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Glycaemic Indices of Carbohydrate-Based Staple Foods Commonly Consumed in Africa: *Zea mays, Triticum spp*, *Digitaria exilis* and Oat (Elkris Super Oat) in Albino Rats

V.N. Ogugua, R.O. Igomu, I.U. Okagu and I.N.E. Onwurah

Department of Biochemistry, University of Nigeria, Nsukka, Enugu State, Nigeria

Abstract: This study was conducted to evaluate the glycaemic index (GI) and blood glucose response (BGR) of staple foods widely consumed in Africa in healthy Wistar rats. The test food samples, maize (*Zea mays*), wheat (*Triticum spp*), acha (*Digitaria exilis*) and oat (Elkris super oat) mixed with (same quantity of palm kernel cake, rice husk/bran, soya beans, crayfish, bone meal, premix and salt) were prepared into diets in the laboratory of the Department of Home Science, Nutrition and Dietetics, University of Nigeria, Nsukka. Proximate compositions of the diets were determined. Twenty four (24) male albino rats were divided into six (6) groups of four (4) rats each. Group 1 (the negative control) received 0.4 ml of distilled water, while group 2 (the positive control) received 2 g/kg b.w of glucose in 0.4 ml of distilled water only. Rats in groups 3 to 6 also received 2 g/kg b.w of glucose in 0.4 ml distilled water and on a separate day received 2 g/kg b.w. available carbohydrate of the test diets of maize, acha, wheat and oat respectively orally. Blood glucose levels of the rats were recorded at 15, 30, 45, 60, 90 and 120 minute intervals. Result of proximate analysis showed that the carbohydrate content of maize diet (62.14 %) was significantly ($p<0.05$) higher than those of oat (60.56%), acha (59.90%) and wheat (57.62%). Also, it was observed that the GI of maize, wheat, acha and oat were 76%, 69.4%, 57.5% and 48.1% respectively. Thus, oat (Elkris super oat) with a considerable lower GI is a preferable diet in achieving better glycaemic control.

Key words: Glycaemic Index · Glycaemic Response · *Zea mays* · *Triticum spp* · *Digitaria exilis* · Oat (Elkris Super Oat) · Chemical composition

INTRODUCTION

Studies have shown that different carbohydrate containing foods have different effects on blood glucose response and hence the need to classify different sources of carbohydrate (CHO) and carbohydrate rich foods in diet becomes imperative. This classification was first introduced by Jenkins *et al*. [1] as glycaemic index (GI). Subsequently, carbohydrate containing foods are graded into three principal levels as high, medium and low GI, where high (GI ≥ 70), intermediate (GI = 56-69) and low (GI ≤ 55) were accepted values by Foster-Powell *et al.* [2] and were found to be dependent on the rate at which blood sugar level rises, which in turn is related to the rate of digestion and absorption of sugars and starches available in food [3]. The very basic and relevant knowledge obtained from glycaemic index studies is linked to the possible therapeutic and physiological effects of diets with low GI on healthy, obese and diabetic subjects. Further to this is the fact that GI has also been related to colon diseases and physical activities of subjects [4]. The importance of dietary management in achieving better glycaemic control to reduce the risk associated with diabetic complications and thus to prolong life expectancy cannot be over-emphasised. Attention has been directed in the nutritional management of diabetes by balancing food intake with endogenous and/or exogenous insulin levels using the improvement of glycaemic control. Nutrition therefore, has been described as the keystone of care in intensive diabetes management [5]. Foster-Powel *et al.* [2] in their research on GI came out with the fact that the glycaemic impact on foods that even

Corresponding Author: Innocent Uzochukwu Okagu, Medical Biochemistry Unit, Department of Biochemistry, University of Nigeria, Nsukka, Nigeria. Tel: +2348034627630.

contain the same amount of carbohydrate (i.e. carbohydrate exchanges) vary glaringly up to five folds. Consequent of this, several prospective observational studies have concluded that the overall GI and glycaemic load of diet (not total carbohydrate) are independently related to the risk of developing different types of diseases viz; type 2 diabetes [6], cardiovascular disease [7] and some cancers [8].

