Abstract

A diet with low glycemic index (GI) has a preventive potential against the development of type 2 diabetes and cardiovascular disease. Moreover, low GI foods reduce hunger and result in a lower energy intake which finally leads to positive weight management. We investigate the GI of cereals containing amaranth, measured the postprandial subjective satiety and analyzed the glucose release in a gastrointestinal in vitro digestion model. In a study with 20 non-diabetic healthy volunteers it was shown that the amaranth cereal has an adjusted GI value of 45.9 and was significantly lower than that of standard cereal (74.1) and popped amaranth (105.2). Amaranth cereal can be classified as a food with a low GI while the standard cereal and popped amaranth can be classified as high GI foods. Measured satiety scores confirm the course of the postprandial blood glucose concentration. The highest in vitro glucose release after 120 min was measured in the popped amaranth sample (51.59 mg glucose/100 g sample), followed by standard cereal (43.26 mg glucose/100 g sample), and amaranth cereal (36.91 mg glucose/100 g sample). The difference concerning glycemic as well as satiating effects between sheer popped amaranth and cereal with popped amaranth may be caused by the influence of the food composition. Substituting popped rice flour and cornflakes with popped amaranth and amaranth flakes are suggested to lower the GI of standard cereals.

ABBREVIATIONS

AC: Amaranth Cereal; GI: Glycemic Index; GI_ad: Adjusted Glycemic Index; IAUC: Incremental Area Under Curve; PA: Popped Amaranth; PFC: Prospective Food Consumption; SC: Standard Cereal; VAS: Visual Analogue Scale; WB: White Bread

INTRODUCTION

The glycemic index (GI) is a parameter of food quality which compares the hyperglycemic effect of a tested food with glucose or another defined standard food (e.g. white bread) and represents the raise in blood glucose concentration following the consumption of the tested foods [1]. It is defined as the incremental area under the blood glucose curve (IAUC) after consumption of the carbohydrate portion of a test food expressed as a percentage of the average IAUC response to the same amount of carbohydrate from a reference food taken by the same subject on a separate occasion. Carbohydrates degraded quickly during digestion have a high GI because their blood glucose response is fast and high, while complex carbohydrates show a low GI due to their delayed and/or limited digestion. A GI value is considered as high > 70, medium (55 < GI ≥ 69) or low (≤ 55), whereas glucose respectively white bread is equal to 100 [2].

The GI of a food cannot be predicted by carbohydrate content alone, but is a function of the type of carbohydrate, the fiber content, other food components (e.g. fat, protein), the proportion and type of sugars and starch, the starch structure, the particle size and the method of preparation [3-5]. Further, the digestion rate and the gastric emptying rate are directly related to glycemic and insulin responses [6]. Moreover, the digestion rate is affected by physical and chemical characteristics of the food [7].

For healthy eating, particularly in persons with diabetes, obesity, and insulin resistance, foods with low GI are recommended as they may help keep the euglycemia and the normal spectrum of lipoproteins [8]. Indeed, recent data support the preventive potential of a low GI diet against the development of type 2 diabetes and cardiovascular disease [9]. Moreover, several studies have shown that low GI foods, or lowering the GI of a food, reduce hunger and result in a lower energy intake which finally leads to positive weight management [4,10].

Breakfast cereals are consumed in many countries and...
therefore provide the opportunity to lower the GI of the diet and hence increase satiety. Berti and colleagues [11] have already investigated the effect of oat, quinoa, rice, wheat, and buckwheat as alternative crop. In Germany the use of amaranth in cereals and bread is increasing and becomes of interest for lowering the GI of foods. Amaranth (Amaranthus spp.) has been consumed throughout history, including by the Inca, Maya and Aztec civilizations, where it has been used as a staple food. Amaranth has high soluble fiber content and protein concentrations between 12.5% and 18.9%. The lipid content shows great variations, ranging between 1.9% and 9.7% depending on the species and the genotype. Amaranth is also of nutritional interest due to its contents in vitamins and minerals, such as riboflavin, niacin, ascorbic acid, calcium, and magnesium. For the use in food stuffs amaranth grains are processed in various ways, of which the expanded respectively popped grain form is probably the most popular [12].

