Research Article Open Access

Glycemic index of some traditional fortified staple meals on the postprandial blood glucose responses of Nigerian undergraduate students: an open-label study

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Submission Date: July 19, 2015, Accepted Date: July 25, 2016, Publication Date: July 30, 2016

ABSTRACT

Background: Staple meals, or meals that are eaten routinely, inexpensive, and are readily available, constitute a dominant portion of the standard diet in a given population. Most of the indigenous staple foods available are based on starchy foods, as is the case in Nigeria. The development of diabetes mellitus, obesity, cancer and cardiovascular disease (CVD) has been reported to be linked to the intake of high starchy foods. Consequently, there is a strong need to determine the glycemic index of commonly consumed fortified staple foods, as well as to determine the extent of their effects on the postprandial blood glucose responses of Nigeria undergraduate students.

Methods: Fifteen volunteers, non- diabetic undergraduate students aged 20–25yrs, on which a standard oral glucose tolerate test was performed were selected randomly after excluding those with family history of diabetes, in addition to smokers and alcoholics. The subjects reported by 8 am at the study centre each day after overnight fasting (10 – 12hrs) with certain precautions for a period of 6 days for the different prepared test meals, including: the glucose tolerance test (control), beans, rice, yam, unripe plantain and garri stews. Fasting blood samples (2ml each) were collected from the prominent arm veins of each student prior to the eating of one of the test meals of each day. Each test meal contained 50g carbohydrate portion per meal. After each meal had been eaten, 2ml venous blood samples were collected at 30 minutes interval for 120 minutes each day from each student and put into the specimen bottles for blood glucose estimations. The random sugar was determined 2hours later. A glucometer was used for measuring the blood sugar using test strips. The mean values of postprandial glucose blood sugar for each test meals from the randomly selected volunteered students were obtained. The glycosylated haemoglobin in the blood of the subjects was determined by the formulae method.

Results: The mean glycosylated haemoglobin of the students was 4.7%±0.002, with fasting blood sugar of 89.02±4.41mg/dl. The ratio of protein and fat contents of the serving portion containing 50g carbohydrate were highest in unripe plantain stew 7.84g and 5.31, respectively, but were lowest in yam stew 4.19g for protein and 2.02 for fat in beans vegetable stew. The glycemic index of the commonly consumed fortified staple test meals was highest in rice stew (107.7± 8.4), followed by yam stew (102.4±1.8), garri and stew (101.4±11.8), beans stew (86.9±6.7), and unripe plantain stew (81.8±8.4) in that order. The carbohydrate content of the commonly consumed fortified staple test meals was highest in garri with stew (68.2±0.2g) and lowest in unripe plantain stew while the fibre content was highest in plantain stew (5.8±0.4g) and lowest in rice stew (2.8±0.12g). The mean blood oral glucose tolerance test of the students was below 120mg/dl, but had the mean peak after an hour interval (112.8±7.3mg/dl).

The increment on the postprandial blood glucose after ingestion of the test meals was highest for garri and stew meal (93.1±2.4mg/dl), but lowest for unripe plantain stew meal (74.3±11.6mg/dl) after 120 minutes the test meals were ingested.

Conclusion: Unripe plantain stew meal had the lowest glycemic index value, with lowest postprandial blood glucose response for the period of time the staple test meals were ingested. This could be attributed to the relatively higher level of fibre content of the unripe plantain than the other staple test meals.

Key Words: glycemic index, postprandial blood glucose concentrations, glucose tolerance test, glycoslated haemoglobin

BACKGROUND

Staple meals are meals eaten routinely, and in such quantities that it constitutes a dominant portion of a standard diet in a given population, supplying a large fraction of the needs for energy-rich materials and a significant proportion of the intake of other nutrients [1]. Although staple foods vary from place to place, are inexpensive, readily available supply one or more of the three organic macronutrients needed for survival and health, and may be eaten as often as every day or every meal, most staple plant foods are derived either from cereals such as wheat, barley, rye, maize, rice, starchy tubers, or root vegetables, such as potatoes, yams, taro, and cassava; for most staples, the primary source of nutrition is plant materials with high contents of carbohydrates [2]. In Nigeria, most indigenous staple foods available are based on starchy foods that are high in glycemic index (GI).

