Glycaemic index of selected staple carbohydrate-rich foods commonly consumed in Botswana

Mahgoub SO, PhD, Associate Professor, Kaplan University, Iowa, USA
Sabone M, PhD, Senior Lecturer, School of Nursing, University of Botswana, Botswana
Jackson J, PhD, Researcher, Centre for Scientific Research, Indigenous Knowledge and Innovation (CesrIKi) University of Botswana, Botswana
Correspondence to: Salah Mahgoub, e-mail: SMahgoub@kaplan.edu
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Abstract

Objectives: Data on the glycaemic index (GI) of foods commonly consumed in Botswana are lacking. The present study aimed to evaluate the GI of some of the staple carbohydrate-rich foods eaten in Botswana.

Design, setting and subjects: Fifty university student volunteers were divided into five groups. Members of each group consumed different test foods based on wheat, maize, sorghum, millet and morama beans to supply 50 g of available carbohydrate after 10-12 hours of overnight fasting. GI was determined using a standard method with white bread.

Outcome measures: The GI values were calculated after measuring blood glucose levels before and after ingestion at 0, 15, 30, 45, 60, 90 and 120 minutes.

Results: The results showed a clear variation in the GI values for the same food when consumed by different individuals. In addition, variations were observed in the GI values of test foods based on the same material. On average, wheat-based foods exhibited the highest GI values (103.1), followed by millet-based foods (95.3), sorghum-based foods (92.5), maize-based foods (9.1) and morama-based foods (86.4). Of the tested food, *mapakiwa* (wheat-based) had the highest GI (110.6) whereas roasted morama had the lowest GI (82.8).

Conclusion: These results could form the basis of dietary advice to consumers, and particularly patients with diabetes. Further studies are needed on more of the commonly consumed foods in Botswana.

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Introduction

Glycaemic index (GI) has been widely studied and reported on in the literature as being associated with the causation and treatment of chronic diseases, e.g. diabetes and obesity.[1-4] It is defined as the incremental blood glucose area (0-2 hours) following ingestion of 50 g of available carbohydrates (no fibre or resistant starch included), expressed as a percentage of the corresponding area, following an equivalent amount of carbohydrate from a standard reference product.[5,6] The GI values of different foods have been studied and reported in different parts of the world.[7-11] GI values for different food products range from less than 20% to approximately 120% when using glucose as a reference.[12]

According to a number of reported studies, the glycaemic response to food (which affects the insulin response) depends on the rate of gastric emptying, as well as on the rate of the digestion and absorption of carbohydrates from the small intestine.[13,14] In addition, there is a range of food factors, such as the type and structure of the carbohydrate, which may be affected by the processing of foods, which in turn influence the GI thereof.[15] For example, foods with a low GI include whole grain cereals, whole kernel bread, beans and many fruits, while examples of food with a high GI include white bread, highly processed grain, cereals and potatoes.

In recent years, there has been a steady global increase in the incidence of noncommunicable diseases, such as diabetes. This includes countries such as Botswana, although the prevalence of such diseases at national and community level is still not very clear. Reports have put the national prevalence as high as 7.2%, while globally it is approximately 6.4%.[16] Selecting low-GI carbohydrate foods for meal plans for individuals with diabetes has been increasingly recommended by the Food and Agricultural Organization ofthe United Nations (FAO)/World Health Organization (WHO).[5,6,17] However, the practical implications of GI and nutritional recommendations that could be made based on diets in Botswana need further clarification. This is largely because of a lack of knowledge of the GI values for many staple foods in Botswana. Therefore, the aim of this study was to measure the GI of a number of key staple carbohydrate-rich foods, based on wheat, maize, sorghum, millet and legumes in the Botswana diet. This is important for researchers seeking to quantify GI through Botswana dietary surveys, and when planning intervention studies and advising consumers. In addition, the study also enabled detailed investigation of various factors that influence the GI of a food.