The purpose of the present study was to determine the GI of cereals containing amaranth and describe the postprandial glucose metabolism. Additionally, postprandial subjective satiety was measured and the glucose release in a gastrointestinal in vitro digestion model was analyzed to compare the subjective satiety respectively the in vitro glucose release with the GI.

MATERIALS AND METHODS

Subjects

Twenty healthy, non-smoking, non-diabetic men and women (body mass index 22.7 ± 2.8 kg/m²; age 28.7 ± 8.8 years old) were enrolled in the study (baseline characteristics are shown in Table 1). The inclusion criteria for participation were an age between 18 and 50 years and a body mass index (BMI) between 18 and 25 kg/m². Exclusion criteria were gastrointestinal disorders, suffering from diabetes, taking medications for any chronic disease conditions, being pregnant, breastfeeding, or having intolerances or allergies to any of the foods tested. The study was approved by the freiburger ethik-komission international (protocol number 012/1406), and conducted to the provisions of the Declaration of Helsinki (2008), and informed consent was obtained from each subject.

Study design and procedures

To determine the GI of the four test foods, a randomized, crossover trial was conducted at the Institute of Food Sciences and Human Nutrition at Leibniz University of Hannover. The four visits at day 0, 7, 14, and 21 were separated by 7 days wash-out phases. The method used for measuring the GI of the test foods was in accordance with ISO 26642, Food Products – Determination of the glycemic index (GI) and recommendation for food classification [13]. Prior to each visit, subjects were instructed to maintain a 12 h overnight fast after consuming a delivered standard dinner (instant pasta dish) [7]. Additionally, subjects were instructed to avoid alcohol or excessive exercise during the previous day. Appropriate subjects were randomly assigned to one of four groups. Randomization was conducted according to gender and age. At each visit anthropometric parameters were measured and blood samples were taken. After the first draw of fasting blood, subjects received the test foods in a randomized order and were instructed to consume the test foods within 5 min, together with 250 ml of water. Subsequent blood sample were taken 15, 30, 45, 60, 90, and 120 min after consumption of the test foods. Additionally, subjects fulfilled the visual analogue scale (VAS) questionnaire at 15, 30, 45, 60, 90, 120, 180, and 240 min to assess the satiety.

Test foods

Three different cereals were investigated in the study (nutritional compositions are shown in Table 2). The cereals were a standard cereal (SC), a cereal with added amaranth (AC), and pure popped amaranth (PA) without further compounds. SC and AC had the same ingredients except that SC contains 20% popped rice flour and 1.5% corn flakes while AC contains 20% popped amaranth and 1.5% amaranth flakes. White bread (WB) was used as reference food because hereby all test foods had to be chewed in order to ensure the comparability. For PA portion size providing the foreseen amounts of 50 g available carbohydrates was found to be too voluminous for subjects to consume comfortably within 5 min. Therefore, all portion sizes were calculated to provide 30 g available carbohydrates.

Anthropometric measurements and blood analyses

Subjects were examined by trained professionals according to standardized methods at the Institute of Food Science and Human Nutrition of Leibniz University Hannover, Germany. Body weight was measured using a calibrated scale, body height was surveyed via tape measure and Body Mass Index (BMI) was calculated as weight (kg)/height (m²). The blood samples were prepared and analyzed by the Hannover Medical Care Center of the LADR network. The blood glucose concentration was measured in 2.4 ml of venous sodium fluoride whole blood. The insulin concentration was measured in 2.7 ml of serum. After each draw, the blood samples were immediately cooled to 4-6 °C in order to prevent breakdown of the blood glucose in the monovette.

Satiety score (VAS)

Visual analogue scale questionnaire was based on five lines of 15 cm in length with words anchored at each end, reporting the most positive and the most negative rating of each question as described elsewhere [14]. The lines measured desire to eat, hunger, satiety, and prospective food consumption (PFC). Quantification was done by measuring the distance from the left end of the line to the mark.

