 15 g sugar and 2.3 g fibre per 100 g (Cernovi, 2020; USDA, 2002 cited in Yeboah, 2018). The starch in the unripe plantain consists of mainly amylose and amylopectin and this is replaced by sucrose, fructose, and glucose during ripening due to the hydrolysis of fat (Marriott & Lancaster, 1983). Sugars accounts for about 1.3% of the total dry matter in unripe plantain, but this rises to around 17% in the ripe fruit (Ogazi, 1996). During ripening, the sugars are in the approximate ratio of glucose, 20: fructose, 15: sucrose, 65. Only traces of other sugars are found (Sweinen, 1990). Plantain is nutritionally a low protein food material but relatively high in carbohydrate, minerals, and vitamins. (Ogazi, 1982; Ketiku, 1973). 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, Riley, Wheatly, & Lowe, 2011) in the plantain.

Health benefits of plantain

The health benefits of plantain will thus be influenced ultimately by the processing and what it is consumed with. Plantain is known to be low in sodium (Chandler, 1995). It contains very little fat and no cholesterol; therefore it is useful in managing patients with high blood pressure and heart disease. They are free from substances that give rise to uric acid therefore,

they are ideal for patients with gout or arthritis. Due to the low sodium and protein content, plantain is used in special diets for kidney disease sufferers. The capacity of the plantain to neutralize free hydrochloric acid suggests its use in peptic ulcer therapy (Gowen, 1995).

A fully ripe plantain mixed with milk powder is especially recommended for ulcer patients. The low lipid and high palatability combination is ideal for the diet of obese people (Gowen, 1995). The plantain plant has also some medical properties. The leaves can be pounded and applied to the wound to suppress bleeding. The plant is a source of food, beverages, fermentable sugars, medicines, flavouring, cooked foods, silage, fragrance, rope, cordage, garlands, shelter, clothing, smoking material and numerous ceremonial and religious uses (Nelson, Ploetz, & Kepler, 2006). Plantain flowers, ripe fruit, unripe fruit, leaves and stem extract and its active constituents have been used for the treatment of a large number of human ailments (Auta & Kumurya, 2015). The main pharmacological effects of this plant are: hepatoprotive, diuretic, analgesic, anti-ulcer, wound healing, hair – growth promoter and haemostatic activity (Kumar, Mishra, Ahuja, Rani, & Nema, 2012). Table 7 presents an indepth analysis of Nutritional composition of plantain as reported by USDA National Nutrient Database for Standard Reference (2011).

Table 7: Nutritional Composition of Plantain per 100 g

Principle	Nutrient Value	Percentage of RDA
Energy	122 Kcal	6
Carbohydrates	31.89 g	24.5
Protein	1.30 g	2
Total Fat	0.37g	2
Cholesterol	0 mg	0
Dietary Fibre	2.30g	6
Sugar	15g	
Vitamins		
Folates	22 µg	5.5
Niacin	0.686 mg	4
Pyridoxine	0.299 mg	23
Riboflavin	0.054 mg	4
Thiamin	0.052 mg	4
Vitamin A	1127 IU	37.5
Vitamin-C	18.4 mg	31
Vitamin-E	0.14 mg	1
Vitamin K	0.7 µg	1
Electrolytes		
Sodium	4 mg	<1
Potassium	499 mg	10.6
Minerals		
Calcium	3 mg	<0.5
Iron	0.60 mg	7.5
Magnesium	37 mg	9
Phosphorus	34 mg	5
Zinc	0.14 mg	1

Source: USDA National Nutrient Database for Standard Reference, 2011

Concept of Glycaemic Index

The GI paradigm was developed in the 1980s purposely to help diabetics to reduce their postprandial rise in blood glucose (Jenkins *et al.*, 1981). Originally, it was introduced as a means of classifying different sources

of carbohydrate and carbohydrate-rich foods in the diet, according to their effect on postprandial glycaemia (Jenkins *et al.*, 1981). It was assumed to apply to foods that primarily deliver available carbohydrate such as sweet potatoes, rice, cereals, etc usually having an energy content of 80% from carbohydrate. The concept of dietary GI came under discussion three decades ago, as a factor that should be controlled to ameliorate chronic diseases. The glycaemic index has proved to be a useful nutritional concept–the chemical classification of carbohydrate (simple or complex, sugars or starches, available or unavailable)–that fosters new insights into the relationship between the physiologic effects of consuming carbohydrate-rich foods and health (Foser-Powell, Holt, & Brand-Miller, 2002).

By definition, it is a measurement used to classify foods according to their potential for raising blood glucose levels (Brand-Miller *et al.*, 2014; Whitney & Rolfes, 2002) and is generally measured by determining the rise in blood glucose concentration following the consumption of a test meal over a set period of time and comparing it with an isoglucidic control meal (normally white bread or glucose) and is expressed as a percentage (Willett, Manson, & Liu, 2002; Goni, Garcia- Alonso, & Saura-Calixto, 1997). Again, the GI compares equal quantities of available carbohydrate in foods and provides a measure of carbohydrate quality. In general, the number is based on how much of a food item raises blood glucose levels in healthy research participants compared with how much pure glucose raises blood glucose of the same group. In effect, the GI is an indicator of the relative glycaemic response to dietary carbohydrates.

White bread and Glucose are often used as the standard (control) foods because they cause the fastest and most dramatic rise in glucose levels. In the assessing the GI of individual foods, either glucose or white bread is assigned a value of 100, the highest index possible. To convert the GI values from glucose scale to bread scale, the glucose scale value is multiplied by 100/70 to arrive at the bread scale value. On the bread scale, low GI foods are those that have a value lower than 70 and high GI foods are those with values greater than 100 (Atkinson, Foster-Powell, & Brand-Miller, 2008). International tables of glycaemic index and glycaemic load values (2008) has foods that are then assigned proportionately lower values on the basis of how they impact serum glucose levels in comparison with glucose or white bread (Johnson, 2002).

Lower GI foods are considered to provide benefits as a result of the relatively low glycaemic response following ingestion compared with high GI foods. In 1997, a committee of experts was brought together by the Food and Agriculture Organisation (FAO) of the United Nations and the World Health Organisation (WHO) to review the available research evidence regarding the importance of carbohydrates in human nutrition and health. The committee endorsed the use of the GI method for classifying carbohydrate rich foods and recommended that the GI values of foods be used in conjunction with information about food composition to guide food choices. To promote good health, the committee advocated the consumption of a high-carbohydrate diet (≥55% of energy from carbohydrate), with the bulk of carbohydrate-containing foods being rich in non-starch polysaccharides with a low GI. In Australia, official dietary guidelines for healthy elderly people specifically

recommend the consumption of low-GI cereal foods for good health (National Health and Medical Research Council, 1999). To assist customers in identifying low-GI foods, a GI trademark certification scheme has been established on food labels (Brand-Miller, Barclay, & Irwin, 2001). GI testing conditions require the use of standardised methods (Riccardi, Clemente, & Giacco, 2003; Rasmussen, 1993). The procedure for the measurement of GI is described in detail in the 1998 FAO/WHO report on carbohydrates in human nutrition (FAO, 1998). Hundreds of foods have been tested for GI with the aim of ranking foods within and between food categories. There are various research methods for assigning a GI value to food. The GI classification system commonly in use is presented in Table 8.

Table 8: Classification of Glycaemic Index

Value	Glycaemic Index
High	>70
Medium	56-69
Low	<55

Source: Allen *et al.*, (2012); Barclay *et al.*, (2005); Brand-Miller (2003).

Carbohydrates that break down quickly during digestion have high GI and the blood glucose response is fast and high, while carbohydrates that break down slowly, releasing glucose gradually into the blood stream, have low GI (Jenkins, Kendall, Augustin, & Vuksan, 2002).

There are some foods that have GI value of above 100, meaning they elevate the blood glucose even faster than when pure glucose is consumed (GI = 100) (Vernon *et al.*, 2004). The clinical and practical value of the GI continues to be studied and there is growing consensus that there are benefits

to health when low GI foods substitute high GI foods in a balanced diet. Thus, low GI foods produce less fluctuation in blood glucose and insulin levels than high GI foods (Brouns *et al.*, 2005).

Determination of Glycaemic Index

GI values of foods must be measured using valid scientific methods. (Riccardi *et al.*, 2003; Rasmussen, 1993). It cannot be predicted by looking at the composition of the food or the nutrition facts on the food package. The accuracy of the calculation depends upon the accuracy of the GI values assigned to foods, which may vary geographically due to local factors such as variety, cooking, processing, etc (Venter, Slabber, & Vorster, 2003). Rice, potatoes and bananas are foods particularly prone to such variation. Again, according to Berger (1995), the accuracy of the measurements of the GI is also influenced particularly by the following factors:

1. method for calculating IAUC
2. method for measuring the pure glucose
3. defining the quantity of the tested food which contains 50 g of avialable carbohydrates
4. the quantity and the kind of standard food used
5. chracteristics of the study participants
6. the glycaemia variability from day to day
7. time of the day the test is carried out.

Following the international standard method described by FAO (1998), the GI value of a food is determined by feeding 10 or more healthy people a portion of the food containing 50 g of digestible (available) carbohydrate and then measuring the effect on their blood glucose levels over the next two

hours. For each person, the area under their two-hour blood glucose response (glucose AUC) for the food is measured. On another occasion, the same 10 people consume an equal-carbohydrate portion of pure glucose (the reference food) and their two-hour blood glucose response is also measured. In addition, the mean, standard deviation and coefficient of variation (CV) of the iAUC of each participant are repeated reference food is calculated. A GI value for the test food is then calculated for each person by dividing their glucose AUC for the test food by their glucose AUC for the reference food. The final GI value for the test food is the average GI value for the 10 people or the total number of people used. The area under the blood glucose response curve is calculated geometrically by applying the trapezoid rule (Brouns *et al.,* 2005). When a blood glucose value falls below the baseline, only the area above the fasting level is included. In the case where the individual GI values for any participant was greater or less than 2 standard deviation (SD) of the group mean, the GI will be considered as an outlier and would be excluded from the analysis. GI values are classified as high (70 - 100), intermediate (55 - 69), or low (<55) (Brand-Miller *et al.,* 2003c). Foods with a high GI contain rapidly digested carbohydrate, which produces a large rapid rise and fall in the level of blood glucose. In contrast, foods with a low GI contain slowly digested carbohydrate, which produces a gradual, relatively low rise in the level of blood glucose.

GI = (iAUC test food/iAUC reference food) × 100.

Calculation of the area under the curve (AUC)

Numerous methods exist for calculating AUC, and because they can result in discrepancies in GI values, this should be standardised. Bruons *et al.*

(2005) identified five methods namely; (1) Total AUC; (2) Incremental area until first return to baseline (incremental AUC $_{cut}$); (3) The area over the baseline under the curve, ignoring area beneath the curve (incremental AUC); (4) Incremental area using the lowest blood glucose as the baseline (incremental AUC_{min}); (5) The net incremental AUC (apply trapezoid rule for all increments positive and negative) (net incremental AUC) and recommended method 3 that is the use of the area over the baseline under the curve, ignoring area beneath the curve (incremental AUC) whereas (FAO, (1998); Wolever, (1990); Venter *et al.*, (2003) outlined four methods namely; Incremental AUC; Net incremental AUC; Incremental area with the lowest glucose value as baseline (AUC_{min}) and Total AUC.

1. Incremental AUC

Wolever (1990) defined the incremental area as the area under the glucose response curve with the fasting glucose value as baseline, and considers it the only method to calculate the GI (Wolever, Jenkins, & Jenkins 1991). This method disregards any area under the fasting blood glucose value. However, in hypoglycaemic non-diabetic participants, reduction in the blood glucose values occurs after initial high glucose concentration. This method is not always accurate in determining how different diets affect glucose levels.

2. Net incremental AUC

The net incremental AUC is a variant of Wolever's method and was used by several researchers (Laine, Thomas, & Levitt, 1987; Gannon, Nuttal, & Krezowski, 1986; Bantle, Laine, & Castle, 1983; Nuttal, Moorandian, & DeMarais, 1983). In this method, the area under the fasting blood glucose curve is subtracted from the area above the fasting blood-glucose curve.

Again, a difference between the incremental and the net incremental areas will only be detected in cases where the postprandial blood glucose concentration drops below the fasting value (Wolever, 1990).

3. Incremental Area with the lowest glucose value as baseline (AUC_{min})

Vorster, Venter, and Silves (1990) proposed an incremental area with the lowest glucose value as baseline to calculate the GI on the premise that the sharp rise in the curve when glucose is used as the standard results in a hypoglycaemic response at approximately 90 min in a large number of healthy participants, which is absent when slowly absorbed ('lente') carbohydrate is consumed. They reported that, in healthy participants experiencing hypoglycaemia or blood glucose levels below the fasting level, the method ignoring these will not produce the true picture. According to this method, hypoglycaemia is regarded as a physiologically undesirable state, as is hyperglycaemia. Vorster *et al.* (1990) posited that in situations were blood glucose values remain above the fasting value as can be expected in diabetics, AUC_{min} method will give the same results as the incremental AUC of Wolever *et al.* (1991).

4. Total AUC

Reaven, Chen Y-DI, and Golay (1987) used the total AUC and defined it as the area under the glucose curve and above a blood glucose value of zero. Wolever (1990) has shown that this method will yield values 3-10 times greater for normal participants and 2-5 times greater for diabetics than the incremental area for the same data. This method has been criticised by Wolver (1990) and Gannon and Nuttal (1987) as being insensitive to detecting differences between the postprandial glycaemic responses of different meals.

The main source of inaccuracy in determining the GI could be the method of calculating the AUC. Confusion evolved when percent differences between the 'total' AUCs for different foods were compared with the differences in their GI's (Coulston, Hollenbeck, & Swiskocki, 1987; Hollenbeck, Coulston, & Reaven, 1986). Thornburn *et al.* (1986) also questioned whether the base of the AUC should be a line extended to the right on the graph from the fasting blood glucose concentration, or a line drawn horizontally, which may occur after the peak rise, between 2 and 3 hours after the test meal. The former is usually applied. Recently, Nell, (2000) found that the AUC_{min} method showed less variation than the incremental AUC method and advocated that the AUC_{min} method is a more relevant physiological method to use in GI calculations. Moreover, authors have not always made it sufficiently clear exactly how the AUC was calculated. Current knowledge indicates that GI calculations should be done with the AUC_{min} method. However, methods used to analyse data should be documented clearly.

In vivo versus in vitro methods in determining the glycaemic index

The relationship between the rate of digestion and absorption and glycaemic response is shown using various in vitro digestion models that mimic the in vivo situation. The financial, experimental time, and ethical burden involved in the determination of glycaemic index in human participants led to in vitro studies on starch digestibility (Goñi, Garcia-Alonso, & Saura-Calixto, 1997) which mimic the in-vivo situation. These in vitro methods include methods simulating the human gastrointestinal tract and determining the rate of carbohydrate hydrolysis, as well as methods calculating the degree of digestion by determining the different starch

fractions including total digestible starch (Foster-Powell *et al.*, 2002). In developing products and research into the variables that affect the rate of carbohydrate digestion in foods, in vitro techniques are usually considered cheaper and faster alternatives (Brand-Miller & Holt, 2004). Currently numerous product development activities include the utilisation of in vitro methodologies to predict GI. For instance, Zabidi and Aziz (2009) studied the GI of bread substituted with different chempedak seed flours (indigenous seed flour from Thailand) based on starch hydrolysis procedures and concluded that chempedak reduces the estimated GI of bread to a great extent. Unfortunately, only few foods have been subjected to both in vitro and in vivo analysis in a single batch, thus it is difficult to assess whether in vitro methods accurately predict GI (Foster-Powell *et al.*, 2002). A very high correlation between the rate of in vitro glucose release from starchy foods, using pancreatic and brush-border enzymes, and the glycaemic response in-vivo have deen observed by Granfeldt *et al.*, 2005; Englyst *et al.*, 2003). Other researchers have reported an association between in vitro measurements of carbohydrate digestion and GI values for foods (Araya *et al.*, 2002; Englyst *et al.*, 1999), and these results have led to assumptions that the laborious task of in vivo testing is no longer necessary for measuring GI values for foods accurately. However, associations between in vivo and in vitro results have not been consistently found (Urooj & Puttaraj, 2000) and other physiological factors (gastrointestinal function, glucose tolerance, the rate of food consumption) and meal factors (physical form, other nutrients) can confound the relationship (Arvidsson-Lenner *et al.*, 2004). Criticisms concerning in vitro methods have been voiced. Some of these concerns include the lack of the incorporation of variables present in

humans, such as the varying rate of gastric emptying, chewing differences and pre-meal effects etc. in human participants. Apart from these, one of the most noteworthy impediments for in vitro glycaemic prediction, for in vivo analysis, is the lack of standardised methodology (Woolnough, Monro, Brennan, & Bird, 2008). In contrast to in vivo methods, results from in vitro methods are not considered acceptable in terms of labelling etc. as no precise value is obtained. In vitro methods are considered to be screening tools in product development, to be followed by in-vivo analysis if necessary. Access to accurate information about the GI values of foods is important for consumers, health professionals and people living with diabetes to assist them in making informed dietary choices. Food manufacturers are urged to undertake GI testing only with experienced laboratories using the standardised in vivo method. If in vitro methods are employed, the findings should never be used to imply that the GI has been tested because by definition the GI is an in vivo measurement of glycaemic response. The International Standard should be applied to ensure that GI values are determined by recognised methodology. Some Methodological consideration for GI determination includes;

Testing period

Brouns *et al.* (2005) recommend administering the test before 10:00 a. m, after a 10–14h overnight fast. This fasted condition is most constant in relation to possible intra-individual differences due to time of the day and meal influences. It is confirmed that the glycaemic response data obtained from a test at lunchtime, after a standard breakfast, differed significantly. For instance, relative glycaemic reponse of two breakfast cereals were studied

after a 10–14h overnight fast or at lunchtime after a standard breakfast. It was observed that the difference in glycaemic response between the cereals when tested in the morning was significantly greater than that observed at lunchtime (Wolever & Bolognesi, 1996c).

Participants preparation

Many factors modify the response to a test meal in participants and differences in these factors between eating occasions are expected to be the potential causes of inaccuracies in GI and GL. These include alcohol intake, physical exercise, cigarette smoking and carbohydrate content of the diet, composition of the evening meal, GI of the evening meal as well as the overnight fast.

Siler, Neese, Christiansen, and Hellerstein (1998) reported that, alcohol consumption significantly influences glucose homeostasis especially in the fasting state, although the effects of alcohol consumption on metabolism the following day do not appear to have been tested.

Acute physical exercise is another inhibitor that can increase muscle glucose uptake on the following day and improve insulin sensitivity for 48 hours (Malkova *et al.*, 2000). This usually results in lower plasma insulin concentrations in response to nutrient ingestion (Tsetsonis *et al.*, 1997; Tsetsonis & Hardman, 1996), although there is no effect on systemic fasting plasma glucose concentrations (Malkova *et al.*, 2000; Tsetsonis *et al.*, 1997; Tsetsonis & Hardman, 1996). Recently, Folch *et al.* (2003) studied the effect of a large starch meal at rest and after exercise in men and women and observed that the contribution of substrate oxidation to energy expenditure as well as fat and glycogen balance, and the effect of previous exercise were

similar in men and women. Post-exercise, however, postprandial plasma glucose levels differed significantly from rest.

Cigarette smoking is another potential confounder since it may cause acute insulin resistance. Frati *et al.* (1996) and Attvall *et al.* (1993) reported that smoking acutely impaired glucose tolerance and insulin sensitivity where the AUC for glucose in smokers was reported to be 25.5 ± 1.03 mmol/l (mean ± SE) (95% CI 22.9–28) during the smoking OGTT and 21.8 ± 0.85 mmol/l (CI 19.2–24.3) in the control OGTT ($P < 0.01$); in nonsmokers, it was 19.7 ± 0.3 mmol/l (CI 18.8–20.5) in the smoking OGTT and 18.7 ± 0.35 mmol/l (CI 17.8–19.5) in the control OGTT ($P < 0.05$).

It has been established that the carbohydrate content of the diet for the few days before an oral glucose tolerance test markedly affects the result, with poorer glucose tolerance being observed after a low carbohydrate diet (Hales, & Randle, 1963). Glucose tolerance may improve upon consumption of dietary resistant starch on the day before a meal challenge (Robertson, Henderson, Vist, & Rumsey, 2002).

The composition of the evening meal the day before a test may also affect the result. Meals rich in either carbohydrate or fat on the evening before a meal-challenge test have significant effects the following day: fat tolerance is poorer following a carbohydrate rich evening meal; glucose tolerance is poorer following a fat-rich (low-carbohydrate) evening meal (Robertson *et al.*, 2002). However, the effect of evening meal macronutrient composition on fat tolerance is much more marked than the effect on glucose tolerance (Robertson *et al.*, 2002).

The GI of the evening meal may also exert an effect independent of macronutrient composition. Low GI evening meals produce better glucose tolerance the following morning compared with high GI evening meals (Thorburn *et al.*, 1993; Wolever *et al.*, 1988b). This effect may be due to colonic fermentation, since it is seen with barley but not with spaghetti with an identical GI (Granfeldt *et al.*, 2005).