Logically, low GI diets should improve glycaemic control, but findings from various randomized controlled trials have mixed conclusions; some have shown statistically significant improvements [9, 10] whereas others have not shown this [11, 12]. This has resulted in various controversies in the study of GI and has led to divergent opinions of leading research experts [13, 14]. As at today there is need for further research on GI because for the controversy, there is no universal approach to the optimal dietary treatment of diabetes about how useful the glycaemic index (GI) is in diabetic meal planning [15]. The foods tested in this study (Maize, Wheat, Acha and Elkris super oat) were selected to represent the nutritional variations in adult Nigerian consumption. The prevalence of chronic diseases such as coronary heart diseases, obesity and diabetes in Nigeria is high and hence the GI of these commonly consumed foods needs to be established. This will provide information based on scientific findings and will enable Nigerians make decision on what to eat and the quantity to eat.

Aim of the Study: The aim of this study is to evaluate the glycaemic index (GI) and blood glucose response (BGR) of staple foods widely consumed in Africa in healthy Wister rats.

MATERIALS AND METHODS

The food samples used for this study and their sources are as follows: the reference food (Allenburry-D-glucose), standard rodent pellet (Vital feeds Nig. Ltd.), wheat, maize, crayfish, bone meal, premix, soya beans, salt and palm kernel were obtained from Ogige main market in Nsukka, the Oat (Elkris super oat) from Enugu main market and rice husk from Adani, all in Enugu State, while the acha was obtained at Romi market in Kaduna South, Kaduna State, Nigeria. The acha was identified as *Digitaria exilis* and belong to the family *Graminae poaceae* with voucher number 182 at the herbarium, Faculty of Biological Science, Ahmadu Bello University, Zaria, Nigeria. Others were identified in the herbarium, Department of Plant Science and Biotechnology, University of Nigeria, Nsukka.

Preparation of Rat Diets: The method described by Ezeanyika [16] was used for the formulation of the rat diets. The food samples used as the carbohydrate sources were prepared separately by stirring in a bowl containing boiled water until they were satisfactorily and consistently made ready for consumption, they were then mixed with other ingredients in a uniform way, as shown in Table 1, to avoid the introduction of a possible variable that might affect the study results. Thereafter, the diets were made into pellet and oven dried at 60ºC and taken for proximate analysis.

Proximate Analysis: The proximate composition of the processed rat diets of protein, fat, carbohydrate, moisture, ash and crude fibre was determined using the standard AOAC methods [17] and the available carbohydrate content calculated by difference. The available carbohydrate for each test diet sample (2 g) was calculated from results of proximate analysis and the measured portion of the diet was served to individual rat per body weight.

Experimental Design: Twenty four (24) albino rats with a body weight range of 150-190 g were used for this study. The animals were obtained from the animal farm of Faculty of Veterinary Medicine, University of Nigeria, Nsukka. They were acclimatized for 7 days in the animal house of the Department of Home Science, Nutrition and Dietetics and had free access to water *ad libitum.* The rats were divided into six (6) groups of four (4) rats each and treated as shown in Table 2.

Procedure for Feed Administration and Blood Collection: After acclimatization, rats were placed in individual cages and trained for a week as follows: each morning, about 7am, a small known amount of standard rat pellet was introduced into each cage and removed after 15 minutes, after which they were given free access to diet from 12 noon to 1pm and 6pm to 7 pm, at which time they were deprived of food overnight. The feeding pattern was designed to mimic human eating behaviour. By the end of the training period, rats were accustomed to eating a given amount of food within 15 minutes. On day 8, after an overnight fast (12±2 hours), fasting blood glucose levels of the rats were checked

Table 1: Composition of diet on dry matter

Ingredients	Diet 1 g	Diet 2 g	Diet 3 g	Diet 4 g
Maize	56.85	-	-	-
Acha	-	56.85	-	-
Wheat	-	-	56.85	-
Elkris super oat	-	-	-	56.85
Palm kernel cake	6.69	6.69	6.69	6.69
Rice Husk + Ban	3.35	3.35	3.35	3.35
Soya beans	22.49	22.49	22.49	22.49
Crayfish	5.62	5.62	5.62	5.62
Bone meal	4.00	4.00	4.00	4.00
Premix	0.50	0.50	0.50	0.50
Salt	0.50	0.50	0.50	0.50

Premix is composed of vitamin A (8, 000, 000 I.U), vitamin D (8, 000 I.U), nicotinic acid (12.0 g), calcium pantothenate (7 g), vitamin B6 (1 g), vitamin B_{12} (8.0 g), folic acid (0.20 g), biotin (0.025 g), choline chloride (50.0 g), zinc (58.50 g), copper (10 g), iodine (0.31 g), cobalt (0.35 g) and selenium (0.04 g).

