Research Article

Glycemic Index Values of Stiff Porridge (Ugali) Prepared from Maize, Millet, and Sorghum Flours: Which One for Diabetes Management?

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Background. The prevalence of diabetes mellitus is increasing worldwide. Knowledge of glycemic index (GI) is important in its prevention and management. The GI measures how rapidly or slowly the blood glucose increases after food consumption. Stiff porridge (ugali) is an African cuisine that can be prepared from various cereal grains and consumed alongside a relish, including milk. The impact of cereal grain type and milk on the GI of ugali is not understood.

Objectives. To determine the GI of ugali prepared from maize, millet, and sorghum and establish the impact of fermented milk on the GI.

Methods. Proximate composition was determined using the Association of Official Analytical Chemists methods. Moisture, fat, protein, ash, and crude fiber content were determined by oven drying, soxhlet, Kjeldahl, dry ashing, and Hennenberg and Stohmann methods, respectively. Carbohydrate content was determined by difference. The GI was determined using standard procedures (ISO 26642:2010). Blood sugar response curves were generated using Microsoft Excel software. The GI was computed by dividing the incremental area under the curve (IAUC) of test food by the IAUC of glucose and then multiplied by 100. Data were analyzed using GenStat 14th Edition software.

Results. Maize ugali had significantly higher carbohydrate content as opposed to millet or sorghum ugali ($P<0.05$). The GI for plain ugali followed the order sorghum (72) > maize (67) > millet (46). When consumed alongside fermented milk, the GI order was maize (70) > millet (67) > sorghum (57).

Conclusion. Millet-based ugali may be used in the management of diabetes. Fermented milk lowers the GI of sorghum ugali and increases the GI of maize and millet ugali.

1. Introduction

Among the major noncommunicable diseases of the 21st century is diabetes mellitus. The prevalence of prediabetes (3.1%) is higher in Kenya compared to that of diabetes (2.4%) [1]. Some regions of the country have reported a much higher prevalence than the national average. For example, a recent cross-sectional study conducted in Meru County reported a diabetes prevalence of 15.4%, with women having the highest prevalence compared to men [2]. Diet planning has been encouraged as a form of control and management of diabetes [3]. Glycemic control, as a diabetic management tool, is practiced by few patients (7%) [1].

Glycemic index (GI) indicates how fast or slow the blood sugar spikes after the consumption of food. Based on the GI, foods have been classified as high (>70), medium (56–69), or low GI (<55) when glucose is the reference food or classified as high (>85), intermediate (60–85) or low GI (<60) when white bread is used as the reference food [4]. Low GI foods have been recommended for blood glucose control [5–7]. The GI of foods is influenced by a number of factors, including the level of starch gelatinization [8], fat, protein [9], processing, fiber [10], and accompaniment of the starch food [11]. For example, cowpea leaves reduced the GI of whole maize ugali, while beef caused an increase [12].

Cereals are the main source of food, and they provide most of the calories, proteins, minerals, and vitamins, especially the B-vitamins [13]. Maize (Zea mays), sorghum (Sorghum bicolor), and finger millet (Eleusine coracana) are among the leading rain-fed cereals in Kenya. Developing countries depend mainly on cereal-based foods, which are
usually cheaper compared to animal-based foods. Most countries have a single cereal grain as the primary staple [13].

Maize (Z. mays) is among the major cereals produced in the world and is adapted to different ecosystems [13]. It is a major staple in Africa and has food, feed, and industrial applications [14]. Wholegrain seeds are a source of carbohydrates, fiber, protein, and minerals [15]. In Kenya, it is used in the preparation of thin porridge (uji) and stiff porridge (ugali) [16, 17]. Green maize can be consumed boiled or roasted, or mixed with beans and boiled into a meal popularly known as githeri or it can be dehulled by pounding in a motor before mixing with beans. In addition, sifted maize flour, breakfast cereals, corn starch, and edible corn oil are the main industrial products [16].