Finally, the exact length of the overnight fast may also be important. The steady state often supposed to exist after overnight fast is, in fact, a time of significant change in terms of falling plasma insulin concentrations and increasing lipolysis (Klein *et al.*, 1993; Samra *et al.*, 1996). In view of all these factors, strict standardisation of diet and activity for 24hrs before the measurement of GI would improve the reproducibility of results. However, such standardisation increases the burden on participants and investigators. Campbell *et al.* (2003) compared tests in which exercise and evening meal on the day before the test, and the length of overnight fast, were strictly controlled, with 'uncontrolled' tests. No smoking was allowed on the morning of the test on either occasion. In contrast to expectations, the variability of results was no greater in the 'uncontrolled' tests and in fact tended to be lower. There was no effect on mean values of glycaemic response. Participants who were smokers (three out of thirteen) reported 'craving' during the controlled tests, but nevertheless retained similar values for glycaemic response and variability under the two conditions. Vigorous physical activity on the day before the 'uncontrolled' tests did not produce a significant effect, although there was a tendency to lower blood glucose concentrations at 90 min. Whilst the effects of many of these measures have been shown under other laboratory

conditions, it appears that they are not of sufficient significance to warrant stricter controls when applied to GI testing.

In contrast, Bruons *et al.* (2005) strongly advise participants to abstain from intense exercise, smoking or dieting on the day before the test. Participants should eat their normal diet on the previous day. The evening before a test each participant should consume a meal of choice and repeat that meal before each test.

Number of Participants

The number of participants enrolled in all studies, determines the width of the confidence interval (CI) for the estimates obtained, and the power of the study to detect differences in GI. Recruiting more participants provides better power and more precise results, but at a higher cost. The 1998 Joint FAO/WHO Expert Consultation on carbohydrates suggested that for the determination of the GI of a food, six participants would be required although the basis for this number was not given (FAO, 1998). A recent recommended sample size was 10 because it allowed a reasonable degree of power and precision for most purposes, although it was acknowledged that more participants would be necessary if greater precision was required (Brouns *et al.*, 2005). However, there are strong indications that using 10 people is insufficient to obtain reliable estimates of GI, particularly if GI levels are high, because variance increases with the mean. Large variation in glycaemic response between- and within-people makes it difficult to show differences among foods. For instance, Henry, Lightowler, Strik, and Storey (2005) assessed eight potato cultivars in groups of 10 participants and reported mean ± s.e.m. GIs ranging from 56±3 to 94±16. Despite a wide range of GIs, it was

not possible to demonstrate statistically significant differences among the potato varieties Studied. Because of the large variation there is the potential to miss-classify foods into categories of low, medium, or high GI. According to Brouns *et al.* (2005), the number of participants can be increased if the aim of the study is to detect small differences in GI or when greater precision is required.

Pathophysiological status of the participants

The glycaemic response to a food is influenced by participant characteristics such as the insulin sensitivity and glucose tolerance status. The physiological or pathophysiological status of the participants needs to be considered for reasons of precision and comparability of GI values. Theoretically, the highest precision of GI values is expected when the within-individual variation of the incremental AUC of the blood glucose response is minimised. Studies by Jenkins *et al.* (1983) on: normal versus diabetic participants ; individuals with type I diabetes versus individuals with type II diabetes (Livesey, 2002); type II diabetic participants on oral agents against on insulin (Jenkins *et al.*, 1986); type II diabetic participants in good versus poor metabolic control (Wolever *et al.*, 1986b); children with type I diabetes versus adults with type I diabetes (Wolever *et al.*, 1988a; Livesey, 2002); rural African versus normal Western participants (Walker & Walker, 1984; Jenkins *et al.*, 1981); glucose tolerance status and BMI (Wolever, 1990a; Wolever *et al.*, 1998) have all reported that participant characteristics have no significant effect on mean GI. A Study by Wolever *et al.*, 1985; Wolever, 1990a) on glycaemic responses for repeated tests of white bread of participants without diabetes with those of participants with type II diabetes

and participants with type I diabetes confirmed an intra-individual variation in glycaemic response to white bread. They observed that normal apparent healthy participants showed intermediate intra-individual variation in glycaemic response, whilst participants with type II diabetes showed a less significant intra-individual variation as compared to those with type I diabetes. Despite broadly comparable results, Brouns *et al.* (2005) and Foster-Powell *et al.* (2002) have recommended the use of apparently healthy individuals in the determination of GI to increase precision because variability in glycaemic response is greater in people with impaired glucose tolerance or diabetes.

Blood sampling methods

Arterial blood is delivered from the heart to the tissues of the body. The concentration of glucose in arterial blood is the measurement of interest because this is the concentration to which the tissues are exposed. However, sampling of arterial blood is an invasive procedure that carries some risk and is unlikely to be applied to the measurement of GI. Other alternatives methods are: (i) capillary blood–which approximates arterial blood in composition–this requires puncture of the skin usually on the finger or earlobe; (ii) venous blood taken from a cannula in a vein, usually on the forearm; (iii) 'arterialised venous' blood, taken from a cannula in a vein draining the hand, the hand then being warmed to open arterio-venous anastomoses so that substrate concentrations resemble arterial blood. The concentration of glucose in a peripheral vein will be lower than that in an artery because the tissues consume glucose. In a study conducted by Frayn *et al.* (1989), the glucose concentration in blood taken from an antecubital vein was 4mmol/l lower than that in arterialised venous blood at 60 min after ingestion of glucose.

Furthermore, they observed that the difference was not consistent because ambient temperature, for example affected the rate of blood flow through the forearm and had a marked effect on venous blood glucose concentrations. Frayn *et al.* (1989) therefore concluded that venous glucose measurement might be expected to be more variable than capillary. This has been confirmed directly in the inter laboratory study of GI, in which laboratories taking venous blood returned CI of >50%, compared with < 30% in all laboratories using capillary blood (Wolever *et al.*, 2002, 2004).

Direct comparisons between capillary and venous blood also bear out this difference. Capillary blood glucose concentrations were consistently greater than venous blood glucose concentrations when assessed during the measurement of GI of various products, so that AUC were 33–40% lower for venous blood glucose (Granfeldt *et al.*, 1995b). However, the measurements of GI were not affected as both reference and test measurements were similarly affected. Sensitivity of the measurement, however, was greater using capillary blood sampling (Granfeldt *et al.*, 1995b). The site at which capillary blood is taken may affect the result. When glucose concentrations are rising or have just risen sharply, fingertip capillary glucose concentrations are greater than those in capillary blood from other sites including forearm, thigh and abdomen (Ellison *et al.*, 2002; Jungheim & Koschinsky, 2002; van der Valk *et al.*, 2002), with variable differences in repeated tests on the same participant (Ellison *et al.*, 2002). On the contrary, when blood glucose concentrations fall, fingertip capillary glucose concentrations are lower than those on the forearm (Jungheim & Koschinsky, 2002). The fingertip capillary sampling is

preferable to other sites. Earlobe and fingertip capillary blood do not seem to have been compared directly.

Conversely, placement of a venous cannula requires some medical or nursing supervision but once in place, blood sampling is painless. Many participants do not like repeated stabs for capillary blood. On the other hand, methods for sampling capillary blood are being refined and with practice the technique can be made almost painless. Placement of a cannula for sampling arterialised venous blood is made in a retrograde direction, which is slightly more difficult than normal cannulation. The hand can then be warmed in a variety of ways although hot water is not recommended as heat transfer to the body is significant, and a box with relatively static air at 55–608C works best in practice (Frayn & Macdonald, 1992). Sampling capillary blood results in relatively smaller volumes. If it is desired to measure substances other than glucose (for example, insulin) this may be possible using micro-methods. However, if a number of hormones or metabolites are to be measured, then larger samples will be needed, and arterialised venous blood may be the method of choice (Wolever, 2004b). Measurement in whole blood is also possible. Whole-blood and plasma glucose concentrations are closely related and one can be calculated from the other if the packed cell volume is known (Dillon, 1965). Accurate results are required to confirm the consistency of plasma or whole blood measurements. It would be inappropriate to utilise plasma on one occasion and whole blood on another. Brouns *et al. (*2005) recommend the use of either capillary or arterialised venous blood and discourage the use of normal venous blood. In order to improve sensitivity and to remove the potential for variations in measured GI due to fluctuations in

factors such as ambient temperature, fingertip capillary blood appears to give the greatest but with improved methods for sampling of capillary blood becoming available. Usually blood is sampled in the fasting state and at 15, 30, 45, 60, 90 and 120 min after starting to eat the test meal in individuals without diabetes. Taking blood samples less frequently (sampling blood every 30 min instead of every 15 min) or for less than 2 hrs in normal participants significantly influences the mean and variation of the resulting AUC (Wolever, 2004b). The mean and variation of the resulting GI values also tend to increase as the frequency and duration of blood sampling decreases. In addition, reduced frequency and duration of blood sampling resulted in the development of statistically significant correlations between the mean AUC of the reference food and the mean GI of the test foods in the different participants, a correlation which is not significant (Wolever, 2004b).

Reference food

A variety of foodstuffs have been used as reference foods for GI measurement. In the updated GI database (Foster-Powell *et al.*, 2002), ten different reference foods for almost 1,300 measurements were used. They were glucose, white bread, wholemeal barley bread, wheat chapatti, potato, rice, corn, wheat and arepa (a Mexican starchy food). However, most of the measurements were done using glucose or white bread as the reference food (90% of studies). In studies using rice, potato or some other local foods as the reference, these were chosen because of the large part taken by these foods in the local carbohydrate intake. However, complete information about the reference foods are sometimes not provided in reports, which limits the applicability of such data. Again, the correspondence between the glucose

raising effect of such or many local reference foods and the glucose-raising effect of the frequently studied white bread and glucose reference foods has been poorly studied. This greatly limits comparison of data from different laboratories and experiments, and it also limits publication of the results at an international level. By contrast, some laboratories have studied systematically the correspondence between GI on either white bread or glucose reference basis (Sugiyama *et al.,* 2003). Of the reference foods used, bread or glucose has been discussed most. Since bread is a common food, it has been argued that choosing this reference allows the determination of GI in a more physiological manner. However, the composition of white bread may vary from one experiment to another and this may make comparison of results from various experiments difficult. Nevertheless, in a recent inter laboratory study it was concluded that GI values for locally obtained bread are no more variable than those for centrally provided (comparable) foods (Wolever & Mehling, 2002). In contrast, white bread from a certain local area may differ in GI compared with a common white bread from another area, as in the case of French white bread baguette (Foster Powell *et al.,* 2002). The GI values obtained when white bread is used are typically about 1·4 times those obtained if glucose is used as standard (FAO, 1998). Glucose is sometimes preferred since the carbohydrate source is more standardised. However, participants can get nauseous after taking a concentrated glucose drink in the morning after an overnight fast (Brouns *et al.,* 2005).

The GI of glucose is 100 (Brouns *et al.,* 2005). Blood glucose responses vary considerably from day-to-day within participants. To obtain a representative mean response to the standard food, it is recommended that the

standard food be repeated at least three times in each participant. Precision will be improved if the measurements on the test food and the reference food are repeated among individuals. However, these come with undesirable expense. Differences in the response to the reference food has greater effect on the results than the corresponding differences in the test foods, because the former is used to calculate the GI value of every test food in the series. It is desirable to obtain as representative a value for the AUC for the reference food for each participant as possible. This can be achieved in practice by using the mean value of several trials of the reference food. The average of three trials of the reference food has been shown to reduce the variation of mean GI values (Wolever *et al.*, 1991, 2002). The suggestion to use three repeated trials, as opposed to some other number, was based on a relatively small number of clinical observations. Although not enough real data exist to determine exactly how many repeats of the reference food should be done, both a simulation study and a theoretical argument presented later indicate that two or three measurements are appropriate. Brouns *et al.* (2005) recommend repeating the trials of the reference food at least once, to obtain at least two values, in each participant.

Diet quantity, composition and consumption time

The determination of the GI of a food usually involves the test of a portion of food containing 50 g available carbohydrate. Since all foods do not have the same carbohydrate content, the quantity of the test portions varies. Quantity and weight of the diet have an impact on the time required for consumption. It is known for both solid and liquid test foods, in normal and diabetic participants that, prolonging the time of ingestion from a few minutes

to several hours markedly flattens the glycaemic response (Jenkins *et al.*, 1990, 1992). Injesting 75 g glucose solution over 10 min as compared with 1m intended to increase blood glucose 60 to 120 min later, possibly because of a significantly smaller insulin response during the first 30 min (Heine *et al.*, 1983). The impact of the food quantity, carbohydrate content and osmolarity on gastric emptying has been well studied (Brouns *et al.*, 1995; Brouns, 1998). However, the effect of quantity of carbohydrate foods has been poorly studied.

The initial quantity of fluids has strong effect on the gastric emptying rate. Accordingly, ingestion time should best be standardised (Brouns, 1998). Unfortunately, the results of studies undertaken to date to evaluate the effect of fluid quantity on glycaemic response are contradictory. Some authors found no significant effect of water quantity (Gregersen *et al.*, 1990), whereas others observed or indicated a relationship between the quantity of water or food and postprandial responses, and sometimes incremental areas (Sievenpiper *et al.*, 2001; Young & Wolever, 1998; Torsdottir & Anderson, 1989). These contradictory results could be explained by differences in physiology between diabetic and non diabetic participants and also by large variations between the protocols used in these studies. Based on current evidence, it is recommended to avoid potential variability in results due to the amount of drink given to the participants during the GI testing. It is also imperative to note that in GI testing, the drink given to the participants is not always water; coffee or tea have also been used. Young and Wolever (1998) reported that neither tea nor coffee significantly affect the incremental area under the glycaemic response curve. However, as quantity, they influence the pattern of blood glucose response. Moreover, caffeine is known to acutely decrease insulin sensitivity

in human particpants (Keijzers *et al.*, 2002; Graham *et al.*, 2000). In the study of Graham *et al.*, (2000), ingestion of 375 mg caffeine resulted in a significant increase in both C-peptide and insulin as well as an increase in the glucose AUC of 24%. Again, non-energetic or stimulant beverages (coffee, tea) may be supplied as long as an identical quantity and type of beverage is administered during the different sessions of each participant.

Brouns *et al.* (2005) recommend supplying a standard amount of 250 ml water to the participants with the test portions, and with the white bread portion if it is used as the control food. If the control is glucose, a solution of 50 g glucose diluted into 250 ml water is recommended. Fluid ingestion is advised to take place within 5–10 min. Solids and semi-solids should be ingested within 10–20 min. depending on the type and taste of the food. The first blood sample should be taken exactly 15 min after the first bite of the food or first sip of the drink. Table 9 presents a summary of methodological considerations needed to determine the GI of foods.

Table 9: Some Methodological Consideration for GI Determination

Parameter	Comments
Participants	10 test participants Healthy participants appropriate (lower within-participant variation than diabetic participants using drugs).
Time of day	Mornings (more pronounced glycaemic response)
Background diet	Fasting participants Standardised evening meal may reduce within-participant variation.
Physical activity	Standardisation so far not successful in decreasing variation.
Determination of glycaemic carbohydrates	‘‘By difference’’ (total carbohydrae minus dietary fibre): Acceptable estimation of digestible carbohydrate in most normal foods, but may overestimate digestible carbohydrate in products with undigestible carbohydrate not determined as dietary fibre (e.g. oligosaccharides, resistant starch, and sugar alcohols). Specific assay of the carbohydrate profile recommended for scientific purpose.
Carbohydrate quantity	50 g available carbohydrate (linear response for 25/50 g).
Reference food	White bread or glucose Other reference than glucose: GI characteristics of the reference maintained over time and recalculated using glucose reference.
Blood sampling methods	Capillary blood (preferable): higher postprandial glucose concentration, less variation Venous blood: lower glycaemic response, larger variation, higher GI than capillary blood Blood glucose analyses based on approved analytical
Calculation	Preferably 2 h incremental area (3 h area may be useful for products with extreme lente characteristics).

Source: Arvidsson-Lenner *et al.*, 2004.

Concept of Glycaemic Load

The quantity and quality of carbohydrate influence the glycaemic response. GI, by definition compares equal quantities of carbohydrate and provides a measure of carbohydrate quality but not quantity. To provide a more accurate description of the quantity and quality of carbohydrate in a meal concurrently, the concept of glycaemic load (GL) was introduced in 1997 by researchers at Harvard University to quantify the overall glycaemic effect of a portion of food (Liu, Willett, & Stampfer, 2000; Salmeron, Manson, Stampfer, & Colditz, 1997; Salmeron, Ascherio, & Rimm, 1997) which takes the concept of GI a step further, accounting not only for how rapidly a food's carbohydrates are converted to glucose but also the relative amounts of carbohydrate the food contains in an average serving. The GL of a food is calculated by multiplying its GI value by the amount of carbohydrates in grammes provided by a serving of food and dividing the total by 100 (American Diabetes Association 2013; Monro & Shaw, 2008; Barclay *et al.*, 2005; Danone Vitapole /FAO, 2001). Generally, it is said to be a more accurate measure of a food's overall effect on pancreatic insulin release and serum glucose levels. Therefore, the GL provides a summary measure of the relative glycaemic impact of a "typical" serving of the food. The higher the GL, the greater the expected elevation in blood glucose and in the insulinogenic effect of the food. Long-term consumption of a diet with a relatively high GL (adjusted for total energy) is associated with an increased risk of type II diabetes and coronary heart disease (Liu *et al.*, 2000). The relationship between GI and GL is not direct; for example, a high GI food can have a low GL if eaten in small quantities. Conversely, a low GI food can

have a high GL dependent upon the portion size eaten (Mendosa, 2008). In general, foods with a low GI tend to have a correspondingly low GL. However, foods with a high GI may differ as to whether their GL is low or high. For instance, the carbohydrates in watermelon are rapidly converted to glucose, so watermelon's GI is high at 72. However, because watermelon is made up primarily of water and contains little absolute carbohydrate content, its GL is relatively low at a value of 4 (Foster *et al.*, 2002). The concern about rating foods as good or bad solely on the basis of their glycaemic index is addressed using the GL concept. For example, although the glycaemic index for carrots is reported to be as high as 131, the glycaemic load for one serving of carrots is small because the amount of carbohydrate in one serving of carrots is minimal (7 g carbohydrate). Undeniably, 700 g carrots (which provides 50 g carbohydrate) must be consumed to produce an incremental glucose response 1.3 times that of 100 g white bread containing 50 g carbohydrate. (Gross *et al*., 2004; Liu, 2002; Liu *et al.*, 2001). A low GL diet could be achieved by selecting small servings of foods relatively high in carbohydrate having a low GI (Venn & Green, 2007). Alternatively, a low GL diet could comprise foods having a high fat, high protein, low carbohydrate content. The heterogeneity of foods that could be used to construct a low GL diet indicates that food selection should not be made on GL alone. Knowledge of other qualities of the food, for example fat content, type of fat, energy density, fibre content and appropriate serving size should be taken into consideration. Table 10 summarises the GL categorisation into low, medium and high values.

Table 10: Classification of Glycaemic Load

Value	Glycaemic Load
High	>20
Medium	11-19
Low	<10

Source: Venn and Green, (2007); Burani (2006); Barclay *et al.*, (2005); Brand-Miller (2003)

Determination of GL

GL may be determined by indirect and direct methods. The indirect method involves multiplying the GI of a food by the amount of available carbohydrate in the portion of food consumed. This method implies that GL is directly proportional to the amount of the particular food eaten. This is perhaps counterintuitive, because the blood glucose AUC does not increase in direct proportion to the amount consumed. For example, eating six times the amount of bread results in an approximately threefold increase in AUC (Brand-Miller *et al.*, 2003c). In other words, as the quantity of food increased the rate of increase in AUC declines (Venn *et al.*, 2006). Therefore, it is implicit in the calculation of GL that the AUC for both the test and the reference foods are attenuated to the same degree with increasing amounts consumed.

Glycaemic equivalence is a method of directly determining GL. In this method, each participant's AUC for glucose is calculated for a range of doses of the reference food measured on different days. A standard curve is constructed for each particpant with increasing amounts of the reference on the x axis with its corresponding AUC for blood glucose on the y axis (Venn

et al., 2006). The AUC in response to a food consumed at any portion size, typically a usual serving, is compared to that individual's glucose standard curve as depicted (Venn *et al., 2006*). Using this technique, glycaemic equivalence is the amount of glucose that would theoretically produce the same blood glucose AUC as that particular portion size of food consumed. Major drawbacks that hamper the use of this method are increased time and cost. The reference must be tested at several doses in each subject and the GL of a food cannot be estimated from currently available GI values. Data from laboratories support the argument that GL is linearly related to the amount of food consumed that is, GL calculated using. GI ×available carbohydrate agrees well with GL measured directly, at least when food is consumed over a range of usual intakes (Venn *et al.*, 2006). Glycaemic Load for each food is determined by the method of Salmeron *et al.* (1997). In each individual, glycaemic load is calculated by taking the percentage of the food's carbohydrate content in a typical serving and multiplying it by its glycaemic index value (Atkinson *et al.*, 2008). GL values were classified as low (≤10), medium (>10 to <20) or high (≥20).

GL_{Food} = (GI_{Food} x amount (g) of available $carbohydrate_{Food}$ per serving)/100

Factors Affecting GIs and GLs of Foods

Many factors affect the glycaemic response to carbohydrate, including the intrinsic properties of the food and also extrinsic factors such as the composition of the meal, the overall diet and biological variations of the host.