The development of diabetes mellitus, obesity, cancer and cardiovascular disease (CVD) has been reported to be linked to the intake of high carbohydrate foods, while intake of low carbohydrate foods has been shown to play a positive role in the treatment of these diseases [3].

Epidemiological studies have demonstrated that high intake of carbohydrate with high glycemic index produce greater insulin resistance and thus greater risk of Type II diabetes than the intake of low GI carbohydrates does. Additionally, high GI and glycemic load of overall diet are associated with greater risk of coronary heart disease in both men and women. Animal models have also revealed that high GI foods promote insulin resistance, fat synthesis and the risk of hypertension and obesity. Evidence from medium term studies suggest that replacing high GI carbohydrates with a low glycemic index forms will improve both blood sugar and blood lipid levels in people with diabetes [4], in addition to reducing hypoglycemic episodes [5].

Additionally, low GI foods enhance satiety and thereby may aid weight control. Therefore, the GI classification of foods helps identify the range of foods that are appropriate for the management of diabetes. Few studies have been carried out in Africa with regards to GI of local foods which are quite different from those of the Western World. In order for African diabetics to benefit from the new concept of dietary management of diabetes, it is important to determine the GI of local food stuff with the aim of identifying those with low glycemic index that can be used in formulating diets for the diabetic subjects [6]. Providing low glycemic index for individuals, especially with those who have a history of diabetes, within adequate nutrients makes no sense. A recent report on American Dietetic Association [7] indicated that many care home residents with diabetes are undergoing other health problems. Therefore, a fortified diet may be appropriate. Food fortification has been shown to be an important method of combating malnutrition across various socio-cultural and economic groups, and ensures adequate dietary intakes without changing cultural habits. Fortification of the major staple foods in Nigeria that are widely consumed as garri, rice, plantain, with available vegetables especially in diabetic condition is therefore an urgent necessity. The study focused on determining the glycemic index of commonly consumed fortified staple foods, as well as determining the extent of their effects on the postprandial blood glucose concentrations of the undergraduate students.

METHODS

Recruitment of Participants: Fifteen (15) randomly selected volunteered clinically healthy undergraduate students of Imo State University, Owerri, Nigeria aged between 20 – 25 years (7 males and 7 females) were recruited by balloting from 40 volunteered students in the Faculty Medicine. The subjects prior to their selection were interviewed to exclude those with a family history of diabetes, as well as those who were smokers and or alcoholics. Their consents were obtained in addition to ethical approval from the university Faculty of Medicine.

Measurements of Physical Characteristics: The weight and height measurements of the subjects were obtained according to the standard procedure of WHO [8]. The measured parameters were used to obtain the body mass index (BMI) of the subjects using the following formulae:

BMI (kg/m^2) = Weight in (kilograms)/Height^2 in meters

Determination of Glycosylated Haemoglobin: The glcosylated haemoglobin (HbA1c) was determined by the method of Rohfing [9] as follows:

HbA1c = MpG +46.7/28.7
Where: HbA1c = glycosylated haemoglobin
MpG = Mean plasma glucose

Procurement of Food Materials: The rice, beans, yam, plantain as well as bitter leaves (V. Amygdalina) and other ingredients for stew such as beef meat, pepper, onions, vegetable oil, tomatoes and condiments were purchased at Owerri Main Market.

Preparation of the Test Meals: The bitter leaves were washed and squeezed before cooking and consumption. Unlike many other leafy vegetables, bitter leaf is cherished in Nigeria for the distinctive flavor it imparts in the diet of which it is a component. The rice (Long grain Abakiliki), bean (brown) grains were cleaned by picking the pebbles and other contaminants, and washed with tap water. The plantain and the yam (white) tubers were peeled and cut into pieces and washed with tap water. Each staple food was cooked with a predetermined quantity of water until they become softened. Garri was put in the boiled hot water to make 'eba'. The stew was prepared in a traditional way using beef cuts (30g in size), onions, pepper and tomatoes, fried in vegetable oil in a cooking pot. Each cooked staple food was blended with the prepared stew to prepare the test meals.

Nutrient Analysis

About 100g sample of each of the prepared blended staples meals were analyzed for protein, lipids, ash content and crude fiber on dry weight basis by the standard AOAC [10]. The carbohydrate content was determined by difference.

