GLYCAEMIC RESPONSE TO THREE DIFFERENT PREPARATIONS OF WHITE YAM IN DIABETIC AND NON-DIABETIC NIGERIANS

BEING A DISSERTATION SUBMITTED TO THE NATIONAL POSTGRADUATE MEDICAL COLLEGE OF NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF FELLOWSHIP OF THE FACULTY OF PATHOLOGY

By

JIMOH, AHMED KAYODE (MBBS, 1995)
(AF/008/02/007/313)
APRIL 2006
CERTIFICATION

I hereby certify that this study was carried out by Dr. Jimoh Ahmed Kayode of the Department of Chemical Pathology & Immunology, University of Ilorin Teaching Hospital, Ilorin under my supervision.

…………………………………….

Prof. A. B. Okesina (MBBS, FWACP, FMCPath, UCSP) Date
Consultant Chemical Pathologist,
Department of Chemical Pathology & Immunology,
University Of Ilorin Teaching Hospital,
Ilorin, Nigeria.
DECLARATION

I hereby declare that this work is original unless otherwise acknowledged. The work has not been presented to any journal for publication nor submitted to any other fellowship body as a dissertation.

…………………………
Dr. Jimoh Ahmed Kayode

…………………………
Date
DEDICATION

This work is dedicated to Almighty God who has helped me to accomplish this task and to all health workers in the management of Diabetes Mellitus.
ACKNOWLEDGEMENTS

My special appreciation goes to my indefatigable supervisor, Prof. A.B. Okesina who remains my evergreen teacher and mentor. My gratitude also goes to my assessor.

I am grateful to my head of department Dr A.A. Akande for the encouragement and advise whenever I called upon him.

I am especially grateful to Dr S.A. Adebisi my humble teacher who thought me the act of article writing for his encouragement; always ready to teach and advise both academically and socially.

I am also indebted to Dr J.K. Olarinoye who willingly and timely read through my script offering corrections and suggestions; and also releasing his patients for the study.

My gratitude goes to my colleagues in the department and Mr. Babawale for their help and support. I also appreciate the effort of Mrs. O.O. Idowu who helped in identifying the specie of yam.

My special appreciation goes to my darling wife who was always ready to prepare the meals and not forgetting my lovely children.
ABBREVIATIONS

1. Diabetes Mellitus  DM
2. Gestational Diabetes Mellitus  GDM
3. Glycaemic Index  GI
4. Incremental area Under the Glucose Curve  IAUGC
5. Peak Plasma Glucose  PPG
6. Maximum Increase in Plasma Glucose  MIPG
7. Hourly Postprandial Plasma Glucose  HPPG
8. Plasma Glucose Response Indices  PGRI
9. Fasting Plasma Glucose  FPG
10. Food and Agricultural Organization  FAO
11. World Health Organization  WHO
12. Glycaemic Load  GL
13. Body Mass Index  BMI
14. Degree of Polymerization  DP
15. American Diabetes Association  ADA
16. Europe and Diabetes  EURODIAB
17. Medical Nutrition Therapy  MNT
18. High Density Lipoprotein  HDL
19. Low Density Lipoprotein  LDL
20. Sodium dependent Transporter  SGLT
21. Glucose Transporter  GLUT
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.</td>
<td>Short Chain Fatty Acid</td>
<td>SCFA</td>
</tr>
<tr>
<td>23.</td>
<td>Kilocalories</td>
<td>Kcal</td>
</tr>
<tr>
<td>24.</td>
<td>Kilojoules</td>
<td>KJ</td>
</tr>
<tr>
<td>25.</td>
<td>Kilogram</td>
<td>Kg</td>
</tr>
<tr>
<td>26.</td>
<td>Gram</td>
<td>g</td>
</tr>
<tr>
<td>27.</td>
<td>Millimole per litre</td>
<td>mmol/l</td>
</tr>
<tr>
<td>28.</td>
<td>Micromole per litre</td>
<td>µmol/l</td>
</tr>
<tr>
<td>29.</td>
<td>Millilitre</td>
<td>ml</td>
</tr>
<tr>
<td>30.</td>
<td>Coefficient of Variation</td>
<td>CV</td>
</tr>
<tr>
<td>31.</td>
<td>Standard Deviation</td>
<td>SD</td>
</tr>
<tr>
<td>32.</td>
<td>Standard Error of Mean</td>
<td>SEM</td>
</tr>
</tbody>
</table>
SUMMARY

Objective

Physical modifications of foods have been known to play a significant role in dietary management of diabetes. This study is aimed at assessing the effect of physical modification of yam on plasma glucose response in both diabetic and non-diabetic Nigerians.

Materials and Methods

A total of forty-eight subjects were studied, comprising twenty-four diabetics and twenty-four non-diabetics with a sex ratio of 1:1. White yam specie (*Dioscorea rotunda*) was used and modified into three forms of boiled yam, pounded yam and browned yam flour (amala). Weighed amount of the yam meals containing 50g carbohydrate (glucose) equivalent were eaten by the subjects. The values of the mean Plasma Glycaemic Response Indices (PGRI); PPG, MIPG, IAUGC and 2HPPG were determined for the foods in all the subjects. Fifty grams of glucose was also given to the non-diabetic subjects only in other to determine the glycaemic indices (GI) of the food preparations.

Results

The mean age (40.04±1.16 vs 37.83±1.42 years), BMI (23.92±0.46 vs 23.64±0.46 kg/m²), height (1.62±0.01 vs 1.63±0.01 m) and weight (63±1.19 vs 62.72±1.54 kg) were comparable in both diabetics and non-diabetics, respectively, while the mean recruitment FPG (5.5±0.14 vs 4.57±0.16 mmol/l; p<0.05) was significantly higher in the diabetic group.
The mean PPG was significantly higher in the diabetics compared with the non-diabetics (p<0.05) for all the yam meal studied. However the mean PPG were still below the recommended level for diabetic control. The mean MIPG was significantly higher in the diabetics compared with the non-diabetics (p<0.05) for the boiled yam (4.3±0.4 vs 1.9±0.3) and amala (1.8±0.2 vs 1.3±0.2). The mean IAUGC was higher in the diabetics groups compared with the non-diabetics but only achieved statistical significance with boiled yam (276.1±21 vs 128.3±19.3; p<0.05). The mean 2HPPG were significantly higher in the diabetics groups compared with the non-diabetics (p<0.05) for all the yam meals. However the mean 2HPPG level was below the recommended level for diabetic control.

There was no statistical difference (p>0.05) between IAUGC after the glucose load when the three groups of non-diabetics that took the yam meals were compared. The glycaemic indices (GI) of the yam meal are 36.8%, 52.9% and 81.6% for amala, boiled yam and pounded yam respectively.

**Conclusion**

Amala that undergo the highest degree of process before been consumed showed the least GI. This is contrary to previous views that the more processed/refined a food is the higher the glycaemic response. The process of gelatinization and subsequent retrogradation of the starch in the preparation of the yam flour could have accounted for this difference.
TABLE OF CONTENTS

CERTIFICATION ii
DECLARATION iii
DEDICATION iv
ACKNOWLEDGEMENT v
ABBREVIATIONS vi
SUMMARY viii
TABLE OF CONTENT x

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND TO THE STUDY 1
1.2 JUSTIFICATION FOR STUDY 3
1.3 AIMS AND OBJECTIVES 3
1.4 SCOPE AND LIMITATION 4

CHAPTER TWO: LITERATURE REVIEW

2.1 CARBOHYDRATE AND NUTRITION 6
2.2 ENERGY VALUE OF CARBOHYDRATE 7
2.3 GLUCOSE AND INSULIN RESPONSES TO CARBOHYDRATE MEALS 8
2.4 FERMENTATION OF DIETARY CARBOHYDRATES 9
2.5 DIETARY CARBOHYDRATES AND FOOD PROCESSING
   2.5.1 Gelatinisation
   2.5.2 Retrogradation
   2.5.3 Parboiling

2.6 GLYCAEMIC INDEX OF FOOD
   2.6.1 DEFINITION OF GLYCAEMIC INDEX
   2.6.2 FACTORS INFLUENCING GLYCAEMIC RESPONSE
      2.6.2.1 Type of carbohydrate
      2.6.2.2 Physical form of carbohydrate
      2.6.2.3 Viscosity
      2.6.2.4 Cooking
      2.6.2.5 Enzyme Inhibitors and Antinutrients
   2.6.3 THE GLYCAEMIC INDEX AND MIXED MEALS
   2.6.4 CLINICAL SIGNIFICANCE OF GLYCAEMIC INDEX

2.7 NUTRITIONAL MANAGEMENT OF DIABETES MELLITUS
   2.7.1 DIABETES MELLITUS AND SUGARS
   2.7.2 DIABETES MELLITUS AND DIETARY FIBRE

2.8 YAMS [Dioscorea spp.]
   2.8.1 BOTANY OF YAMS
   2.8.2 PRODUCTION AREAS
   2.8.3 COMPOSITION OF D. rotunda
CHAPTER THREE: MATERIALS AND METHODS

3.1 LOCATION OF STUDY

3.2 MATERIALS

3.2.1 SUBJECTS

3.2.1.1 Inclusion criteria

3.2.1.2 Exclusion criteria

3.2.2 Ethical Consideration

3.2.3 Equipment

3.2.4 Reagents

3.3 METHOD

3.3.1 Food preparation

3.3.2 Reference food procedure

3.4 BLOOD SAMPLE COLLECTION AND TREATMENT

3.5 ANALYTICAL METHODS

3.6 DATA HANDLING AND ANALYSIS

CHAPTER FOUR: RESULTS

4.1 GLUCOSE ASSAY PERFORMANCE

4.2 CHARACTERISTICS OF THE STUDY SUBJECTS

4.3 FASTING PLASMA GLUCOSE CONCENTRATION BY YAM MEAL GROUPS

4.4 PLASMA GLUCOSE RESPONSE TO YAM MEALS
CHAPTER FIVE: DISCUSSION

5.1 DISCUSSION

5.2 CONCLUSION

5.3 RECOMMENDATIONS

REFERENCES

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The term diabetes mellitus (DM) historically, was coined from two Greek words “siphon” – meaning high urine flow and “mellitus” meaning honey. Diabetes mellitus is a metabolic disorder of multiple aetiologies characterised by chronic hyperglycaemia with disturbance of carbohydrate, fat and protein metabolism resulting from defects in insulin secretion, insulin action or both. It is the commonest metabolic disorder in Nigeria, similar to the experience in other parts of the world.