Carbohydrate contents of foods

Dietary carbohydrates could increase blood glucose levels especially in the postprandial period. However, not all carbohydrate-rich foods result in

hyperglycaemia when consumed. Differences in postprandial blood glucose responses to various carbohydrate-containing foods have also been demonstrated in both healthy and diabetic participants, even when consumed in portions containing identical amounts of carbohydrate (Gabriele, Angela, & Rosalba, 2008; Liljeberg, Granfeldt, & Bjorck, 1992). This indicates that there could be differences in individual components of carbohydrates that are responsible for the reported variations to postprandial blood glucose responses after consumption of the various carbohydrate containing foods by both healthy and diabetic individuals. These variations in glycaemic responses to carbohydrate foods and which also tend to affect the GL of foods, were reported to arise from different components of carbohydrates present in foods and their properties such as: starch composition/properties (digestible, indigestible, amylose/amylopectin ratio, gelatinization, retrogradation), dietary fibre content, (Bahado-Singh, Riley, Wheatley, & Lowe, 2011; Urooj & Puttraj, 1999), sugars as well as other factors such as: insulin response, protein contents, processing techniques, variety, particle size, fat, acidity, storage and time of harvest.

Starch composition

Starch contributes about 70–80% of the total carbohydrates in normal diet. For nutritional purposes, Sajilata, Singhal, and Kulkarni (2006) and Englyst, Kingman, and Cummings (1992) classified starches on the basis of their rate and extent of digestion into 3 categories, namely: rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS). RDS is the starch fraction that is rapidly digested and absorbed in the duodenum and the small intestine leading to a rapid increase in blood glucose and usually a

subsequent episode of hypoglycaemia. RDS consists mainly of amorphous and dispersed starch and it is found in high amounts in starchy foods cooked by moist heat, such as bread and potatoes. It is measured chemically as the starch that is converted to the constituent glucose molecules within 20 min of enzyme digestion (Sajilata *et al.*, 2006). These rapid and large increases in blood glucose levels can further lead to cell, tissue and organ damage (Erik, Itziar, Arne, & Alfredo, 2011).

SDS is the starch fraction that is digested slowly but completely in the small intestine to provide sustained glucose release with a low initial glycaemia and subsequently a slow and prolonged release of glucose, leading to prolonged energy availability (Erik *et al.*, 2011).

This category consists of physically inaccessible amorphous and raw starch with types A and type C crystalline structures, such as cereals and type B starch, either in granule form or retrograded form in cooked foods. It is measured chemically as the starch that is converted to glucose after a further 100 min of enzyme digestion (Sajilata *et al.*, 2006). Examples include most raw cereals (Erik *et al.*, 2011). The potential health benefits of SDS include stable glucose metabolism and diabetes management. Resistant Starch (RS) is not digested in the upper gastrointestinal tract but is fermented by the gut microflora, producing short chain fatty acids that provide additional energy to the body. Hence its definition by Sagilata and colleagues as the fraction of dietary starch that escapes digestion in the small intestine. RS is measured chemically as the difference between total starch (TS) (obtained from homogenized and chemically treated sample) and the sum of RDS and SDS, generated from non-homogenized food samples by enzyme digestion.

Mathematically, RS = TS − (RDS + SDS) (Sajilata *et al.,* 2006). It is not all resistant starches that are the same. There are 4 classes of resistant starches and they include:

Type 1 which refers to a starch that resists digestion because it is bound within the fibrous cell walls that make it physically inaccessible. Examples include: partly milled grains and seeds as well as legumes. Type 1 is heat stable in most normal cooking operations and enables its use as an ingredient in a wide variety of conventional foods.

Type 2 which refers to a starch that is in a certain granular form and resistant to enzyme digestion. This type is found in some starchy foods, including raw potatoes and green (unripe) bananas.

Type 3 which represent the most resistant starch fraction. It is formed when certain starchy foods, including potatoes and rice, are cooked and cooled. The cooling converts some of the gelatinized digestible starches into resistant starches through the process of retrogradation (Sajilata *et al.,* 2006). A lot of starchy foods cooked by moist heat can therefore contain some fractions of Type 3 as a result of retrogradation. Type 3 is entirely resistant to digestion by pancreatic amylases.

Type 4 which is man-made and it refers to the RS where new chemical bonds other than α-(1, 4) or α-(1, 6) are formed. Modified starches obtained by various chemical processes fall under this category.

Studies in humans show that RS can have powerful health benefits such as improved insulin sensitivity in type II diabetic patients and reduction of blood glucose levels (Nurgent, 2005). Other health benefits that have been reported to be associated with consumption of foods rich in RS include:

prevention of colon cancer, substrate for the growth of probiotics, reduction of gall stone formation, hypocholesterolemic effects, inhibition of fat accumulation, and increase in absorption of minerals (Sajilata *et al.,* 2006; Hyun-Jung, Dong-Hoon, & Seung-Taik, 2008).

Various physical factors like stirring, water-starch ratio, cooking and cooling regimes affect resistant starch formation (Deepa, Singh, & Naidu, 2010). RS formation is also influenced by amylose amylopectin ratio (Frei, Siddhuraju, & Becker, 2003).

Amylose-amylopectin ratio

Amylose is more slowly digested and absorbed than is the amylopectin component of starch. Amylose molecules tend to form tight, compact units that are harder to digest, whereas amylopectin molecules are more open because of their branched structure and are easier to digest. Foods with a higher amount of amylose, such as long-grain rice, have lower GI numbers (Englyst *et al.*, 1999; O'Dea, Snow, & Nestel, 1981; Snow & O'Dea, 1981). Evidence shows that amylose slows digestion and insulin response time, providing a lower glycaemic index (Higgins, 2004). Studies by Miller *et al.*, 1992) showed that rice with higher amylose content (Doongara, 28% amylose) gave a significantly lower glycaemic index (GI) and insulin index than the normal amylose versus amylopectin rice varieties (Calrose and Pelde, 20% amylose).

Furthermore, amylopectin/amylose ratio and amylose combined with lipids affect the rate of starch hydrolysis. The extent of digestibility of starches generally decreases as amylose content increase (Vesterinen, Myllärinen, Forssell, Söderling, & Autio, 2002) although amylose content alone is not a

sole predictor of digestibility (Htoon, Shrestha, Flanagan, Lopez-Rubio, Bird, & Gilbert, 2009). Similarly, amylose combined with lipid is more resistant to attack by hydrolytic enzymes than is free carbohydrate.

Gelatinization

When starch is heated to a temperature of about 50°C, in the presence of water, the amylose in the granule swells; the crystalline structure of the amylopectin disintegrates and the granule ruptures. The polysaccharide chains take up a random configuration, causing swelling of the starch and thickening of the surrounding matrix. The process, known as gelatinization, makes the starch easily digestible (Sajilata *et al.*, 2006). The greater the gelatinization, the more viscous the starch would be and the higher will be its GI and this could also affect the GL. Foods containing starch molecules that are fully gelatinized, such as a baked potato, make it easier for digestive enzymes to attack (Englyst, *et al.*, 1999; Jenkins *et al.*, 1983; Jenkins, Ghafari, & Wolever, 1982). Foods such as spaghetti have a dense food matrix, which hinders enzymatic hydrolysis, and legumes contain resistant starch and a fibrous coating and, therefore, both are digested less rapidly than other carbohydrate foods and cause a slower and lower glycaemic response. Gelatinized starch samples are more susceptible to degradation by α-amylase than are native starch granules (Htoon *et al.*, 2009; Vesterinen *et al.*, 2002).

Retrogradation

After starch is gelatinized, when it gets cold (low temperature), the gelatinized starch gradually begins to undergo rearrangement of its amylose and amylopectin macromolecules which leads to increase in crystalline nature of starch molecules. This process is known as retrogradation. Retrogradation

becomes more intense as time passes and temperatures go down. The higher the amylose content of starch, the greater the effectiveness of the retrogradation process and the more resistant to digestion the starch will be due to stronger hydrogen bonding leading to lower GI of the starch (Bahado-Singh *et al.*, 2011) and this could also lower the GL of starch.

Through the process of retrogradation, gelatinized or solubilised starch can be transformed from an unstructured into a more ordered or crystalline state. This physical change causes heat processed starchy foods to harden or become stale as they spontaneously approach a meta stable state of lower free energy. This has been reported to decrease the GI value, due to an increased resistance to amylase (Chung, Lim, & Lim, 2006). Consequently, the duration of the first stage of retrogradation depends on the amylose content of starch. High molecular weight amylose promotes retrogradation more than lower molecular weight polymers (Dona, Guilhem, Robert, & Philip, 2010).

Dietary fibre

A study conducted by Slavin, Martini, Jacobs, and Marquart (1999) showed that viscous soluble fibre plays an important role in controlling postprandial glycaemic and insulin responses because of its effect on gastric emptying and macronutrient absorption from the gut. Surprisingly, some prospective studies found that insoluble and not soluble fibre was inversely related to the incidence of type II diabetes *mellitus* (Krishnan, Rosenberg, Singer, Hu, Djoussé, Cupples, & Palmer, 2007; Montonen, Knekt, Järvinen, Aromaa, & Reunanen, 2003).

Several studies conducted during the last decade regarding the effect of dietary fibre on insulin sensitivity provided controversial results (Babio,

Balanza, Basulto, Bullo, & Salas-Salvado, 2010; Pereira, Jacobs, Jr Pins, Raatz, Gross, Slavin, & Seaquist, 2002; Weickert, Möhlig, Schöfl, Arafat, Otto, Viehoff, Koebnick, Kohl, Spranger, & Pfeiffer, 2006; Giacco, Parillo, Rivellese, Lasorella, Giacco, D'Episcopo, & Riccardi, 2000; Chandalia, Garg, Lutjohann, Von Bergmann, Grundy, & Brinkley, 2000; Jenkins, Kendall, Augustin, Martini, Axelsen, & Faulkner, 2002). In a randomized crossover study, Pereira *et al.*, (2002) used a euglycaemic-hyperinsulinemic clamp test to measure insulin sensitivity in eleven obese hyperinsulinaemic participants. Their study showed that consumption of a whole grain diet led to a postprandial improvement in insulin sensitivity when compared to a refined grain diet.

Similarly, Weickert *et al.* (2006) used the same method to measure insulin sensitivity in overweight and obese women and found that this increased after 3 days of consuming a diet containing bread enriched with insoluble fibre compared to another diet containing white bread. Giacco *et al.* (2000) carried out a 6 months randomized parallel study comparing a diet containing 50 g/d of soluble fibre with a diet containing only 15 g/d of fibre. They found an improvement in the daily blood glucose profile and glycated hemoglobin (HbA1C) levels and a marked reduction in the number of hypoglycaemic events. Chandalia *et al.* (2000) also demonstrated that high fibre diets contributed to better metabolic control in thirteen type II diabetic patients. In acrossover study in which patients were randomized to a diet containing moderate amount of fibre (8 g of soluble fibre and 16 g insoluble fibre) or to a diet containing high amount of fibre (25 g of soluble fibre and 25

g insoluble fibre), plasma glucose concentrations were significantly lower for the high fibre diet than for the low fibre diet (Babio *et al.*, 2010).

In contrast, Jenkins *et al.* (2002) used acrossover design to study the effects of a diet high in cereal fibre in type II diabetic patients and found no improvement in conventional markers of glycaemic control after 3 months of intervention.

In clinical studies using fibre supplements, only the viscous variety of soluble fibre plays a significant role in reducing postprandial glycaemia. This is in contrast to the findings from different authors where insoluble fibre, but not soluble fibre, from natural food sources was inversely related to the risk of diabetes. (Krishnan *et al.*, 2007; Montonen *et al.*, 2003; Meyer, Kushi, Jacobs Jr, Slavin, Sellers, & Folsom, 2000).

Currently, the American Diabetes Association recommends that diabetic patients consume 14 g/1000 kcal/day of fibre because a high amount of fibre is necessary to improve glycaemic control (Babio *et al.*, 2010; ADA, 2008).

However, while the short term beneficial effects of fibre on the glycaemic profile may have been documented, there have not been enough trials to prove categorically that soluble fibre supplements would be an effective tool for ameliorating glycaemic control in the long term. Although prospective studies have shown that fibre in the diet could protect an individual from diabetes, clinical trials are still needed to corroborate these reports (Babio *et al.*, 2010).

Sugars

GI is affected by the composition of sugar in a food. For example, sucrose which is made up of glucose and fructose has a lower GI than glucose because half of the sucrose molecule is made up of fructose, a type of sugar that elicits low blood glucose response (Pi-Suyer, 2002). In addition, while the GI of sucrose is 68, the GI of glucose is 100 (Pi-Suyer, 2002). This variation in GI as a result of composition of sugar could also affect the GL. Foods containing sucrose or fructose tends to have lower glycaemic responses (Brand-Miller, Pang, & Broomhead, 1995; Wolever, Nguyen, & Chiasson, 1994). This is because fructose from the disaccharide sucrose, added, or found naturally in foods is stored in the liver as glycogen and slowly converted (if at all) into glucose to enter the general circulation. Wolever *et al.* (1994) reported that the diet's GI is inversely associated with simple sugar intake because foods rich in sugars, such as milk and fruit, have relatively low GI values due to the increased galactose and fructose intake in sugars compared to starches, which are polymers of glucose.

Other factors

Insulin response

Another factor that has been found to have considerable effect on the blood glucose level of an individual following consumption of a carbohydrate rich diet is insulin response. Insulin is the primary hormone the body uses to maintain blood glucose levels within a healthy range. Therefore, in a well fed state or when foods especially with considerable amounts of carbohydrates (depending on their composition) are eaten, elevated levels of intracellular glucose in the hepatocyte allows glucokinase to phosphorylate the excess

glucose to glucose-6-phosphate. This reaction stimulates insulin response or activation which makes for conversion of the excess glucose to glycogen. The conversion of glucose-6-phosphate to glycogen (glycogenesis) is favoured by inactivation of glycogen phosphorylase and activation of glycogen synthase. Elevated insulin level results in overall increased glycogen synthesis or glycogenesis and inadequate secretion of insulin (poor response) could result in improper metabolism of carbohydrates, proteins and fats, leading to hyperglycaemia.

Miller, Pang, and Bramall (1992) in their study noted a negative relationship between the GI and insulin response of some foods, a typical example being Calrose brown rice with a GI of 83 but with a contrasting insulin index (response) of 51. Although it is known that insulin responses to carbohydrate foods is potentiated by addition of fats to the food, the reports of Miller *et al.* (1992) indicated that the fat contents of the rice was negligible. Therefore, insulin response should be a factor of consideration when determining the optimal carbohydrate foods for diabetic patients.

Protein content

Protein-rich foods increase insulin secretion leading to lowering of postprandial blood glucose concentrations. Thus, the natural protein contents of some foods might be the reason why their starches are not easily hydrolysed which confers them with lower GIs. A typical example is the case of pasta in cereals and gluten that slow the action of pancreatic amylases, thereby leading to lower GIs. Protein may influence gastric emptying and insulin secretion, but effects on GI are generally not seen unless relatively large amounts of about 30 g of protein and 50 g of fat per 50 g carbohydrates are added (Wolever *et*

al., 1994). An exception is milk protein, which increases the insulin response. Although addition of protein to a meal containing carbohydrates may result in a lower glucose response, the relative difference between starch-rich foods with different GI values remains (Bornet *et al.*, 1987). Adding protein to a carbohydrate containing food can also lower overall GI (Miller *et al.*, 2006).

Fat

Fat increases the time it takes for food to leave the stomach and enter the intestine. By slowing the rate at which dietary carbohydrates are digested in the intestine, fat containing foods may affect the rise in blood glucose and yield a lower GI than similar foods without fat. For example, the GI of potato chips is 57, French fries is 75 and baked potato is 85 (Brand-Miller, 2003).

Processing techniques

It has been established that different food processing techniques affect the digestibility of starch which has some implications on the GIs of these foods. Processing techniques may affect both the gelatinization and retrogradation processes, influencing resistant starch formation. For example, roasted and fried foods were reported to have higher GIs than boiled foods (Deepa *et al*, 2010). In another study, steam cooking was reported to aid the production of RS17 and starches isolated from several steam-heated legumes were reported to be rich in indigestible RS (19% to 31%, dry matter basis), which was not observed in raw beans (Tovar & Melito, 1996). Again, Bahado-Singh *et al.* (2011) reported that processing of sweet potatoes by boiling elicited lower GI values when compared to frying, baking, and roasting of sweet potatoes. The study of Deepa *et al.* (2010) showed that the beneficial effects of dietary fibre in hindering the actions of hydrolytic enzymes are

nullified when whole grains are ground as they are hydrolyzed at the same rate as polished grain flour.

A typical case of the effect of processing a food on its effect on blood glucose levels is seen in the study of Alegbejo, Ameh, and Ogala (2008) which reported that boiled cocoyam has a high GI and so may not be good for diabetics, a finding that contradicted the traditional use of cocoyam (either boiled or other processed forms) in Nigerian ethnomedicine in the management of diabetes whereas the study of Eleazu , Okafor, and Ifeoma (2014) reported the hypoglycaemic action of oven dried cocoyam in experimental diabetic rats and which findings corroborated the traditional use of cocoyam (either boiled or other processed forms) in Nigerian ethnomedicine in the management of diabetes.

These reports point to the fact that methods of processing of food samples usually affect their GIs. Finally, processing of foods using high temperatures could induce gelatinization, thereby permanently disrupting the amylose-amylopectin structure of the starch complex, making it more readily accessible by digestive enzymes.

Cooking

Raw starches have a much slower and lower glycaemic response compared with the cooked form of these starches; raw foods are not as readily digested as cooked foods (Snow & O'Dea, 1981). Cooking splits the starch granules, thereby making them more available to amylase. For example, ingestion of raw starches such as purified amylopectin or cornstarch causes a much flatter glycaemic and insulinemia response as compared to cooked forms of these starches.

Variety

Variety is a key factor that affects the GIs of foods. Deepa *et al.* (2010) reported inconsistencies in GI of rice and attributed these discrepancies to the difference in their varieties. Another example is the case of boiled dasheen (*Colocassia esculenta*) that was reported to have a GI of 77, whereas boiled eddoes (*Colocassia esculenta*) were reported to have a GI of 66 (Dan, Renee, Surujpa, & Thomas, 2004). Surprisingly with same variety, glycaemic indices may vary possibly due to differences in accessions within the same variety. For example, the GI of white potatoes tends to range from moderate to very high even with the same variety.

Particle size

The physical structure of food affects the rate of absorption and subsequent rise in glucose. When food form is transformed significant increase in glucose response and insulin secretion occur (Collier & O'Dea, 1982; Wong & O'Dea, 1983; Jarvi, Karlstrom, & Granfeldt, 1995). Mechanically blended food for example, causes faster absorption and more rapid rises in blood glucose than does food blended less thoroughly by hand. When starchy foods are ground, their particles sizes become much finer which neccisitate their hydrolysis by digestive enzymes, thereby increasing their rate of absorption (Roberts, 2000; Uroo & Puttraj, 1999; Goni *et al.*, 1997; Bjorck, Granfeldt, Liljeberg, & Tovar, 1994; Wolever, Jenkins, Jenkins, & Josse, 1991). For instance, there are inconsistencies in the reported GI of rice due to particle size (Miller *et al.*, 1992). Digestibility of starch is affected by the size of the granule and surface area to starch ratio for action of hydrolytic enzymes (Urooj & Puttraj, 1999). Foods such as nuts, pasta, non-starchy vegetables,

fruit, and legumes are dense and compact in nature and may hinder penetration of starch digesting enzymes, the amylases. This translates into slower glucose release into the bloodstream and a lower GI.

Presence of anti-nutrients

Some foods contain natural substances that slow digestion. For instance, taro is reported to contain anti-nutrients such as mucilage, oxalic acid, tannins, cyanide, lectins, alpha–amylase inhibitors and protease inhibitors (Ramanatha, Matthews, Eyzaguirre, & Hunter, 2010). Anti-nutrients found in taro root have negative implications for taro as a food, yet they also have positive implications for taro as a crop that can be grown with minimal use of fungicides and pesticides. Lectins, phytates, tannins, and starch/protein and starch/ lipid combinations may survive processing and cooking and affect absorption rates (Hughes, Atchison, Hazelrig, & Boshell, 1989).

Acidity

Acid in food slows down stomach emptying, thereby slowing the rate at which dietary carbohydrates are digested. Thus increasing the acidity in a meal can lower its GI and blood glucose (Pi-Suyer, 2002).

These factors as enumerated above therefore tend to affect the validity and reproducibility of GIs and GLs of foods. Therefore, in calculating the GIs of foods, all these parameters have to be considered otherwise, such data reported may not be a true representation of the GI of the food material being investigated. Table 11 captures the summary of the food factors affecting GI.

Table 11: Food factors affecting the GI of foods and meals

Food factor	Examples of influencing factors	Effect on GI
Structure		
Gross structure	Grinding, heat treatment	Higher GI when homogenised
Cellular structure (cell wall integrity)	Ripeness	Higher GI with increased ripeness
Starch		
Granular structure (intact or gelatinised)	Heat treatment	Higher GI when gelatinised
Amylose (unbranched)	Genotype of raw material	Lower GI compared to amylopectin
Amylopectin (branched)	Genotype of raw material	Higher GI compared to amylose
Other factors		
Gel-forming types of dietary fibre	Genotype of raw material Added fibres	Lowers GI
Organic acids	Fermentation Added acids	Lowers GI
Amylase inhibitor	Heat treatment	Lowers GI
Monosaccharide	Type of added sugar eg glucose: fructose	Lower GI with increased Composition ratio
Molecular composition of carbohydrate	type of raw materials added	lowers GI with increased number bonds other than 1-4 and 1-6 Composition
Resistance starch Content	heating – cooling cycles	Indifferent when testing equal amount of available carbohydrate.