Sorghum (S. bicolor) is a major cereal in Africa, and among its uses are stiff porridge preparation and beer production [18]. In Kenya, the crop grows in semiarid Eastern, Western, and Coastal regions. It is drought tolerant, a good source of calories, and can grow in areas where maize struggles because of poor soils, low rainfall, or high temperatures. All these characteristics make it an attractive alternative to maize [13]. In Kenya, sorghum is traditionally used in the preparation of thin porridge (uji), thick porridge (ugali), and alcoholic drink production. Sorghum wholegrain kernel is a source of starch, proteins, lipids, pyridoxine, niacin, and riboflavin [13, 19].

Finger millet (E. coracana) is a drought-resistant minor cereal, which is a source of dietary fiber and polyphenols that have functional health benefits, including antidiabetic and weight management [20], minerals, vitamins, and proteins [13]. It also withstands harsh environmental conditions like sorghum and, in addition, has a short growing cycle, thus making it of high value, especially in semiarid regions [13]. It is used in the preparation of thin porridge (uji), stiff porridge (ugali), and a local brew (busaa) [16, 21].

Stiff porridge (ugali) is an African cuisine prepared from flours of maize, sorghum, millet, cassava, or their blends [22]. During its preparation, flour is mixed into boiling water, where the starch gelatinizes and forms a firm mass [17]. Stiff porridge is commonly consumed during breakfast as left overs together with tea or lunch or dinner together with a side dish or relish. In some communities, whole-milled flours from the aforementioned cereals have been recommended to individuals with noncommunicable diseases, including diabetes mellitus [22]. Ugali is normally consumed alongside a variety of side dishes, including beef, fish, and vegetables [16, 23].

Dairy products have been found to be inversely associated with diabetes mellitus [24]. They have been shown to have a low to medium GI [25]. For instance, cheese has been shown to reduce the GI of bread [26], and ripened cheese and whey dairy could also decrease glycemic response [27]. Fermented milk (mala) is a commercialized traditional sour milk that used to be popularly known as maziwa lala in Kenya. It is produced by inoculating pasteurized milk with a mesophilic culture composed of Streptococcus cremoris, Streptococcus lactis, Streptococcus diacetylactis, and Leuconostoc cremoris [28].

Since the effect of milk on GI seems to be dependent on the dairy product as well as the type of probiotic culture used [27] and the fact that the determination of GI should be specific to the product [29], this study determined the effect of fermented milk on the GI of stiff porridge prepared from maize, sorghum, and millet. This study will provide healthcare personnel with information on appropriate diet choices and food combinations for patients with diabetes mellitus and the general population. Focusing on traditional food gives an economically friendly and culturally acceptable diet, which is a better option as opposed to expensive medical care. It will also add to the GI data of traditional African foods.

2. Materials and Methods

Maize, finger millet, and sorghum grains were sourced from the Kakamega municipal market in Kakamega County, which is located in the western part of Kenya about 30 km north of the Equator, covering an area of 3,224.9 km². The main crops grown in the county are maize, finger millet, sorghum, beans, cassava, sweet potatoes, tomatoes, tea, and sugarcane. Maize meal is the main staple food for the county.

The cereals were cleaned to remove any foreign material and then milled using a hammer mill at a local posho mill in Nchiru market, Meru County. The flours were then stored in clean, dry plastic containers and stored at room temperature. Fermented milk was purchased from a local supermarket in Meru County. The milk was manufactured by Kenya Cooperative Creameries.

2.1. Stiff Porridge Preparation. During the preparation of stiff porridge, the ratio of flour to water used was 3:5. Water was boiled in a cooking pan. Flour was then added gradually to boiling water in portions and mixed thoroughly using a wooden spoon until a firm, consistent texture devoid of lumps was achieved. The stiff porridge was left to cool before the proximate analysis and served warm during GI analysis.