### Table 1: Characteristics of subjects (n=20).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean ± SD</th>
<th>Min – Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age [years]</td>
<td>28.7 ± 8.8</td>
<td>19 – 49</td>
</tr>
<tr>
<td>Weight [kg]</td>
<td>69.6 ± 10.8</td>
<td>52.3 – 96.1</td>
</tr>
<tr>
<td>Height [m]</td>
<td>1.75 ± 0.09</td>
<td>1.59 – 1.90</td>
</tr>
<tr>
<td>BMI [kg/m²]</td>
<td>22.7 ± 2.8</td>
<td>19.8 – 28.4</td>
</tr>
<tr>
<td>Glucose [mmol/l]</td>
<td>4.5 ± 0.4</td>
<td>3.9 – 5.3</td>
</tr>
<tr>
<td>Insulin [pmol/l]</td>
<td>49.5 ± 16.0</td>
<td>27.1 – 96.4</td>
</tr>
</tbody>
</table>

Abbreviations: SD: Standard deviation; Min: Minimum; Max: Maximum; BMI Body Mass Index.
Post hoc test (Bonferroni). The statistically significance was tested. Multiple comparisons were performed by ANOVA and subject:

The area below the baseline. To calculate the IAUC, the raw data were calculated geometrically using the trapezoid rule, ignoring zero-value corrected. The GI of each test food was calculated as well as satiety values at the various time points, the raw data were used and were determined for each subject as well as for the four test foods. To calculate glucose and insulin concentrations as well as satiety values from PA and WB. The GI of the four test foods was statistically significant different (p=0.002), whereby GI of PA was significantly higher (Post hoc test p<0.001) than AC. The mean (± SD) postprandial glycemic response following consumption of the test foods expressed as maximal glucose concentration (c max) was 1.8 ± 0.6 mmol/l for SC, 1.8 ± 0.5 mmol/l for AC, 2.7 ± 0.1 mmol/l for PA, and 1.9 ± 0.1 mmol/l for WB. Maximal blood glucose concentration were statistically significant (p<0.0001) between the four test foods, where c max glucose was significant higher (Post hoc test p<0.05) in the PA group than in the other groups. The mean (± SD) time to reach the maximal glucose concentration (t max) was 33.8 ± 8.3 min for SC, 32.3 ± 7.3 min for AC, 36.8 ± 10.3 min for PA, and 39.8 ± 10.1 min for WB. The difference of t max glucose concentration between the treatment groups had a clear tendency to significance (p=0.052). Blood glucose curves after test food consumption showed similar courses (Figure 1). The maximal insulin concentration and the time to reach c max insulin were not significantly different between the four test foods. No abnormal findings were found in the subjects’ insulin homeostasis, which confirms that subjects were healthy.

In vitro digestion of test foods

For each sample 200 g test food (SC, AC, PA, and WB) was finely crushed in a kitchen shredder (Moulinette, Krups, Offenbach/Main, Germany) and mixed. 100 mg sample was solved in 25 ml phosphate buffer (pH 6.9) and homogenized with an Ultraturrax® (IKA®, Staufen, Germany) for 30 s. Subsequently, 10U invertase (Sigma-Aldrich, Seelze, Germany), 25U pancreatin (Merck, Darmstadt, Germany) and 40U amyloglucosidase (Sigma-Aldrich, Seelze, Germany) were added. Samples were gently shaken and put in a water bath at 37°C. At each time point after 0, 15, 30, 60, and 120 min prior incubation 1 ml was taken from the samples and transferred into a preheated tube. To break enzymatic reaction samples were incubated for 5 min at 99°C and 750 rpm in a theromixer (Eppendorf, Hamburg, Germany). Samples were stored in a fridge (4–6°C) until spectrometric measurement. Directly before spectrometric measurement 4 ml deionized water was added to each sample and centrifuged for 5 min at 2000 rpm. Glucose concentrations were measured using a D-Glucose test-kit (R-Biopharm, Darmstadt, Germany) according to the manufactures protocol and a spectral photometer (Specord 205, Analytik Jena, Jena, Germany). Experiments were repeated sixfold for SC and AC and fourfold for PA and WB because of the homogeneity of the samples from PA and WB.