Diabetes mellitus can be broadly classified into Type 1 diabetes mellitus, Type 2 diabetes mellitus, other specific types, and Gestational Diabetes Mellitus (GDM). Over 90% of all cases of diabetes mellitus are accounted for by Type 2 DM. It is estimated that there are at least 150 million people worldwide with diabetes now. This figure is expected to double by the year 2025. The prevalence of DM varies all over the world; the highest prevalence is reported in Pima Indians of Arizona and Micronesians estimated at over 40% among adults. The prevalence in US is about 10%. A national survey in Nigeria showed a prevalence rate of 2.2%. Same survey estimated that not less than 1.05 million Nigerians are likely to be diabetic.
with only about 225,000 being aware of their condition and about 198,000 on treatment. Diabetes mellitus is associated with development of both acute and long-term complications.

Diabetes mellitus remains a universal health problem, and its management requires a multidisciplinary healthcare approach which includes a combination of diet, drug or insulin therapy, exercise, and behavioural modifications to ensure long-term compliance. However whether the disease is managed by insulin or oral drugs, dietary measures are necessary and inevitable to sustain an ideal body weight, uphold the control of blood glucose, improve metabolic control and prevent acute and chronic complications.\textsuperscript{9}

Nigeria is made up of people of diverse ethnic groups, cultures, religious and socio-economic levels and hence differences in food choice and food habits. It is important to establish the glycaemic index of some of the common local foods for appropriate dietary recommendation in each locality, since diet therapy and the maintenance of an ideal body weight are cornerstones in the management of diabetes mellitus.

Yam is a root tuber that is grown virtually in every part of Nigeria, and is relatively cheap. Starch is the major constituent of the yam tuber and accounts for up to 85\% of its dry weight. It can be prepared into various delicacies after various modes of modification of the tuber.

The glycaemic index or GI is a useful concept because it measures how rapidly the carbohydrates are absorbed and result in blood glucose and insulin elevations. The GI is a measure of the rise in blood sugar caused by the intake of a measured quantity of a particular food. The GI is not related to whether the carbohydrate is simple or complex.
In recent years a great deal of attention has been focused on the variable metabolic responses seen after ingestion of different types of simple and complex carbohydrates.\textsuperscript{10} Data also abound on the glycaemic index of various foods in different societies. The importance of food forms on glycaemic index has been demonstrated in a number of studies.\textsuperscript{10}

In Nigeria few studies have been carried out on the blood glucose response and glycaemic indices of foods \textsuperscript{11, 12, 13,14,15,16}. None of these studies was designed to specifically determine the effect of physical modifications of these foods. Is there a significant difference in the blood glucose response as a result of physical modifications of some of Nigerian foods? Is there a significant difference in the blood glucose response in diabetic and non-diabetic Nigerians as a result of these physical modifications? Therefore there is a need to study the effect of physical modifications on some of these foods.

This study was therefore aimed at determining the effect of physical modifications of white yam on glycaemic response in both diabetic and non-diabetic Nigerians and subsequently determines the glycaemic indices of these foods.

1.2 JUSTIFICATION FOR THE STUDY

The prevalence of Diabetes mellitus in Nigeria is rising. Dietary modification forms the cornerstone of management of the disease especially in Nigeria where most anti-diabetic drugs are either not readily available or not affordable. Lifestyle intervention including dietary modification reduces the incidence of diabetics in high risk individuals. One of the major staple foods eaten in Nigeria is yam. Physical processing of food has been known to affect its postprandial glucose and insulin responses\textsuperscript{10} which are crucial to the control of diabetes. This
study will provide information that will help in advising people with diabetes on the best form of their yam-derived meals.

1.3 AIMS AND OBJECTIVES

(a) The general objectives of this study are as follow

   i) To assess the effect of food processing on glycaemic response (glycaemic index) of yam meals.

   ii) To determine if there are any differences in the glycaemic response to different forms of yam meals in diabetics and non-diabetics.

(b) The specific aims of this study are as follow

   i) To determine the blood glucose response (glycaemic index) to boiled yam, pounded yam, and ‘amala’ (from yam flour) in non-diabetic individuals.

   ii) To determine the blood glucose response to boiled yam, pounded yam, and ‘amala’ (from yam flour) in diabetic individuals.

1.4 THE SCOPE AND LIMITATIONS OF THE STUDY

In order to monitor and ensure adequacy of daily carbohydrate intake, uniformity of activity and homogeneity of foods intake among the subjects, they should have been placed in the same residential environment (preferably Hospital premise) three days prior to starting the study and during the period of the study. The cost of admission and stay in the hospital to achieve this is a limitation to this study.

In non-diabetics blood insulin response to the ingested food is determined by the component of the food. Insulin responses to these meals were not investigated. Non-availability of insulin assay reagents for determination of plasma insulin and high cost when available is another limitation to the scope of this study.
Starch digestibility of the yam meal, which can be determined by incubating the various yam meals in digestive enzymes (e.g. disaccharidases, amylase) extracted from human or other animals, *in vitro* was not done to explain some of the observed differences in glycaemic responses *in vivo*.

The glycaemic indices for the meals in this study were derived from one set of incremental area under glucose curve (IAUGC) for the meal of interest and one set of IAUGC for glucose load in the same subject. The FAO/WHO expert consultation panel \(^{17}\) recommends the derivation of glycaemic index from one set of IAUGC for the food of interest and an average of about three sets of IAUGC for glucose load in the same subjects. The choice of one glucose tolerance test in determining the glycaemic indices in this study was to enhance the compliance with the number of visits. The IAUGC is derived by determining the area under the plasma glucose response curve above the fasting plasma glucose calculated geometrically using the trapezoid rule. The area of the triangles and trapezoids that are formed under the curve (i.e. the level of the fasting plasma glucose is the base, while the various half hourly peaks is the height) are summed together to give the incremental area under the curve. This incremental area is the critical value altered by acute ingestion of meals \(^{18}\).

It would have been ideal to analyse the composition of each yam meal to be more certain of the content but given the available resources, this was not possible. The meal composition was estimated from meal tables as other workers had previously done.\(^{13,15,16}\)
CHAPTER TWO
LITERATURE REVIEW

2.1 CARBOHYDRATE AND NUTRITION

Carbohydrates play a major role in human diets, comprising some 40-75% of energy intake. Their most important nutritional property is digestibility. McCance and Lawrence in 1929 divided dietary carbohydrates into available and unavailable carbohydrates in their attempt to prepare food tables for diabetic diet. Available carbohydrates are those that are hydrolys ed by enzymes of the human gastrointestinal system to monosaccharides that are absorbed in the small intestine and enter the pathways of carbohydrate metabolism, while unavailable carbohydrates are not hydrolysed by endogenous human enzymes, although they may be fermented in the large intestines to varying extents.

A formal definition of a carbohydrate commonly accepted is that carbohydrates are "polyhydroxy aldehydes, ketones, alcohols, acids, their simple derivatives and polymers having polymeric linkages of the acetal type". Carbohydrates are further classified according to their degree of polymerisation (DP) as: sugars (mono- and disaccharides), oligosaccharides (three to nine monosaccharide units), and polysaccharides (ten or more monosaccharide
Each of these three groups may be subdivided on the basis of the monosaccharide compositions. Sugars comprise monosaccharides, disaccharides and polyols (sugar alcohols). Oligosaccharides include malto-oligosaccharides, principally those occurring from the hydrolysis of starch, and other oligosaccharides, e.g. \( \alpha \)-galactosides (raffinose, stachyose etc.) and fructo-oligosaccharides. The final groups are the polysaccharides which may be divided into starch (\( \alpha \)-glucans) and non-starch polysaccharides of which the major components are the polysaccharides of the plant cell wall such as cellulose, hemicellulose and pectin.

### 2.2 ENERGY VALUE OF CARBOHYDRATES:

Dietary carbohydrates have an energy value of 4 kcal/g (17kJ/g); when expressed as monosaccharides, the value of 3.75 kcal/g (15.7 kJ/g) is used. A number of carbohydrates are only partly or not at all digested in the small intestine and are fermented in the large bowel to short chain fatty acids. These include the non-digestible oligosaccharides, resistant starch and non-starch polysaccharides. The process of fermentation is metabolically less efficient than absorption in the small intestine and these carbohydrates provide the body with less energy.\(^{17}\)

### 2.3 GLUCOSE AND INSULIN RESPONSES TO CARBOHYDRATE MEALS:

The digestion of dietary carbohydrates starts in the mouth, where salivary \( \alpha \)-amylase initiates starch degradation. The starch fragments thus formed include maltose, some glucose and dextrins containing the 1,6-\( \alpha \) glycosidic branching points of amylepectin. The \( \alpha \)-amylase degradation of starch is completed by the pancreatic amylase active in the small intestine. Dietary disaccharides, as well as degradation products of starch, need to be broken down to monosaccharides in order to be absorbed. This final hydrolysis is accomplished by hydrolases attached to the intestinal brush-border membrane, referred to as "disaccharidases".
Disaccharidase deficiencies occur as rare genetic defects, causing malabsorption and intolerance of the corresponding disaccharide. Glucose and galactose are transported actively against a concentration gradient into the intestinal mucosal cells by a sodium dependent transporter (SGLT 1). Glucose is pumped out of the enterocyte into the extracellular space by the glucose transporter 2 (GLUT 2). Fructose undergoes facilitated transport by another mechanism (GLUT 5).17

When delivered to the circulation, the absorbed carbohydrates cause an elevation of the blood glucose concentration. Fructose and galactose have to be converted to glucose mainly in the liver and therefore produce less pronounced blood glucose elevation. The extent and duration of the blood glucose rise after a meal is dependent upon the rate of absorption, which in turn depends upon factors such as gastric emptying, as well as the rate of hydrolysis and diffusion of products of hydrolysis in the small intestine.