Method

Recruitment of participants

Subjects were identified from student and staff populations of the University of Botswana through an active recruitment drive using the student and staff associations on campus, as well as the university intranet. Candidates were informed about the objectives of the study. They were also informed that they would be screened for eligibility to participate. Inclusion and exclusion criteria were communicated. The participants were informed about the commitment that would be required of them, i.e. to avoid heavy meals, alcohol and vigorous exercise on the day preceding the test and on the morning of the test, to fast for 10 hours, be at the testing site at 08h00 once a week over a period of six weeks and to spend two hours at the testing site to consume samples of food, as well as have finger-prick tests.

Screening of candidates

Candidates who expressed an interest in participating in the study were screened by a trained research assistant using a screening form developed by the research team. Demographic profiles of age and gender, as well as anthropometric profiles of body weight (kg) and height (m), were taken. Body mass index (BMI) was calculated using the formula BMI = weight/height x height and recorded. Obtained health status information included asking candidates about current and past treatment for gastrointestinal disorders and diabetes mellitus. Participants were asked to list any current medications taken for such diseases. Pregnancy, breastfeeding and possible allergies to food items were also investigated. Candidates were excluded if they reported a history of gastrointestinal disorders and diabetes mellitus, and if they were currently pregnant or breastfeeding. These exclusions were executed to avoid any complications relating to these health conditions, and arising from consumption of the test foods. Health status assessment was based on self-report, rather than objective tests.

Data collection

Fifty subjects, 41 women and nine men, all third- or fourth-year University of Botswana students, were deemed to be eligible for participation in the study, based on eligibility screening. Their distribution into different test groups was determined by their availability on a given day of the week. Data collection was carried out over a period of six weeks by trained research assistants recruited from the School of Nursing and the Department of Family and Consumer Sciences. At least one researcher oversaw the testing process at the test sessions.

The method used to measure and calculate the GI of the foods was in accordance with FAO/WHO recommendations.[5] Subjects were given the standard reference food of white bread during the first and last visits. During the second to the fifth visits, they were given foods that were randomly assigned to them as shown and described in Tables I and II. Each food item was consumed by 10 different subjects to provide statistical power required for the data analysis. Nineteen different foods based on morama, wheat, maize, millet and sorghum, which comprise the staple carbohydrate foods consumed in Botswana, were prepared in the traditional manner and served. The foods were prepared and cooked by the staff of a university-based cafeteria who had been given specific and detailed preparation instructions. Portion sizes were determined using the food composition database programme FoodFinder 3® (Medical Research Council, Tygerberg, South Africa) to provide 50 g available carbohydrate [5,6] for each food item. The reference used was 50 g white bread consumed with 250 ml water.

Blood glucose concentrations were measured in capillary whole blood obtained by a finger prick (Accu-Chek® Advantage System, Roche Diagnostics, Lewes, the UK) in the fasted state and at 15, 30, 45, 60, 90 and 120 minutes after commencement of the consumption of food. The blood glucose analysis was performed by two registered nurses.

Study protocol assumptions

The study protocol made certain assumptions, namely that:

- The study protocol was adhered to and the foods were prepared and consumed in the recommended quantities.
- The only difference between the subjects was the type of product they were requested to consume.
- The subjects provided honest responses to all questions.

Table I: Food items tested per food group

Week	Day 1: Group 1 (Morama based)	Day 2: Group 2 (Wheat based)	Day 3: Group 3 (Maize based)	Day 4: Group 4 (Millet based)	Day 5: Group 5 (Sorghum based)
1	White bread	White bread	White bread	White bread	White bread
2	No food	Fat cakes	*Mpsapsa* with beans	Plain stiff porridge *(mosoko)*	*Bogobe jwa madila*
3	Roasted morama	*Diphaphatha*	Maize meal stiff porridge	*Bogobe jwa lerotse*	*Mosutlhane*
4	Morama and sorghum porridge	Dumplings	Samp only	Soft porridge with full-cream milk	Fermented soft porridge
5	Morama and maize porridge	*Mapakiwa*	Samp and beans	Plain soft porridge	Soft porridge with full-cream milk
6	White bread	White bread	White bread	White bread	White bread