Table 2: Nutritional composition of the four test foods (SC: Standard Cereal; AC: Amaranth Cereal; PA: Popped Amaranth; WB: White Bread).

<table>
<thead>
<tr>
<th>Nutritional values</th>
<th>SC</th>
<th>AC</th>
<th>PA</th>
<th>WB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>per 100g</td>
<td>per 47 g</td>
<td>per 100g</td>
<td>per 52 g</td>
</tr>
<tr>
<td>Energy [kcal]</td>
<td>384</td>
<td>181</td>
<td>390</td>
<td>203</td>
</tr>
<tr>
<td>Carbohydrates [g]</td>
<td>64.4</td>
<td>30.3</td>
<td>58.1</td>
<td>30.2</td>
</tr>
<tr>
<td>Sugars [g]</td>
<td>4.7</td>
<td>2.2</td>
<td>7.1</td>
<td>3.7</td>
</tr>
<tr>
<td>Protein [g]</td>
<td>11.4</td>
<td>5.4</td>
<td>13.4</td>
<td>7.0</td>
</tr>
<tr>
<td>Fat [g]</td>
<td>7.2</td>
<td>3.4</td>
<td>9.0</td>
<td>4.7</td>
</tr>
<tr>
<td>Total fiber [g]</td>
<td>8.1</td>
<td>3.8</td>
<td>10.9</td>
<td>5.7</td>
</tr>
</tbody>
</table>

**RESULTS**

Subjects

20 healthy males and females (men: n=10, women: n=10) participated in the study (Table 1). Their mean age was 28.7 ± 8.8 years and mean BMI was 22.7 ± 2.8 kg/m². Parameters indicating impaired glucose tolerance (fasting glucose, fasting insulin) were within the reference range for all subjects and did not provide any signs of physiological impairment. Due to the crossover study design, baseline levels were not significantly different between the treatment groups. One male subject was excluded from the analysis of the satiety questionnaire because the subject was not-compliant while completing the visual analogue scale (VAS) to assess satiety. Hence, the data of 20 subjects were included in the glucose metabolism and GI evaluation and data of 19 subjects were included in the satiety evaluation.

GI and glucose metabolism

The calculated mean (± SD) GI value for SC was 104.4 ± 50.3, for AC 64.6 ± 65.8, and for PA 148.2 ± 88.2, with GI =100 for WB. The adjusted GI ad value for SC was 74.1, for AC 45.9, and for PA 105.2, with adjusted GI ad =71 for WB (Table 3). GI of the four test foods were statistically significant different (p=0.002), whereby GI of PA was significantly higher (Post hoc test p=0.001) than AC. The mean (± SD) postprandial glycemic response following consumption of the test foods expressed as maximal glucose concentration (c max) was 1.8 ± 0.6 mmol/l for SC, 1.8 ± 0.5 mmol/l for AC, 2.7 ± 0.1 mmol/l for PA, and 1.9 ± 0.1 mmol/l for WB. Maximal blood glucose concentration were statistically significant (p<0.0001) between the four test foods, where c max glucose was significant higher (Post hoc test p<0.05) in the PA group than in the other groups. The mean (± SD) time to reach the maximal glucose concentration (t max) was 33.8 ± 8.3 min for SC, 32.3 ± 7.3 min for AC, 36.8 ± 10.3 min for PA, and 39.8 ± 10.1 min for WB. The difference of t max glucose concentration between the treatment groups had a clear tendency to significance (p=0.052). Blood glucose curves after test food consumption showed similar courses (Figure 1). The maximal insulin concentration and the time to reach c max insulin were not significantly different between the four test foods. No abnormal findings were found in the subjects’ insulin homeostasis, which confirms that subjects were healthy.