Feeding Procedure

The procedure for the feeding was explained to the volunteered subjects and each volunteer signed a consent form. They were instructed to: consume no other meal after dinner (not later than 8.00pm) until breakfast except water; not to take alcohol or smoke, and to maintain the same level of physical exercise. The inclusions and exclusions for the feeding program are stated in table A. The subjects consumed the test meals and the standard (control meal, the glucose) each day for breakfast (between 7am – 8am for a period of six days, using one test meal per day after overnight fasting (10 – 12 hours).

On the first day after overnight fasting and 30 minutes of rest, on arrival at the feeding center, the fasting blood sample of the subjects were collected. They were fed with 50g glucose (equivalent of 50g carbohydrate) and with about 30cl of water. Blood samples (2ml) from each subject were collected at 30 minute intervals for 180 minutes. The same procedure was repeated on the second day to the sixth day consecutively, for each of the test meals using the calculated quantity of the test meal that will give the equivalent of 50g available carbohydrate for each subject.

Table A: The Inclusion and Exclusion for the Feeding Procedures

Inclusion	**Exclusion**
Aged 20 – 25years	Below 20 years or above 25 years
Non Diabetic	Diabetic
Clinically normal (values of the parameters used fall within normal ranges)	Unhealthy/Below or Above normal ranges of the parameters
Non - smokers	Smokers
Non -alcoholics	Alcoholics
Water allowed even after dinner	Water allowed
Non strenuous exercise(same level of physical exercise	Strenuous exercise
No other meal eaten after dinner(8p.m) i.e overnight fasting for 10 – 12 hours	Consumption of meal after dinner(8pm) i.e no overnight fasting

Determination of Blood Glucose

In each of the six days of the study, finger-prick capillary blood samples were collected from each subject; taken at 0 (fasting), 30, 60, 120 and 180 min after each of the test meal. The blood glucose was determined from the blood collected using glucometer (Accu-Check-Active Model) and test strips. Volunteer's fingers were punctured with an autolet device using autoclix lancets at 30 min intervals.

Each blood sample was placed on a test strip which was inserted into a calibrated glucometer which gave direct readings after 5 seconds. Analyses were done in duplicate. The mean values were obtained for the subjects for each test meal. The mean values of the respective blood glucose concentrations after the consumption of the test meals were used to draw a blood glucose response curve for the 3hr period.

Determination of Glycemic Index (GI)

In each volunteer, the GI (%) was calculated by dividing the incremental geometric area under the 3hour (IAUC) for the tested food by the IAUCS for the standard reference food and multiplied by 100.

$$GI = \frac{IAUC \times 100}{IAUCS}$$

Where:

IAUC = incremental Area Under the blood glucose response curve for the tested meal.
IAUCS =Incremental Area Under the blood glucose response for the standard reference meal.

The GI for every test meal was calculated as the mean from the respective average GIs of the fifteen subjects.

Statistical Analysis

The means of the glycosylated haemoglobin (HbA1c), blood glucose concentrations and the GIs of the subjects were calculated and standard deviation determined. The significant differences among the staple test meals for the parameters were obtained by ANOVA. The test for equality of means between pairs of the test meals was done using multiple comparison of means method by honestly significant difference (HSD) [11].

RESULTS:

The results of the health characteristics of the subjects fell within the average values of all the parameters used to examine their health status (Table 1).

Table 2 shows that the carbohydrate contents of rice vegetable stew were the highest, followed by yam, garri, beans and plantain vegetable stews in that order, while the fibre content was highest in plantain and lowest in yam vegetable stews. Beans vegetable stew had the highest protein content (12.1 ± 0.63g), followed by plantain vegetable stew (10.4 ± 1.06g) while the lipids contents of the staple test meal were highest in yam vegetable stew (6.80 ± 0.14g) (Table 2).