Insulin is secreted as a response to blood glucose elevation but is modified by many neural and endocrine stimuli. Insulin secretion is also influenced by food related factors, especially by the amount and the amino acid composition of dietary proteins, particularly arginine, lysine, leucine and phenylalanine. Insulin has important regulatory functions in both carbohydrate and lipid metabolism and is necessary for glucose uptake by most body cells.17

2.4 FERMENTATION OF DIETARY CARBOHYDRATES: Fermentation is the colonic phase of the digestive process and describes the breakdown in the large intestine of carbohydrates not digested and absorbed in the upper gut. This process involves gut microflora and is unique to the colon of humans because it occurs without the availability of oxygen. It thus results in the formation of gases e.g. hydrogen, methane and carbon dioxide, as well as
short chain fatty acids (SCFA) (acetate, propionate and butyrate), and stimulates bacterial
growth (biomass). The gases are either absorbed and excreted in breath, or passed out via the
rectum. The major products of such fermentation are the SCFA, which are rapidly absorbed
and metabolised by the body.\textsuperscript{17}

2.5 DIETARY CARBOHYDRATES AND FOOD PROCESSING

2.5.1 Gelatinisation: - Gelatinisation refers to the irreversible loss of the crystalline
regions in starch granules that occur upon heating in the presence of water. Gelatinisation
increases the availability of starch for digestion by amylolytic enzymes. Starch granules are
not completely dissolved during food processing, thus food can be regarded as dispersion in
which starch granules and/or granular remnants constitute the disperse phase. The degree of
gelatinisation achieved by most commonly used food processes, however, is sufficient to
permit the starch to be rapidly digested. Consequently even food processes, which result in a
low degree of gelatinisation (e.g. steaming and flaking of cereals), produce postprandial blood
-glucose and insulin increment similar to that with completely gelatinised foods.\textsuperscript{17}

2.5.2 Retrogradation: - Gelatinised starch is not in thermodynamic equilibrium. There
is, therefore, a progressive re-association of the starch molecules upon ageing of the starch
molecules. This recrystallisation is referred to as retrogradation, and may reduce the
digestibility of the starch. The retrogradation of the amylopectin component is a long-term
phenomenon occurring gradually upon storage of starchy foods. Amylose, however, re-
associates more quickly. The crystallinity of retrograded amylopectin is lost following re-
heating to approximately 70°C, whereas temperatures above 145°C are required to remove
crystallinity of retrograded amylose. This is a temperature well above the range used for
processing of starchy foods. This implies that retrograded amylose, once formed, will retain its crystallinity following re-heating of the food.\textsuperscript{17}

2.5.3 \textbf{Par-boiling:} - During par-boiling of rice, the kernels are subjected to a pre-treatment involving heating and drying. This process reduces the stickiness of the rice, possibly by allowing leached amylose to retrograde and/or form inclusion complexes with polar lipids on the kernel surface. Parboiling also affects the final cooking properties of the rice.\textsuperscript{17}

2.6 \textbf{GLYCAEMIC INDEX OF FOOD}

- Epidemiological studies\textsuperscript{22} have reported that as nations become more affluent, the nature of the people’s carbohydrate consumption changes such that the ratio of complex (starches) to simple carbohydrates decreases. It has been suggested that this change in dietary pattern is responsible for the occurrence of various diseases, such as atherosclerosis, diabetes and hyperlipidaemia. One proposed physiologic basis underlying such suggestions is a traditionally held tenet that simple carbohydrates are more readily available for immediate absorption by the gut than are more complex carbohydrates and that they therefore produce a greater and faster rise in postprandial plasma glucose and insulin responses than do the supposedly more gradually digested and absorbed complex carbohydrate. Consequently, diets restricted in simple carbohydrates have been recommended in disease states in which control of plasma glucose and/or insulin is felt to be important. Dahiqvist and Borghstrom\textsuperscript{23} as well as Fogel and Gray\textsuperscript{24} have challenged this concept of carbohydrate digestion and absorption. These workers demonstrated that after test meals, more than enough intraluminal amylase is
present to rapidly hydrolyse ingested starch. They concluded that absorption, not intraluminal digestion, was the rate-limiting step in overall starch assimilation.

It has also been shown\textsuperscript{25} that complex carbohydrates resulted in lower glucose and insulin responses than equivalent amounts of glucose or sucrose, indicating that despite adequate amylase, the process of starch digestion proceeds more slowly. It was also found that glucose and insulin responses to cooked potato were significantly higher than the glucose and insulin responses to rice. These latter findings suggest that not all starches are treated identically by gastrointestinal digestive and absorptive processes.

Evidence favouring the active reduction of blood lipids continues to accumulate, and several major diabetes associations now recommend that diabetic patients should reduce fat intake and increase carbohydrate intake to approximately 50\% of total calories. Since one aim of diabetic therapy is to prevent large fluctuations in blood glucose throughout the day diabetics are advised to select carbohydrate foods that minimise the postprandial blood glucose excursions. In the absence of adequate information specific advice on food selection is not given, although high-fibre foods have been advocated\textsuperscript{26}. Before detailed advice can be given, comparative data on the physiological effects of carbohydrate foods are required.

Otto \textit{et al} recorded large differences in glycaemic response between carbohydrate foods in diabetic patients\textsuperscript{27}. One of the aims of such studies was to develop tables from which diabetic diets could be constructed based on the biological equivalence of the foods prescribed. A similar method that permits such comparisons involves classification of foods in terms of their glycaemic indices (GI)\textsuperscript{28,29}

\[
\text{GI} = \frac{\text{Blood glucose area under curve of test food}}{\text{Blood glucose area under curve of standard food}} \times 100
\]
where the valuable carbohydrate content of the test and reference foods is the same. This method allows results of food testing in individuals with different glucose tolerance to be pooled and comparison made between findings of different investigators. In general, results of studies in young adult, normal weight, non-diabetic volunteers agree well with those in middle-aged and elderly, overweight, diabetic patients.  

2.6.1 DEFINITION OF GLYCAEMIC INDEX

The blood glucose responses of carbohydrate foods can be classified by the glycaemic index (GI). The GI is considered to be a valid index of the biological value of dietary carbohydrates. It is defined as the glycaemic response elicited by a 50g carbohydrate portion of a food expressed as a per cent of that elicited by a 50g carbohydrate portion of a standard food. The glycaemic response is defined as the incremental area under the blood glucose response curve, ignoring the area beneath the fasting concentration (i.e. the area beneath the curve). The standard food has been glucose or white bread. If glucose is the standard, (i.e. GI of glucose = 100) the GI values of foods are lower than if white bread is the standard by a factor of 1.38 because the glycaemic response of glucose is 1.38 times that of white bread. GI values for several hundreds foods have been published.

2.6.2 FACTORS INFLUENCING GLYCAEMIC RESPONSE

2.6.2.1 Type of carbohydrate: Crapo et al studied the effects of four different kinds of dietary starch (potato, rice, corn, and wheat) on postprandial plasma glucose and insulin responses and showed that there is a range of plasma glucose and insulin responses to different
starches, with rice and corn producing the lowest response curves.\textsuperscript{35} In an earlier study\textsuperscript{25}, Crapo proposed that the rate of digestion and absorption is not the same for all orally ingested starch molecules. The mechanism(s) for the differences between starches is not clear, although gastric emptying time, physical availability of starch to hydrolytic enzymes, and differences in the stimulation of gastrointestinal insulinogenic hormones may be factors.

\textbf{2.6.2.2 Physical form of carbohydrates:} Altering the physical form of a complex carbohydrate (e.g., grinding of rice) changes the postprandial glucose and insulin responses to it.\textsuperscript{36} It was also demonstrated that a close correlation exists between the rates at which the starch in ground rice and unground rice was hydrolysed \textit{in vitro} and the glucose and insulin responses to equal loads of these different physical forms of rice \textit{in vivo}.\textsuperscript{37} Evaluation of brown rice and white rice demonstrated that there was no significant difference in glycaemic response between whole white rice and brown rice but glycaemic response to both were significantly and dramatically higher when the rice was ground into flours.\textsuperscript{36} Similar results were seen with whole and ground lentils\textsuperscript{38}. Pureed apples and apple and orange juice elicit higher blood insulin responses than do whole apples or oranges.\textsuperscript{39,40} Thus on the basis of these and other results it has been suggested that the rate of digestion and absorption of complex carbohydrates are critical factors in determining the metabolic response to dietary carbohydrates, and that this principle could be applied to the design of diets for the treatment of diabetes. Choosing foods that are most slowly digested and absorbed should flatten the postprandial glucose response curve and thereby reduce the insulin requirement. O’Dea and Collier showed that the flattening of the postprandial glucose curve after rice relative to ground rice or glucose was more striking in diabetic than in normal subjects.\textsuperscript{41} This underlines
the importance of not simply recommending that diabetics increase their consumption of complex carbohydrates to improve metabolic control. The actual form of the complex carbohydrates is critical in determining the metabolic response to it. Booher et al. concluded in 1951 that conditions which increase the digestibility of starches include those modifications which produce obvious hydration of the granules, distinct from changes in chemical nature, or disruption of the organised structure. In general, it appears that the more change in physical form a food is, the higher the glycaemic response it will produce.

2.6.2.3 Viscosity: Certain gelling fibers (guar gum, pectin, tragacanth) when mixed with glucose during a glucose tolerance test result in a dose dependent flattening of postprandial glucose and insulin responses which has been attributed to the viscosity of the fiber. *In vitro* studies demonstrating a reduced rate of passage of glucose out of a dialysis sac when these gelling fibers were present support this suggestion. Similarly, it has been shown that carbohydrates of leguminous origin such as lentils and red kidney beans result in flattened postprandial glycaemic responses reminiscent of the guar-glucose mixture.