Table 2: Grouping of animals and treatment administered

Groups	No of animals per group	Diets
Group 1	4	Water (Negative control)
Group 2	4	Glucose solution (positive control)
Group 3	4	Maize flour-containing diet
Group 4	4	Acha containing diet
Group 5	4	Wheat containing diet
Group 6	4	Oat (Elkris super oat)

(this was regarded as the zero time). Thereafter, rats in group 1 received 0.4 ml of distilled water while those in group 2 to 6 received 2 g/kg b.w of glucose dissolved in 0.4 ml of distilled water orally using gastric cannula. Blood samples were collected from the tip of the tail at 15, 30, 45, 60, 90 and 120 minutes, to measure blood glucose level, using Accu-check glucometer. On the day 10, rats in groups 3 to 6 received 2 g/kg b.w. of available carbohydrate of the test diets as corn, acha, wheat and oat diet and the blood glucose level was recorded at the stipulated time intervals as day 8.

Glycaemic Index Calculation and Statistics: The incremental areas under the curve (IAUC), excluding the area beneath the fasting level was calculated geometrically [18]. The GI was then calculated by expressing the glycaemic response area for the test diets as a percentage of the mean response area of the reference food (glucose) taken. The data obtained were analysed using IBM Statistical Product and Service Solutions (SPSS), version 16. The data obtained were expressed as mean ± standard deviation. One way analysis of variance (ANOVA) and a turkey post Hoc was used to compare the means. Statistical significance was set at $p < 0.05$.

RESULTS

Proximate Compositions of Rat Diets: Table 3 shows result of proximate analysis of test diet showing that the carbohydrate content of maize diet (62.14 %) was significantly ($p<0.05$) higher than oat (60.56%), acha (59.90%) and wheat (57.62%). Wheat had the highest protein content (19 %), followed by oat (16.45%), maize (15.46%) and acha (9.57%). However, the different test diets had some similarities in terms of nutrient composition, especially in carbohydrate, protein and fibre contents. This could be as a result of ingredients incorporated as shown in Table 3.

Comparative effect of water, standard (glucose) and test diets on the blood glucose response: Table 4 shows the mean incremental area under the blood glucose response curve of the test samples for the six groups. There was no IAUC/IAUCS value for the group that received water since the blood sugar concentrations were below the baseline throughout the experiment. There was no significant ($p>0.05$) difference in the IAUCS values of the test diets groups when compared to the positive control group, whereas the mean IAUC values of the test diets were significantly ($p<0.05$) lower than the value of the standard glucose (positive control) (Fig. 1).

Table 3: Proximate compositions (%) of rat diet

Rat Diet	Ash	Fat	Protein	Moisture	Fibre	CHO
Acha	4.33±0.05[a]	5.40±0.07[a]	9.57±0.06[a]	11.42±0.05[a]	9.36±0.12[a]	59.90±0.25[a]
Wheat	3.96±0.16[b]	4.67±0.35[b]	19.00±0.41[b]	6.90±0.05[b]	7.87±0.17[b]	57.62±0.32[b]
Oat	2.84±0.04[c]	3.00±0.04[c]	16.45±0.64[c]	8.67±0.06[c]	8.50±0.02[c]	60.56±0.56[a]
Maize	4.10±0.12[ab]	3.68±0.14[d]	15.46±0.37[c]	10.09±0.05[d]	4.52±0.09[d]	62.14±0.56[c]

Values are expressed as mean ± SD. Values with different superscripts in a column are significantly different at p<0.05

CHO: carbohydrates

Table 4: Incremental area under the blood glucose response curve of the standard food (IAUCS) and the food sample (IAUC) as consumed by individual groups

Groups	IAUCS	IAUC
Group one (water)	Zero (0)	Zero(0)
Group two (glucose)	2880±333.96[a]	2880±333.96[a]
Group three (maize)	2667.5±188.59[a]	2122±499.24[b]
Group four (acha)	2325±127.50[a]	1337.5±208.48[c]
Group five (Wheat)	2805±169.04[a]	1947.5±404.88[b]
Group six (Elkris oat)	2775±312.03[a]	1335±65.38[c]

Values are expressed as mean ± SD (n= 4). Values with different superscripts in a column are significantly different at p<0.05