Table 1: Health Characteristics of the Subjects

Parameters	**n**	**ẋ**	**SD**
Age (yr)	15	21.8	1.62
BMI (kg/m2) (18.5 – 24.0 kg/m ^{3})	15	19.14	1.80
Fasting blood sugar (mg/dl) (70 – 120mg/dl)	15	81.0	4.41
Blood Pressure (mm/Hg) (120/80mm/Hg)			
Systolic (< 120mm/Hg)	15	115	10.60
Diastolic(< 80mm/Hg)	15	75:6	10.60
Glycosylated Haemoglobin (%) (4.0 – 5.6%)	15	4.7	0.002

Values in parentheses are normal range for the parameter

Table 2: Nutrient Analysis of Cooked Test Meals

Cooked test Meal	**Protein (g)**	**Lipids (g)**	**Crude fiber (g)**	**Carbohydrate (g)**	**Total Ash (g)**
Beans Vegetable Stew	12.1±0.13	2.6±0.15	7.4±0.14	74.1±.03	4.1±030
Rice Vegetable Stew	10.4±0.98	4.2±0.30	4.8±0.90	76.0±0.70	2.8±0.12
PlantainVegetable Stew	9.6±1.06	6.5±0.94	7.6±6.9	61.2±2.9	5.8±0.04
Garri and Vegetable Stew	8.7±0.90	6.7±0.67	3.3±0.18	68.3±3.02	4.5±0.70
Yam Vegetable Stew	6. 6.2±0.65	6. 6.8±0.4	1. 1.9±0.12	7.74.0±4.9	2. 2.4±0.3

Values are the means ± standard error of mean (SEM) of four determinants.

The calculated carbohydrate contents and serving portions of the fortified staple test meals containing 50g carbohydrate portions are shown in table 3. Though the amount of carbohydrate served remained constant for all the test meals, the protein and fat contents varied. The proportions of protein served were consistently higher than the proportions of fat in the serving portions of the staple test meals. However, the proportions of the protein and fat contents in the serving portion of plantain were highest and lowest in yam stew for protein and beans stew for fat (table 3).

The mean blood glucose concentrations and blood glucose curves of the subjects for each staple test meal after ingestion of the staple test meals are shown in table 4 and graphically in the figure below (Table 4).

Table 3: Calculated carbohydrate of prepared test meals and serving size used for blood glucose concentration determination

Staple Test Meal	Calculated carbohydrate in 100gof prepared test meals	Serving portions(g)	Ratio of the nutrients in serving portion expressed in percentages		
			Carbohydrate (g)	Protein(g)	Fat(g)
Beans Vegetable Stew	64.1	78.0	50.0 98.70%	4.65 14.84%	2.02 6.47%
Rice Vegetable Stew	76.0	65.8	50.0 83.92%	6.84 11.44%	2.76 4.63%
Plantain Vegetable Stew	61.2	81.7	50.0 99.21%	7.84 12.37%	5.31 8.42%
Garri Vegetable Stew	68.3	73.2	50.0 70.35%	6.37 22.75%	4.91 6.91%
Yam Vegetable Stew	74.0	68.0	50.0 85.09%	4.19 7.13%	4.59 7.77%

Table 4: Mean Blood Glucose Response to Test Meals of Subjects (mg/dl)

Cooked test Meals	0 Mins	30 Mins	60 Mins	120 Mins	180 Mins
Glucose (Control)	93.1 ± 7.8^{a}	111.7 ± 3.5^{a}	112.8 ± 7.3^{a}	$103.3\pm.8.7^{a}$	87.6 ± 6.6^{a}
Beans Vegetable Stew	92.5 ± 4.2^{a}	91.3 ± 8.4^{b}	90.5 ± 8.7^{bc}	$88\ .4\pm4.9^{bc}$	$84.8\pm.4.8^{a}$
Rice Vegetable Stew	$9\ 2.3\pm7.2^{a}$	104.0 ± 6.8^{a}	89.4 ± 8.9^{b}	84.3 ± 8.1^{bc}	78.2 ± 5.0^{b}
Plantain Vegetable Stew	$8\ 4.2\pm9.5^{b}$	86.7 ± 7.9^{b}	$85.5\pm9.^{bd}$	74.3 ± 11.6^{b}	73.0 ± 3.8^{b}
Garri and Vegetable Stew	87.8 ± 8.7^{b}	103.2 ± 11.4^{a}	97.2 ± 4.7^{e}	$93\ .1\pm2.4^{b}$	86.1 ± 8.7^{a}
Yam Vegetable Stew	89.6 ± 7.3^{b}	103.2 ± 5.5^{a}	95.2 ± 4.8^{bd}	87.4 ± 2.8^{b}	76.7 ± 4.7^{b}

Values within the same column with same superscript are not significantly different ($P<0.05$).