2.6.2.4 Cooking: Cooking not only increases the viscosity but also splits the starch granules, thereby increasing the availability of the starch to amylase. The responses of serum glucose and insulin to both cooked and raw starch were studied in eleven medical students by Collings et al. It was observed that the response of serum glucose to glucose monohydrate and cooked starch were closely similar, while that to raw starch was significantly less. The serum insulin response was greatest with glucose monohydrate meal, and the area under this response curve was significantly greater than that after the cooked starch meal, which in turn
was significantly greater than that after starch meal. The effect of moist and dry heat on \textit{in vivo} and \textit{in vitro} legume starch digestibility showed that boiling and pressure-cooking resulted in faster rates of digestion than roasting\textsuperscript{44}. In addition, Jenkins \textit{et al}\textsuperscript{45} found that drying cooked red lentils in a warm oven for 12h resulted in a significantly enhanced glycaemic response and rate of \textit{in vitro} starch digestion compared with lentils boiled for 20 minutes. Therefore, the type and time of cooking may influence the \textit{in vivo} and \textit{in vitro} digestibility of carbohydrate foods.

\textbf{2.6.2.5 Enzyme Inhibitors and Anti-nutrients:} Enzyme inhibitors and lectins have been shown to produce hypoglycemia and decreased growth rate in rats\textsuperscript{44}. Furthermore, it has been shown that starch digestion may be inhibited in the gastrointestinal tract by anti-nutrients. Certain amylase inhibitors (Bay d 7791), are known to cause decreased glucose absorption in dogs, rats, and humans as judged by peripheral blood glucose response\textsuperscript{46}. Amylase and sucrase inhibitors\textsuperscript{47}, which have been shown to reduce the rate of carbohydrate digestion and absorption, have been used in the treatment of diabetes\textsuperscript{48}, although only those of bacterial origin have, as yet, proved truly effective. Inhibition of intestinal $\alpha$-glucosidases delays the digestion of starch and sucrose and flattens postprandial blood glucose excursions in type 2 diabetes; the $\alpha$-glucosidase inhibitor, acarbose, is used widely in the management of type 2 diabetic patients. An additional action of $\alpha$-glucosidase inhibitors may be to inhibit the entry of glucose into enterocytes\textsuperscript{49}. Furthermore, phytic acid supplements added to unleavened white bread decreased rates of release of starch digestion products \textit{in vitro}, and decreased blood glucose responses compared with plain unleavened white bread\textsuperscript{44}. 

\textsuperscript{44}
2.6.3 THE GLYCAEMIC INDEX AND MIXED MEALS

The validity of the GI has been the subject of much controversy, mostly because of supposed lack of application to mixed meals. Much of the controversy has been because of application of inappropriate methods to estimate the expected glycaemic responses for mixed meals. When properly applied, the GI predicts, with reasonable accuracy, the relative blood glucose responses of mixed meals of the same composition but consisting of different carbohydrate foods.\(^{17}\)

2.6.4 CLINICAL SIGNIFICANCE OF GLYCAEMIC INDEX

Twenty years have passed since the first index of the relative glycaemic effects of carbohydrate exchanges from 51 foods was published by Jenkins \textit{et al}.\(^{28}\) Despite controversial beginnings, the GI is now widely recognised as a reliable, physiologically based classification of foods according to their postprandial glycaemic effects.

In 1997 the Food and Agriculture Organisation (FAO) of the United Nations and the World Health Organisation (WHO) reviewed available research evidence regarding the importance of carbohydrates in human nutrition and health,\(^{17}\) and 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. In Australia, official dietary guidelines for healthy elderly people specifically recommend the consumption of low-GI cereal foods for good health, and a GI trademark certification program is in place to put GI values on food labels as a means of helping consumers to select low-GI foods.\(^{50}\) Many laboratories around the world currently conduct commercial GI testing of foods.
for the food industry. Many recent popular diet books contain extensive lists of the GI values of individual foods or advocate the consumption of low-GI, carbohydrate-rich foods for weight control and good health.

Reliable tables of GI compiled from the scientific literature are instrumental in improving the quality of research examining the relation between the dietary glycaemic effect and health. Several studies from Harvard University indicate that the long-term consumption of a diet with a high glycaemic load (GL) (GL = GI x dietary carbohydrate content) is a significant independent predictor of the risk of developing type 2 diabetes and cardiovascular disease. More recently, evidence has been accumulating that a low-GI diet might also protect against the development of obesity, colon cancer, and breast cancer.50

The EURODIAB (Europe and Diabetes) study, involving >3000 subjects with type 1 diabetes in 31 clinics throughout Europe, showed that the GI rating of self-selected diets was independently related to blood concentrations of glycated haemoglobin in men and women51 and to waist circumference in men.52 In addition, higher blood HDL-cholesterol concentrations were observed in patients consuming low-GI diets from the northern, eastern, and western European centers participating in the study.52 Indeed, several studies have shown that the dietary GI is a good predictor of HDL concentrations in the healthy population, whereas the amount and type of fat are not.50 Thus, the GI has proven to be a more useful nutritional concept than is the chemical classification of carbohydrate (as simple or complex, as sugars or starches, or as available or unavailable), providing new insights into the relation between foods and health.
In parallel with these advances there have been studies documenting the importance of postprandial glycaemia *per se* for all-cause mortality and cardiovascular disease mortality in healthy populations. In the Hoorn study there was a significant association between the 8-year risk of cardiovascular death and 2-hour postload blood glucose concentrations in subjects with normal fasting glucose concentrations, even after adjustment for known risk factors. Multiple mechanisms are probably involved. Recurring, excessive postprandial glycaemia could decrease blood HDL-cholesterol concentrations, increase triglyceridaemia, and also be directly toxic by increasing protein glycation, generating oxidative stress, and causing transient hypercoagulation and impaired endothelial function. If postprandial glycaemia is indeed important, then dietary treatment for the prevention or management of chronic diseases must consider both the amount and type of carbohydrate consumed. In the USA three intervention studies in adults and children with type 1 diabetes showed that low-GI diets improve glycated haemoglobin concentrations. In subjects with cardiovascular disease, low-GI diets were shown to be associated with improvements in insulin sensitivity and blood lipid concentrations.

In addition, evidence from both short-term and long-term studies in animals and humans indicate that low-GI foods may be useful for weight control. Laboratory studies examining the short-term satiating effects of foods have shown that low-GI foods are relatively more satiating than are their high-GI counterparts. Compared with low-GI meals, high-GI meals induce a greater rise and fall in blood glucose and a greater rise in blood insulin, leading to lower concentrations of the body's 2 main fuels (blood glucose and fatty acids) in the
immediate postabsorptive period. The reduced availability of metabolic fuels may act as a signal to stimulate eating.

It is also important to emphasise that many low-GI foods are relatively less refined than are their high-GI counterparts and are more difficult to consume. The lower energy density and palatability of these foods are important determinants of their greater satiating capacity. In obese children, the ad libitum consumption of a low-GI diet has been associated with greater reductions in body mass indexes. However, some experts have raised concerns about the difficulties of putting advice about GI values into practice and of the potentially adverse effects on food choice and fat intake. For this reason, the American Diabetes Association does not recommend the use of GI values for dietary counseling. However, the European Association for the Study of Diabetes, the Canadian Diabetes Association, and the Dietitians Association of Australia all recommend high-fiber, low-GI foods for individuals with diabetes as a means of improving postprandial glycaemia and weight control.

There is also some evidence that the glycaemic index is relevant to sports nutrition and appetite regulation. Low GI foods eaten before prolonged strenuous exercise increased endurance time and provided higher concentrations of plasma fuels toward the end of exercise. However, high GI foods led to faster replenishment of muscle glycogen after exercise.

2.7 NUTRITIONAL MANAGEMENT OF DIABETES MELLITUS

The prevalence of diabetes mellitus (DM) is increasing around the world and at a rate that appears as dramatic as to have been characterised as an epidemic. Many factors have been postulated to contribute to the DM epidemic. Environmental factors have drawn particular
attention because of the rapidity of the increase in type 2 DM. Because DM is a disease directly related to carbohydrate, lipid, and protein metabolism, nutrition has always had an integral role in its management. The contemporary term used to describe the dietary prescriptions is medical nutrition therapy (MNT). Before the advent of insulin therapy in the early 20th century, MNT was the only form of therapy for DM.

The goals of MNT for diabetes include:

- Achieve and maintain near normal blood glucose goals
- Achieve and/or maintain optimal blood lipid levels
- Achieve and/or maintain normal blood pressure
- Prevent, delay or treat nutrition related complications
- Provide adequate kcalories for achievement of reasonable body weight
- Provide optimal nutrition for maximising health and for growth, development, pregnancy, and lactation

2.7.1 DIABETES MELLITUS AND SUGARS

The ADA recommends that the classifications sugars, starch, and fiber be used as the functional definitions of carbohydrates for MNT. Previously used terms such as simple sugars, complex carbohydrates, and fast-acting carbohydrates are now discouraged from further usage. With respect to carbohydrates, the key emphasis of MNT for DM is on the total amount of carbohydrate in terms of energy intake. Regarding the type of carbohydrate ingested, the guidelines for MNT in DM clearly stress the value of selecting vegetables, fruit, and grains so that the starches consumed will include adequate amounts of both fiber and micronutrients.
Sucrose and other sugars can be consumed by those with DM and need to be considered primarily from the perspective of energy consumed and thus substituted for other sources of carbohydrate. This perception of the sensitivity of metabolic control in DM to energy balance underlies the recommendations that emphasise carbohydrate content as a key point for patient education. The 3 points stressed are:

1) Knowledge concerning which foods contain carbohydrates,

2) Recognition of the portion size for carbohydrate within a meal (with 15 g being the basis for estimating 1 carbohydrate serving), and

3) Knowledge of how many carbohydrate servings is appropriate within a meal or snack.

Negative energy balance can promptly induce reductions in hyperglycaemia and hypertriglyceridaemia, even before the achievement of substantial weight loss, whereas consumption of excess energy has the opposite effect. Increased energy consumption regardless of source, but certainly including carbohydrate, directly induces insulin resistance.