Source: Adapted from Arvidsson-Lenner *et al.*, 2004

Mixed meals

One important point when using the GI concept is its applicability to mixed meals. Some studies using measured GI values of the key foods responsible for differences in GI have shown that the GI of a composite meal

can be predicted from the GI values of the different carbohydrate-rich foods included (Collier, Wolever, Wong, & Josse, 1996; Ja ¨rvi, Karlstro, Granfeldt, Bjo¨rck, Vessby, & Asp, 1995; Chew, Brand, Thorburn, & Truswell, 1988; Wolever & Jenkins, 1986), However, other studies have concluded that differences in GI between foods are diminished when incorporated in composite meals (Hollenbeck & Coulston, 1991). In one study, using GI values of the included food items from the international table (Foster-Powell *et al.*, 2002) and measuring the GI value of the final meal according to WHO (FAO/WHO 1998), no correlation between the measured and calculated values of 14 European breakfast meals was found (Møller, Flint, Pedersen, Raben, Tetens, & Holst, 2003). In addition to the considerable range of values for the same food making it difficult to choose the relevant one, different countries might have different names for the same foods or the same name for foods with different compositions. Fat and protein may influence gastric emptying and insulin secretion, but effects on GI are generally not seen unless relatively large amounts (about 30 g of protein and 50 g of fat per 50 g carbohydrates) are added (Wolever, Katzman-Relle, Jenkins, Vuksan, Josse, & Jenkins, 1994). An exception is milk protein, which increases the insulin response. Although addition of fat and protein to a meal containing carbohydrates may result in a lower glucose response, the relative difference between starch-rich foods with different GI values remains (Bornet *et al.*, 1987). Proponents for the GI concept report that the relative rankings of GI remain the same in a mixed meal (Cui, Yang, Bian, & He, 1999; Wolever, 1990).

Clinical Significance of GI and GL

The significance of low GI foods to healthy people is an ongoing discussion within the scientific community and official bodies in different countries. Health problems associated with being overweight are a major concern for countries all over the world. The World Health Organisation and Food and Agriculture Organisation of the United Nations (WHO/FAO) have stated that, globally, overweight is a bigger problem than undernourishment. They have recommended that people in industrialized countries base their diets on carbohydrate-based low GI foods to prevent lifestyle-related diseases (FAO/WHO, 1997). 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).

For individuals with diabetes, the use of the glycaemic index and glycaemic load may provide a modest additional benefit for glycaemic control over that observed when total carbohydrate is considered alone (ADA, 2011).

European Food Safety Authority (EFSA) evaluated a number of ingredients as related to blood glucose lowering effects and concluded: "The Panel considers that the reduction of postprandial glycaemic responses may be a beneficial physiological effect." Corresponding favourable opinions have been issued for the polyols, isomalt, lactitol, maltitol, mannitol, sorbitol, xylitol and erythritol, as well as for isomaltulose and a number of other carbohydrate ingredients as well as for intense sweeteners (EFSA, 2011).

A growing number of studies suggest that reducing the glycaemic impact of the diet may help consumers eat fewer calories, however not all investigators and reviewers have reached the same conclusion (Hubrich & Nabors, 2006).

Pawlak, Ebbeling, and Ludwig (2002) concluded that obese patients should be advised to follow a low GI diet based on a concern that the reduction in fat intake widely advocated in the prevention and treatment of obesity has the potential to encourage an increase in the consumption of high GI carbohydrates.

Raben (2002) recommended low GI in the management of diabetes. A systematic review was undertaken of intervention studies comparing high and low GI foods and diets on appetite, food intake, energy expenditure and body weight. Of 31 short-term studies, low GI was associated with a greater feeling of fullness or reduced hunger in 15. No difference was seen in 16. In 20 longer term studies, weight loss occurred in four low GI and two high GI trials, however it should be noted that many of the diets had the same number of calories (Raben, 2002).

ILSI Europe, a regional group of the International Life Sciences Institute (ILSI), published a concise monograph on "Food, Glycaemic Response and Health" in 2011, which reviewed the scientific evidence for an influence of the glycaemic response on health indicators related to blood glucose management, insulin resistance, plasma lipids, satiety and body weight. This review concludes that "there is a growing body of scientific evidence that compositional changes affecting the glycaemic response to foods is associated with beneficial outcomes related to key public health priorities, including type II diabetes, weight management and CHD". Dietary interventions that lower the GI and/or GL of the diet have been shown to improve fasting blood glucose in individuals with impaired blood glucose

control, e.g. diabetics. Similarly, glycated proteins (associated with tissue damage) are reduced, with the effect being greater in participants.

The GI concept has been accepted by many nutritionists, dietitians and the public as a fundamental health principle (Irwin, 2001). The FAO/WHO and numerous other international organisations with a health focus have endorsed the GI concept (Ludwig & Eckel, 2002).

Contrasting Opinions on the Use of GI/GL

The 1998 FAO/WHO Expert Consultation reported that the GI concept is a useful tool for selecting the most appropriate carbohydrate containing food for the maintenance of health and the prevention of certain diseases (Mann, Cummings, Englyst, Key, Liu, Ricchardi, Summerbell, Uauy, van Dam, Venn, Vorster, & Wiseman, 2007; Nantel, 1999; FAO/WHO, 1998). More specifically, the FAO/WHO (1998) recommends that when considering carbohydrate foods, the "glycaemic index be used to compare foods of similar composition within food groups". Many guidelines for diabetes positively recommend the use of low GI foods. The European Association for the Study of Diabetes (EASD) stated that carbohydrates foods which are rich in dietary fibre and have a low GI can be recommended as part of the diabetic diet (The Diabetes and Nutrition Study Group of the European Association for the Study of Diabetes, 2000). The WHO/FAO and health agencies in Europe, Canada and Australia all acknowledge the GI concept and advocate the consumption of a controlled GI diet (Ludwig, 2007; Frost & Dornhurst, 2000). Food-based dietary guidelines are considered one of the most effective approaches to public communication of nutrition (Englyst *et al.,* 2007). In South Africa, the South African Food-Based Dietary Guidelines acknowledge the GI concept,

referring to the specific healthful effects of low GI foods in preventing chronic disease and recommend the consumption of unrefined starches and fibre.

The utility of GI and GL has been querried by several authors. Thus, failure to consider the insulin response (Coulston *et al.*, 1984), the high intra- and inter-participant variation in glucose response to a food (Pi-Sunyer, 2002), and a loss of discriminating power when foods are combined in a mixed meal (Flint *et al.*, 2004). Moreover, foods with a high sugar (sucrose) content and those containing both carbohydrate and fat may have a low GI, but may not be regarded as particularly appropriate choices because of their energy density and nature of dietary fat (Freeman, 2005). In addition, many organisations do not agree with these statements, and many researchers suggest quite the opposite (Sievenpiper, 2004). However, the optimism surrounding GI as a dietary tool is not evident everywhere. Few governmental agencies in the United States of America (USA) have accepted the GI concept as a dietary approach and the concept is still being debated heatedly (Frost & Dornhurst, 2000; Weichselbaum, 2010). Most diabetic associations, including the Canadian Diabetic Association, Diabetes Australia, the European Association for the Study of Diabetes and Diabetes UK, include the GI concept in their recommendations. However, the American Dietetic Association maintain their position that carbohydrate quantity is more important than quality, dismissing the use of the GI in diabetes therapy (Sievenpiper, 2004). Ludwig (2007) reported that no governmental agency or major professional association in the USA advocates the consumption of a low GI diet. He states that data inconsistency, uncertainty in measuring mixed meal effects, and the practicality of a low GI diet, are the three main points central to the GI debate

in the USA. It is evident that counselling individuals on the benefits of a controlled GI diet is still a matter of dispute (Frost & Dornhurst, 2000; Weichselbaum, 2010). Published studies have reported improved glucose tolerance and other health gains by using GI to determine food choice, but questions are still being asked regarding the practicality, clinical utility and validity of the GI concept in meal planning (Kraus, Eckel, Howard, Appel, Dasniels, Deckelbaum, Erdman, Kris Etherton, Goldberg, Kotchen, Lictenstein, Mitch, Mullis, Robinson, Wylie-Rosett, Sachiko St.Jeor, Suttie, Tribble, & Bazarre, 2000).

Although some researchers and health professionals question the relevance and practicality or express concerns related to the validity and reliability of data, GI values in combination with food composition data seem to be a more useful source of dietary advice than the chemical classification of carbohydrates alone (Foster-Powell *et al.*, 2002; Ludwig, 2007).

GI/GL and Health

The rate of glucose entry into blood and the duration of the elevated blood glucose is known to induce many hormonal and metabolic changes that may affect health and disease parameters. In this respect, low-GI foods were often found to induce benefits on risk factors for certain chronic diseases. Because of these observations it was proposed that GI data for foods could be used to make priorities for food selection within food groups. Meanwhile, many studies have examined the short-term biological and health effects of foods, meals and diets of varying GI (Benton *et al.*, 2003; Wolever & Mehling, 2003; Foster-Powell *et al.*, 2002; Kaplan *et al.*, 2000; Ja¨rvi *et al.*, 1999 Wolever & Bolognesi, 1996a; Brand-Miller, 1994; Jenkins *et al.*, 1987).

More recently, intervention studies were developed (Rizkalla *et al.*, 2004; Bouche´ *et al.*, 2002; Wolever & Mehling, 2002; Gilbertson *et al.*, 2001 Giacco *et al.*, 2000; Frost *et al.*, 1998, 1994; Brand *et al.*, 1991) and some epidemiological studies based on prospective cohorts have provided new conclusions about the possible implications of GI on health; for example, diabetes (Rondini & Bennink, 2007; Foster-Powell *et al.*, 2002; Meyer *et al.*, 2000; Salmeron *et al.*, 1997a,b), cardiovascular diseases (CVD) (Liu *et al.*, 2000, 2001; Frost *et al.*, 1999; van Dam *et al.*, 2000) and cancer (Augustin *et al.*, 2003, 2001; Franceschi *et al.*,2001; Jenkins & Franceschi, 2001; Slattery *et al.*, 1997). GI may also have relevance for sports performance (Beavers & Leutholtz, 2008 ; Bernard *et al.*, 2005; DeMarco *et al.*, 1999; Thomas *et al.*, 1991), appetite control (Holt *et al.*, 1996) and cognitive performance (Benton *et al.*, 2003), whereas its role for obesity has recently been debated (Pawlak *et al.*, 2002; Raben, 2002). Recently, Livesey (2002) addressed the effects of low and high glycaemic meals and diets on health and disease-related parameters. Based on recent observations it is expected that reductions in daily glycaemic load (GL) may lead to a reduced risk for developing diabetes and CVD. Salmeron (1997a, b) showed that the GL of the daily diet correlates with the risk of developing diabetes in women but not in men. Brand-Miller (2003) observed a clinically significant decrease of protein glycation with a reduction of GL of the diet. Such observations encompass the potential to reduce the glycaemic response to foods by such means as the substitution of available carbohydrate with indigestible or non-availablecarbohydrate or with protein and/or fat. In contrast, in the Framingham Offspring Cohort it was recently demonstrated that whole-grain intake is inversely associated with homeostasis

model assessment of relative insulin resistance (HOMA-IR), and a lower prevalence of the dysmetabolic syndrome, whereas dietary GI, but not GL, is positively associated with HOMA-IR and the prevalence of the dysmetabolic syndrome (McKeown *et al.,* 2004). According to Brand-Miller (2004), the quality of carbohydrate more often shows a significant association with disease risk (diabetes, CVD and cancer) than does the carbohydrate content or GL of the diet. Recently, several other studies and reviews addressed the impact of GI and GL on health aspects (Frost *et al.,* 2004; Kelly *et al.,* 2004; Opperman *et al.,* 2004; Tavani *et al.,* 2003). No benefits occurred in the Frost study, but according to the authors it cannot be excluded that potential effects may have been concealed due to drug therapy. In the Tavani study, a higher GI slightly increased risk for acute myocardial infarction but only in elderly individuals (more than 60 years) in association with overweight. On the other hand, the meta-analysis by Opperman *et al.* (2004) support the value of low-GI foods to lower total cholesterol and improve metabolic control of diabetes. The benefits in the Kelly study were modest, and appeared mainly on total cholesterol and glycated haemoglobin. Based on the publications listed above there is accumulating evidence (Brand-Miller, 2004) that diets containing a preponderance of foods that elicit low glycaemic responses ('low-GI foods or diets'), as originally defined by Jenkins *et al.* (1981) induce modest to clinically important benefits in the intermediate term as shown by intervention studies, and from epidemiological studies of health benefits in the longer (6–10 year) term.

Glycaemic index labelling

The consumer has the right to be informed about the impact that a food may have on metabolism and health. Food labelling in terms of compositional information aims at informing the consumer about the composition of a food and to assist the consumer in the selection of a healthy diet (Venter *et al.*, 2003). Consumers in most developed countries have been exposed to the GI concept from the 1990s, through numerous public books and media inserts. As a result consumer interest is ready for food labelling to include GI indications in a similar fashion to other nutritional components such as protein and fat content (Irwin, 2001). The GI concept has quickly become a highly sought after tool used in conjunction with other composition information to guide food choices. According to Mitchell (2008), the GI concept can be considered the most promising form of labelling to date, however in global terms, labelling legislation has not caught up with this demand. However, labelling of a food in terms of its GI is a complex matter and special consideration is needed before foods are labelled with GI values as an aspect of nutritional information and healthy eating (Arvidsson-Lennor *et al.*, 2004). The three common justifications for GI labelling include (1) that the GI to be assessed needs to be done in an experienced laboratory or clinic, (2) that the foods labelled with GI be high carbohydrate foods, and (3) that the comparison of GI of different foods should be limited to foods within the same food groups (Arvidsson-Lennor *et al.*, 2004; Venter *et al.*, 2003). It is recommended by Venter *et al.* (2003) that only foods containing more than 10 g carbohydrate per 100 g portion, or supply a total of at least 40 % of energy from carbohydrate, should be labelled with GI. The labelling of low carbohydrate

foods for GI is not meaningful (Venter *et al.,* 2003), but in some cases it is done for the benefit of the producer while misleading the consumer. Many consumers are unaware of the GI concept, and do not understand why certain foods are labelled for GI and others not. Often food manufacturers who supply GI on their food labels do not necessarily intend to educate consumers about the concept, but rather just want to inform the consumer that their product is superior to a competitor's product. It is strongly recommended that consumers be educated that all nutrients in a food should be considered as a whole, and that GI should not be considered as the only factor influencing food choice (Ludwig, 2007).

There are many ways of presenting the GI of a food on the product label. The way in which the GI of a food product is presented on the product label is critically important for optimal impact: the food label needs to be simple and understandable, but include enough information to educate the consumer. Irwin (2001) recommends the use of a symbol to indicate a food product's GI. By using a simple and easily recognisable symbol, Irwin (2001) states that consumers will gain a better understanding of the relationship between GI and health, dietitians, and other health professionals will be supported in their educational efforts and the food industry will make a contribution to increasing the recognition by consumers of healthy food choices. Various countries have introduced some form of GI indication on the labels of food products, with Australia being considered the leader in this context. In Australia, official dietary guidelines for healthy consumers as well as an official GI trademark have been developed (Foster-Powell & Miller, 1995). The Dietary Guidelines for Older Australians specifically recommend:

"Eat plenty of cereals, bread and pasta – prefer high fibre foods and those with a lower glycaemic index" (National Health & Medical Research Council, 2003). In the United Kingdom (UK) many of the major supermarket chains have developed their own symbols on packaging and within stores. Some supermarkets have also determined GI of selected healthy products, and supported this with nutritional information in the form of in-store leaflets, websites, journal articles, GI diet advice and diet plans (Mitchell, 2008). In South Africa, GIFSA, based in Nelspruit, evaluates GI response by means of how fast and to what extent an ingested carbohydrate containing food affects the blood glucose levels of a selected trained panel. The Nutrition Information Centre of the University of Stellenbosch (NICUS) applies a similar method to determine carbohydrate digestion rate in human participants. The food industry, more specifically Woolworths, also demand in-house in vivo testing before GI indications are allowed on their product label. However, Ghana is yet to consider GI labelling.

Trends on Hypertension Diabetes and Obesity in Central Region

Table 12 shows the trends on hypertension, diabetes and obesity in Central Region from 2014- 2018.

Table 12: Trends on Hypertension, Diabetes and Obesity from 2014 to 2018

	YEAR				
NCDs	2014	2015	2016	2017	2018
Hypertension	106,775	65,999	64,612	73,801	56,926
Diabetes	29,541	19,838	18,559	30,042	19,336
Obesity	630	338	362	414	320

Source: District Health Information Management System (DHIMS 2), 23/12/19

Review of GI/GL of the study food samples

Table 123: Emperical studies on food samples

Food sample	Cooking method /cooking time	Country of determination	GI	Serving	GL
Sweet potatoes	Boiled	Australia	44	150	11
	peeled, cubed,	Jamaica	46±5	150	15
	boiled for 30 min	Australia	61±6	150	11
	orange flesh, cut into pieces and boiled for 10 min	New Zealand	77±12	150	19
	_	Jamaica	76±7	150	34
	Peeled and fried	Jamaica	82±5	150	37
	Peeled and roasted	China	77±4	150	16
	Orange flesh	Australia	75±5	150	22
	Purple skin, white flesh	Canada	48 ±6	150	
	Sweet potato, NS				16
Taro (*Colocasia esculantus*	peeled, boiled 30 min, refrigerated, reheated for 1 min	_	77±10	150	44
Dasheen	peeled, boiled, peeled, boiled)	China	48±5	150	4
Eddoe (*Colocasia esculenta var. antiquorum*),		Australia	54	150	4

	peeled, boiled 30 min,	New Zealand	56±12	150	4
	uncrushed (whole), refrigerated, reheated for 1 min		75±12	150	43
	peeled, boiled 30 min, refrigerated, reheated for 1 min		61±10	150	21
Unripe plantain (*Musa paradisiaca*)	Raw	Ghana	40 ± 4	120	13
Green plantain (*Musa paradisiaca*),	peeled, fried in vegetable oil				
Green plantain		Jamaica	40±3	120	14
Ripe plantain	peeled boiled 10 min	Jamaica	39±4	120	9
Ripe plantain (*Musa paradisiaca*),	peeled, fried in vegetable oil	Jamaica	90±6	120	26
	peeled, boiled 10 min	Jamaica	66±2	120	13

Source: Adapted from Mendosa 2008; Foster-Powell *et al.*, 2002

CHAPTER THREE

RESEARCH METHODS

This chapter presents the materials, procedures and methods that were employed in carrying out the study. Emphasis is placed on research design, description of study site, population, study food samples, study participants, preparation of test foods, data collection, processing and analysis.

Research Design

Experimental design, specifically the crossover design was used for the study. In an experimental study, the researcher manipulates at least one independent variable, controls other relevant variables and observes what will happen to the participants as a result. Experimental design is one that is conducted in a controlled environment. The principal advantage of this approach to research is that it identifies cause and effect relationships. According to Creswell (2012), it involves direct manipulation of the independent variables and control of extraneous factors for the purpose of determining their effects on behaviour. It is upon this assertion that the researcher deemed it appropriate to adopt the use of experimental design, specifically true experimental design, in carrying out the study. This is because the researcher intended to manipulate the staples (sweet potatoes, taro and firm ripe plantain) in order to determine their glycaemic index and load.

A crossover design involves repeated measurements designed such that each experimental unit (participant) receives different treatments during the different time periods (i.e., the participants cross over from one treatment to another during the course of the trial). This design was considered because according to Steven (2005), it yields a more efficient comparison of

treatments. Few participants may be required in the crossover design in order to attain a high level of statistical power or precision. Intuitively, each participant serves as his/her own matched control. Every participant receives treatments. A comparison is made between the participants' response and the treatments given. Thus in the case of this study, every participant received three treatments. The participants crossed over from one treatment to another during the course of the clinical trial at different times. This brought out the differences in participants' glucose response for the reference and test foods which were used to calculate the GI/GL of the test food samples (treatments). Although the main disadvantage of a crossover design is carryover effect, the impact of carryover effects was diminished by incorporating lengthy washed out periods which did not lead to mortality (attrition) – loss of participants. A washout period is defined as the time between treatment periods. Therefore instead of immediately stopping and then starting the new treatment, there was a period of time where the reference food and test foods are washed out of the participants' system. In this study, the washout periods were four and six day intervals for reference and test foods respectively. Although there are other threats to internal validity such as history, maturation and instrumentation, it was deemed appropriate to minimize the threat of history by admonishing the participants to follow the protocol and time lines given. This was done by reminding the participants on phone a day before each scheduled session to stick to protocol. With regards to maturation, which is the process of physical/biological change that takes place within the participants over a period of time, refreshment in the form of snacks and meals were given to the participants after the each session to offset this threat to experimental validity.

Greater control of extraneous variables and environment were observed. Again, the proximate analysis of the food samples was ascertained through experimentation.

Description of Study Site

Permission was sought from Central Regional Health Directorate to undertake the clinical trial test for the glycaemic index determination at Biriwa Baobab Medical Centre in the Mfantseman Municipality (see Appendix C). Biriwa is one of the towns in Mfantseman Municipality in the Central Region of Ghana. According to Ghana Statistical Service's 2010 population and housing census, the population of Biriwa is 7,086. The main occupation is fishing with a few people engaged in farming. Its adjoining communities are Anomabo and Yamoransa. The Baobab Medical Centre serves clients from all over the Mfantseman municipality.

This site was chosen because it is well resourced and has professionals who could easily assist in the collection of data. Being a health facility that attends to diabetic patients and patients with other related non communicable diseases, the researcher was sure to learn more especially in the process of taking blood samples and checking blood glucose.