Table II: Test food description

Group 1: Morama-based food items
Roasted morama: Dried morama beans roasted in the oven or iron cast pot for a few minutes, depending on the portion size.
Morama and sorghum blend porridge: Dried morama beans and whole grain sorghum flour were mixed and boiled in water to form porridge.
Morama maize blend porridge: Dried morama beans and whole grain maize flour were mixed and boiled in water to form porridge.
Group 2: Wheat-based food items
Fat cakes: White wheat flour mixed with water to make dough, divided into sizeable portions and deep fried in sunflower oil.
Diphaphatha *(flat cakes):* White wheat flour mixed with water to make dough, divided into sizeable flattened portions and cooked uncovered over a hot metal surface.
Dumplings: White wheat flour mixed with water to make dough, divided into sizeable portions and boiled in water.
Mapakiwa *(baked bread):* White wheat flour mixed with water to make dough, divided into sizeable portions and baked in an oven or cast iron pot.
Group 3: Maize-based food items
Mpsapsa (letshotlho) *with beans:* Parboiled maize and dried whole grain maize mixed with white beans and boiled in water.
Maize meal stiff porridge: Mealie meal mixed with boiling water to a thick consistency and left to cook slowly.
Samp only: Samp cooked slowly in boiling water.
Samp and beans: Samp mixed with white beans and slowly cooked in boiling water.
Group 4: Millet-based food items
Millet stiff porridge (mosoko): Millet flour mixed with water and cooked to a stiff-consistency porridge.
Bogobe jwa lerotse: Millet flour boiled in melon juice or mash.
Soft porridge with milk: Millet meal boiled in water to a soft consistency and served with pasteurised full-cream milk.
Plain soft porridge: Millet flour boiled in water to a soft-consistency porridge.
Group 5: Sorghum-based food items
Bogobe jwa madila: Sorghum flour boiled in water to a medium-consistency porridge and served with fermented or sour milk.
Mosutlhane: De-husked sorghum grains boiled in water.
Fermented soft porridge: Sorghum flour fermented by mixing it with warm water and leaving it to stand for a few days before it is cooked in boiling water.
Soft porridge with milk: Sorghum flour boiled in water to a soft consistency and served with pasteurised full-cream milk.

Ethical considerations

Permission to conduct the study was obtained from the Ethics Committee of the Ministry of Health, Botswana. The subjects were made aware of the study objectives and of what was expected from them. They were informed that participation was voluntary, that they were free to withdraw at any time if they no longer wished to participate, and that confidentiality pertaining to the data that were obtained from them would be protected. The participants provided written consent before participating. As an incentive, each of them was given a lunch voucher once daily during the participation period. Each recruited subject was assigned an identity number that was used throughout the test period, as well as in the data entry and analysis.

Data management

Data were entered in a form designed for the study. Research assistants checked the case report forms for completeness and accuracy. Forms that had been checked and found to be complete and accurate were then signed for purposes of quality control and kept in a locked cabinet. In preparation for the analysis, data were entered into a Microsoft® Excel® spreadsheet. Password restrictions on the use of the project work stations were employed to ensure security and confidentiality of the data.

Data analysis

Data were analysed according to the method recommended by the FAO/WHO.[5] The incremental area under the curve for glucose (IAUCG), expressed as a percentage of the mean IAUCG for the two repeats of the isocarbohydrate reference food (white bread) consumed by the same subject, was computed. The GI of each food was then calculated as the mean value across all subjects consuming that food. IAUCG and GI were calculated using Microsoft® Excel®. Statistical differences between the GI values of the different foods were investigated by comparing the means using nonparametric Mann-Whitney U-tests, in SPSS®.