Metabolic studies have been used to compare the glycaemic response to sugars consumption in persons with DM with isocaloric consumption of other sources of carbohydrates. Bantle et al compared the postprandial glycaemic response to various forms of carbohydrates (42 g separately of glucose, fructose, sucrose, potato starch, and wheat starch) that composed 25% of total energy within a mixed meal also containing protein and fat. Fructose ingestion led to a lower postprandial glycaemic response in those with DM, but the other forms of carbohydrate had nearly identical responses. The recommendation is that if sucrose is consumed, it should be substituted for other carbohydrates.
2.7.2 DIABETES MELLITUS AND DIETARY FIBRE

There has been specific interest in the role that dietary fiber may have in the nutritional management of DM. Benefits of fiber were found with regard to glycaemic control, HDL and LDL cholesterol, and triacylglycerols.\textsuperscript{66} However, a 3-month study by Jenkins \textit{et al}\textsuperscript{67} did not find a metabolic advantage of high-fiber over low fiber cereals. Also Erasmus \textit{et al}\textsuperscript{68} in a 3-week study showed that treatment with guar gum does not lower the postprandial glucose level in both non-diabetic and diabetic Nigerian subjects.

In consideration of the available data as a whole, the ADA expert committee did not perceive that there was value in recommending an increase in fiber intake above general recommendations for persons with DM.\textsuperscript{69}

2.8 YAMS [\textit{Dioscorea spp.}]

Of all the tropical food crops, few are as closely associated with a particular cultural area as are certain species of yam with West Africa.\textsuperscript{70} Yams are extensively grown and used in other parts of the world, but nowhere else, except perhaps in Melanesia, are they of such central importance. In much of West Africa yams are still today the preferred staple food among many of those inhabiting the forest and wetter parts of the Guinea savanna zones, although they were relatively more important before the introduction of American food crops such as maize, cassava, and tannia [\textit{Xanthosoma}].

The economically important yams belong to the genus \textit{Dioscorea}, which is the largest genus of the family Dioscoreaceae. It is of pantropic distribution and contains some 600 species.\textsuperscript{70}

2.8.1 BOTANY OF YAMS: During the wet season the plant in the wild or primitive agriculture grows as a ‘vine’, which twines through trees or undergrowth, but in cultivation, it
is usually trained on stakes, strings or wires. At the end of the wet season, the vine dies completely and the plant survives the dry season as dormant tubers. It is these tubers that are economically useful as human food.\textsuperscript{70}

2.8.2 PRODUCTION AREAS: The main areas of yam production in the world are West Africa, the Caribbean, and parts of South-East Asia, New Guinea and the islands of the Pacific. Production of yams in West Africa is largely confined to the West African ‘yam zone’, which extend from the Central Ivory Coast to Cameroun, spanning both the forest and the more humid parts of Guinea savanna. The commonly found varieties in Nigeria include \textit{D. rotunda} [white yam, mainly in southern Nigeria], \textit{D. cayenensis} [yellow yam, mainly in eastern Nigeria] and \textit{D. alata} [water yam].\textsuperscript{70}

2.8.3 COMPOSITION OF \textit{D. rotunda}: \textit{D. rotunda} is made up of 67% moisture. By dry weight the yam is composed of 80% starch, 7% protein, 7% minerals, 3% fibre and 1.7% lipids. 100g of the yam give 385kcal energy.\textsuperscript{71}

2.8.4 PLASMA GLUCOSE RESPONSE TO YAM MEAL: Ohwovoriole \textit{et al}\textsuperscript{11} in a study of isocaloric amounts of commonly eaten Nigerian meals showed that yam occupied an intermediate position in terms of the five indices of glycaemic response studied, a result similar to what was obtained by Oli \textit{et al}\textsuperscript{12} who showed a high response to boiled yam in terms of the glycaemic response studied. Akanji \textit{et al}\textsuperscript{15} investigated the influence of salt on the glycaemic responses, and the study showed the high glycaemic response of yam when compared with beans. Brakohiapa \textit{et al}\textsuperscript{72} in Ghana showed a high glycaemic index for yam among five Ghanaian diets studied in healthy adult males. The fibre content of tuber flours is generally higher than that of fresh tubers. Balogun\textsuperscript{13} who studied the glycaemic indices of
some common Nigerian meals showed that boiled yam has the highest glycaemic index and ‘amala’ (yam flour) has an intermediate value. However, Wheatley et al.\textsuperscript{73} studied the relationship between amylose content and the \textit{in vitro} digestibility and glycaemic index of some Jamaican yam (Dioscorea spp.) starches and showed that white yam starch (\textit{D. rotunda}) has a high amylose content, low glycaemic index and one of the least digestible.

**CHAPTER THREE**

**MATERIALS AND METHODS**

3.1 LOCATION OF STUDY

This project, a cross-sectional study, was carried out in the Departments of Chemical Pathology and Internal Medicine of the University of Ilorin Teaching Hospital, a tertiary health institution in Ilorin, Kwara State Nigeria. The services of the teaching hospital also cover Kogi, Oyo, Niger, Ondo, Ekiti and Osun State.

3.2 MATERIALS AND SUBJECTS

3.2.1 SUBJECTS

A total of 48 subjects with a male to female ratio of 1:1 were recruited into the study as follows:

i) Twenty-four non-diabetics healthy subjects consisting of 12 males and 12 females.

ii) Twenty-four type 2 diabetics as defined by WHO classification of diabetes mellitus\textsuperscript{2} consisting of 12 males and 12 females.

The age, height, weight, blood pressure and baseline fasting plasma glucose were determined for all subjects.
3.2.1.1 Inclusion criteria: **Non-diabetic** subjects recruited had no family history of diabetes, were not on any drug that could affect carbohydrate metabolism, and had no evidence of hepatic or renal insufficiency, were between 27 and 50 years of age (as age advances glucose tolerance becomes poorer\(^7\)), and had body mass index (BMI) of less than 30kg/m\(^2\) (insulin sensitivity has been shown to decline with increasing BMI\(^7\)). Non-diabetics with impaired fasting glycaemia (Fasting plasma glucose >6.1-7mmol/l) were excluded from the study.

**Diabetic** subjects recruited were maintained with diet alone or diet and oral hypoglycaemic agents, had good glycaemic control (FPG at recruitment between 4-6.7mmol/l), less than 50 years of age, BMI less than 30kg/m\(^2\), absence of symptoms and signs of autonomic neuropathy, and absence of hepatic or renal insufficiency. Diabetic subjects were on their regular medication except on the morning of the test meal consumption.

3.2.1.2 Exclusion criteria: Subjects with BMI >30kg/m\(^2\), above 50 years of age, presence of gastrointestinal, renal or hepatic disease were excluded from the study. Diabetic subjects with chronic complications of diabetes suggestive of gastric stasis gastroparesis (a condition in which the normal rate at which the stomach empties food into the duodenum is slowed) were also excluded.
3.2.2 Ethical Consideration: Informed written consent was obtained from the subjects before recruitment into the study. Approval for the study was obtained from the Ethical Review Committee of the University of Ilorin Teaching Hospital before commencing the study. (Appendix 1)

3.2.3 Equipment: Fluoride oxalate specimen bottles, needle and syringes, cannulae, spirit swab, weighing scales, meter rule, blood pressure measuring apparatus; pipettes, micropipettes and tips, test tubes, test tube rack, disposable gloves, pipette bulb, spectrophotometer; measuring jar.

3.2.4 Reagents: Randox Glucose reagents kits with lot no 1455GL and expiring date of December 2006 was used for the glucose analysis. Quality control was ensured by analysing with Bovine precision multi-sera samples to determine the precision and accuracy of the method. Reagents were stored in the refrigerator at 8°C when not in use.

3.3 METHOD

3.3.1 Food preparation: The specie of yam (*D. rotunda*-white yam) was sourced from the local market (with the help of an agriculturist) and prepared as follows:

(i) Boiled yam: Peeled yam sliced and cooked until softened with salt added to taste.

(ii) Pounded yam: Peeled yam sliced and cooked until softened and pounded in a mortar using a pestle to a smooth dough consistency.

(iii) Amala: This was prepared from browned yam flour. In Nigeria browned yam flour “elubo”, is traditionally made by parboiling yam chips at about 80°C till the chips are pliable, then the chips are sun-dried for about 72 hours and ground into flour. The yam flour was
reconstituted by boiling in water and cooked with continuous stirring until a thick brown or grey-coloured smooth paste is formed (amala) 76.

Each of the three preparations was consumed with the same quantity of stew composed of fresh pepper and tomato cooked with red palm oil and salt added to taste, of about 30ml with a piece of meat (beef only) of uniform size (about 35g) and 250ml of water.

The non-diabetic subjects were on their regular staple diet (which have adequate carbohydrate content in this locality), while diabetic subjects were on their regular anti-diabetic diets. Each subject fasted for 10-14 hours overnight preceding the day of the test.

3.3.2 Reference food procedure: Fifty grams of glucose as recommended by the WHO/FAO expert consultation panel17 was weighed and dissolved in 350ml of portable water and given to the non-diabetic subject following the overnight fast after the fasting blood samples had been taken. Blood sample was collected every 30 minutes for two hours.

(b) Test food procedure: This was conducted with at least a day interval after the reference food procedure for the non-diabetic subjects. The food varieties were prepared in the morning of the test by the same individual. Using food composition tables for local foods77-79 10g of carbohydrate equivalent (i.e. 10g of glucose) was contained in 35g of boiled yam; 45g of pounded yam and 56g of amala. Weighed amount of each food to contain 50g glucose (i.e. 175g of boiled yam, 225g of pounded yam and 280g of amala) were measured. These were eaten with about 30ml of the prepared stew within 15minutes after collection of the fasting blood sample. Blood samples were collected at 30, 60, 90 and 120minutes by doing a
venepuncture at each sampling period with a fresh needle and syringe. Timing for sample collection was commenced with the first bite of the food.

3.4 BLOOD SAMPLE COLLECTION AND TREATMENT

Ante-cubital vein area was disinfected with methylated spirit and venous blood collected with minimum stasis. Two ml of blood was taken at each sampling period into a fluoride oxalate specimen bottles and mixed properly. Plasma was retrieved into plain bottles after centrifuging and stored in the refrigerator until analysis same day. Analytical precision (by determining the coefficient of variation) and accuracy (by determining the % bias), was ensured by analysing commercial Bovine precision multi-sera samples (by Randox) normal and high with each analytical run. The low precision and accuracy multi-sera samples were not available during the period of analyses.