2.2. Proximate Composition Determination. Proximate analysis was carried out according to the Association of Official Analytical Chemists (AOAC) methods [30]. Moisture content (MC) was determined by oven drying method (AOAC method 925.10). The stiff porridge sample was dried in the oven to a constant weight. Percent MC was computed as the weight of water lost after drying divided by the weight of the sample and then multiplied by 100. Fat content was determined by using the soxhlet method (AOAC method 996.01), and the percent of fat was computed as the weight of fat extracted divided by the weight of sample multiplied by 100.

Protein content was estimated using the Kjeldahl method (AOAC method 960.52). The crude protein was determined by measuring the total nitrogen in the sample. Nitrogen obtained was multiplied by an appropriate conversion factor of nitrogen into proteins. Ash content was determined by the dry ashing method (AOAC method 923.03) using the muffle furnace and calculated as the weight of ash remained/weight of the sample multiplied by 100. Crude fiber content was determined using the Hennenberg and Stohmann method.
2.3. Inclusion and Exclusion Criteria for GI Participants. Volunteers from Meru University of Science and Technology were recruited for this study. They were required to be healthy with a normal body mass index (BMI) (18.5–24.9 kg/m²), normal fasting blood glucose (<5.5 mmol/L), and normal blood pressure (90/60–120/80 mmHg) [31, 32]. Individuals who were ill or under medication, overweight/obese, hypertensive, had a recent surgery, or were suffering from diabetes, or were lactating were excluded from the study. Overweight participants were counseled before they left the study, and those with high blood pressure were referred to the university health facility for confirmation and management.

2.4. Screening of Participants. Weight, height, blood pressure, and blood glucose were measured according to standard procedures. Weight was determined with participants having no shoes or belts using a weighing scale (QF-2003 B, China). Height was recorded using a stadiometer (NL-260101, Amoi Technology Co., Ltd., China). The BMI was calculated using the formula weight/height². Blood pressure was determined using an automatic sphygmomanometer (Omron, Vietnam Co., Ltd. Vietnam). Fasting blood glucose levels were determined using a glucometer (On Call Plus, Acon laboratories, San Diego, CA, USA). A verbal interview was used to determine those under medication, ill, or who had undergone recent surgery.

2.5. GI Determination. The GI was determined using standard procedures [33, 34], in which 10 healthy participants were included in the study and advised to have a 10–12 hr overnight fast prior to the day of the study. They were also required to avoid alcohol, smoking, and extraneous physical activity.

The reference and test food were randomly tested with a wash-out period of 2 days. On the first day, participants consumed 50 g of glucose dissolve in 250 mL of portable water within 10 min. The reference food (glucose) was measured thrice. The test foods were later consumed on separate days for each meal (ugali plain or ugali with mala) within 10 min, following an overnight fast. The test foods were also consumed with 250 mL of potable water.

Using a sterile lancet, the disinfected fingertip was pricked, and a blood sample of at least 1 µL was placed on a strip on a glucometer (On Call Plus, Acon laboratories, San Diego, CA, USA), and postprandial blood glucose was measured. The fingertip was disinfected using cotton wool soaked in surgical spirit prior to pricking. After each prick, the lancet was discarded into a 5 L safety biohazard box (Twokay Chemicals Ltd., Nairobi, Kenya). Blood glucose measurement was taken at 0, 15, 30, 45, 60, 90, and 120th min.

2.6. Data Analysis. The results of blood sugar responses at 0, 15, 30, 45, 60, 90, and 120th min were entered into a Microsoft Excel spreadsheet. A scatter diagram was used to plot the recorded results, and the incremental area under the curve (IAUC) was calculated using the trapezoidal rule [7, 34]. To compute the GI, IAUC for test food was divided by IAUC for reference food multiplied by 100 for each individual. The mean of all individuals was the GI of the food [7, 33, 34].

Proximate analysis was carried out in triplicate, and the values were expressed on dry weight basis. The results were reported as means and standard deviation in MS Excel. The statistical difference was determined using Duncan multiple tests at a 95% confidence level using GenStat 14th Edition. P value of less than 0.05 was considered significant.