Results

Seventy-nine individuals responded to the call for volunteers to participate in the study. All of them were University of Botswana students, representing different faculties and levels of education. Fifty-nine met the stipulated requirements. Fifty volunteers completed all parts of the study. As Table III shows, the majority of

Table III: Characteristics of the participants

Characteristics	Value
Total number of participants	50
Men/women	9/41
Average age (years)	21 ± 2
Average body mass index (kg/m^2)	21.5 ± 3
Average fasting plasma glucose (mmol/l)	5.21 ± 0.34

Values are presented as mean ± standard deviation

Table IV: Gylcaemic index of test foods calculated for the individual participants

Wheat-based foods	Fat cakes	*Diphaphatha*	Dumplings	*Mapakiwa*
	92.1	88.4	92.8	103.5
	95.2	90.5	96.6	106.2
	98.3	93.8	99.7	108.4
	100.5	94.1	101.3	109.8
	100.8	95.7	103.9	110.2
	101.2	98.6	104.1	111.4
	102.4	102.5	105.4	112.3
	103.3	103.5	106.7	113.4
	103.8	105.2	107.8	113.8
	104.3	110.9	112.8	117.4
Maize-based foods	***Mpsapsa***	**Maize meal stiff porridge**	**Samp**	**Samp with beans**
	91.1	76.2	84.1	83.3
	92.9	87.8	87.3	85.4
	93.2	87.9	88.3	85.6
	93.2	89.6	88.6	87.1
	93.3	89.8	89.6	89
	94.3	90.4	90.4	89.3
	95.8	91.6	94.1	90.8
	96.6	93.3	94.9	91
	96.9	94.6	96	91.2
	99.4	98.9	97	92.5
	(8.3)*	(22.7)*	(12.9)*	(9.2)*
	91.1	76.2	84.1	83.3
Millet-based foods	**Stiff porridge**	***Bogobe jwa lerotse***	**Soft porridge and full-cream milk**	**Plain soft porridge**
	89.8	87.5	97.6	87.4
	90.5	91.7	98.4	91
	91.1	91.9	98.9	91.7
	91.3	92.4	100.8	92.4
	91.8	92.9	100.8	92.8
	92.3	93.4	101.2	93.4
	93	94.1	102.4	93.7
	94.2	95.2	102.9	93.9
	95.3	96.6	103.4	95.1
	101.2	100	108.1	97.8
	(11.4)*	(12.5)*	(10.5)*	(10.4)*
Sorghum-based foods	**Bogobe jwa madila**	***Mosutlhane***	**Fermented porridge**	**Soft porridge and full-cream milk**
	84.2	87.2	82.4	82.4
	84.9	88	91.2	91.2
	89.2	90.2	92.7	92.7
	89.8	91.4	92.9	92.9
	90.2	91.7	93.6	93.6
	90.4	92.4	94.2	94.2
	91.5	93.1	95	95
	92	94.6	96.1	96.1
	92.4	98.3	96.8	96.8
	100.2	108.8	99.7	99.7
	84.2	(21.6)*	(17.3)*	(17.3)*
Morama-based foods	**Roasted morama**	**Morama and sorghum**	**Morama and maize**	
	80.8	81.6	72.6	
	81.6	86.6	86.4	
	81.8	88.6	86.5	
	82	89.4	86.6	
	82.6	90.7	87.1	
	82.9	90.8	87.8	
	83	91	88.3	
	83.3	91.1	89.1	
	84.6	91.7	89.7	
	85.4	92.7	95.6	
	(3.8)*	(11.1)*	(23)*	

*: Indicates the difference between the highest and lowest glycaemic index values of the same food

them (82%) were women with a mean age of 21 ± 2 years, mean BMI of 21.5 ± 3 and mean fasting plasma glucose concentration of 5.21 ± 0.34 mmol/l.

Table IV shows a clear variation in the GI values of the same food when consumed by different participants. The highest observed difference was 23 in the case of morama and maize porridge, and the lowest was 3.8 for the roasted morama. The results also indicate that there were variations in the GI values of the test foods based on the same material. The range of the GI values for wheat-based foods was between 88.4 *(diphaphatha)* and 117.4 *(mapakiwa).* The GI value range fell between 76.2 (maize stiff porridge) and 99.4 *(mpsapsa)* for maize-based foods. The GI value range for millet-based foods was between 87.4 (millet soft porridge) and 108.1 (millet soft porridge with full-cream milk). The GI value range was between 82.4 (fermented sorghum porridge) and 108.8 *(mosuthane)* for sorghum-based foods. The GI value range was between 72.6 and 95.6 (both morama and maize blend porridge) for morama-based foods.