3.5 ANALYTICAL METHODS

Many analytical procedures are use to measure blood glucose concentrations. All commonly used techniques are now enzymatic (e.g., hexokinase, glucose oxidase, or glucose dehydrogenase), and older methods such as the oxidation-reduction techniques (o-toluidine, Neocuprine), are rarely used. The hexokinase method is the reference method for glucose estimation because it is highly accurate and precise; however it is time consuming for routine use in clinical laboratory. Plasma was analysed for glucose using the Glucose Oxidase method. The glucose oxidase method is an established routine method that is highly specific for estimation of glucose in body fluids and it is simpler and faster.
Principle of Glucose Oxidase Method:

Glucose Oxidase is a specific enzyme which promotes the oxidation of glucose to gluconic acid with the production of an equivalent amount of hydrogen peroxide. In the presence of peroxidase, oxygen from peroxide is transferred to a chromogen acceptor 4-aminophenzone with the production of a coloured end product. Other oxygen chromogen acceptor that can be used include o-dianisidine, however 4-aminophenazone is preferred because it is not affected by high concentration of creatinine, uric acid or haemoglobin. The intensity of the colour developed after incubation, measured at 520nm with spectrophotometer, is proportional to the concentration of glucose in the plasma.

Reaction principle:

\[
\text{Glucose} + \text{O}_2 + \text{H}_2\text{O} \xrightarrow{\text{Glucose oxidase}} \text{Gluconic acid} + \text{H}_2\text{O}_2 \\
\text{H}_2\text{O}_2 + 4\text{-aminophenazone} + \text{phenol} \xrightarrow{\text{Peroxidase}} \text{quinoneimine} + 4\text{H}_2\text{O}
\]

Specimen type, collection and storage:

About 2ml of patient blood was collected into fluoride oxalate bottle. The specimen was gently but thoroughly mixed. The plasma was separated after centrifugation into a plain bottle and stored in the refrigerator (at 8°C) until analysed the same day.

Reagents:

1) Buffer
   - Phosphate buffer 0.1mol/l, pH 7.0
   - Phenol 11mmol/l

2) Colour Reagent
   - 4-aminophenazone 0.77mmol/l
Glucose oxidase  >1.5kU/l  
Peroxidase  >1.5kU/l  
3) Standard  
Glucose  5.55mmol/l  

Procedure:

<table>
<thead>
<tr>
<th></th>
<th>Test</th>
<th>Standard</th>
<th>Blank</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>20µl</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Standard</td>
<td>-</td>
<td>20µl</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Blank</td>
<td>-</td>
<td>-</td>
<td>20µl</td>
<td>-</td>
</tr>
<tr>
<td>Control</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>20µl</td>
</tr>
<tr>
<td>Glucose reagent</td>
<td>2ml</td>
<td>2ml</td>
<td>2ml</td>
<td>2ml</td>
</tr>
</tbody>
</table>

Mix and incubate for 25min at room temperature. The absorbance of the sample, standard and control was measured against the reagent blank at 520nm within 30min.

Calculations:

Glucose concentration  =  \frac{\text{Absorbance of sample}}{\text{Absorbance of standard}} \times 5.55 \text{ (mmol/l)}

Precision control (expressed as coefficient of variation (CV%))

= \frac{\text{Standard deviation}}{\text{Mean}} \times 100

Accuracy control (expressed as % bias)

= \frac{\text{True value of control sample} - \text{Measured value of control sample}}{\text{True value of control sample}} \times 100

3.6 DATA HANDLING AND ANALYSIS

Data obtained from the study were grouped and presented in tables, line graphs and vertical bar charts. Plasma glucose response was assessed for each food preparation by the peak plasma glucose concentration (PPG), defined as the maximum plasma glucose level following the consumption of a food which may occur between the 60 and 90minute period; maximum increase in plasma glucose (MIPG), calculated by subtracting the fasting plasma glucose level from the Peak Plasma Glucose irrespective of when the peak was attained; 2-hour postprandial plasma glucose level (2HPPG), incremental area under glucose curve (IAUGC) (which is the area under the plasma glucose response curve above the fasting plasma...
glucose calculated geometrically by using the trapezoid rule); and the glycaemic index (GI) defined as the incremental area under the blood glucose response curve of a 50g carbohydrate portion of a test food expressed as a per cent of the response to the same amount of carbohydrate from a reference food (glucose) taken by the same subject\textsuperscript{17}. The Student’s t-test was used to compare the various plasma glucose response indices between the diabetics and non-diabetics while ANOVA was use to compare between the meals. Statistical significance was taken as p value less than 0.05. Statistical analysis was done using the Epi Info 2002 version 6.

**CHAPTER FOUR**

**RESULT**

4.1 GLUCOSE ASSAY PERFORMANCE

The Bovine precision multi-sera samples normal and high was use to assess the precision and accuracy of this assay. The low precision and accuracy multi-sera samples were not done because it was not available during the period of these analyses. However, since mean is related to the accuracy or systematic error while the standard deviation is related to the precision or random error, the accuracy of the analysis was determined by comparing the mean of the measured normal and high multi-sera samples during each analytical runs with the true values. The inter-assay coefficient of variation for normal and high samples, included in each analytical run, was calculated from 18 consecutive runs in a batch of twenty (20) samples on
different days. The intra-assay coefficients of variation was obtained by determining the concentrations of normal and high samples twenty (20) times in one analytical run.

The precision and accuracy of the plasma glucose assay are shown in Table 1 below.

<table>
<thead>
<tr>
<th>Type of Sample</th>
<th>Mean (mmol/l)</th>
<th>SD (mmol/l)</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>4.16</td>
<td>0.16</td>
<td>3.8</td>
</tr>
<tr>
<td>High</td>
<td>9.93</td>
<td>0.31</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Table 1: Precision Of The Plasma Glucose Assay

<table>
<thead>
<tr>
<th>Type of Sample</th>
<th>Mean (mmol/l)</th>
<th>True Value (mmol/l)</th>
<th>Bias (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>3.97</td>
<td>4.15</td>
<td>4.3</td>
</tr>
<tr>
<td>High</td>
<td>10.07</td>
<td>10.35</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Accuracy Of The Plasma Glucose Assay

4.2 CHARACTERISTICS OF THE STUDY SUBJECTS

Table 2: Characteristics of study subjects

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Diabetics (n = 24) (Mean±sem)</th>
<th>Non-diabetics (n = 24) (Mean±sem)</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) (Range)</td>
<td>40.04±1.16 (29-48)</td>
<td>37.83±1.42 (27-49)</td>
<td>p&gt;0.05</td>
</tr>
<tr>
<td>Weight (kg) (Range)</td>
<td>63±1.19 (53-75)</td>
<td>62.72±1.54 (52-76)</td>
<td>p&gt;0.05</td>
</tr>
<tr>
<td>Height (m) (Range)</td>
<td>1.62±0.01 (1.55-1.71)</td>
<td>1.63±0.01 (1.56-1.77)</td>
<td>p&gt;0.05</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.92±0.46</td>
<td>23.64±0.46</td>
<td>p&gt;0.05</td>
</tr>
</tbody>
</table>
Table 2 shows the comparison of the demographic, anthropometric and FPG at recruitment of subjects studied.

The diabetics and the non-diabetics were similar in their anthropometric indices. However the FPG at recruitment was significantly higher (p<0.05) in the diabetics group. All the diabetic subjects were however in good glycaemic control.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Diabetics</th>
<th>Non-Diabetics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meal Group</strong></td>
<td><strong>BOILED</strong></td>
<td><strong>POUNDED</strong></td>
</tr>
<tr>
<td></td>
<td><strong>YAM</strong> (n=8) (Mean±sem)</td>
<td><strong>YAM</strong> (n=8) (Mean±sem)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>42.5±1.82</td>
<td>38.62±2.19</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>63.87±1.77</td>
<td>63.62±2.74</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.62±0.01</td>
<td>1.61±0.01</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.29±0.75</td>
<td>24.61±0.8</td>
</tr>
<tr>
<td>FPG (mmol/l) at recruitment</td>
<td>5.5±0.26</td>
<td>5.6±0.18</td>
</tr>
</tbody>
</table>
Table 3 shows the demographic and the anthropometric features of the study subjects by meal groups.

All the diabetic and non-diabetic subjects who took the various yam meal preparations were comparable.

4.3 FASTING PLASMA GLUCOSE CONCENTRATION BY YAM MEAL GROUPS

Fig 1 shows the FPG levels of diabetics and non-diabetics by yam meal groups.
Fig 1: FPG levels of study subjects.
The FPG levels before the consumption of all meals were in the recommended range in both the diabetics and non-diabetics. There was significant difference between the mean FPG level in the diabetics and non-diabetics for all meal types (p<0.05).

4.4 PLASMA GLUCOSE RESPONSE TO YAM MEALS
4.4.1 General profile of plasma glucose response to yam meals and glucose.
The general profile of plasma glucose levels following consumption of yam meals in diabetics is shown in Table 4 and the corresponding fig 2.

**TABLE 4: Plasma glucose response to yam meals in diabetics**

<table>
<thead>
<tr>
<th></th>
<th>FASTING</th>
<th>30Minutes</th>
<th>60Minutes</th>
<th>90Minutes</th>
<th>120Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOILED YAM (mmol/l)</td>
<td>5.7</td>
<td>8.9</td>
<td>10.1</td>
<td>7.3</td>
<td>6.1</td>
</tr>
<tr>
<td>POUNDED YAM (mmol/l)</td>
<td>5.9</td>
<td>8.6</td>
<td>9.2</td>
<td>7.5</td>
<td>6.5</td>
</tr>
<tr>
<td>AMALA (mmol/l)</td>
<td>5.7</td>
<td>7.1</td>
<td>6.9</td>
<td>6.4</td>
<td>5.6</td>
</tr>
</tbody>
</table>

**Fig 2: Plasma glucose response to yam meals in diabetic subjects.**

Plasma glucose response showed the lowest level with ‘amala’ (browned yam flour) at all postprandial times. Plasma glucose levels peaked at 1hr for both the boiled yam and pounded yam with boiled yam having the highest peak, while ‘amala’ had its peak at 30min.

The general profile of plasma glucose levels following consumption of yam meals in non-diabetics is shown in Table 5 and the corresponding fig 3.