**Nutritional values per 100g per portion**

| Carbohydrates | 64.4 | 30.3 | 58.1 | 30.2 | 56.8 | 30.1 | 44.8 | 30.0 |
| Sugars | 4.7 | 2.2 | 7.1 | 3.7 | 1.5 | 0.8 | 3.9 | 2.6 |
| Protein | 11.4 | 5.4 | 13.4 | 7.0 | 15.8 | 8.4 | 8.5 | 5.7 |
| Fat | 7.2 | 3.4 | 9.0 | 4.7 | 8.8 | 4.7 | 3.7 | 2.5 |
| Total fiber | 8.1 | 3.8 | 10.9 | 5.7 | 15.7 | 8.3 | 3.5 | 2.4 |

**GI in brackets**

GI = [IAUC test food/IAUC reference food] x 100.

Final GI values were expressed relative to glucose (adjusted GI: GI ad) because white bread instead of glucose was used as reference food. The GI of white bread, relative to glucose, is 71.

Normality of variables was tested by Kolmogorov-Smirnov test. Multiple comparisons were performed by ANOVA and Post hoc test (Bonferroni). The statistically significance was considered as probability less than 5% (p<0.05). Analysis was carried out using SPSS 21 software (SPSS Inc., Chicago, IL, USA).
Table 3: GI and postprandial glucose and insulin concentrations during 2 h after test food consumption (n=20).

<table>
<thead>
<tr>
<th>Variables</th>
<th>SC</th>
<th>AC</th>
<th>PA</th>
<th>WB</th>
<th>p'</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>104.4 ± 50.3</td>
<td>64.6 ± 65.8</td>
<td>148.2 ± 88.2#</td>
<td>100 ± 0</td>
<td>0.002</td>
</tr>
<tr>
<td>GIad</td>
<td>74.1 ± 35.7</td>
<td>45.9 ± 46.7</td>
<td>105.2 ± 62.6#</td>
<td>71 ± 0</td>
<td>0.002</td>
</tr>
<tr>
<td>Glucose ∆ t0 [mmol/l]</td>
<td>1.8 ± 0.6</td>
<td>1.8 ± 0.5</td>
<td>2.7 ± 0.1#†‡</td>
<td>1.9 ± 0.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Tmax Glucose [min]</td>
<td>33.8 ± 8.3</td>
<td>32.3 ± 7.3</td>
<td>36.8 ± 10.3</td>
<td>39.8 ± 10.1</td>
<td>0.052</td>
</tr>
<tr>
<td>Insulin ∆ t0 [pmol/l]</td>
<td>195.9 ± 97.9</td>
<td>210.4 ± 86.8</td>
<td>258.4 ± 127.1</td>
<td>241 ± 150</td>
<td>0.334</td>
</tr>
<tr>
<td>Tmax Insulin [min]</td>
<td>28.2 ± 14.1</td>
<td>30.3 ± 12.5</td>
<td>37.2 ± 18.3</td>
<td>42.8 ± 12.2</td>
<td>0.560</td>
</tr>
</tbody>
</table>

Abbreviations: GI glycemic index, ∆ t0 difference to baseline, SC: Standard Cereal, AC: Amaranth Cereal, PA: Popped Amaranth, WB: White Bread; [*] ANOVA followed by Bonferroni post hoc analysis, [#] p<0.05 compared to AC, [†] p<0.05 compared to SC, [‡] p<0.05 compared to WB; c<sub>max</sub> adjusted to zero-values.

Figure 1 Postprandial blood glucose concentration 2 h after test food consumption (n=20); adjusted to zero-value (SC: Standard Cereal; AC: Amaranth Cereal; PA: Popped Amaranth; WB: White Bread).

Table 4: Postprandial satiety scores during 2 h and 4 h after test food consumption (n=19).