There were significant differences in the mean blood glucose concentrations of the subjects among the fortified staple test meals after their ingestion under the period of 3 hours ($p < 0.05$) (Table 4). The mean blood glucose responses of the subjects after consumption of the staple test meals were the highest in garri and stew, but lowest in plantain after 30 – 60 minutes of ingestion of the staple test meals (table 4)

The figure shows the mean blood glucose curves of subjects fed with fortified staple test meals as compared with the control (glucose test meal). The postprandial blood glucose responses for all the staple meals rose remarkably between 0 minute to 30 minutes after the test meals consumption but fell rapidly afterwards and below the control glucose responses. The differences in the blood glucose responses of the subjects fed with the test meals were significantly lowest in plantain vegetable stew ($p < 0.05$) relative to the test meals.

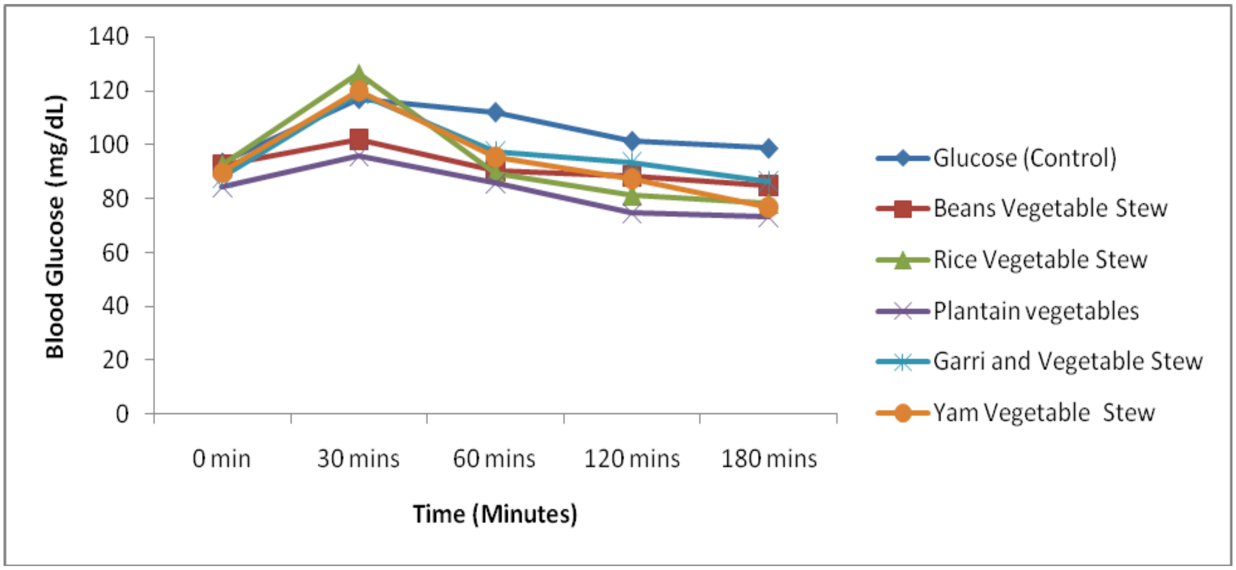

Figure 1: The mean Blood Glucose Curve of Subjects After Consumption of Test Meals Compared With Control

The mean glycosylated haemoglobin of the subjects that consumed the staple test meals was lowest in the consumption of unripe plantain vegetable stew, followed by garri, yam, rice stews in that order (table 5). The differences in the mean glycosylated haemoglobin of the subjects among the staple test meals were not significant ($p > 0.05$)

Table 5: Mean Glycosylated Haemoglobin of the Subjects by Staple Test Meals

Staple test meal	n	ẋ	SD
Glucose (control)	15	4.87 [a]	0.29
Beans vegetable stew	15	4.85 [a]	0.14
Rice vegetable stew	15	4.84 [a]	0.27
Unripe plantain vegetable stew	15	4.56 [a]	0.21
Garri and vegetable stew	15	4.68 [a]	0.25
Yam vegetable stew	15	4.74 [a]	0.23

The glycemic indexes of the staple test meals were significantly different but highest in rice vegetable stew, followed by yam, garri, bean and unripe plantain vegetable stews in that order (Table 5).