Population of the Study

Population is the broader group of people or objects the researcher intends to generalise the results of the study to (Williman, 2011). In other words, a well-defined or complete set of elements (persons, organisations, even events or objects) that possess some common characteristics. In this study, the population included both persons and objects (food samples). Thus all 'healthy' individuals in Central Region with no medical conditions that met

the inclusion criteria. This type of study required the use of healthy individuals and the results generalised to people with or without Chronic Non Communicable Diseases (CNCDs). The accessible population was all 'healthy' individuals in Mfantseman Municipality who were willing and able to meet the inclusion criteria. In the case of the food samples, root tubers and firm ripe plantain were considered.

Study Food Samples

The food samples for the study were purchased from Mankessim in Mfantseman Municipality since the variety of the staples required for the study could be purchased at Mankessim. Specifically, sweet potatoes (CSIR CRI Ligri – pale yellow variety), taro, and firm ripe plantain (false horn variety -'apantu') were sampled for the study. From the market women, the food samples were brought to the market space a day after harvesting. All the food samples purchased were wholesome and were thoroughly washed to remove all dirt/soil before they were used to prepare the test meals.

Study Participants

Ethical clearance for the study was obtained from the Institutional Review Board, University of Cape Coast and Ghana Health Service Ethics Review Committee (see Appendix A and D). Following the approval, nineteen (19) healthy participants consisting of 9 males and 10 females aged between 20 and 50 years with no medical conditions, willing to participate and had fulfilled the inclusion and exclusion criteria from Mfantseman Municipality were purposively recruited for the clinical trial. After the initial screening, more than nineteen (19) participants were selected. This called for additional criteria for selection. However, nineteen of the participants were randomly

selected out of the 38 initially selected for the study. The selected participants signed consent forms shown in Appendix E.

The recruitment of the nineteen participants was in line with the FAO/WHO (1998) recommended method for the determination of Glycaemic Index. This number was defined according to two recommendations.

1) Each volunteer may perform up to six glycaemic response measurements: 3 after consumption of the standard food (glucose) and one measurement for each food to be tested with a maximum of three foods/person.
2) Each food should be tested by a minimum of 6 persons.

Inclusion Criteria

Participants should:

1. be healthy males or non-pregnant females at least 6 weeks postpartum and non – lactating.
2. be in the age group of 20 – 50 years.
3. be within the normal BMI range of 18.5 – 25 kg/m^2
4. not have any food allergies with respect to the food samples for the study.
5. have their fasting blood glucose within 4 - 7 mmol/L.

Exclusion Criteria

Participants:

1. less than 20 years and greater than 50 years.
2. having known history of *Diabetes mellitus* or the use of anti-hyperglycaemic drugs.

3. having gastrointestinal disease that may affect nutrient absorption distribution, metabolism and excretion.
4. having a major medical or surgical events requiring hospitalization within the preceding period.
5. having BMI greater than 25 kg/m^2.
6. currently on a course of medication.

Screening of Participants

Two qualified medical practitioners were employed to screen the participants who agreed to undertake the clinical trial using the test instrument shown in Appendix F. Age and gender as well as anthropometric measurements such as body weight (in kg), height (m), body mass index (BMI) and waist circumference were recorded. Participants' blood pressure was also checked. Medical history of the participants was also taken. This was a self-report rather than an objective test.

After the screening, the participants who fell within the inclusion criteria were taken through a 2 day orientation before the start date of the experiment. They were counseled on the rules to observe during the clinical trial and the need to adhere to the rules of engagement in the research. In addition, the participants were briefed on the importance of the study. Participants were informed of a strict abstinence from smoking or drinking within the period of the study. Siler *et al.* (1998) and Attvall *et al*. (1993) indicate that alcohol consumption and cigarette smoking may have profound effects on glucose homeostasis and cause acute insulin resistance respectively. They were also not to engage in any strenuous activity prior to testing days as acute physical exercise may increase muscle glucose uptake on the following day and improve insulin sensitivity for 48 hours (Malkova *et al.*, 2000). This usually results in lower plasma insulin concentrations in response to nutrient

ingestion (Tsetsonis *et al.*, 1997; Tsetsonis & Hardman, 1996), although generally there is no effect on systemic fasting plasma glucose concentrations.

Protocol

All participants were made to undergo a 10 to 12 hr fast from the time of taking the last meal of the previous night to the morning of testing. All participants reported to Baobab Medical Centre, Biriwa at 7:30 a.m. The reporting time and venue was the same for both reference and test foods. The participants 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 for each participant each time there was a test. In addition, their waist circumference was taken using tape measure. The average heights and weights obtained were used to calculate their BMI and subsequently used during the analysis stage of the study (see Appendix I)

Preparation of Test Foods

Boiled sweet potatoes, taro and firm ripe plantain 'ampesi' and garden egg stew

The test foods were prepared professionally following hygienic protocol in the expected quality and quantity. Figure 6 represents a flow chart showing the processing and food preparation methods for the test foods. All the test foods were eaten with the same amount of garden eggs stew as is usually done in Ghana. Detailed recipe for the test foods has also been presented in Appendex J. Each of the test foods was portioned, packaged and labeled in disposable bowls based on their 50 g available carbohydrates content (see Appendix K).

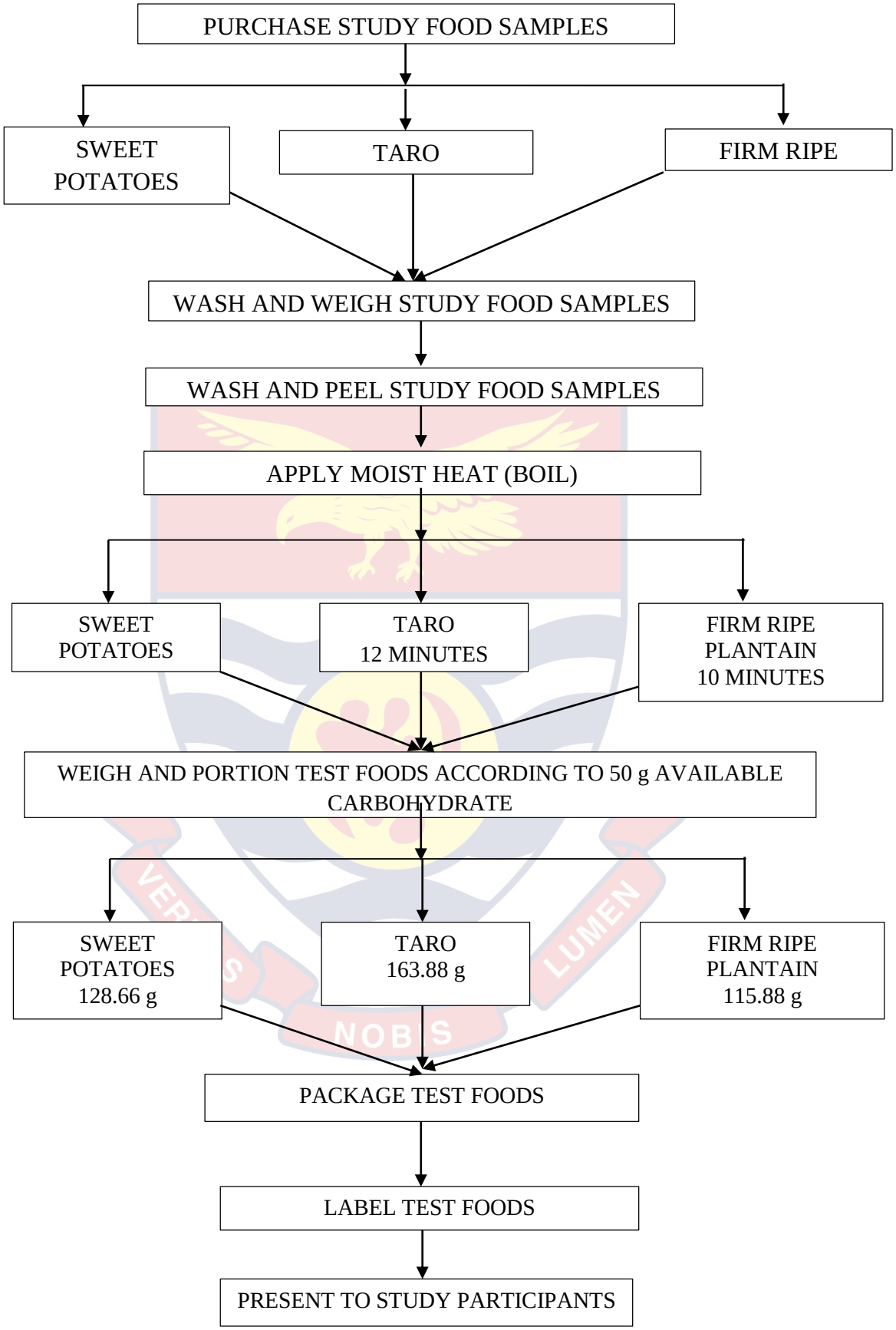

Figure 6: A flow chart showing food preparation methods of the test foods.

Source: Researcher's Construct

Proximate Analysis

The proximate composition of the food samples was carried out at the Teaching and Research Farm of the School of Agriculture of University of Cape Coast using Association of Official Analytical Chemists (AOAC) protocol. The proximate compositions for the three food samples with equal amount of garden eggs stew were determined using a standard AOAC (2005) method and the available carbohydrate content for each test meal calculated by difference using the FAO/WHO procedure. The portion of food tested contained 50 g of glycaemic (available) carbohydrate. In practice, glycaemic carbohydrate is often measured as total carbohydrate minus dietary fibre, as determined by the AOAC method. All determinations reported were carried out in triplicates. Determination of nutrients in the food samples was used to ascertain the available carbohydrate to use for the clinical trial test.

Moisture content determination

Porcelain crucibles were washed, dried and weighed. Ten grams of fresh samples were placed into the crucibles and weighed. The crucibles containing the fresh samples were placed in the oven at a temperature of 105ºc for 48 hrs. At the end of the period the crucibles were removed, cooled in a dessicator and weighed. The moisture content was then calculated as a percentage of moisture lost by the sample.

Dry matter determination

After the calculation of the moisture lost, the dry sample weight was recorded and expressed as a percentage of the fresh weight.

Ash determination

The dried samples in the crucibles were transferred to a hot plate and charred over a period for the smoke to go out. The charred samples were then transferred into a muffle furnace in desiccators and weighed. The percentage of ash was then computed as:

$$\% \text{ Ash} = \frac{\text{weight of ash} \times 100}{\text{Original weight of sample}}$$

Crude protein determination

Protein was determined by weighing 0.2 g of the milled sample into a Kjedahl digestion flask. 4.5 ml of digestion mixture was added and the sample was digested at 360ºc for 2 hrs. The digest was allowed to cool and diluted to 50 ml with distilled water.

20 ml of the digest was immediately distilled after adding 10 ml of alkali mixture using 5 ml of boric acid as indicator. 50 ml of the distillate was collected and titrated against 0.007142 Molarity of hydrochloric acid to pink end point.

Percentage protein was calculated using the formula;

$$\% \text{ N} = \frac{(\text{Sample Titre} - \text{Blank Titre}) \times \text{Molarity of HCl} \times 14.007 \times 100}{\text{Sample weight (mg)}}$$

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

Fat/Oil determination

Twenty grams of the milled sample was weighted into a 50 x10 mm soxhlet extraction thimble. This was transferred into a 50 ml capacity soxhlet extractor. A dried clean 250 ml round bottom flask was weighed. About 150 ml of petroleum spirit of boiling point 40-60ºc was added and connected to the

Soxhlet extractor. After 5 to 6 hrs of extraction, the flask was removed, cooled in a dessicator and weighed. The percentage fat/oil was calculated as followed.

$$\text{Crude Fat (\%)} = \frac{\text{Weight of Oil} \times 100}{\text{Sample Weight (g)}}$$

Fibre determination

0.5 g of the sample was weighed into a boiling flask, 100 ml of 1.25% sulphuric acid solution was added and boiled for 30 min. Filtration was carried out in a numbered sintered glass crucible. The residue was transferred into the boiling flask and 100 ml of 1.25% sodium hydroxide solution added. It was then boiled for 30 min. Filtration was continued after the boiling and the residue washed with water and methanol. The crucible was dried in an oven overnight at 105ºc and weighed. The weighed crucible was placed in a furnace at 500ºc for 3 hrs. The crucible was slowly cooled and weighed.

$$\text{\% Crude fibre} = \frac{\text{weight loss through ashing x 100}}{\text{Original weight of sample}}$$

Carbohydrate determination

Some of the milled sample was weighed into a 50 ml conical flask and 30 ml of distilled water was added. The content was allowed to simmer gently on a hot plate for 2 hrs. It was toppled periodically to 30 ml and allowed to cool after the 2 hrs. The solution was filtered into a 50 ml conical flask and topped to volume. The extract was kept for colour development.

Two mililitres of glucose standard solution and the extract were pipetted into a set of boiling tubes. Ten mililitres of anthrone solution was rapidly added to the boiling tubes, mixed thoroughly and cooled under running tap water. The tubes were placed in a beaker containing boiling water in a dark

fume cupboard for 10 min. The tubes were allowed to cool in cooled water in the dark.

The optical density of the standards and the sample solution was measured at 625 min using the spectrophotometer. A calibration graph was drawn from the standards and used to obtain the miligrams of glucose in the sample aliquot.

$$\% \text{ carbohydrate} = \frac{C(mg) \times \text{Extract volume}}{10 \times \text{aliquot} \times \text{sample weight (g)}}$$

Where C (mg) = carbohydrate concentration from the graph.

The calculations were based on 100 g. Table 14 presents the chemical composition of the test meals based on 50 g available carbohydrate.

Table 14: Chemical Composition of Test Foods per 50 g Available Carbohydrate

Food sample	Weight (g) Serving ingested	Dry Matter	Moisture	Ash	Protein	Fat/Oil	Fibre	CHO
Sweet Potatoes	128.66g	39.35589	89.30410	1.2619	16.91467	15.76621	4.5673	50
Taro	163.88g	50.97733	112.90266	1.5634	14.32638	19.40716	6.7383	50
Firm ripe Plantain	115.85g	31.84064	84.0093	1.1502	13.28756	13.14576	2.8204	50

Source: Bartels, 2020

Ethical Consideration

Confidentiality of information provided by respondents, voluntary participation and anonymity of identity were ensured during the study. Confidentiality ensured participants' information were well kept and that they were protected from undue access to their privacy. Participants' right to be excluded from the study without any penalty was respected.

Anonymity was maintained by identifying respondents solely by numbers and codes rather than by names. It is imperative to note that participants agreed that their pictures be taken for the study. Strict precautions were observed at the laboratory during the proximate analysis, preparation and serving of meals as well as during the clinical trials at the Biriwa Baobab Medical Centre. The principle behind obtaining ethical research is to ensure no harm is caused to participants. Possible risks were identified and methods that could minimize the risks were selected. The researcher ensured that accurate data was collected and recorded without any distortion.

A storage system that was safe and accessible was devised. In cases where data needed to be transmitted, the method of transmission was secured and not open to unauthorized access. Finally, the data collected was analysed immediately and disposed of as early as possible by removing all labels and titles that could lead to identification. The disposal methods were shredding documents, formatting discs and deleting all saved pictures.

Data Collection Procedure

Data obtained from the proximate analysis was recorded and used accordingly. In determining the glycaemic index and load of the three food samples, all the participants for the study were made to fast between 10 and 12

hours from the time of taking the last meal of the previous night to the morning of the testing. All the participants reported at the Biriwa Baobab Medical Centre at 7:30 a.m for all the clinical trials. According to FAO/WHO report (1998), a standard drink of water, tea or coffee could be given with each test meal. In this study, the standard drink used was water. The time and venue was the same for the reference and test food samples. The anthropometric measurements of the participants were taken and recorded using the international standard glycaemic index test protocol ISO 2010 (1S0/FDIS 26642: 2010) as outlined by Finocchiaro *et al.,* (2012), which is in line with WHO's recommendation. In addition, the blood pressure of participants was recorded.

Fasting blood glucose

The capillary blood sample of each participant was taken to check their Fasting Blood Glucose (FBG) levels using URIT-26 blood glucose meter. Blood was obtained by pricking the fore finger using a Lancing Device. Prior to the finger-prick, participants were encouraged to warm their hands to increase blood flow. Fingers were not squeezed to extract blood from the fingertip so as to minimize plasma dilution. The time for taking the fast blood glucose was recorded to confirm that each participant had undergone the 12 hr fast prior to the test.

Administering of reference food

Glucose obtained from a pharmaceutical shop was used as the reference food for the study. The glucose was subjected to test to check the extent of purity through visual examination, solubility in water and pH. It was

observed to be a white powdery substance, completely soluble in water and had pH of 6. The test results proved that product was pure.

The participants were given a solution containing 50 g of glucose diluted into 250 ml water twice on two different occasions. Each participant was given a stop clock to check on the accuracy for the time schedule. Fluid ingestion took place within 5 to 10 min. The first blood samples were taken exactly 15 min after first sip of the drink. Soon after, their blood glucose was checked. The time that each participant took the solution was noted. Capillary blood glucose was checked using finger-prick samples from fasting participants during the 15^{th}, 30^{th}, 45^{th}, 60^{th}, 90^{th} and 120^{th} min after the consumption of the glucose solution and their corresponding glucose concentration recorded in mmol/L following the recommendations made by Brouns *et al.* (2005). A detailed sugar profile sheet for recording participants' glucose response level is presented in Appendix G.

The participants' recorded glucose concentration was used to plot their glycaemic response curve. According to the same protocol the amount of food and standard of that food was tested to ensure availability of 50 g of glycaemic carbohydrate. It was considered as standard food to glucose as above. The participants were refreshed with snacks (sponge cakes and yoghurt, and digestive biscuits and malt after each session) and were allowed to go and continue with their normal duties.

Administering of test foods

The test foods were given to the participants following the same procedure as it was done for the reference test. The last meal and time the last meal was taken was recorded. Before any test food was given, capillary blood

was taken and a fasting blood glucose assayed for and appropriately recorded. The consumption of the three food samples was done at different time periods (intervention stage). This was done to minimize carryover effects. The experimental period was executed in three weeks – once in a week using the same protocol. A standard amount of 250 ml water was given to the participants with the test portions. This is in line with the recommendation of Brouns *et al.,* (2005). The test foods were ingested within 10 to 15 min. The first bite in the mouth was set as time 0 and the first blood sample was taken conventionally at exactly 15 min afterwards. The subsequent blood samples were taken on the 30^{th}, 45^{th}, 60^{th}, 90^{th} and 120^{th} min and glucose concentrations recorded in mmol/L. The three foods (sweet potatoes, taro and firm ripe plantain all eaten with equal amount of garden egg stew) were tested under the same preconditions and procedures. See Appendix H for pictures. Participants were given packed meals after each exercise and released.

Data Processing and Analysis

Data preparation began with a preliminary check of all data on the sugar profile sheet for completeness and quality. A more thorough editing was subsequently carried out. Editing consisted of screening to identify illegible, incomplete, inconsistent or ambiguous responses. Such responses were attended to by returning sheets to the field and appealing to participants to provide right responses. The editing was done to, as much as possible, eliminate errors in the data to ensure conclusive validity. The next step was coding. A numeric or alphanumeric code was assigned to represent a specific response to a specific question along with the column position or field that code occupied. A codebook containing the coding instructions and the

necessary information about the variables in the dataset was also prepared. The coded data was entered directly into a data analysis package.

The data was cleaned to check for consistency and treatment of missing responses. Forms that had been checked and found to be complete and accurate were then signed for purposes of quality control. Password restrictions on the use of the project work stations were employed to ensure security and confidentiality of the data.

Data collected on the research questions and hypotheses was analysed using parametric measures as well as Microsoft Excel computer software. The hypotheses 1, 2 and 3 and research question 1 were analysed using one-way analysis of variances (ANOVA) with Tukey Post Hoc test being used to locate the difference while values of $p \leq 0.05$ were considered statistically significant. The value of the test of homogeneity for the GI and GL of the test foods were 0.502 and 0.076 while that of the chemical composition of the test foods were 0.464, 0.401, 0.253, 0.231, 0.077, 0.990 and 0.074 for dry matter (DM), moisture, ash, protein, fats and oils, fibre and carbohydrate (CHO) respectively. The values above were greater than $p \leq 0.05$ indicating that homogeneity of variances was assumed equal. The research question 2 was analysed by comparing the field data on the glycaemic index and load of the test foods with the standard propounded by Allen *et al.* (2012), Venn & Green (2007), Burani (2006), Barclay *et al.* (2005) and Brand-Miller (2003).

The food product Incremental Area Under the Curve (IAUC) and G1/GL was calculated using Microsoft Excel 2013. The data was presented in tables using frequencies, percentages, means and standard deviations. A line

graph was also used. Subsequent statistical analyses were performed using IBM-SPSS version 25 for Windows.

The GI was calculated using the method described by FAO/WHO (1998) as the area under the blood glucose response curve of a 50 g carbohydrate portion of the test food, expressed as a percent of the response to the same amount of carbohydrate from a standard food taken by the same subject. The area under the blood glucose response curve was calculated geometrically by applying the trapezoid rule (Brouns *et al.,* 2005). When a blood glucose value falls below the baseline, only the area above the fasting level is included. All GIs that were 2 standard deviation above or below the mean GI value for a given test were ignored as outliers (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 GI of each test food was calculated as the mean GI as obtained by each participant in the study. The GI of each meal tested was taken as the mean (±s.e.m.) for the whole group. The GI values were calculated as:

$$GI = \frac{\text{IAUC test food}}{\text{IAUC standard reference food}} \times 100$$

GI values were later classified as high (70 - 100), intermediate (55 - 69), or low (<55) (Brand-Miller *et al.,* 2003) with low GI values being considered as healthy.