<table>
<thead>
<tr>
<th>Satiety variables</th>
<th>SC</th>
<th>AC</th>
<th>PA</th>
<th>WB</th>
<th>p'</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAUC desire to eat [mm*h]</td>
<td>2 h</td>
<td>1043 ± 1513#‡</td>
<td>2936 ± 2502</td>
<td>3760 ± 3093</td>
<td>3310 ± 2104</td>
</tr>
<tr>
<td></td>
<td>4 h</td>
<td>4626 ± 3234#‡</td>
<td>10790 ± 4952</td>
<td>12458 ± 6003</td>
<td>12073 ± 1344</td>
</tr>
<tr>
<td>IAUC hunger [mm*h]</td>
<td>2 h</td>
<td>1155 ± 1626#†‡</td>
<td>11 ± 28#†‡</td>
<td>3111 ± 2890</td>
<td>3390 ± 1990</td>
</tr>
<tr>
<td></td>
<td>4 h</td>
<td>4779 ± 3496#†‡</td>
<td>234 ± 380#†‡</td>
<td>10907 ± 5586</td>
<td>12147 ± 4225</td>
</tr>
<tr>
<td>IAUC satiety [mm*h]</td>
<td>2 h</td>
<td>3577 ± 2730#†‡</td>
<td>6161 ± 2704#†‡</td>
<td>420 ± 376</td>
<td>236 ± 215</td>
</tr>
<tr>
<td></td>
<td>4 h</td>
<td>4649 ± 3322#†‡</td>
<td>8384 ± 4237#†‡</td>
<td>420 ± 377</td>
<td>236 ± 215</td>
</tr>
<tr>
<td>IAUC PFC [mm*h]</td>
<td>2 h</td>
<td>485 ± 726</td>
<td>1888 ± 1907#†</td>
<td>2694 ± 1925#†</td>
<td>1154 ± 1355</td>
</tr>
<tr>
<td></td>
<td>4 h</td>
<td>2285 ± 1938</td>
<td>7484 ± 3902#†</td>
<td>9502 ± 4005#†</td>
<td>5431 ± 3360</td>
</tr>
</tbody>
</table>

Abbreviations: SC: Standard Cereal; AC: Amaranth Cereal; PA: Popped Amaranth; WB: White Bread; [*] ANOVA followed by Bonferroni post hoc analysis, [#] p<0.05 compared to PA; [†] p<0.05 compared to SC; [‡] p<0.05 compared to WB; adjusted to zero-values.

Satiety score (VAS)

Concerning the satiety assessment (Table 4), significant differences (p<0.05) between the treatment groups were found in all satiety variables (desire to eat, hunger, satiety, prospective food consumption). In general, the mean average hunger IAUC and satiety IAUC showed that AC led to the greatest feelings of satiety and the slightest feelings of hunger (IAUC satiety 6161 ± 2704 mm*h, IAUC hunger 11 ± 28 mm*h) over the 120 min post-ingestion period, followed by SC, PA, and WB. Hunger and Satiety were in the AC group as well as in the SC group significantly different (Post hoc test p<0.05) to every other treatment group. The minor desire to eat over the 120 min post-ingestion period were found in the SC group, followed by AC, WB, and PA. The minor prospective food consumption was determined in the SC group followed by WB, AC, and PA. Graphic presentation of postprandial hunger and satiety score showed that feelings of satiety persists about 60-90 min and from that moment graphs approaches baseline (Figures 2A and 2B). In either case WB
produced slightest satiety which persists only short term. The order of the other test foods order is not obvious, but each test food had a longer lasting satiating effect than WB. Findings from satiety scores over the 240 min post-ingestion period correspond to those over the 120 min post-ingestion period.

In vitro digestion of test foods

The highest glucose release after 120 min was measured in the PA sample (51.59 mg glucose/100 g sample), followed by SC (43.26 mg glucose/100 g sample), and with comparable releases AC (36.91 mg glucose/100 g sample) and WB (35.39 mg glucose/100 g sample) (Table 5). Glucose release were significantly different (p<0.0001) between the test foods at all time points. Glucose release was more than twice as high in PA sample (13.09 mg glucose /100 mg sample) compared to the other test foods already at the beginning (0 min).

DISCUSSION

With regard to the potential of low GI diets concerning the prevention of diabetes mellitus and coronary heart disease consumption of low GI foods is preferable [15]. In subjects with type 2 diabetes it was possible to improve metabolic control by exchanging the conventional high GI breakfast for a low GI meal [16]. There is also evidence from studies in healthy subjects that in particular a low GI breakfast meal may have beneficial metabolic effects beyond the postprandial phase [17]. Thus, dietary food composition may influence postprandial glucose homeostasis and satiety and therefore may affect long change in weight [18]. The present study examined GI values of cereals containing amaranth, and additionally, determined the effects on subjective satiety and analyzed the glucose release in a gastrointestinal in vitro digestion model. The aim was to demonstrate that cereals containing amaranth have lower GI values than standard cereals.