3. Results

3.1. Proximate Composition of the Test Food. Proximate analysis was determined for all the stiff porridge samples. The aim was to establish the amount of available carbohydrates in the samples, which determined the serving size given to participants. Finger millet ugali had the highest MC compared to other stiff porridges (Table 1).

The carbohydrate content was significantly higher in maize stiff porridge as opposed to that prepared from millet or sorghum (P<0.05). In terms of fiber, the order was millet ugali > sorghum ugali > maize ugali. Protein content was highest in sorghum, followed by maize, and the least was found in millet-based ugali. Fat content was highest in maize, followed by finger millet then sorghum. These results are shown in Table 1.

3.2. Characteristics of GI Participants. Fifteen volunteers were recruited, and they all signed an informed consent form before beginning the study. Upon screening, 10 subjects met the inclusion criteria.

The participants were aged 20–29 years, and the mean age was about 23 years. The BMI ranged from 19.8 to 24.5 kg/m², and the mean was 23.1 kg/m². Blood sugar ranged from 3.5 to 5.4 mmol/L, while systolic and diastolic blood

<table>
<thead>
<tr>
<th>Ugali types</th>
<th>MC (%)</th>
<th>Fat (%)</th>
<th>Protein (%)</th>
<th>Ash (%)</th>
<th>Fiber (%)</th>
<th>Available CHO (%)</th>
<th>Energy (kcal/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole maize</td>
<td>63 ± 0.3a</td>
<td>5.9 ± 1.7a</td>
<td>6.6 ± 0.2b</td>
<td>1.9 ± 0.2b</td>
<td>4.1 ± 1.1b</td>
<td>81.6 ± 0.8b</td>
<td>421.9 ± 9b</td>
</tr>
<tr>
<td>Finger millet</td>
<td>67 ± 0.3b</td>
<td>5.2 ± 0.4a</td>
<td>4.9 ± 0.1a</td>
<td>3.7 ± 0.5c</td>
<td>10.5 ± 3.1b</td>
<td>75.7 ± 2.3a</td>
<td>404 ± 10.6a</td>
</tr>
<tr>
<td>Sorghum</td>
<td>65 ± 0.6b</td>
<td>4.6 ± 1.1a</td>
<td>10.2 ± 0.1c</td>
<td>0.2 ± 0.1a</td>
<td>8 ± 2.5b</td>
<td>76.9 ± 1.9a</td>
<td>422.4 ± 5.3b</td>
</tr>
</tbody>
</table>

Note: MC: moisture content presented in as-is-bases. Values are means of three trials ± SD. CHO: carbohydrates. Fat, protein, ash, fiber, and CHO were presented in dry weight basis. Superscripts in each column represent the significant differences among the stiff porridges at 95% confidence level.

(AOAC method 978.10). The percentage of crude fiber content was calculated by subtracting the weight of the sample after ashing from the weight of the sample before ashing, and the result was divided by the weight of the sample and then multiplied by 100. The total carbohydrate content (%) was calculated by difference [100–(fat + protein + ash + MC)]. The available carbohydrate was determined by subtracting crude fiber from total carbohydrates.

**Table 1: Proximate composition of stiff porridges (%).**
pressure ranged from 90 to 120 and 60 to 80 mmHg, respectively. These results are shown in Table 2.