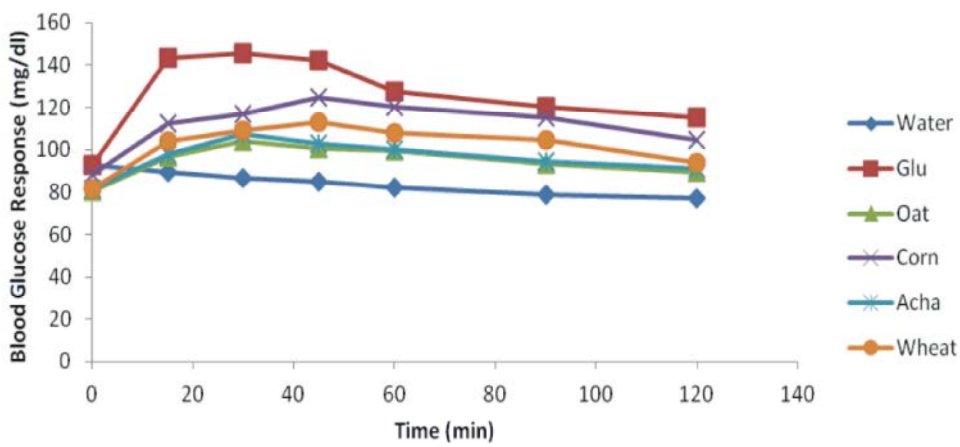

Fig. 1: Average two-hour blood glucose response curves for water, glucose and test diets (acha, wheat, corn and oat) diets

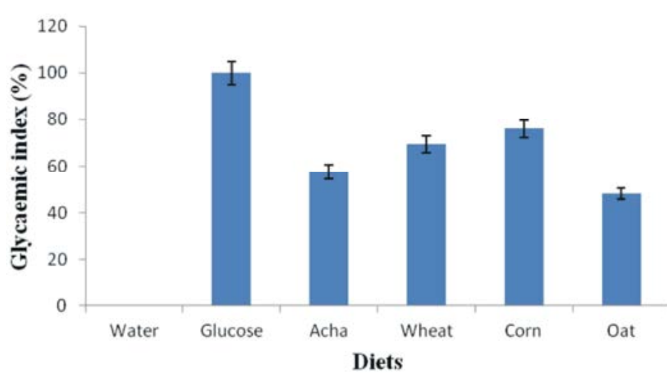

Fig. 2: A bar chart showing the glycaemic indices of the food samples and standard glucose

Glycaemic Index of Test Diets: Results of glycaemic index of test diets was determined by expressing the IAUC for each test diet as a percentage of IAUCS of the reference food (glucose) taken within same group. The GI values obtained were: acha diet (57.5%), wheat diet (69.4%), corn diet (76%) and oat diet having the lowest of (48.1%) (Fig. 2).

DISCUSSION

The common notion in our contextual African society, Nigeria in particular of semi-solid foods/soups (i.e. swallow foods) which seemingly are heavy foods tends to have a high GI irrespective of the carbohydrate source. Health experts however are encouraging the processing of other food sources i.e. soybeans, wheat and oat into these semi-solid foods especially as a delicacy for diabetic and obese individuals with the belief of not flooding the blood stream with glucose thereby checkmating blood sugar level. This study was undertaken primarily to determine the relative glycaemic indices of four test diets recommended mainly for adult Nigerians/diabetic patients since dietary management is key in achieving better glycaemic control by balancing food intake with endogenous and/or insulin levels. The effects of corn, acha, wheat and oat diets on blood glucose response of the test animals relative to reference (glucose) were studied. It was observed that the test (corn, acha, wheat and Elkris super oat) diets induced lower responses in blood glucose than the reference, indicating a slower release of glucose from test diets relative to the reference. This could be attributed to the diets composition, especially their content of fibre, fat and protein. Fibre in food is known to delay gastric emptying thus slowing the rate of glucose release into circulation [19]. Oat beta-glucan which is a soluble dietary fibre slows down the rate of cholesterol absorption and thus facilitates the improvement of gastrointestinal functions and glucose metabolism [20]. Beta-glucan along with insoluble fibre delays the overall absorption of cholesterol and glucose [21]. Elkris super oat had relative higher fibre content (8.50±0.06%) with acha having the highest of (9.36±0.12%). This could be the reason of them having lower glycaemic glucose response as compared to other test diets of wheat (7.87±0.17%) and corn (4.52±0.09%) that elicited higher glycaemic glucose response and glycaemic index values as well. This is further buttressed by the works of McKeown *et al.* [22] and Bell and Sears [23], which showed that foods rich in fibre have a protective effect against hyperglycaemia and hyperinsulinaemia because they reduce postprandial blood glucose levels, hence glycaemic index.