Table V shows the mean GI values and ranges for foods based on cereals usually consumed in Botswana, in addition to the morama bean. *Diphaphatha* was found to have the lowest GI (98.3) and *mapakiwa* the highest (110.6) of the wheat-based foods. Samp with beans had the lowest GI (88.5) and *mpsapsa* the highest (94.7) of the maize-based foods. The lowest GI for the millet-based foods was the stiff porridge (93.1), and the highest recorded GI, soft porridge with full-cream milk (101.5). Of the sorghum-based foods, 90.5 was the lowest GI recorded for *bogobe jwa madila,* while the highest was 93.6 for *mosutlhane.* The lowest GI was 82.8 for roasted morama, and the highest, 89.4 for morama and sorghum porridge, for the morama-based foods. When the average GI values of foods based on different cereals were compared, wheat-based foods were found to have the highest GI average (103.1), followed by millet-based foods (95.3), then sorghum-based foods (92.5), maize-based foods (91.1) and finally, morama-based foods (86.4).

Table V: Mean glycaemic index values of the different tested foods

Food	N	Mean (range)	SD
Wheat-based foods			
Fat cakes	10	100.2 (92.1-104.3)	5.2
Diphaphatha	10	93.3 (88.4-110.9)	8.2
Dumplings	10	103.1 (92.8-112.8)	6.8
Mapakiwa	10	110.6 (103-117.4)	6
Average		103.1	
Maize-based foods			
Mpsapsa	10	94.7 (91.1-99.4)	2.5
Maize meal stiff porridge	10	90 (76.2-98.9)	6.6
Samp	10	91 (84.1-97)	4.5
Samp with beans	10	88.5 (83.3-92.5)	3.3
Average		91.1	
Millet-based foods			
Soft porridge	10	92.9 (87.4-97.8)	4.3
Soft porridge with full-cream milk	10	101.5 (97.6-108.1)	3.8
Stiff porridge	10	93.1 (89.8-101.2)	4.4
Bogobe jwa lerotse	10	93.6 (87.5-100)	4.8
Average		95.3	
Sorghum-based foods			
Fermented soft porridge	10	93.5 (82.4-99.7)	6.6
Bogobe jwa madila	10	90.5 (84.2-100.2)	5.8
Mosutlhane	10	93.6 (87.2-108.8)	8.3
Soft porridge with full-cream milk	10	92.2 (87.9-97)	4.1
Average		92.5	
Morama-based foods			
Roasted morama	10	82.8 (80.8-85.4)	2.9
Morama and sorghum porridge	10	89.4 (81.6-92.7)	4.1
Morama and maize porridge	10	87 (72.6-95.6)	8.4
Average		86.4	

SD: standard deviation

Discussion

The aim of the present study was to determine the GI of various staple carbohydrate-rich foods in the Botswana diet and to consider factors which influence the GI of the foods. This is important for researchers seeking to quantify GI through Botswana dietary surveys, and when planning intervention studies and advising consumers. The outcome of the study may also enable detailed investigation of various factors which might influence the GI of a particular food, such as the effect of food type, cooking methods and fibre content.