GL for each food was determined by the method as proposed by Atkinson, Foster-Powell & Brand-Miller (2008), Burani (2006) and Salmeron *et al.* (1997). In each individual, glycaemic load was calculated by taking the percentage of the food's carbohydrate content in a typical serving and

multiplying it by its GI value. The GL of a serving of each food was calculated as follows:

$$GL = \frac{(\text{GI of the test food} \times \text{carbohydrate content of a serving of the test food[g]}}{100}$$

GL values were classified as low (≤10), medium (>10 to <20) or high (≥20) (Venn & Green, 2007).

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

This chapter presents the results and discussion of the study. The results presentation is in two parts: the first is the demographic and general anthropometric characteristics of participants, and the second is the results based on the research questions and hypotheses of the study.

The demographic information of the participants is presented in Table 15.

Table 15: Demographic information of Participants

Variable	Frequency(n)	Percentage (%)
Male	9	47
Female	10	53
Age (Years)		
20 – 25	4	21
26 – 31	6	32
32 – 37	3	16
38 – 43	5	26
44 – 49	1	5

Source: Field data, Bartels (2020)

As seen from Table 15, nineteen participants were enrolled in the study for the selected test meals. All the participants were Ghanaians and consisted of 9 males and 10 females. Majority of the participants were females (53%) and the rest were males (47%). The age range with highest number of participants was 26 – 31 years. The least number of participants fell within the age range of 44 – 49 years. Most of the participants were young adults aged 31 and below.

General Anthropometric Characteristics of Participants

The general anthropometric characteristics of the participants with regard to the measurements of their height, weight, body mass indexes (BMIs) and waist circumference are presented in Table 16.

Table 16: General Anthropometric Characteristics of Participants

Statistic	Height (cm)	Weight (Kg)	Age (years)	BMI (Kg/m^2)	Waist circumference (cm)
Minimum	150.00	44.60	21	18.58	63.50
25 Percentile	160.00	57.40	27	19.90	71.12
Median	165.00	62.20	33	23.17	78.74
75 Percentile	172.00	66.00	40	24.60	83.82
Maximum	181.00	79.00	44	25.00	90.17
Mean	165.41	62.28	32.26	22.42	77.93
Std. Error of Mean	1.77	1.99	1.66	0.51	1.76
Std. Deviation	7.73	8.66	7.23	2.24	7.68
Coefficient of variation	0.05	0.14	0.22	0.10	0.09

Source: Field data, Bartels (2020)

The difference between the maximum and minimum height of the participants was 31cm. The mean and median values were 165.41 and 165 cm respectively. The difference in the height of the participants was not statistically significant. The difference in the weight of the participants was 34.4 Kg. The difference of 34.4 Kg was more than twice the weight of the median and even the mean weight. The difference between the 75 and 25 percentile of the participants was 8.6 Kg with reference to the weight.

The minimum age of the participants was 21 years and the maximum was 44 years. The median and mean age of the participants were almost the same indicating that the participants were about the same age. The difference between the minimum and maximum age however was less than the median age of the participants. The least Body Mass Index (BMI) was 18.58 Kg/m^2 and the difference between this and the maximum BMI was 7.02 Kg/m^2. The mean and the median value with reference to the BMI was almost the same. The BMI of the participants ranged from 18.58 Kg/m^2 to 25 Kg/m^2 which fell within the normal body weight per the classification of the World Health Organisation (2006) using BMI results. The mean waist circumference was 77.93 cm–almost the same as the median (78.74 cm). The difference between the minimum and the maximum waist circumference was 26.67 cm, which was high. It was higher than a third of the 25 percentile result. The data in Table 16 indicate that all the participants in the study fell within the inclusion criteria.

Hypothesis 1

H_o: There is no statistically significant difference in the glycaemic indices of sweet potatoes, taro and firm ripe plantain.

In testing hypothesis one, the mean and ANOVA results of the glycaemic index have been presented in Tables 17 and 18 for analysis.

Table 17: Mean results on Glycaemic Index of Test Foods

Test Food	N	Mean	Std. Deviation
Taro	19	98.76	71.23
Sweet Potato	19	33.92	44.13
Firm Ripe Plantain	19	58.89	53.12
Total	57	63.86	62.36

Source: Field data, Bartels (2020)

The results in Table 17 present the names of the test foods, mean results of the glycaemic index and standard deviation. The results show that taro had the highest mean of 98.76 with sweet potatoes having the least mean of 33.92. The mean difference between the highest and the next highest was 39.87. This difference was higher than GI of sweet potatoes by 5.95. The difference in the mean figure between sweet potato and firm ripe plantain was 24.97.

Table 18: ANOVA results on Glycaemic Index of Test Foods

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	40645.47	2	20322.73	6.19	0.004
Within Groups	177157.47	54	3280.69		
Total	217802.93	56			

Source: Field data, Bartels (2020)

Table 18 presents the results on ANOVA calculation on the glycaemic index of the test foods. The results indicate that there is a statistically significant difference [F (2, 54) = [6.19], p = 0.004] within and between the groups. This is an indication that the glycaemic index for the three test foods differ in their mean results. In determining which pairs of the test foods were statistically significant, a Post Hoc test was conducted. Turkey's HSD was used for the Post Hoc test and the results presented in Table 19.

Table 19: Post Hoc Tests for the GI of Test Foods

(I) Test foods	(J) Test foods	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Taro	Sweet potatoes	64.842 *	18.583	.003	20.06	109.63
	Firm Ripe Plantain	39.873	18.583	.090	-4.91	84.66
Sweet potatoes	Taro	-64.842 *	18.583	.003	-109.63	-20.06
	Firm Ripe Plantain	-24.969	18.583	.378	-69.75	19.82
Firm Ripe Plantain	Taro	-39.873	18.583	.090	-84.66	4.91
	Sweet potatoes	24.969	18.583	.378	-19.82	69.75

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

Source: Field data, Bartels (2020)

The results in Table 19 indicate that there is a statistically significant difference between taro and sweet potatoes with the mean difference of 64.8418 at .003.

With reference to the results in Tables 17 and 18, there is a statistically significant difference in the glycaemic index of the test foods at $p<0.05$. The null hypothesis is therefore rejected and the alternative hypothesis accepted. Therefore, there is statistically significant difference in the glycaemic index of sweet potatoes, taro and firm ripe plantain. On the contrary, the Post Hoc results in Table 19 recorded no statistically significant differences between taro and firm ripe plantain as well as sweet potatoes and firm ripe plantain. Therefore, the null hypothesis is accepted and the alternate rejected with regards to the comparison above.

Hypothesis 2

H_o: There is no statistically significant difference in the glycaemic load of sweet potatoes, taro and firm ripe plantain.

In addressing hypothesis 2, which looked at the glycaemic load of the test foods, the mean, ANOVA and Post Hoc results are presented in Tables 20, 21, and 22.

Table 20: Mean result on Glycaemic Load of Test Foods

Test Food	N	Mean	Std. Deviation
Taro	19	161.85	116.73
Sweet Potato	19	43.64	56.77
Firm Ripe Plantain	19	68.22	61.54
Total	57	91.24	96.29

Field data, Bartels (2020)

Table 20 presents the mean results on the glycaemic load of the test foods. Results indicate that the mean for taro was higher than the other two test foods. The next test food which had a figure close to that of taro was firm ripe plantain (taro > firm ripe plantain > sweet potato). The mean difference between the food with the highest mean and food with the least mean value was 118.212. The results in Table 21 indicate that the significant value was less than the alpha value [F(2, 54) = [10.75], p = 0.000)]. The results thus show that there was a statistically significant difference between and within the groups.

Table 21: ANOVA result on Glycaemic Load of Test Foods

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	147852.36	2	73926.18	10.75	0.000
Within Groups	371446.69	54	6878.64		
Total	519299.05	56			

Source: Field data, Bartels (2020)

The ANOVA results indicate that there was a significant difference in the mean results of the glycaemic load. Thus, it became necessary to conduct further test. Post Hoc test was conducted to locate where exactly the differences in the test foods lie. The Tukey Post Hoc test for the GLs of the

test foods as presented in Table 22 show statistically significant pairwise differences between taro and sweet potatoes with mean difference of 118.212 at .000 as well as taro and firm ripe plantain with a mean difference of 93.630 at .003.

Table 22: Post Hoc Tests for GL of Test Foods

(I) Test foods	(J) Test foods	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Taro	Sweet potatoes	118.212 *	26.908	.000	53.36	183.06
	Firm Ripe Plantain	93.630 *	26.908	.003	28.78	158.48
Sweet potatoes	Taro	-118.212 *	26.908	.000	-183.06	-53.36
	Firm Plantain	-24.583	26.908	.634	-89.43	40.27
Firm Plantain	Taro	-93.630 *	26.908	.003	-158.48	-28.78
	Sweet potatoes	24.583	26.908	.634	-40.27	89.43

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

Source: Field data, Bartels (2020).

It can therefore be concluded from Tables 20, 21, and 22 that there was a statistically significant difference in the results. Hence, there was a significant difference in the glycaemic loads of sweet potatoes, taro and firm ripe plantain. The null hypothesis is rejected and the alternate hypothesis is accepted. However, no statistically significant difference was found between sweet potatoes and firm ripe plantain when the Post Hoc test was conducted.

Hypothesis 3

H_o: There is no statistically significant difference in the chemical composition of sweet potatoes, taro and firm ripe plantain.

In testing this hypothesis, the chemical composition of the test foods, their mean and standard deviation and the ANOVA results are presented in Tables 23 and 24. The chemical composition of the test foods in Table 23 was based on their dry matter (DM), moisture, ash, protein, fibre and carbohydrate contents.

Table 23: The mean result on the Chemical Composition of the Test Foods

Chemical Composition	Test Foods	N	Mean	Std. Deviation
DM	sweet potato	3	30.59	.176
	Taro	3	31.11	.464
	Firm Ripe Plantain	3	27.48	.330
	Total	9	29.73	1.72
Moisture	sweet potato	3	69. 40	.154
	Taro	3	68.89	.464
	Firm Ripe Plantain	3	72.52	.330
	Total	9	70.27	1.72
Ash	sweet potato	3	.98	.019
	Taro	3	.95	.039
	Firm Ripe Plantain	3	.99	.048
	Total	9	.98	.037
Protein	sweet potato	3	13.15	.126
	Taro	3	8.74	.160
	Firm Ripe Plantain	3	11.47	.303
	Total	9	11.12	1.93
Fat and Oil	sweet potato	3	12.25	.183
	Taro	3	11.54	.505
	Firm Ripe Plantain	3	11.34	.038
	Total	9	11.71	.495
Fibre	sweet potato	3	3.55	.120
	Taro	3	4.11	.115
	Firm Ripe Plantain	3	2.43	.112
	Total	9	3.37	.746
CHO	sweet potato	3	38.86	.297
	Taro	3	30.51	.407
	Firm Ripe Plantain	3	43.16	.098
	Total	9	37.51	5.58

Source: Field data, Bartels (2020)

The results in Table 23 show that taro recorded the highest dry matter content with the mean value of 31.11 while firm ripe plantain recorded the least mean of 27.48.With regards to the moisture content, firm ripe plantain had the highest mean value of 72.52 whereas taro recorded the least mean of 68.89.

The moisture content of the food indicates the shelf life of the foods since microorganisms thrive in that condition. Intuitively, it means that with regards to the test foods, firm ripe plantain is likely to deteriorate faster than taro and sweet potatoes.

Again, in comparing their ash content, it was revealed that all the test foods had mean values closer to each other. This ranged from .95 - .99.

For the protein content, the results in Table 23 show that sweet potatoes recorded the highest mean value of 13.81 compared to firm ripe plantain and taro.

Also in relation to their fats and oils content, sweet potatoes recorded the highest mean value of 12.25 while taro and firm ripe plantain recorded almost similar values of11.54 and 11.25 respectively.

In the case of the fibre content, taro recorded the highest mean value of 4.11 contrary to figures obtained by sweet potatoes and firm ripe plantain 3.55 and 2.40 respectively.

Finally, firm ripe plantain had the highest carbohydrate content of 43.16 with taro recording the least figure of 30.51.

Table 24: ANOVA result on the chemical composition in test Foods

		Sum of Squares	Df	Mean Square	F	Sig.
Dry Matter	Between Groups	23.027	2	11.513	97.09	0.00
	Within Groups	0.711	6	0.119		
Moisture	Between Groups	23.100	2	11.550	99.42	0.00
	Within Groups	.697	6	.116		
Ash	Between Groups	.003	2	.001	.91	0.45
	Within Groups	.009	6	.001		
Protein	Between Groups	29.655	2	14.828	332.98	0.00
	Within Groups	0.267	6	0.045		
Fat/Oil	Between Groups	1.377	2	0.688	7.13	0.03
	Within Groups	.580	6	0.097		
Fibre	Between Groups	4.374	2	2.187	163.63	0.00
	Within Groups	.080	6	0.013		
Carbohydrate	Between Groups	248.197	2	124.098	1415.34	0.00
	Within Groups	.526	6	0.088		

Source: Field data, Bartels (2020)

Table 24 presents the F-statistic and the significant value of the chemical composition found in the test foods. The chemical composition of the test foods covered the dry matter (DM), the moisture content, ash, protein, fat/oil, fibre and carbohydrate. The results in Table 24 indicate that all but one of the chemical compositions in the test foods had significant values less than the alpha value. The DM, moisture, protein, fat/oil, fibre and carbohydrate had significant values less than ($p < 0.05$). However, the ash content value (0.45) was more than the alpha value at which the hypothesis was tested.

The Post Hoc analysis to find out which of the test foods' chemical constituent was statistically significant is presented in Table 25.

Table 25: Post Hoc Test on Chemical Composition of the Test Foods

Tukey HSD Dependent Variable	(I) Test foods	(J) Test foods	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
DM	Sweet potato	Taro	-.517	.281	.236	-1.38	.345
		Firm Ripe Plantain	3.105*	.281	.000	2.24	3.97
	Taro	sweet potato	.517	.281	.236	-.345	1.38
		Firm Ripe Plantain	3.622 *	.281	.000	2.76	4.48
	Firm Ripe Plantain	sweet potato	-3.105 *	.281	.000	-3.97	-2.24
		Taro	-3.622 *	.281	.000	-4.48	-2.76
Moisture	sweet potato	Taro	.503	.278	.245	-.351	1.36
		Firm Ripe Plantain	-3.119 *	.278	.000	-3.97	-2.26
	Taro	sweet potato	-.503	.278	.245	-1.36	.351
		Firm Ripe Plantain	-3.622 *	.278	.000	-4.48	-2.77
	Firm Ripe Plantain	sweet potato	3.119 *	.278	.000	2.26	3.97
		Taro	3.622 *	.278	.000	2.77	4.48
Ash	sweet potato	Taro	.028	.031	.657	-.066	.122
		Firm Ripe Plantain	-.013	.031	.912	-.107	.082
	Taro	sweet potato	-.028	.031	.657	-.122	.066
		Firm Ripe Plantain	-.041	.031	.436	-.135	.054
	Firm Ripe Plantain	sweet potato	.013	.031	.912	-.082	.107
		Taro	.041	.031	.436	-.054	.135
Protein	sweet potato	Taro	4.405*	.172	.000	3.88	4.93
		Firm Ripe Plantain	1.677 *	.172	.000	1.15	2.21
	Taro	sweet potato	-4.405 *	.172	.000	-4.93	-3.88

		Firm Ripe Plantain	-2.728 *	.172	.000	-3.26	-2.20
	Firm Ripe Plantain	sweet potato	-1.677*	.172	.000	-2.21	-1.15
		Taro	2.728 *	.172	.000	2.20	3.26
		Taro	.711	.254	.070	-.068	1.49
	sweet potato	Firm Ripe Plantain	.912 *	.254	.027	.133	1.69
		sweet potato	-.711	.254	.070	-1.49	.068
Fat & Oil	Taro	Firm Ripe Plantain	.201	.254	.721	-.578	.9 80
	Firm Ripe Plantain	sweet potato	-.912 *	.254	.027	-1.69	-.133
		Taro	-.201	.254	.721	-.980	.578
		Taro	-.562 *	.094	.002	-.851	-.272
	sweet potato	Firm Ripe Plantain	1.116 *	.094	.000	.826	1.41
		sweet potato	.562 *	.094	.002	.272	.851
Fibre	Taro	Firm Ripe Plantain	1.677 *	.094	.000	1.39	1.97
	Firm Ripe Plantain	sweet potato	-1.116 *	.094	.000	-1.41	-.826
		Taro	-1.677 *	.094	.000	-1.97	-1.39
		Taro	8.351 *	.242	.000	7.61	9.09
	sweet potato	Firm Ripe Plantain	-4.297 *	.242	.000	-5.04	-3.56
		sweet potato	-8.351 *	.242	.000	-9.09	-7.61
CHO	Taro	Firm Ripe Plantain	12.649 *	.242	.000	-13.39	-11.91
	Firm Ripe Plantain	sweet potato	4.297*	.242	.000	3.56	5.04
		Taro	-12.649 *	.242	.000	11.91	13.39

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

Source: Field data, Bartels (2020)

From Table 25, the multiple comparison of the dry matter of the tests foods show that there were statistically significant differences between sweet potatoes and firm ripe plantain, taro and firm ripe plantain at .000. Again, considering their moisture content, it was revealed that, there were statistically significant differences between the pairwise comparison of sweet potatoes and firm ripe plantain, taro and firm ripe plantain at .000.

While in the case of their fats and oils content, statistically significant differences were recorded between sweet potatoes and firm ripe plantain at .027. The result clearly show that the p-values for their ash content were greater than the alpha value at which the hypothesis was tested ($p>0.05$).

Finally, the pairwise comparison of all the test foods showed that there were statistically significant differences among the test foods with regards to their protein, fibre and carbohydrate contents at .000.

The mean, ANOVA and Post Hoc results as presented in Tables 23, 24 and 25 show that ash composition was not statistically significant. In view of the results presented in Tables 23 and 24, the null hypothesis was rejected and the alternative hypothesis accepted ($p<0.05$ in all cases except ash composition). Thus there was astatistically significant difference in the chemical composition of sweet potatoes, taro and firm ripe plantain. However, Post Hoc test results in Table 25 reveal that there was no statistically significant difference between sweet potatoes and taro with regards to their dry matter and moisture content. Similarly, no statistically significant difference was located between sweet potatoes and taro as well as taro and firm ripe plantain based on their fats and oils content. In all these cases, the null hypothesis is accepted and the alternate rejected.

Research Question 1

To what extent does 50g of available carbohydrate of sweet potatoes, taro and firm ripe plantain impact on consumers' blood glucose level?

In addressing this research question, the glucose response curve was used to present the pictorial form of what happened in the various participants' blood glucose levels. The graph of the glucose response curve is presented in Figure 7.

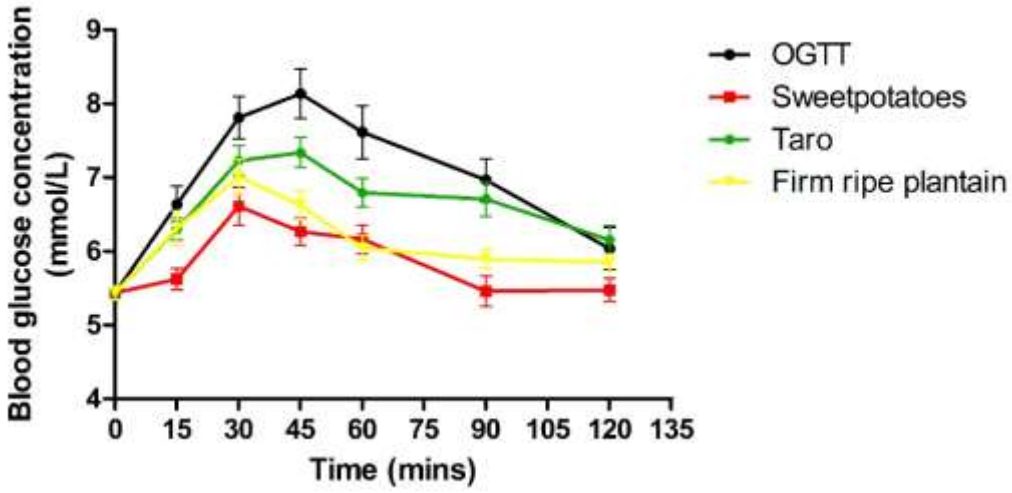

Figure 7: A line graph showing glycaemic response of sweet potatoes, taro and firm ripe plantain on participants' blood glucose levels.

Source: Field data, Bartels (2020)

The Oral Glucose Tolerance Test (OGTT) for the participants was done before the ingestion of the test foods. The glucose as the reference food was to help compare the test foods to see how the blood of the participants responded to the test foods after they were ingested. The line graph as shown in figure 7 indicates that at the time the reference food and the test foods were ingested (time zero), the concentration of the glucose in the participants' blood was around 5.4 mmol/L. By the 15th min, the blood concentration for OGTT

moved up sharply compared to taro and firm ripe plantain. In the case of sweet potato, the increase was gradual. However, it moved to 30th min and to its peak at the 45th min and started to fall gradually to the 90th min before leveling at the 120th min.