Table 6: Glycemic Index Values of the Test Meals (%)

Cooked test Meals	n	ẋ	SD
Beans Vegetable Stew	15	86.9[b]	6.7
Rice Vegetable Stew	15	107.7[a]	4.8
Plantain Vegetable Stew	15	81.8 [b]	8.4
Garri and Vegetable Stew	15	101.4[b]	11.8
Yam Vegetable Stew	15	102.4[a]	1.8

Values within the same column with the same superscript are not significantly different ($P \leq 0.05$)

DISCUSSIONS:

The mean values of the glycoslated haemoglobin of the subjects were within the normal range (4.0 – 5.65%). This indicates that the subjects were not diabetic and had reduced risk of suffering from diabetes [9].

The results from the study showed that the fiber content of the plantain vegetable stew was the highest, but was the lowest in carbohydrate; additionally, blood glucose responses under the 3 hour period after the ingestion of unripe plantain test meal relative to the other test meals were also lowest. This effect could be explained by the high fiber content of the fortified unripe plantain vegetable stew. It is known that dietary components such as fiber [12] can influence gut motor functions. The fiber naturally occurring in foods might reduce the rate of small intestinal digestion by delaying the penetration of the food by digestive enzymes.

This could explain the lowest blood glucose responses the subjects had when plantain vegetable stew was consumed in relation to the consumption of other test meals. Jenkin et al; [13] found a relationship between the dietary fiber content of foods and both starch digestibility and glycemic response, but the fat content showed a stronger relationship. Therefore, they concluded that other factors in addition to dietary fiber might influence the rate of digestion and glycemic response of starchy foods. Similarly, Brand-miller [14] evaluated over 600 tested foods around the world and observed that the chemical composition of the food, including fiber and sugar content, has little predictive power in assessing the glycemic index. Nevertheless, the rate of carbohydrate digestion in vitro demonstrates a strong correlation with glycemic index [15].

Based on the universal classification of glycemic index of food [16], the results obtained from this study indicated that the glycemic index for Nigerian fortified staple meals were moderately low for plantain and beans vegetable stews and high for other starchy staples vegetable stews. This could be a result of the ratio of Amylose to Amylopectin present in the cooked starch staple meals, which has been shown to be responsible for the slow release of glucose from starch [17]. Most carbohydrate foods contain 25 to 30% amylose and 70 to 75% amylopectin [18]. The amount of amylose contents of unripe plantain could have been lower than other staple test meals. Amylose is a long chain of glucose units which is easily soluble in water and is mainly responsible for the stiffening of cooked rice on keeping [14]. The higher the amylose contents the higher the glycemic index. On the other hand, amylopectin has more glucose units arranged in branches. Differences in rate of digestibility have been adduced to the larger surface area of amylopectin [18]. The present of higher content of amylopectin with its branched chained in the unripe plantain could have reduced the rate of digestibility of the starch contained in the unripe plantain.

The encouragement of unripe plantain vegetable stew to the menu of Nigerian diabetics will increase the variety of foods available for management of diabetic mellitus and reduce the complaints about the monotony in diet which make dietary compliance by Nigerian diabetics difficult. Foods with low to medium glycemic indices are encouraged for use in the management of type II diabetic mellitus.

CONCLUSIONS:

The results revealed that unripe plantain vegetable stew had the lowest postprandial blood glucose response and lowest glycemic index value among the fortified Nigerian staple foods and should be preferred in the management of diabetes mellitus including individual who may be suffering from obesity.

Lists of abbreviations used: CVD, cardiovascular diseases; GI, glycemic index; HbA1c, glycosylated haemoglobin AOAC, association of official analytical chemists; IAUC, incremental Area Under the blood glucose response curve; BMI, body mass index; SEM, standard error of means.

Authors' contributions: CO was the Principal Investigator and together with HU and AM, contributed to the writing, data analyses, and interpretation that are part of this manuscript. JK: contributed in the data analyses.

Funding: The present study was supported by the principal investigator.

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