The adjusted GI value for AC (45.9) was notably lower than that of the other test foods (SC=74.1, PA=105.2). Thus, AC can be classified as a food with a low GI (GI value <55) while SC and PA can be classified as high GI foods (GI value > 70). These findings are in accordance with measured GI values for standard cereals ranging from 55 to 60 while GI for white bread varies from 70 to 75 [19-21].The digestion of starch-containing foods and the absorption of glucose are subjects to various influencing factors. The notably wide range of standard deviations of GI values for individual foods corresponds to the experience of others and illustrates the inter individual glycemic variability [22-24].

Furthermore, comparing the GI values of the test foods it is obvious, that the measured GI value of PA is more than twice as high as that of AC, and even GI of SC is distinctly higher than that of AC. Hence, substituting popped rice flour and cornflakes in the SC with popped amaranth and amaranth flakes (AC) had lowered the GI of AC compared to SC. Besides, the GI value of PA (105.2) is nearly 50 units higher than that of the reference food (WB). Findings from Guerra-Matias and Aréas [25] showed a mean GI value for extruded amaranth that was similar to that of white bread and therefore, contrasts our findings.

![Figure 2](https://example.com/figure2.png)

**Figure 2** Postprandial A) hunger and B) satiety scores during 2 h after test food consumption (n=19); adjusted to zero-value (SC Standard cereal, AC Amaranth cereal, PA Popped Amaranth, WB White bread).

<table>
<thead>
<tr>
<th>Time [min]</th>
<th>SC</th>
<th>AC</th>
<th>PA</th>
<th>WB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.40 ± 1.15</td>
<td>6.51 ± 0.99</td>
<td>13.09 ± 0.49</td>
<td>5.33 ± 0.49</td>
</tr>
<tr>
<td>15</td>
<td>15.24 ± 1.44</td>
<td>13.81 ± 1.32</td>
<td>22.71 ± 1.41</td>
<td>14.61 ± 0.71</td>
</tr>
<tr>
<td>30</td>
<td>21.18 ± 2.11</td>
<td>18.54 ± 1.35</td>
<td>29.69 ± 1.22</td>
<td>20.39 ± 1.23</td>
</tr>
<tr>
<td>60</td>
<td>30.34 ± 2.54</td>
<td>25.40 ± 1.49</td>
<td>38.99 ± 2.10</td>
<td>26.72 ± 0.95</td>
</tr>
<tr>
<td>120</td>
<td>43.26 ± 2.44</td>
<td>36.91 ± 2.06</td>
<td>51.59 ± 0.28</td>
<td>35.39 ± 0.66</td>
</tr>
</tbody>
</table>

**Table 5:** In vitro glucose release (sum of free glucose, sucrose and complex carbohydrates) during 120min.

**Abbreviations:** SC: Standard Cereal; AC: Amaranth cereal; PA: Popped Amaranth; WB: White bread
Although content of carbohydrate in PA (56.8 g/100 g) is comparable to that of AC (58.1 g/100 g) and even to that of SC (64.4 g/100 g) GI value of PA was considerably higher than that of the other test foods (AC and SC). The GI of starch foods depends on the rate at which the food can be absorbed and transferred into the blood, and the extent to which the food can raise the concentration of blood glucose [26]. Likewise, the higher GI value of PA might due to the increased surface area compared to unprocessed amaranth [27]. Bigger surfaces facilitate starch break down enzymes (amylase) to get across the interface [28]. Furthermore, amaranth processing (popped or extruded amaranth) increases the content of digestible starch [29]. The higher GI value of PA might due to the increased surface area compared to unprocessed amaranth [27]. Bigger surfaces facilitate starch break down enzymes (amylase) to get across the interface [28]. Furthermore, amaranth processing (popped or extruded amaranth) increases the content of digestible starch [29]. This probably explains the higher glucose absorption as reflected by the maximal glucose concentration.