The blood glucose level for the test foods reached their peak at the 30th min except for taro and the reference food at 45th min. The sweet potato, firm ripe plantain, taro and glucose recorded 6.8mmol/L, 7mmol/L, 7.2mmol/L and 7.9mmol/L respectively and fell gradually until the 120th min. At the 120th min, sweet potato, firm ripe plantain, glucose and taro recorded 5.5mmol/L, 5.9mmol/L, 6mmol/L and 6.1mmol/L respectively. From the graph, the concentration of the reference food fell a little below that of taro. This confirms the assertion that some foods have GI values above 100 (Vernon *et al.*, 2004). Such foods elevate the blood glucose levels even faster than when pure glucose was eaten (Vernon *et al.*, 2004). This was seen at the 120th min when pure glucose and taro recorded 6mmol/L and 6.1mmol/L respectively, though the difference was not very statistically significant.

There were differences in the glycaemic responses of the reference food and that of the test foods as shown in Figure 7. Postprandial glucose levels of the reference food were high at each time interval as compared to the test foods when they were ingested, except at the 120th min. This could have resulted in the high GI (100) of glucose, as reported by Foster-Powell, Holt and Brand-Miller (2002) when they studied the "International table of glycaemic index and glycaemic load values". Brouns *et al.* (2005) in their study state that glycaemic response among participants varied; and even with the same participant there are variations in each test food. This was confirmed

in this study. The variations in the postprandial blood glucose levels at different time intervals could be attributed to this. It can therefore be concluded that sweet potato has the least glycaemic response among the foods that were studied and can be considered as having hypoglycaemic effect. Thus, it has slowly digestible carbohydrates that elicit a reduced postprandial glucose response. Also, taro and firm ripe plantain have hyper and intermediate glycaemic effects respectively.

Research Question 2

What health implications do glycaemic indices and loads of sweet potatoes taro and firm ripe plantain have on consumers?

Table 26, and footnotes extracted from Tables 8 and 10 were used to answer research question 2. Table 26 presents the results of the glycaemic index and load of the test foods and the classification of GI according to Allen *et al.* (2012), Barclay *et al.* (2005) and Brand-Miller (2003) has been presented as footnotes extracted from Table 8. Also, Table 10 presents the classification of glycaemic load and its impact on blood glucose level. The results from the field as presented in Table 26 show that the glycaemic index of the test foods range from 33.92 to 98.78 per the classification category in the foot notes, sweet potato had a GI of less than 55. This makes sweet potato a low GI food. In the case of medium classification of GI foods, firm ripe plantain fell in this category with a GI range of 56 – 69. Meanwhile, per the classification of high GI foods, taro with a GI more than 70 was found to have high GI.

In the case of the load, the figures ranged from 43.64 to 161.85 as presented in Table 26. Comparing field data in Table 26 and Table 10 all the

test foods fell in the high category. From this, it can be concluded that the glycaemic loads of the three test foods were high and that they may have some implications on consumer's health.

Table 26: Glycaemic Index and Load of Test Foods

Test Foods	Glycaemic Index	Glycaemic Load
Sweet potato	33.92	43.64
Taro	98.76	161.85
Firm ripe Plantain	58.89	68.22

Source: Field data, Bartels (2020)

Footnotes: Classification of Glycaemic Index and Load

Low GI <55; Medium 56-69; High >70

Low GL <10; Medium GL 11 to 19; High GL >20

Source: Allen *et al.* (2012); Venn & Green, (2007); Burani (2006); Barclay *et al.*, (2005); Brand-Miller (2003)

Discussion

In Ghana, most of the staple foods found in the various regions are rich in carbohydrate. The FAO and WHO (1998) suggests that individuals in modern and developed countries need to plan their meals and center these on low glycaemic index foods to avoid developing chronic diseases which include coronary heart disease, obesity and diabetes (Jenkins *et al.*, 2002; Liu & Willet, 2002; Ludwig, 2002; Raben, 2002: Bruns *et al.*, 1989; Gannon *et al.*, 1986). The three main groups of GI are foods with low GI (GI ≤ 55% or less), foods with medium GI (GI 56-69%) and foods with high GI (GI ≥ 70%).

In this study, basic anthropometric measurements such as weight, height, body mass index and waist circumference were used to select participants who were deemed fit for the study. This study required an

inclusion of participants who were not obese, diabetic or with any form of metabolic disorder. Participants who were obese based on the calculation of their BMI and waist circumference were not selected because of their high risk for diabetes, cardiovascular diseases and poor glucose metabolism.

According to WHO (1995), a waist circumference of 88 cm (35 inches) or more indicates an increased risk to chronic diseases for women, and a measurement of 102 cm (40 inches) or more indicates a higher risk to chronic diseases for men. Therefore, the larger your waist circumference, the higher your risk of developing chronic diseases such as type II diabetes, heart diseases and some cancers. Participants involved in this study were below these ranges. The relationship between obesity and the risk of developing type II diabetes has been repeatedly observed in both cross sectional studies (Shaten *et al.,* 1993) and in prospective studies (Cassano *et al.,* 1992). This factor was why obese individuals were not included in this study.

Again, a body mass index of 30kg/m^2 and above indicates the presence of obesity. Even though both waist circumference and body mass index are good predictors of obesity, waist circumference correlates more closely to abdominal adipose tissue than body mass index. Waist circumference is considered an independent risk factor of diabetes, dyslipidemia, hypertension and cardiovascular disease

The relationship between basic anthropometric and glycaemic index exists in the sense that, it helps in selecting qualified participants for the study.

The staple foods that had their glycaemic index assessed and tested were sweet potatoes, firm ripe plantain and taro. Results from hypothesis one revealed that, there was a statistically significant difference among the

glycaemic index of the three test foods. Either of the test foods contributes to the GI and each can have a particular effect on the blood glucose after consuming a certain quantity. The GI of 33.92, 58.89 and 98.76 for sweet potatoes, firm ripe plantain and taro respectively implies that these would have different physiological impact on postprandial blood glucose (Jenkins, Wolever, Taylor, Barker, Fielden, Baldwin, Bowling, Newman, Jenkins, & Goff, 1981).

Juxtaposing this study's results with the official classification of GI by Allen *et al.* (2012), Barclay *et al.* (2005) and Brand-Miller (2003), boiled sweet potatoes presented a favourable glycaemic response, ranking it as a food with a low GI (33.92). The GIs of boiled firm ripe plantain and boiled taro are medium (58.89) and high (98.76) respectively. The GIs of sweet potatoes and firm ripe plantain in this study were similar to the GIs of related foods from the International GI/GL table where Mendosa (2008), Foster-Powell *et al.* (2002) and Bahalo-Sign (2011) reported the GI of sweet potatoes to be 44 and 46.5 whereas for ripe plantain they recorded 66±2. Their report however did not indicate the variety of the food samples. Foods with low glycaemic index have less of an immediate impact on blood glucose levels, and therefore can help diabetics control their blood glucose (Dutta, 2015).

The study also revealed a high GI for taro which confirms what Mendosa (2008) and Foster-Powell *et al.* (2002) reported (77±10). It is interesting to note that the same International GI table showed low GI values for taro in different countries – China (48±5), Australia (54) and New Zealand (56±12). Many factors may have accounted for the variations in the indices.

For Pi-Sunyer (2002), "there exist a number of factors that affect the reproducibility of the GI of a food".

Effects of sugar

GI is affected by the composition of sugar in a food**.** Sweet potatoes and firm ripe plantain have been reported to contain more natural sugars than taro (Cernovi, 2020; USDA, 2011). Again, Kassim (1977) and Ogazi (1982) in their independent research reported that the sugar content of unripe plantain increase during ripening while the carbohydrate content decreases.This occurs when enzymes break down complex carbohydrates to disaccharides and monosaccharides. This may result in their varying GIs. Foods containing sucrose or fructose tend to have lower glycaemic responses (Brand-Miller, Pang, & Broomhead, 1995; Wolever, Nguyen, & Chiasson, 1994). This is because fructose from the disaccharide sucrose, added or found naturally in foods is stored in the liver as glycogen and slowly converted (if at all) into glucose to enter the general circulation.

Effect of dietary fibre

The fibre contents in the tests foods per 50 g available carbohydrate presented in Table 14 were 6.74 g, 4.57 g, and 2.82 g for taro, sweet potatoes, and firm ripe plantain respectively. Interestingly, although taro recorded the highest fibre content, its GI was rather high as confirmed in Jenkins *et al.* (2002) where acrossover design was used to study the effects of a diet high in cereal fibre in type II diabetic patients. There was no improvement in conventional markers of glycaemic control after 3 months of intervention. However, Slavin *et al.* (1999) reported that viscous soluble fibre plays an important role in controlling postprandial glycaemic and insulin responses

because of its effect on gastric emptying and macronutrient absorption from the gut. Although taro root is a starchy vegetable, it contains two types of carbohydrates that are beneficial for blood glucose management: fibre and resistant starch. This combination of resistant starch and fibre makes taro root a good carbohydrate option, especially for people with diabetes (Gunua & Kokoa, 1995). In addition, Lewu *et al.* (2010), Vinning (2003), Lee (1999) and Oke (1990) reported that taro roots are good sources of energy with easily digestible small starch grains which are about a tenth of that of potato (1-6.5 micrometers). This may explain why taro was reported to have the highest GI value. The taro starch has low amylose with A-type crystalline structure; hence its high GI.

Gelatinization

Gelatinization makes starch easily digestible (Sajilata *et al.*, 2006). The greater the gelatinization, the more viscous the starch would be and the higher its GI will be. Foods containing starch molecules that are fully gelatinized, such as a baked potato, make it easier for digestive enzymes to attack (Englyst *et al.*, 1999; Jenkins *et al.*, 1983; Jenkins, Ghafari & Wolever, 1982). Gelatinized starch samples are far more susceptible than native starch granules to degradation by α-amylase (Htoon *et al.*, 2008; Vesterinen *et al.*, 2002). In this study, moist heat was applied to all the test foods for 10-15 minutes. This, in a way, led to gelatinization.

Protein content

Protein-rich diets stimulate the release of insulin, resulting in a decrease in postprandial blood glucose levels. Thus, the natural protein contents of some foods may be the reason why their starches are not easily

hydrolyzed, which confers them with lower GIs. This study recorded 16.9 g, 14.2 g and 13.3 g as the protein content of the 50 g available carbohydrates for sweet potatoes, taro and firm ripe plantain respectively as shown in Table 14. Indeed, salmon which is an oily fish was added to the sauce (garden egg stew: main dish to the test foods).

Protein may influence gastric emptying and insulin secretion, but its effects on GI are generally not seen unless relatively large amounts (about 30 g of protein and 50 g of fat per 50 g carbohydrates) are added (Wolever *et.al,* 1994). From the above, it can be concluded that the protein contents in the test foods though varying did not have any effect on the GIs of the tests foods. Although the addition of protein to a meal containing carbohydrates may result in a lower glucose response, the relative difference between starch-rich foods with different GI values remains (Bornet *et al.,* 1987).

Fat

Fat increases the time it takes for food to leave the stomach and enter the small intestine. By slowing the rate at which dietary carbohydrates are digested in the intestine, fat containing foods may affect the rise in blood glucose and yield a lower GI than similar foods without fat. For example, the GI of potato chips is 57, French fries is 75 and baked potato is 85 (Brand-Miller, 2003). The fat content per 50 g available carbohydrate of the tests foods were 15.77 g, 19.41 g and 13.14 g, which indeed are less than 50 g fat reported by Wolever *et al.* (1994). The fat content of the test foods had no effect on their GIs.

Ripeness

Another factor affecting the GI is the stage of ripeness. Arvidsson-Lenner *et al.* (2004) asserted that increased ripeness increases GI. On the contrary, Pi-Sunyer (2002) observed that the GI of the same fruit tends to decrease with fruit ripeness. Also, Kassim (1977) and Ogazi (1982) in their independent research reported that the moisture, sugar, protein, lipid, and fibre contents of unripe plantain increase during ripening while the carbohydrate content decreases. In this study, green mature false horn variety of plantain was stored at room temperature to ripe for 6-7 days. The GI of firm ripe plantain (58.89) in this study corresponded with already reported GI values of ripe plantain (66±2) extrapolated from the International GI/GL table (Mendosa 2008; Foster-Powell *et al.*, 2002). Both samples were boiled for 10-15 minutes. To confirm if ripeness increases GI, a comparison was done between GIs of green/unripe plantain that from the international GI table determined in Jamaica and Ghana (39±4 and 40±4 respectively). The GI of firm ripe plantain from the study was (58.89). It was deduced that, the unripe plantain had low GI values whereas the firm ripe plantain recorded a medium GI value. This is an indication that the state and stage of ripeness of the test food may increase GI.

Effects of portion size

The GI of taro, which had the largest available carbohydrate portion (163.88 g), was the highest among the test foods. However, the same could not be said for sweet potatoes and firm ripe plantain. Sweet potatoes had the next largely available carbohydrate portion size (128.66 g) than firm ripe plantain (115.85 g) but elicited a lower glycaemic response. 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.

Hypothesis 2

The results on the second hypothesis tested using ANOVA and Post Hoc test rejected the null hypothesis and accepted the alternative hypothesis in all cases except between sweet potatoes and firm ripe plantain. Thus, there was a statistically significant difference among the glycaemic load of the test foods (sweet potato, taro and firm ripe plantain). Literature has reported a direct link between GI and GL. The GI helps to determine the GL. The GI of given foods have to be determined first before GL could be calculated. GL evaluated in this study allows comparisons of the glycaemic effect of realistic portions of different foods. It was calculated by multiplying the amount of carbohydrate in one serving by the GI of the food and dividing it by 100 (Venn & Green, 2007; Barclay *et al.*, 2005; Brand-Miller 2003). In this study, the GLs of the test foods were 161.85, 68.22 and 43.64 for taro, firm ripe plantain and sweet potatoes respectively, with their corresponding GI values being 98.76, 58.89 and 33.92. According to the GL classification, all the test foods had high GLs although there were differences in value. Mendosa (2008) stated that in order to improve control of glycaemic response in *Diabetes mellitus* management and prevention, GI data must be associated to GL. The relationship between GL and GI is not straightforward–higher GI foods can have medium GL and GL depends on the portion size eaten (Mendosa, 2008). As already noted by Mendosa (2008), foods that have a low GL almost always have a low GI, and foods with an intermediate or high GL range from very

low to very high GI. An increase in blood glucose level is proportionally produced in response to an increase in GL (Venn *et al.,* 2006). In this study, sweet potatoes had low GI and high GL, firm ripe plantain had medium GI and high GL, and taro had high GI and high GL. Therefore, people who are more concerned about their postprandial glucose response should be very cautious about the serving size of their food, since higher GL foods may raise the blood glucose response. Their consumption should be limited because they could increase the insulin response. Therefore sweet potatoes eaten with garden egg stew (GL 43.64) is the food that has the lowest glycaemic carbohydrate among the test foods. Thus, although all three test foods can negatively influence health, sweet potatoes with garden egg stew would give the least negative influence. The food should be limited regardless of its respective GI in order to avoid metabolic disturbance related to their overconsumption (Willett *et al.,* 2002).

Therefore finding that there is a statistically significant difference among the test foods with respect to GI is the initial point of calculating GL. The findings actually confirm the earlier finding in this study that there is a statistically significant difference in the GI for the test foods.

The chemical composition of the test foods presented in Tables 23 and 24 established a statistically significant difference in the chemical composition of sweet potatoes, taro and firm ripe plantain. The various chemical compositions in the test foods have varied values and this is what caused the statistically significant difference in the ANOVA results. The detailed analysis of the chemical composition indicated that the test foods' ash value was not statistically significant ($p > 0.05$). In addition, the Post Hoc analysis in Table

25 indicates that, the results for protein, fibre and carbohydrate were statistically significant. However, with regards to their dry matter and moisture contents, not all their pairwise comparisons were statistically significant. The differences in the chemical composition of the test foods reflect the account reported by USDA (2011) on sweet potatoes, taro and plantain although the report did not specify the varieties used. It has been established that the chemical composition of the meal may have inlfuence on their glycaemic response, glycaemic index and load. For instance, fat and protein had been identified to influence gastric emptying and insulin secretion (Wolever *et al.*, 1994).

Research Question 2

Results revealed that the glycaemic load of the test foods were high. The results therefore suggest that consuming sweet potatoes, taro or firm ripe plantain beyond a certain quantity could lead to other health related issues though sweet potato has the least response to blood glucose.

Some epidemiological, observational cohort and interventional studies have reported on the link between GI/GL and chronic non-communicable diseases such as cancers, diabetes, CVDs, obesity, stroke and myocardial infarction. Aside these Chronic Non-communicable Diseases (CNCDs), GI/GL have been reported to improve appetite (satiety), sports performance and cognitive performance (Benton *et al.*, 2003).

The overall health benefit of low GI foods is that they may aid weight control because they promote satiety (Brand –Miller *et al.*, 2002). Low GI foods maintain a longer feeling of fullness than their high GI counterparts. People who eat low GI foods tend to eat smaller meals - their food craving

diminishes (Bornet *et al.*, 2007; Hubrich & Nabor, 2006). Additionally, a meta-analysis by Opperman *et al.* (2004) emphasizes the importance of low-GI meals in decreasing total cholesterol and improving metabolic control of diabetes. The Kelly *et al.* (2004) study, found modest benefits with the greatest effect on total cholesterol and glycated haemoglobin. Thus, low GI diets have been found to help with weight management, to improve insulin sensitivity and glycated haemoglobin, and reduce the overall risk of diabetes (Marsh *et al.*, 2011). On the contrary, Tavani *et al.* (2003) study that a higher GI slightly increased risk for acute myocardial infarction, but only in elderly individuals (more than 60 years) in association with overweight. Again, consistent consumption of high GI foods may increase risk factors associated with obesity, type II diabetes and heart diseases. Grau *et al.* (2011) found out in a retrospective analysis of cardiovascular deaths that men who ate high GI diets were more likely to die of heart diseases in Denmark. In an Italian cohort (The EPICOR study), a high GL diet increased the overall risk of CVDs in women, but not in men (Sieri *et al.*, 2010). High GL foods have been associated with a high risk of insulin resistance syndrome and type II diabetes (Schulze *et al.*, 2004). A high GI diet induces elevated glycaemia and insulinemia, which can lead to a group of metabolic abnormalities including hypertnsion and high triglycerides that increase the risk of heart disease via syndrome X (Liu *et al.*, 2000). High GI was associated with low HDL cholesterol levels, a risk factor for heart disease, in the Third National Health and Nutrition Examination Study (Ford & Liu, 2001). Reductions in daily glycaemic load (GL) may lead to a reduced risk for developing diabetes and

CVD. For example, Salmeron (1997a, b) showed that the GL of the daily diet correlates with the risk of developing diabetes in women but not in men.

Based on the publications listed above, there is accumulating evidence that diets containing a preponderance of foods that elicit low glycaemic responses, as originally defined by Jenkins *et al.* (1981), induce modest to clinically important benefits in the intermediate term as shown by intervention studies and from epidemiological studies of health benefits in the longer (6–10 year) term (Brand-Miller, 2004).

Thus the inability of the human system to make use of all the glucose in the blood stream or the rise in blood glucose level from consumption of carbohydrates quickly creates poison in the human system (Ahmed, 2002). The direct negative effects such as type II diabetes, heart diseases, kidney failure among others are situations that according to medical experts are difficult to cure. Diseases associated with the consumption of foods that have high carbohydrate could be avoided if knowledge abounds. The development of type II diabetes is purely related to lifestyle changes and is leading to pre-mature deaths (American Diabetes Association, 2013; Salehi *et al.*, 2012; Salgado *et al.*, 2010). The consumption of plantain in Ghana, especially by residents in the big cities, is becoming alarming. Fried ripe plantains, popularly known ‘red red’ or ‘kelewele’ in Ghana and are eaten in large quantities. The oils used, especially those containing high cholesterol, have side effects that may inhibit smooth blood flow from the heart to other parts of the body. The current study shows that firm ripe plantain is high in glycaemic load. This is worrying. The consumption of firm ripe plantain in whatever form and quantity has to be controlled else the benefits of consuming plantain

may be eroded. The other two test foods (sweet potato and taro) are also patronized by Ghanaians in large quantities. Consumption of these foods in large quantities can be detrimental to their health. They must be consumed in reasonable quantities to avert their negative repercussions on health.

This study may defuse the perception that sweet-based starchy foods are more detrimental to health since it recorded low and medium GI values for sweet potatoes and firm ripe plantain respectively.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the summary of the findings, conclusions, the recommendations made based on the findings and suggestions for further studies. The overview of the study is also presented in this chapter.

Summary

The study determined the glycaemic index and load of sweet potatoes, taro and firm ripe plantain consumed in Ghana. The study looked at three research hypotheses, and two research questions. The needed theoretical and empirical literature related to the study were reviewed. The research design adopted was a true experimental design since there were variables to be manipulated. The test foods were prepared and served to the participants and their capillary blood samples and glucose levels were taken. The blood samples were taken by pricking the forefinger at different time intervals. The GI and GL were calculated using the trapezoid rule which helps in testing hypotheses using the appropriate statistical tools. The research questions were also analysed for the results.

Key Findings

The major findings have been summarised as follow:

1. There was a statistically significant difference in the glycaemic index of sweet potatoes, taro and firm ripe plantain at $p<0.004$. The mean GI values of the test foods were 33.92, 58.89 and 98.76 for sweet potatoes, firn ripe plantain and taro respectively.
2. Sweet potatoes had the least GI of 33.92 with reference to the food types studied and how it responds in the blood stream.