3.3. Portion Sizes Served to Participants. The portion sizes served to participants provided 50 g of available carbohydrate and was expressed as follows:

For consumption of plain stiff porridges

Test food (g) = \( \frac{50 \times 100}{\text{available CHO (g) in wet weight basis}} \)

For instance:
Plain whole maize ugali \( 50 \times 100/30.2 = 166 \) g

For consumption of stiff porridge alongside fermented milk

Test food (g) = \( (50 - 4.5) \times 100/\text{available CHO (g) in wet weight basis} \)

For instance:
Whole maize ugali alongside mala \( 45.5 \times 100/30.2 = 151 \) g

Based on the nutritional information provided by the manufacturer (Kenya Corporate Creameries) on the fermented milk package, 100 g of mala contained 4.5 g of carbohydrates. This was factored in the calculation of samples consumed alongside fermented milk by subtracting 4.5 from 50 g. A weighing scale (model UA2204N, UMS Ltd., UK) was used to measure the portion sizes provided to the participants for consumption. The portion sizes were served to the participants using disposable white plastic plates and cups purchased from a local supermarket in Meru County. The stiff porridges were consumed alongside 100 mL of fermented milk (mala).

Consequently, the serving sizes were 166, 198, and 187 g for maize, millet, and sorghum, respectively. When consumed alongside fermented milk, the portion sizes were adjusted to take into account the amount of carbohydrates in the milk. Fermented milk lowered the GI of sorghum from 72 (high) to 57 (medium) while raising the blood sugar response for maize and millet ugali from 67 (medium) and 46 (low) to 79 (high) and 67 (medium), respectively, as shown in Table 4.

3.4. Blood Sugar Response Curves and GI Values of Stiff Porridges. The postprandial blood sugar results showed glucose and sorghum produced the highest peak response at the 45th min.

Plain millet and whole maize ugali had their highest peak at the 30th min. Stiff porridge is usually consumed alongside a side dish such as fermented milk. Fermented milk increased the blood sugar response for maize and millet-based ugali but lowered the response for sorghum ugali. These results are shown in Figure 1.

From the blood sugar response curves, the IAUC was computed, and the GI was calculated. For the plain stiff porridge consumed without an accompaniment, the order was sorghum (72) > maize (67) > millet (46). These results are shown in Table 4. When consumed alongside fermented milk, the portion sizes were adjusted to take into account the amount of carbohydrates in the milk. Fermented milk lowered the GI of sorghum from 72 (high) to 57 (medium) while raising the blood sugar response for maize and millet ugali from 67 (medium) and 46 (low) to 79 (high) and 67 (medium), respectively, as shown in Table 4.

4. Discussion

4.1. Proximate Composition of the Food Samples. Finger millet ugali had the highest MC compared to other stiff porridges. This may be due to high water absorption [35] and water binding capacity (256.9) [36] when compared to maize, whose water binding capacity was 64.5 [37]. Maize ugali presented the highest carbohydrate content (81.6%), whereas millet ugali had the least content (75.7%). Similar values of carbohydrate content were recorded in a study conducted in Côte d’Ivoire on maize ugali, which contained 81.2% [38].

![Table 2: Characteristics of the study participants.](image)

<table>
<thead>
<tr>
<th>Characteristics of the participants</th>
<th>Means ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.4 ± 2</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>23.1 ± 1.4</td>
</tr>
<tr>
<td>Fasting blood glucose (mmol/L)</td>
<td>4.72 ± 0.56</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>107.5 ± 12</td>
</tr>
<tr>
<td>Diastolic blood pressure (mmHg)</td>
<td>71.1 ± 8.5</td>
</tr>
</tbody>
</table>

![Table 3: Food samples containing 50 g of available carbohydrates.](image)

<table>
<thead>
<tr>
<th>Food sample</th>
<th>Ration size per participant (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain whole maize ugali</td>
<td>166</td>
</tr>
<tr>
<td>Plain millet ugali</td>
<td>198</td>
</tr>
<tr>
<td>Plain sorghum ugali</td>
<td>187</td>
</tr>
<tr>
<td>Whole maize ugali + mala</td>
<td>151 + 100</td>
</tr>
<tr>
<td>Millet + mala</td>
<td>180 + 100</td>
</tr>
<tr>
<td>Sorghum + mala</td>
<td>170 + 100</td>
</tr>
</tbody>
</table>

![Figure 1: Blood sugar responses after consumption of glucose and test foods.](image)
The high-fat content in maize ugali could be attributed to the size of the germ and the fact that fat is also present in the pericarp and aleurone layer [39]. The protein content of sorghum was high, indicating it is a good source of proteins [40, 41]. Millet ugali had the highest ash and fiber content, 3.7% and 10.5%, respectively. Millet contains more fiber compared to other cereals [42] although the fiber content was lower than that presented by Shobana and Malleshi [43]. This difference could be attributed to possible differences in varieties.