According to Foster-Powell, Holt and Brand-Miller,[18] the number of participants in most GI studies ranges between five and 10. The number of participants in each group was 10 in the present study. The average age of the participants was 21 years. Their average BMI was 21.5 kg/m^2, which was within the normal range of 18.5-24.9 kg/m^2, as suggested by the WHO. Average fasting plasma glucose concentration was 5.21 mmol/l, which fell within the normal range (random plasma glucose of < 11.1 mmol/l), as described by Franz.[19]

The GI of the five food groups commonly consumed in Botswana, described in Table I, were determined in the present study using a standard protocol. The selected foods for testing were based on the results from 24-hour recall[6] and food balance sheets.[19] The test food items included one or two products from a group. The same product was cooked using different methods or a mix of the product with another type of food. Two products from a single group could be expected to have different GIs because of the differences in the available surface area for the release of glucose into the bloodstream. Different opinions have been expressed in relation to the relevance of classifying foods according to their glycaemic response by using the GI.[20] Part of the controversy is because of the methodological variables (food portion size, the method of blood sampling, sample size, subject characteristics, standard food used, available carbohydrates, and volume and type of drinks consumed with test meals) that can markedly affect the interpretation of glycaemic responses and the GI values obtained.[8,21] Notwithstanding these controversies, the GI concept was endorsed in the joint FAO/WHO report[5] that reviewed the available research evidence on the importance of carbohydrates in human nutrition.

Both within- and between-subject variations affected glycaemic responses to a particular food.[22,23] The variability between individuals was larger than that within individual subjects.[24] This variability was also observed in the present study, as demonstrated in Table IV. The wide GI ranges between the different subjects with regard to the same food might be owing to subjects' genetic factors having a significant influence on metabolic processes.

Venter et al[25] suggest that it would be helpful to inform patients and consumers that physiological responses to a food may vary between individuals when using the GI concept to choose carbohydrate food. Therefore, if it is indicated that the food has a high GI, it does not mean that this will be the case in other individuals. A specific food may have a high GI in some individuals, and a medium, or even a low, GI, in others. This could be attributed to genetic variations between individuals and means that the absorption of test meals or their metabolism within the body cannot necessarily be determined.

A mixture of products may increase or decrease its GI, depending on the glucose composition of the food items. The consistency (hardness or softness) of the product may also influence the availability of its glucose to the bloodstream. This may explain the difference in the GI for *diphaphatha* and *mapakiwa* in the present study. The former was hard and the latter soft, although the ingredients are similar.

In the present study, GI range for the tested foods was wide. Beneficial health effects could result if those consuming a high-GI diet reduced their intake of a high GI staple food, and increased their consumption of food with intermediate- and low-GI values. This is particularly important since small changes in the diet GI are associated with a significant reduction in coronary heart disease risk,[26] diabetes risk[2] and improvements in insulin sensitivity and glycaemic control.[27, 28] Low-GI staples and diets need to be identified and their usage promoted. However, further studies are required in this regard. The findings of the present study may provide useful guidance for dietitians who are involved in meal planning for patients with diabetes and health education programmes. The findings can also be used to achieve healthy eating and to plan chronic disease risk reduction programmes in high-risk populations.

A number of studies have been conducted on determining the GI of maize-based foods. Reported GI values vary widely, and range between 44 for maize porridge[29] and 92.3 for Agidi (maize-based food).[30] Other reported GI values for maize are 74[18] and 86.8.[29] These differences may partly be attributed to the method of preparation or other factors. The average GI value for maize-based foods in the present study was 91.1, which falls within the range of some of the reported GI values.

Omoregie and Osagie[29] also reported GI values for a millet-based food *(tuwo gero)* and a sorghum-based food *(tuwo dawa)* of 93.6 and 85.3, respectively. These values are not significantly different to the findings in the present study (95.2 for millet-based foods and 92.2 for sorghum-based foods).

The method of food preparation has a clear effect on the GI value of the food, based on the same staple. Th results in Tables IV and V reflect this, and indicate that foods prepared from the same cereal using different methods have different GI values.

Foods are usually not consumed in isolation, but in combination in mixed meals, and as a component of a complex diet. Therefore, it is important to ensure that the GI concept is also applied in the context of mixed meals.[30]

Conclusion

The GI values of the foods tested in the present study can be regarded as high. The range of the GI values for the tested foods was wide. Choosing foods with a low to intermediate GI would result in beneficial health effects. More studies on GI values for other foods consumed in Botswana need to be conducted.

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