**TABLE 5: Plasma glucose response to yam meals and glucose load in non-diabetics**

<table>
<thead>
<tr>
<th></th>
<th>FASTING</th>
<th>30Minutes</th>
<th>60Minutes</th>
<th>90Minutes</th>
<th>120Minutes</th>
</tr>
</thead>
</table>
Fig 3: Plasma glucose response to yam meals compared with glucose load in non-diabetes subjects.

The plasma response to glucose load was high at all times except at the 120min where it was at the same level with boiled yam. However none of them fall below the fasting level.

4.4.2 Plasma Glucose Response To yam meal Compared With Glucose Load In non-diabetics.
The plasma glucose response to the various yam meal compared with glucose load in non-diabetics are shown in fig 4, 5 and 6.

![Plasma glucose response to boiled yam compared with glucose load in non-diabetics](image)

**Fig 4:** The plasma glucose response to boiled yam compared with glucose load in non-diabetics.

The plasma glucose response was comparable at both the fasting and the 2hr postprandial time, but the glucose load had higher levels at 30, 60 and 90 minutes respectively.
Fig 5: The plasma glucose response to pounded yam compared with glucose load in non-diabetic subjects.

The plasma glucose response was consistently lower at all times for the pounded yam meal.
Plasma glucose response to yam flour (amala) compared with glucose load in nondiabetics

Fig 6: The plasma glucose response to ‘amala’ (yam flour) compared with glucose load in non-diabetic subjects. The plasma glucose response was consistently lower at all times for the ‘amala’ meal giving a characteristic flat curve.

4.4.3 Glycaemic Response Indices of Different Preparations Of Yam Meals
Table 6: Glycaemic Response Indices of Different Preparations Of Yam Meals

<table>
<thead>
<tr>
<th></th>
<th>BOILED YAM (n=8)</th>
<th>POUNDED YAM (n=8)</th>
<th>AMALA (n=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Mean±sem)</td>
<td>(Mean±sem)</td>
<td>(Mean±sem)</td>
</tr>
<tr>
<td>NON DIABETIC SUBJECTS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI (%)</td>
<td>52.9±7</td>
<td>81.6±10.1</td>
<td>36.8±7</td>
</tr>
<tr>
<td></td>
<td>(26-93)</td>
<td>(23-127)</td>
<td>(14-78)</td>
</tr>
<tr>
<td>IAUGC (GLUCOSE 50G)</td>
<td>241.1±19</td>
<td>201.7±19</td>
<td>213.9±25</td>
</tr>
<tr>
<td>(mmol.min/l)</td>
<td>(164.3-315)</td>
<td>(127.5-280)</td>
<td>(115-355)</td>
</tr>
<tr>
<td>IAUGC (mmol.min/l)</td>
<td>128.3±19.4</td>
<td>159.7±20.1</td>
<td>74.8±13.9</td>
</tr>
<tr>
<td></td>
<td>(54.7-195)</td>
<td>(40.9-219)</td>
<td>(22.1-144.5)</td>
</tr>
<tr>
<td>PPG (mmol/l)</td>
<td>6.2±0.30</td>
<td>6.2±0.13</td>
<td>5.4±0.15</td>
</tr>
<tr>
<td></td>
<td>(5.2-7.2)</td>
<td>(5.6-6.7)</td>
<td>(4.7-6.1)</td>
</tr>
<tr>
<td>MIPG (mmol/l)</td>
<td>1.9±0.25</td>
<td>2.26±0.23</td>
<td>1.25±0.16</td>
</tr>
<tr>
<td></td>
<td>(0.7-2.7)</td>
<td>(0.9-3.2)</td>
<td>(0.6-1.8)</td>
</tr>
<tr>
<td>2HPPG (mmol/l)</td>
<td>4.8±0.14</td>
<td>4.1±0.14</td>
<td>4.4±0.14</td>
</tr>
<tr>
<td></td>
<td>(4.1-5.2)</td>
<td>(3.6-4.6)</td>
<td>(3.8-4.8)</td>
</tr>
<tr>
<td>DIABETIC SUBJECTS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IAUGC (mmol.min/l)</td>
<td>276.1±21.4</td>
<td>228.8±54.9</td>
<td>103.9±15.1</td>
</tr>
<tr>
<td></td>
<td>(171-357)</td>
<td>(106.7-471)</td>
<td>(48.8-165)</td>
</tr>
<tr>
<td>PPG (mmol/l)</td>
<td>10.1±0.27</td>
<td>9.25±0.78</td>
<td>7.1±0.29</td>
</tr>
<tr>
<td></td>
<td>(8.6-11.1)</td>
<td>(6.5-12.6)</td>
<td>(5.9-8.2)</td>
</tr>
<tr>
<td>MIPG (mmol/l)</td>
<td>4.3±0.39</td>
<td>3.5±0.76</td>
<td>1.8±0.21</td>
</tr>
<tr>
<td></td>
<td>(2.4-5.7)</td>
<td>(1.6-7.3)</td>
<td>(1.1-2.5)</td>
</tr>
<tr>
<td>2HPPG (mmol/l)</td>
<td>6.1±0.13</td>
<td>6.5±0.20</td>
<td>5.6±0.14</td>
</tr>
<tr>
<td></td>
<td>(5.7-6.8)</td>
<td>(5.8-7.5)</td>
<td>(4.9-6.2)</td>
</tr>
</tbody>
</table>

Table 6 shows the Glycaemic Response Indices to different preparation of yam meals in diabetics and non-diabetics.

Amongst the non-diabetics pounded yam had the worst indices, except the PPG and the 2HPPG where boiled yam had higher indices while amala had the best indices except the 2HPPG level where pounded yam had the lowest level. All the yam meals show a lower IAUGC compared with the corresponding 50g glucose load.

Amongst the diabetics, boiled yam had the worst indices for IAUGC, PPG and MIPG. Pounded yam had the highest 2HPPG. Amala had the lowest level of all the indices.
Fig 8: Glycaemic indices of the yam meals.

The Glycaemic index of glucose is 100%.
Fig 9: The incremental area under plasma glucose curve for glucose compared with yam meals in the same subject.

There was no statistical difference (p>0.05) between the incremental areas for the glucose load for each meal group.
CHAPTER FIVE
DISCUSSION

The mean fasting plasma glucose of 4.57mmol/l for the non-diabetics studied is well below the cut-off point recommended for the diagnosis of diabetes mellitus by WHO\(^2\). The mean FPG level of non-diabetics in this study is comparable to those of Oli et al\(^{12}\) of 4.6mmol/l and Ekpebegh\(^{16}\) of 4.8mmol/l, but slightly higher than the level reported by Balogun\(^{13}\) of 4.2mmol/l and Ohwovoriole\(^{14}\) of 3.4mmol/l. The FPG are generally lower than those reported among the Caucasians\(^{22}\) of 5.1mmol/l. The diabetics at recruitment had mean FPG levels that were less than 6.7mmol/l which is within current treatment goals for type 2 diabetes mellitus\(^{81}\). The diabetics in this study had much lower mean FPG levels when compared with those reported by Ohwovoriole\(^{14}\). This could result from the withdrawal of hypoglycaemic agents and insulin therapy 48hours before consumption of the meal in their study. In this study, subjects were instructed not to use oral hypoglycaemic agent only in the morning of the day of consumption of the meals.

Non-diabetics had similar mean PPG levels after boiled yam and pounded yam meals; 6.2±0.2 mmol/l and 6.2±0.1 mmol/l respectively, while amala (browned yam flour) with PPG level of 5.45±0.1mmol/l was significantly lower. The mean PPG level after the boiled yam meal is lower than the mean PPG of 6.8±0.4 mmol/l reported by Akanji\(^{15}\) and 7.4 mmol/l reported by Balogun\(^{13}\) but slightly higher than 5.5mmol/l as reported by Ohwovoriole\(^{11}\) after a boiled yam meal. However the PPG of 5.45mmol/l for amala was similar to the PPG level of 6.0mmol/l reported by Balogun\(^{13}\). The mean PPG of the pounded and boiled yam meals were also comparable to that of the maize and sorghum meals (6.8 ±0.2 mmol/l and 6.4 ±0.3 mmol/l
respectively) reported by Ekpebegh. This shows that yam meals produce comparable mean PPG levels as other carbohydrate meals consumed by Nigerians.

The mean PPG for the diabetics are 10.1±0.27mmol/l for boiled yam, 9.4±0.73mmol/l for pounded yam and 7.5±0.3 for amala. These values are within current recommended PPG levels for the treatment of diabetes. The mean PPG after a corn meal in glucose intolerant subjects of 10.8mmol/l as reported by Crapo was comparable to that of boiled and pounded yam but higher than that of amala. The mean PPG of 10.1mmol/l after boiled yam meal in this study is less than the 16mmol/l reported by Ohwovoriole in diabetic subjects after a food tolerance test which included boiled yam. This high level in Ohwovoriole’s study may be accounted for by the high mean FPG of 9.9mmol/l before consumption of meal as against 5.75mmol/l in this study. The subjects had stopped medications 48hours earlier.

The mean MIPG levels to yam meals in non-diabetics were 1.9±0.3mmol/l for boiled yam; 2.3±0.2mmol/l for pounded yam and 1.3±0.2mmol/l for amala. The MIPG for amala was significantly lower when compared with the value for boiled yam and pounded yam. The MIPG levels are lower than 3.2 mmol/l for boiled yam and 1.8 mmol/l for amala as reported by Balogun. These levels are also lower than MIPG levels of 2.6mmol/l and 2.5mmol/l after yam meals in studies by Akanji and Jenkins, but are comparable with MIPG levels for maize and sorghum pap of 2.2±0.3mmol/l and 2.0±0.2mmol/l respectively in the study by Ekpebegh. This difference may be accounted for by the carbohydrate equivalents use in the studies. Balogun and Akanji used 75g carbohydrate equivalent in their study while in this study and that of Ekpebegh 50g carbohydrate equivalent was used.
The mean MIPG levels to yam meal in diabetics were 4.3±0.4mmol/l for boiled yam, 3.5±0.8mmol/l for pounded yam and 1.8±0.2mmol/l for amala. The MIPG level for boiled yam is lower than the 7.0mmol/l as reported by Ohwovoriole \(^{14}\) in diabetics after a food tolerance test which included boiled yam. The MIPG level for boiled yam was comparable to the 4.3 mmol/l for sorghum meal by reported Mani \(^{84}\) and 4.5 mmol/l for corn meal reported by Crapo \(^{82}\). The MIPG level for pounded yam was comparable to the 3.5 mmol/l reported for both maize and sorghum pap meals in diabetics \(^{16}\). The MIPG levels after the yam meals were significantly greater in diabetics when compared with non-diabetics. This is consistent with reports of a greater glycaemic response in diabetics compared with non-diabetics \(^{82}\).