Fat is also known to reduce jejunal motility and postprandial flow rates in the intestine, hence decreasing the glycaemic response [24]. This suggests that there is showed no correlation with the oat diet as it had the lowest fat content (3.00±0.04%) yet had the lowest glucose response. However, the acha diet had the highest fat content (5.40±0.07%) and a considerably lower blood glucose response and glycaemic index when compared with the wheat (4.67±0.35%) and corn (3.68±0.14%) diets that elicited a higher glucose response and glycaemic index. According to Wolever *et al.* [19] however, fat levels of 50 g per 50 g available carbohydrate is needed to affect the glycaemic response and hence the glycaemic index values. More so, the addition of protein into a carbohydrate-rich meal has been found to decrease GI values but at least 30 g of protein is needed to cause a significant effect [25] and going by this, test diets consumed by animals contained less than the required grams to cause a significant effect on the glycaemic index values.

The variability in the blood glucose responses to test diets may be attributed to the nature of starch (amylose/amylopectin content) present. Starch is normally composed of one-quarter amylose, with the remaining three quarters being amylopectin but proportions vary generally according to food/variety. Jideani and Akingbala [26] reported that the amylose content of acha grains, procured from a local market in Nigeria to be 28 % of amylose. According to Foley *et al.* [27], both corn and wheat contain 25% amylose respectively. Also, the amylose content of oat starch ranges from 16 to 33.6%, varying among cultivars and especially, with the presence of starch lipid content [28, 29]. High amylose starch has been shown to be digested far more slowly than the high amylopectin starch [30]. This was supported by the work of Kabir *et al.* [31], which reported that when starches with different amylose-amylopectin ratios were incorporated into a meal, the one with the higher amylopectin starch showed higher glycaemic index than that of the low amylopectin starch for normal and diabetic rats. There is therefore a need to compare the ratio of amylose to amylopectin among test foods in further studies.

Generally, several foods are processed before by cooking (i.e. boiling, roasting, frying, steaming, baking), drying, mashing, grinding into flour before consumption [13]. In this study, the test foods were basically dried and ground into flour (except the acha) then reconstituted to paste with hot water before incorporation of other components of rat diet. Thus, the particle sizes were reduced and the starch was retrograded to a variable extent and increased processing and starch retrogression can lead to an increase in glycaemic index [13]. This could be the reason why maize and wheat had a higher G.I compared to acha. Nonetheless the oat (Elkris super oat) purchased seem to be the most processed/ refined in particle size among the test diets yet still had the lowest G.I. Thus, the quality of the carbohydrate still matters irrespective of the mode of processing among different carbohydrate sources. This study agrees with the finding of Omoregie and Osagie [32] were similarly processed maize flour had a high glycaemic index, though a slight variance in wheat specifically (semolina) with a high glycaemic index (GI= 95.3) compared to the moderate glycaemic index value of (GI = 69.4) of wheat observed in this study. This study is also in agreement with the findings in Dakar by Djibril *et al.* [33], which showed that acha (Fonio) had a moderate glycaemic index (GI = 66).

CONCLUSIONS

The glycaemic indices of test diets were: corn (76%), wheat (69.4%), acha (57.5%) and oat (48.1%). Thus based on the glycaemic index rating, the corn diet been above 70% can be said to have a high glycaemic index while both wheat and acha are intermediate (56-69) and oat a low glycaemic diet since it's less than 55. This study showed that oat has a considerably lower glycaemic index among the test diets while wheat and acha have intermediate glycaemic indices hence are preferable diet in achieving better glycaemic control. These observations may serve as a valuable guide to health professionals, including dieticians and nutritionists, who often need to recommend diets for different people bearing in minds the health benefits associated with the intake of low glycaemic index foods in terms of proper management of diabetes, obesity as well as in coronary heart diseases. This study could also assist food manufacturers and processors to develop a greater range of low glycaemic index processed foods from African farm produce.

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