4.2. GI Values of the Test Foods. The GI of plain maize stiff porridge was similar to the observations made by Ebere et al. [12], which was 62. When compared to the GI of maize stiff porridge from Ivory Coast 74 [38], it was lower. This might be due to different cooking/processing methods [44–46] or maize varieties [47, 48] that have been shown to influence the GI.

Plain millet stiff porridge had a low GI. This result is within the GI range for millet (45–104) [49]. The results of this study also agree with a recent study that established that millet-based foods had a low GI [50]. The low GI could be attributed to the fat present, which has been shown to delay the rate of digestion [51]. Millet is also high in resistant starch [52], which has been reported to be inversely associated with blood sugar response [53]. In addition, millet ugali was high in fiber, which also lowers the GI since it inhibits amylase activity, delays starch hydrolysis, and reduces glucose absorption [54]. This study supports the findings of a recent review that recommended the use of millet meals for the prevention and management of diabetes mellitus [55].

The high GI of plain sorghum ugali may be due to the ratio of the vitreous and floury endosperm. The floury endosperm has an increased rate of digestion compared to a vitreous endosperm [56]. Additionally, the protein present in sorghum is not bioavailable [40], and as a result, it may not produce the effect of delaying the digestion of the stiff porridge. This supports the high GI (>70) findings reported in Botswana for sorghum-based foods [57]. Contrary to these findings, a separate study has reported low to medium GI for some sorghum products [58]. The differences in GI values could be attributed to the genotype [58] as well as methods of processing [45, 46].

The GI of whole maize and millet ugali increased upon consumption with mala. However, sorghum consumed alongside mala had a reduced glycemic response. The starch digestibility of millet in the presence of organic acids increases and consequently influences the GI [52, 59]. This could explain the increased GI of millet ugali. The starch digestibility of maize flour has been shown to increase in the presence of lactic acid bacterium which is a probiotic found in fermented dairy products [60]. This might explain the increase in the GI of maize ugali when consumed alongside fermented milk. It is not clear why fermented milk lowered the GI of sorghum ugali as opposed to that of maize and millet.

The effect of dairy on the GI of foods seems to be inconsistent. Although milk has been shown to reduce the GI of other foods, such as bread [61, 62] and sorghum ugali in this study, this might not apply to all foods. This study, therefore, supports the earlier recommendation that the determination of GI should be specific to the product [29]. In addition, the effect of milk on GI seems to depend on the dairy product as well as the type of probiotic culture used [27].

5. Conclusion

Plain millet stiff porridge possesses low GI, whereas when consumed alongside fermented milk, it elicits a medium GI. Millet stiff porridge can, therefore, be recommended in the prevention and management of T2DM. Consumption of mala alongside stiff porridge increases the GI of maize and milled stiff porridge but lowers the GI of sorghum ugali.

Future studies should focus on the impact of various accompaniments of the GI of the stiff porridges prepared from different cereal grains.

Data Availability

Data supporting the findings of this study are available from the corresponding author upon request.

Ethical Approval

The study was approved by Meru University of Science and Technology Institutional Research Ethics Review Committee reference number MU/1/39/28(01).

Consent

Participation was voluntary, and all participants signed an informed consent form.

Disclosure

The participants’ information was stored with access only provided to the research team. A preprint has previously been published as part of the proceedings of the Inaugural MUSTIC 2022 [63].

Conflicts of Interest

The authors declare that there are no conflicts of interest.
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