The importance of the 2-hour postprandial plasma glucose level in the diagnosis and treatment of diabetes mellitus cannot be over emphasis. 2-hour plasma glucose level equal to or above 11.1 mmol/l after a 75g glucose load is a diagnostic criterion for diabetes mellitus while values between 7.8 mmol/l and 11.1 mmol/l are diagnostic of impaired glucose tolerance \(^{2}\). The current recommended maximum 2-HPPG for the management of diabetes mellitus is from 7.5 mmol/l to 7.8 mmol/l \(^{85}\). Ohwovoriole \(^{14}\) has shown that blood glucose patterns during an OGTT are similar to those of a food tolerance test. The subjects in this study consumed approximately 50g carbohydrate equivalents of test meals; thus the 2HPPG levels following meals in this study may not be comparable with results of standard 75g OGTT.

The mean 2HPPG in non-diabetics after yam meal are significantly higher than that of a 50g glucose load except for boiled yam. The 2HPPG levels of 4.8±0.14 mmol/l, 4.1±0.14 mmol/l and 4.4±0.14 mmol/l for boiled yam, pounded yam and amala respectively, are lower when compared to 5.5mmol/l and 5.0mmol/l for boiled yam and amala respectively as reported by
Balogun 13, who used 75g carbohydrate equivalents of yam meals. The 2HPPG levels in this study are however comparable with 4.9mmol/l and 4.5mmol/l for maize and sorghum pap meal as reported by Ekpebegh 16 who used 50g carbohydrate equivalent of pap meals. However pounded yam and amala had lower 2 hour postprandial plasma glucose when compared with that of OGTT and agrees with those of other workers 13, 11, 12, 15, but that of boiled yam did not achieve statistical significance which is in agreement with Balogun’s findings 13.

The 2HPPG levels in diabetic subjects of 6.1±0.1mmol/l, 6.5±0.2mmol/l and 5.6±0.1mmol/l for boiled yam, pounded yam and amala respectively, were significantly higher than the levels in the non-diabetic subjects, although the levels were within current recommendations for glycaemic control in diabetics 18. The 2HPPG levels compare with that of 6.7 ±0.6 mmol/l for maize and sorghum pap meals reported by Ekpebegh 16.

The mean IAUGC of the yam meals for non-diabetics in this study of 128.3±19 mmol.min/l for boiled yam, 159.7±20 mmol.min/l for pounded yam and 74.8 ±13.9 mmol.min/l for amala were higher than the 225.2 mmol.min/l for boiled yam and 150 mmol.min/l for amala as reported by Balogun 13. The 75g carbohydrate equivalent used by Balogun in his study as against 50g carbohydrate equivalent used in this study may account for the differences. However the IAUGC in this study is comparable with 127.2 ±2 mmol.min/l and 133.3 mmol.min/l for maize and sorghum pap meals, respectively, reported by Ekpebegh 16, and higher than the 103 mmol.min/l and 104.2 mmol.min/l for sweet potato and yam, respectively, reported by Jenkins et al 83 who used 50g carbohydrate equivalent of the meals in their studies.
The IAUGC of the yam meals for the diabetics in this study of 276.1±21mmol.min/l for boiled yam, 228.8±54.9mmol.min/l for pounded yam and 103.9±15.1mmol.min/l for amala were higher when compared to the non-diabetics, with only boiled yam achieving a significant statistical difference. The IAUGC of diabetics in this study are comparable with 256mmols.min/l and 258mmols.min/l for sorghum and maize pap meals, respectively, reported by Ekpebegh 16, who also used 50g carbohydrate equivalent of the studied meals.

The glycaemic indices of the yam meals are different from one another. The glycaemic index of boiled yam was 52.9%, which is comparable with 51% reported by Jenkins et al28 but lower than 85% reported by Balogun 13 and 120% reported by Akanji 15. The reasons for the differences between this study and that of Balogun and Akanji could partly be due to the fact that both used a 75g carbohydrate equivalent as against 50g carbohydrate equivalent used by Jenkins and this study. Possibility of differences in yam species accounting for this difference is minimal since this study and that of Akanji and Balogun were done in the same region of the country. The stew used in consumption of this meal could also partly be responsible. Palm oil as a source of fat and beef for protein was used in this study whereas Balogun used Vegetable oil as source of fat and Akanji only added salt without use of fat or protein. Fat is known to delay gastric emptying and protein stimulates insulin secretion, two factors known to negatively correlate glycaemic index 28, 35, 86. The delay in gastric emptying into the intestine by the fat content leads to lower glucose response than expected if fat was not there. The increase in insulin secretion leads to rapid transfer of glucose into the peripheral tissues leading to reduction in blood glucose.
Pounded yam had the highest glycaemic index of 81.6% in this study, although this was not statistically different from that of boiled yam. Pounding of boiled yam (without salt) in a mortar with intermittent addition of water makes the yam softer and finer and increases the surface area upon which digestive enzymes will act, thus bringing about more rapid absorption of the glucose compared to boiled yam. Altering the physical form of carbohydrate changes the postprandial glucose and insulin response to it\textsuperscript{36}, thus pounding of boiled yam had increased its postprandial plasma glucose response. This is consistent with the findings of O’Dea \textit{et al} \textsuperscript{41} in which after grounding of brown rice, its postprandial glucose response was higher than the ungrounded rice in both normal and diabetic subjects. The physical form of the food is a determinant of the rate at which the starch is hydrolysed \textsuperscript{38}.

Amala had the least glycaemic index among the yam meals studied. Of the three yam meals, amala undergoes more processing. Booher \textit{et al}\textsuperscript{42} concluded in 1951 that the more processed a food is, the higher the glycaemic response it will produce. This appears to be negated by the response to amala in this study. Wheatley \textit{et al}\textsuperscript{73} studied the relationship between amylose content and the \textit{in vitro} digestibility and glycaemic index of some Jamaican yam (Dioscorea spp.) starches and showed that white yam starch (\textit{D. rotunda}) has a high amylose content, low glycaemic index and one of the least digestible. During the process of boiling of yam in water, gelatinisation of the starch molecule occurs, thus increasing the availability of starch for digestion by digestive enzymes. This is what occurs when boiled yam is eaten directly and also in pounded yam without further processing. However in the preparation of yam flour \textsuperscript{76}, the parboiled yam is sun-dried for about 3 days, loosing almost all of its water content with a progressive re-association of the starch molecules (retrogradation) \textsuperscript{17}. This re-association
reduces the digestibility of the starch molecule. The amylose component of starch re-associates more quickly than the amylopectin. The crystallinity of retrograded amylopectin is lost following re-heating to approximately 70°C, whereas temperatures above 145°C are required to remove crystallinity of retrograded amylose. This is a temperature well above the range used for processing of yam flour (about 100°C). This implies that retrograded amylose, once formed, will retain its crystallinity following re-heating of the food, thus reducing the digestibility of the grounded yam flour.

The processing of yam to produce yam flour results in an increase in the content of fiber. Various studies have shown the importance of viscosity (a property of the fiber content of food) on postprandial glucose response to food. Reports from studies among the Caucasians show a lowering effect of guar gum on postprandial plasma glucose response. However study done by Erasmus et al. in Ilorin on healthy and diabetic Nigerians does not support this lowering effect of guar gum on postprandial plasma glucose response.

In the preparation of amala, yam flour is usually sprinkled on boiled water and only very rarely is it boiled continuously as in other meals. This might also reduce the availability of starch from it, as observed by Collings et al. in other foods. Furthermore amala is usually swallowed without chewing and this has been reported to reduce the in vivo glycaemic effect of meals. Thus the lowered postprandial plasma glucose response indices of amala when compared with that of the other yam meals studied may be due to various factors, most important of which, may be the gelatinisation and retrogradation that occurs during the processing of the yam to produce yam flour.
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Physical modifications of yam meals have significant effects on plasma glucose response.
2. All the yam meal preparations used in this study had a lower glycaemic index than glucose.
3. ‘Amala’ (browned yam flour) had the lowest glycaemic index among the yam meals used in this study.
4. The patterns of glycaemic response to yam meals are similar in diabetics and non-diabetics, although the responses were quantitatively higher in the diabetics.

RECOMMENDATIONS

1. Boiled yam and pounded yam produce high glycaemic responses and should be consumed by diabetics in limited quantities.
2. Amala (browned yam flour) meal is preferable to other yam meals for diabetics considering its low glycaemic response indices.
3. Other species of yam available in the country need to be studied to determine their relative glycaemic index and suitability as meals in diabetics.
4. Other yam meal preparations such as roasted yam, fried yam and ‘asaro’ which are also consumed in Nigeria should be studied to determine their relative glycaemic index and suitability as meals for diabetics.
5. The effect of mixing yam meals with other foods such as beans and vegetables should be studied to determine their relative glycaemic index and suitability as mixed meals for diabetics.
REFERENCES


42. Booher C E, Behan I, McNeans E: Biologic utilization of unmodified and modified food starches. *J of Nutr* 1951; **45**:75.


73. Wheatly OA, Riley CK, Bahado-Singh PS, Smith TM, Asemota HN, Morrison FY. Relationship between amylose content and the in vitro digestibility and glycemic index of some Jamaican yam (Dioscorea spp) starches. *Dia Metab* 2003; **29**: 4S198(abstr).


84. Mani UV, Prabhu BM, Damle SS, Mani I: Glycaemic index of some commonly consumed foods in Western India. Asia Pac J Clin Nutr 1993; 2: 111-114.


90. Smith U, Holm G: Effect of a modified guar gum preparation on glucose and lipid levels in diabetics and healthy volunteers. *Atherosclerosis* 1982; **45**: 1