The significant higher $c_{\text{max}}$ glucose concentration in PA indicates a considerably larger glucose release than from the other test foods. This can be explained by the small starch granule size, reduced contents of resistant starch and soluble fibers in amaranth as well as in cooked, popped, and extruded amaranth seeds [29]. Besides, the clear trend to significant higher $t_{\text{max}}$ glucose in PA and WB indicates delayed glucose absorption compared to the other test foods. The larger volume of the total PA as well as WB sample in the stomach could have slowed the transit time from stomach to small intestine which prolongs the rate of carbohydrate absorption [30].

Additionally, even if the measured satiety scores (VAS) are inconsistent, VAS data mostly confirm the measured GI and course of the postprandial blood glucose concentration. IAUC hunger and IAUC satiety showed likewise data to glycemic parameters, while IAUC desire to eat and IAUC PFC were inconsistent to them. Glucostatic hypothesis of the regulation of food intake predicates that a high glucose concentration in blood produces satiety [31]. After the intake of highly digestible carbohydrates, hunger decreases rapidly and satisfaction increases in a short period of time. Moreover, when blood glucose concentration starts to decrease, hunger appears again and feeling of satisfaction decrease [32]. In our study, both contrary questions concerning hunger and satiety seem to be good assessable. On the other hand, questions about desire to eat and prospective food consumption might be influenced by subjective factors like conditioning regarding meal habits or frequency [33,34]. Furthermore, especially volume of the PA portion could lead to aversion to this test food and increase satiety [23]. Subjects stated unpleasant taste right up to lightly feeling of sickness concerning the PA. Unsatisfying taste could increase desire to pleasant taste adventure and therefore could influence subjective satiety parameters [35].

Moreover, the nutritional composition can influence satiety as well. Lower energy foods that are rich in fiber are associated with prolonged satiety and lowered postprandial glycaemia [36,37,39]. Based on the fiber content of the test foods it would be expected that PA (15.7 g fiber/100 g) had the most satiating effect and leads to the lowest GI compared with AC (10.9 g fiber/100 g), SC (8.1 g fiber/100 g), and WB (3.5 g fiber/100 g). Nevertheless, our data concerning satiety and GI are not correlated to the fiber content of the test foods. Several clinical trials found heterogeneous data as well [29]. Even macronutrients such as fat and protein may influence the GI as well as the satiety. But, this effect appears only when large amounts of fat or protein are consumed [40], whereas our test foods are rich in carbohydrates.

In vitro digestion of test foods showed a glucose release from PA sample which was more than twice as high as in the other test foods already at the beginning (0 min), which is due to high content of free glucose in the sample. Even if the glucose release from SC and AC was similar, the GI value of SC ($G_{\text{ad}}=74.1$) was larger than that of AC ($G_{\text{ad}}=45.9$). This underlines that GI is not determined by glucose entry into blood but to glucose removal by tissue [41]. By comparing the glucose entry into blood (see Figure 1) with the in vitro glucose release (see Table 5) a relation could be determined. Nevertheless, in vitro glucose release does not allow conclusions about the GI. Our in vitro digestion data correspond to the results from comparable human intervention and in vitro studies [29,42,43].

CONCLUSION

In summary, this study shows that, among three cereals containing similar amounts of available carbohydrate, AC can be classified as a low GI food and led to the greatest subjective feelings of satiety, SC and PA can be classified as high GI foods and led to lower subjective satiety over a 120 min period after ingestion. Likewise, the correlation between a low GI and a prolonged satiety could be proved. Thus, our data from postprandial glucose metabolism and in vitro glucose release showed similar data. The big difference concerning glycemie effect as well as satiating effect between shee popped amaranth (PA) and cereal with popped amaranth (AC) shows the great influence of the composition of the food. Thus, even if PA is classified as a high GI food our data indicates that adding PA to other breakfast cereals may reduce GI. Cereals containing amaranth thus offer an alternative to standard cereals in order to lower GI in the diet and help prevent weight gain. Nevertheless, this result should be validated in a forthcoming controlled intervention study, which should determine the effect of a diet with cereals containing amaranth on weight loss compared to a standard diet.

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