3. There was a statistically significant difference in the glycaemic load of sweet potatoes, taro and firm ripe plantain at $p<0.000$. The mean GL values of the test foods were 43.64, 68.22 and 161.85 for sweet potatoes, firm ripe plantain and taro respectively.

4. The glycaemic loads of the three test foods were high ($GL \geq 20$).

5. There was a statistically significant difference in the chemical composition of sweet potatoes, taro and firm ripe plantain at $p<0.000$ except in their ash composition which was not statistically significant.

Conclusions

This study has established the GI and GL of three common carbohydrate- rich staples consumed in Ghana. Low to moderately high GIs and high GLs were observed. The boiled taro with garden eggs stew recorded high GI and high GL. It is therefore a hyperglycaemic food. This food must be eaten in very small quantities. Boiled sweet potatoes and boiled firm ripe plantain with garden eggs stew were determined to be low and medium GI foods respectively but their GLs remained high. These meals must be consumed moderately. Additionally, the study examined the impact of the three staple foods on blood glucose levels, indicating that these staples are of different carbohydrate quality and quantity and will influence blood glucose levels differently. Comparison of the chemical composition of the tests foods brought to light that there was statistically significant differences in the chemical composition of the three test foods though ash values for the test foods were statistically not significant. Possible health implications were also analysed. It is reported that reduced consumption of high GI foods and increased intake of low and intermediate GI may lead to better management of

diabetes, coronary heart disease and obesity (Augustin *et al.*, 2015; Brand-Miller *et al.*, 2002). Therefore, it is important that low and intermediate GI foods are identified and their consumption recommended. The results obtained will serve as nutritional guidelines used by professionals for the prevention and the management of *Diabetes mellitus* and other CNCDs in Ghana. They are less expensive than foreign foods whose GI/GL have been determined.

Recommendations

The following recommendations are made based on the findings from this study.

1. Since it has been determined that there is a statistically significant difference in the GI and GL of sweet potato, taro and firm ripe plantain, dieticians should educate the general public on the consequences of consuming these foods vis-à-vis other staples.
2. Sweet potatoes, having a low glycaemic index, can be recommended for all individuals especially those suffering from diabetes as well as other CNCDs.
3. Taro recording high GI/GL means that it is easily digested and absorbed into the blood stream. It may be recommended for people with hypoglycaemia. It may also be recommended for infants' complementary feed bearing in mind the quantity. However, experts' recommendation is highly recommended.

Suggestions For further studies

Further work could be undertaken by other researchers on the determination of GIs and GLs of carbohydrate- rich Ghanaian foods; especially root tubers

which are commonly consumed though their GIs and GLs are currently unknown.

A study on GI/GL labeling in Ghana is also recommended to give consumers broader spectrum of food choices.

Again, the effects of sweet potatoes, taro, and firm ripe plantain can be experimentally investigated on diabetic patients to provide more evidence on their efficacy or effectiveness in managing blood glucose levels.

Finally, effects of cooking methods on GI determination of the test foods could also be investigated by other researchers.

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APPENDICES

APPENDIX A

ETHICAL CLEARANCE

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OUR REF: UCC/IRB/A/2016/577
YOUR REF:
OMB NO: 0990-0279
IORG #: IORG0009096

C/O Directorate of Research, Innovation and Consultancy

7TH FEBRUARY, 2020

Addinalla Bartels
Department of Vocational and Technical Education
University of Cape Coast

Dear Ms. Bartels,

ETHICAL CLEARANCE – ID (UCCIRB/CES/2019/56)

The University of Cape Coast Institutional Review Board (UCCIRB) has granted **Provisional Approval** for the implementation of your research protocol titled **Determining the Glycemic Index and Load of Some Selected Staple Foods in Ghana.** This approval is valid from 7th February, 2020 to 6th February, 2021. You may apply for a renewal subject to submission of all the required documents that will be prescribed by the UCCIRB.

Please note that any modification to the project must be submitted to the UCCIRB for review and approval before its implementation. You are required to submit periodic review of the protocol to the Board and a final full review to the UCCIRB on completion of the research. The UCCIRB may observe or cause to be observed procedures and records of the research during and after implementation.

You are also required to report all serious adverse events related to this study to the UCCIRB within seven days verbally and fourteen days in writing.

Always quote the protocol identification number in all future correspondence with us in relation to this protocol.

Yours faithfully,

Prof. P.K. Buah-Bassuah
UCCIRB Chairperson

CHAIRPERSON
INSTITUTIONAL REVIEW BOARD
UNIVERSITY OF CAPE COAST

APPENDIX B

INTRODUCTORY LETTER

UNIVERSITY OF CAPE COAST
COLLEGE OF EDUCATION STUDIES
FACULTY OF SCIENCE AND TECHNOLOGY EDUCATION
DEPARTMENT OF VOCATIONAL AND TECHNICAL EDUCATION

Direct: 03320-91097
TELEX: 2552, UCC, GH.
Telegrams & Cables: University, Cape Coast

University Post Office
Cape Coast, Ghana

Our Ref: VTE/ IAL^{B}/V.2/3

17th December, 2018

The Head
Teaching and Research Farm
School of Agriculture
UCC

Dear Sir

INTRODUCTORY LETTER

We have the pleasure of introducing to you **Addinalla Bartels** who is an M.Phil Student of this Department and working on the thesis topic "**The determination of glycemic load and index of some selected staple foods in Ghana**".

She is currently on the data collection stage and requires permission to conduct proximate analysis of food samples to determine their chemical composition.

We would be grateful if you could give her the necessary information required to complete her research work.

Thank you.

Yours faithfully,

Dr. Augustina Araba Amissah
HEAD OF DEPARTMENT

APPENDIX C

PERMISSION LETTER FROM GHANA HEALTH SERVICE

In case of the reply, the number and the date of this letter should be quoted.

GHS Core values
PEOPLE CENTRED
PROFESSIONALISM
TEAMWORK
INNOVATION/EXCELLENCE
DISCIPLINE
INTEGRITY

GHANA HEALTH SERVICE
Your Health • Our Concern

GHANA HEALTH SERVICE
REGIONAL HEALTH
DIRECTORATE
P. O. BOX 63
CAPE COAST.
CENTRAL REGION.
GHANA
Tel: 042 32281/2
Fax: 042 34785
rdhs.central@ghsmail.org

My Ref. No.CR/G- 263/893
Your Ref. No...

17th December, 2019

MS. ADDINALLA BARTELS
DEPT. OF VOCATIONAL AND TECHNICAL EDUCATION
FACULTY OF SCIENCE AND TECHNOLOGY EDUCATION
COLLEGE OF EDUCATION STUDIES
UNIVERSITY OF CAPE COAST
CAPE COAST

RE: PERMISSION TO UNDERTAKE A RESEARCH ON THE TOPIC "DETERMINING THE GLYCEMIC LOAD AND INDEX OF SOME SELECTED STAPLE FOODS IN GHANA"

Reference your introductory letter Ref. No. VTE/IAP/V.3 and dated 13th November 2019, seeking permission to conduct the above-mentioned research work in the Mfantseman Municipality of the Central Region, I write to grant you the permission to conduct the research on the following conditions:

1. A copy of the proposal of the study in full should be lodged with the Research and Development Unit of the Central Regional Health Directorate;
2. Ethical clearance from the **Ghana Health Service Ethics Review Committee (GHS-ERC)** should be obtained for the study;
3. Data collection should commence **only upon receipt of clearance from the GHS-ERC** and a copy of the clearance certificate lodged with the Research and Development Unit of the Central Regional Health Directorate; and
4. A copy of the final report of the study in full should be lodged with the Research and Development Unit of the Central Regional Health Directorate.

By copy of this letter, Municipal Director of Health Services, Mfantseman Municipal Area and Medical Superintendent of Biriwa Baobab Medical Centre are directed to facilitate the research.

Thank you.

DR. ALEXIS NANG-BEIFUBAH
REGIONAL DIRECTOR OF HEALTH SERVICES
CENTRAL REGION

CC: - Municipal Director of Health Services, Mfantseman Municipal Area, Saltpond.
- Medical Supt., Biriwa Baobab Medical Centre.

APPENDIX D

ETHICAL CLEARANCE FROM GHANA HEALTH SERVICES

GHANA HEALTH SERVICE ETHICS REVIEW COMMITTEE

In case of reply the number and date of this Letter should be quoted.

Research & Development Division
Ghana Health Service
P. O. Box MB 190
Accra
GPS Address: GA-050-3303
Tel: +233-302-681109
Fax + 233-302-685424
Email: ethics.research@ghsmail.org

MyRef. GHS/RDD/ERC/Admin/App/20/215
Your Ref. No.

23rd June, 2020

Addinalla Bartels
University of Cape Coast
Vocational and Technical Department
P. O. Box AN 31
Anomabo
C/R

The Ghana Health Service Ethics Review Committee has reviewed and given approval for the implementation of your Study Protocol.

GHS-ERC Number	**GHS-ERC 056/03/20**
Project Title	Determining the Glycemic Index and Load of some selected Staple Foods in Ghana
Approval Date	23rd June, 2020
Expiry Date	22nd June, 2021
GHS-ERC Decision	**Approved**

This approval requires the following from the Principal Investigator

- Submission of yearly progress report of the study to the Ethics Review Committee (ERC)
- Renewal of ethical approval if the study lasts for more than 12 months,
- Reporting of all serious adverse events related to this study to the ERC within three days verbally and seven days in writing.
- Submission of a final report after completion of the study
- Informing ERC if study cannot be implemented or is discontinued and reasons why
- Informing the ERC and your sponsor (where applicable) before any publication of the research findings.

You are kindly advised to adhere to the national guidelines or protocols on the prevention of COVID -19

Please note that any modification of the study without ERC approval of the amendment is invalid.

The ERC may observe or cause to be observed procedures and records of the study during and after implementation.

Kindly quote the protocol identification number in all future correspondence in relation to this approved protocol

SIGNED.....
Dr. James Ayarzili
(Head, Ethics & Research Management Department)

Cc: The Director, Research & Development Division, Ghana Health Service, Accra

APPENDIX E

INFORMED CONSENT FORM

Title: Determining the glycaemic index and load of some selected staple foods in Ghana.

Principal Investigator: Addinalla Bartels
Department of VOTEC
University of Cape Coast
Cape Coast - Ghana

General Data about Research

The study seeks to investigate the glycaemic index which indicates the rate at which the blood glucose rises after consuming a carbohydrate rich food that is boiled sweet potatoes, taro "brobey" and firm ripe plantain and also determine carbohydrate quality (glycaemic load) and the chemical composition of the food samples as well as examine possible health implications of the food samples on consumers. Hopefully, the information given will be of great importance to people with special health conditions like diabetes, obesity and circulatory diseases, in their choice of foods especially carbohydrate based foods. It will again help health practitioners especially nutritionists, dieticians and diet therapists to plan interventive diets for their clients as well as serve as a tool for counselling their clients. The findings in the study will among other things serve as a guide to food manufacturers. It is will extend the data base of metabolic effect of African diets as well as creating awareness of the concept of glycaemic index and load on sweet potatoes, taro and firm ripe plantain.

The study will be carried out at Biriwa Boabab Medical Centre in the Mfantseman Municipality. It will be a five session event conducted within one month. The first week will be used for administering the reference food - glucose - which will be duplicated on different days within the week and ones

every week for the test foods respectively. There will be inclusion and exclusion schedule for participants who will be willing to participate and only those who will be able to satisfy the inclusion criteria will be recruited for the study.

Procedures

To enable me find answers to the research questions and hypotheses, I request you participate in this research project. If you choose to accept, you will be obliged to take part with 18 other persons who will meet the inclusion criteria. This exercise will be moderated by me and 2 other trained health personnel.

A week before the clinical trial, the researcher will ran a 2-day orientation for you to acquaint yourself with the protocol for the study. As part of the study you will be required to observe the following protocols:

Undergo 10 to 12 hour overnight fast during the period, (before each session)

Not to engage in any rigorous or strenuous activity/exercise such as weeding, skipping, running, playing football and weight lifting.

No consumption of drink alcohol,

No smoking and

No intake of breakfast before the exercise but can you can eat after the clinical trial each day Arrive at the facility at 7:30 am for every session.

Anthropometric measures (BMI, Blood pressure, waist circumference weight and height) will be taken by trained health personnel and recorded by the researcher any time you visit the health facility for the clinical trial.

The last meal eaten a day before each session will also be recorded during study. If the protocols are not observed, it will affect the outcome of the study.

In addition, capillary blood will be taken during each session to ascertain fasting blood glucose through finger prick.

A solution containing 50g of pure glucose dissolved in 250ml water will be given to you to drink and the corresponding blood concentration will be recorded by the researcher at the 15th, 30th, 45th, 60th 90th and 120th minutes. (2 hour schedule thus the expected duration for each session will be 2 hrs).

You will again be expected to consume three food samples namely boiled sweet potatoes, taro and firm ripe plantain containing 50g of available carbohydrate with equal quantities of garden egg stew following the same protocol. Invariably, capillary blood shall be taken 7 times during each session.

If you have allergies to any or all the food samples you are permitted to fall out. You are being selected to take part in the study because the researcher feels that you have ample time and fall within the inclusion criteria needed to gather data for the study.

Photographs will be taken during the entire clinical trial and edited so that **no-one will be identified by name as evidence of work**. Additionally it will be confidentially kept and no one else except the researcher and Principal supervisor and co -supervisor will have access to the photographs. The duration for the study shall be one month. (Twice in a week for reference food and once a week for the three food samples).

Possible Risks and Discomforts

In the course of the study, it may be possible that you may feel nausea or a bit drowsy when the glucose solution is drank. This does not happen to all persons. You will again experience little pains when the blood samples are taken through finger prick not only that but also undergo between 10 to 12 hour overnight fast before the clinical trials. Finally, you may be required to

commute from where you are to the health facility where the research work would be carried out. However, the researcher will make arrangement for a vehicle to pick you from your place of abode to the study area.

Possible Benefits

Directly you will be taken through free anthropometric measures (weight, blood pressure, height, body mass index) and free blood glucose test on each session and a possible weight loss may occur as a result of the number of overnight fast you will undergo during the period of study. Socially, you will meet other people for social intercourse. At the end of the study the result will be published and the needed action will be taken which will be beneficial to you and the nation as whole especially to individuals with diabetes (type II) and other Non-communicable diseases in their food choices and the result may further medical knowledge. Copies of the result will be made obtainable to you as well.

Confidentiality

All data collected during the trial will be kept strictly confidential. The study code names / numbers only will be identified. In every article or presentation, no names or identification details will be used. In this report, no information will be transmitted to you except the researcher. The findings of the clinical trial will be transmitted to the investigator's subordinates in an anonymous form (that is without the identity of the participant). The Institute Review Board (IRB) is allowed to analyze the initial results and registers of clinical evidence at the research place for a review of the data. It is an independent committee of ethics to analyze the ethical implications of the study and protect the interests and health of study participants. The object of this disclosure to regulatory bodies and surveillance authorities is the proper conduct of the

study, the preservation of your rights and your health as a researcher and the ethical conduct of the study or for other purposes authorized by statute. The details of the participant shall not be revealed or transmitted further. Data is stored with a special password encrypted and saved online in computerized archives. The researcher's personal custody for documents, hard copies, photos and all other identifiable participant material is locked to a file office. The findings of this study will be released but be confident we will not expose your name. The publication is faithful to the original. The individuals assigned for data analysis are protected by strict secrecy and data security compliance. The researcher would make every attempt to protect your privacy.

Compensation

You will be given refreshment in the form of snacks and meals at the end of each session. In addition, all transportation expenses would be borne by the researcher. Any form of injury that may occur as a result of the study shall be addressed accordingly medical action will be obtainable in the occasion of research connected injury.

Voluntary Participation and Right to Leave the Research

You are absolutely prepared to take part in this report. The decision to take or not to engage in this research is your duty. You will be asked to sign a consent form if you wish to engage in this report. You are also allowed to revoke your consent at any point after signing the consent document and to discontinue participation without any cost or discrimination.

If you withdraw from this study, there will be no negative consequences for your relationship with the researcher. Data from you will be destroyed if you withdraw from the analysis before data collection is complete.

Contacts for Additional Information

Please contact Addinalla Bartels, MPhil Home Economics, and a student in Vocational and Technical Education, University at Cape Coast directly by telephone at 0243333836 or email address addesbart@gmail.com or Professor Sarah Darkwa, snaadom@gmail.com at a time when you have questions about this research or if you suffer adverse effects arising from involvement in this research.

Your rights as a Participant

The Institutional Review Board of the University of Cape Coast (UCCIRB) has reviewed and accepted this research. You should email the administrator at the IRB office between 8:00 am and 4:30 p.m. if you have any concerns about your rights as a study participant by e-mail: irb@ucc.edu.gh or by calling 0558093143/0508878309/0244207814.

Volunteer Agreement

The above document describes the benefits, risks and procedures for the research title, 'Determining the glycaemic index and load of some selected staple food in Ghana has been explained to me'.

I have been given an opportunity to have any questions about the research answered to my satisfaction.

I agree to participate as a volunteer.

_____ _____

Date Name and signature or mark of volunteer

If volunteers cannot read the form themselves, a witness must sign here:
I was present while the benefits, risks and procedures were read to the volunteer. All questions were answered and the volunteer has agreed to take part in the research.

_____ _____

Date Name and signature of witness

I certify that the nature and purpose, the potential benefits, and possible risks associated with participating in this research have been explained to the above individual.

_____ _____

Date Name Signature of Person Who Obtained Consent

APPENDIX F

INCLUSION CRITERIA FORM

UNIVERSITY OF CAPE COAST

Glycaemic Index and Load Research

Researcher: ADDINALLA BARTELS M.Phil. Home Economics (Foods and Nutrition)

Inclusion Criteria Sheet

Participant's Code :..... Waist Circumference:.....

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

SEX : …… HEIGHT :.....

BMI:..... ……. BP:…….

Please tick [√] if you have history or family history of any of the underlisted Chronic non communicable diseases.

Chronic Non Communicable Diseases	YES	NO
Diabetes		
Hypertension		
Stroke		
Obesity		

APPENDIX G

QUESTIONNAIRE FOR PARTICIPANTS

UNIVERSITY OF CAPE COAST

Glycaemic Load and Index Research

Sugar Profile Sheet

Researcher: ADDINALLA BARTELS

M. Phil. Home Economics (Foods and Nutrition)

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

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

SEX : …… HEIGHT :.....

BMI:..... BP:……

WEEK 1

Date:……

Last Meal :.....

Time of Last Meal:

OGTT 1

Day 1

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

DAY 2

BP: ……..... Date: ……..

Weight : ……... Last Meal :……

Time of Last Meal:……..

OGTT 2

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

WEEK 2

BP: Date:

Weight Last Meal:.....

Time of Last Meal:

SWEET POTATOES

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

WEEK 3

BP:……. Date: ……

Weight:…… Last Meal:.....

Time of Last Meal:……..

TARO

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

WEEK 4

BP:…… Date:……

Weight…… Last Meal:.....

Time of Last Meal:……..

FIRM RIPE PLANTAIN

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

APPENDIX H

PICTURES SHOWING INGESTION OF TEST FOODS AND CHECKING OF BLOOD GLUCOSE RESPONSE OF PARTICIPANTS






APPENDIX I

PICTURES SHOWING ANTHROPOMETRIC MEASUREMENT OF PARTICIPANTS

APPENDIX J

A TABLE SHOWING THE RECEIPE FOR THE TEST FOODS

Test food	Ingredient	Quantity	Preparation and Cooking Method
Boiled Sweet Potatoes (*Ipomoea batatas*)	Sweet potatoes	1,862 g	• Wash and peel the sweet potatoes • Wash and cut into desirable shapes. • Add to boiling water, add salt to taste and allow to cook for 15 minutes. • Strain stock away. • Serve hot with vegetable stew / sauce.
	Salt	25 g	
Boiled Taro (*Colocasia esculenta (L.) Schott*)	Taro	2,294 g	• Wash and peel the taro. • Wash and cut into desirable shapes. • Add to boiling water, add salt to taste and allow tocook for 12 minutes. Strain stock away if cooked. • Serve hot with vegetable stew / sauce.
	Salt	25 g	
Boiled ripe plantain (*Musa paradisiacal*)	Firm ripe plantain	1,622 g	• Wash and peel the firm ripe plantain. • Wash and cut into desirable shapes. • Add to boiling water, add salt to taste and allow to boil for 10 minutes. • Strain stock away if cooked. • Serve with vegetable stew sauce.
	Salt	25 g	
Garden eggs stew	Garden eggs	1,320 g	• Boil garden eggs, turkey berries and pepper. • Strain the stock and keep. • Put palm oil on fire add chopped onions when hot. • Add ground pepper, onion and tomato puree. • Cover and allow to stew for 10 minutes. • Add chopped tomatoes. • Clean smoked fish and add to sauce. • Mash boiled garden eggs and turkey berries and add to sauce. • Correct seasoning. • Leave on a gentle heat for 5-10 minutes. • Serve with the study food samples.
	Fresh tomatoes	740 g	
	Tomatoe puree	240 g	
	Onion	600 g	
	Fresh pepper	40 g	
	Turkey berry	150 g	
	Palm oil	600 ml	
	Smoked fish(salmon)	570 g	
	Salt	30 g	

Source: Field data, Bartels, 2020

APPENDIX K

PACKAGED TEST FOODS

Sweet potato with garden eggs stew

Taro with garden eggs stew

Firm Ripe Plantain with garden eggs stew