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# Food processing methods influence the glycaemic indices of some commonly eaten West Indian carbohydrate-rich foods

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Glycaemic index (GI) values for fourteen commonly eaten carbohydrate-rich foods processed by various methods were determined using ten healthy subjects. The foods studied were round leaf yellow yam (*Dioscorea cayenensis*), negro and lucea yams (*Dioscorea rotundata*), white and sweet yams (*Dioscorea alata*), sweet potato (*Solanum tuberosum*), Irish potato (*Ipomoea batatas*), coco yam (*Xanthosoma* spp.), dasheen (*Colocasia esculenta*), pumpkin (*Cucurbita moschata*), breadfruit (*Artocarpus altilis*), green banana (*Musa sapientum*), and green and ripe plantain (*Musa paradisiaca*). The foods were processed by boiling, frying, baking and roasting where applicable. Pure glucose was used as the standard with a GI value of 100. The results revealed marked differences in GI among the different foods studied ranging from 35 (SE 3) to 94 (SE 8). The area under the glucose response curve and GI value of some of the roasted and baked foods were significantly higher than foods boiled or fried ($P<0·05$). The results indicate that foods processed by roasting or baking may result in higher GI. Conversely, boiling of foods may contribute to a lower GI diet.

**Glycaemic index: Diabetes: Diet**

Recent studies have shown that the Caribbean diet, comprising mostly roots and tuber crops, is rich in vast amounts of complex carbohydrates (Samuda *et al.* 1998). It has been implied by some researchers that the increase in type 2 diabetes mellitus over the last decades is attributable to the carbohydrate-rich traditional diet of the region. However, this increased incidence of diabetes may be directly linked to the changes in dietary consumption patterns. This has led to epidemic increases in obesity and may have been influenced by the insurgency of the fast food industry over recent times. In support, Ragoobirsingh *et al.* (2004) reported that Jamaica, the largest English-speaking Caribbean island, has a point prevalence of truncal obesity of 36·2 % and gynoid obesity of 34·1 %, within the adult population. It has been shown that in Jamaica, diabetic cases have risen in excess of 300,000 in a population just fewer than 3 million, with the 15 years and over age group accounting for 17·9 % of the reported cases (Ragoobirsingh *et al.* 1995) and an additional 1·7 % have impaired glucose tolerance (Ragoobirsingh *et al.* 2004). Similarly, increases were observed in other Caribbean countries. Barceló *et al.* (2003) reported that glucose intolerance increased from 8·4 % in 1971 to 24·8 % in 1998 among adults in Cuba, while the prevalence of diabetes in Barbados was near 17 % in 1993.

The type 2 diabetes epidemic has caused tremendous economic stress on the health care system, loss of labour hours and disruption of families (Barceló *et al.* 2003). The burning question is how to solve or manage this rising dilemma. Studies with large numbers of diabetics have indicated that those who maintain their blood sugar under tight control best avoid the complications from this disease (Gilbertson *et al.* 2001). It has been suggested that this problem may be associated with the consumption of complex carbohydrates with high glycaemic indices (GI) (Wheatley *et al.* 2002).

The GI is a classification of the glucose-raising potential of carbohydrate foods relative to glucose (Wolever *et al.* 1991) or white bread (Foster-Powell & Brand-Miller, 1995). GI obtained using any of these references are easily inter-converted. Research into GI has clearly proven that equal exchanges of carbohydrate do not elicit similar glycaemic responses. As a result, the classification of carbohydrate into simple and complex has been dispelled. In addition, blood glucose may also be affected by other physiological and nutritional factors, which include the digestibility of the starch, interactions of the starch with protein, the amounts and kinds of fat, sugar and fibre, the presence of other constituents, such as molecules that bind starch, and the level and type of the food processing (Kritchevsky, 1988; Whitney *et al.* 1990; Englyst *et al.* 1996). Research by Cummings (1978) suggests that consumption of dietary fibre alters the digestion and absorption of carbohydrates and lipids in the small intestine. In particular, viscous fibre has been reported to bring about slower intestinal absorption via delaying gastric emptying (Leeds, 1982) and/or interaction with digestive enzymes in the intestine (Schneeman, 1982). In addition to fibre, there is some evidence that fat and protein influence glycaemic responses by delaying upper gastrointestinal transit (Welch

**Abbreviation:** GI, glycaemic index.

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*et al.* 1987) and increasing insulin secretion (Nuttall *et al.* 1984). However, it has been reported that the fat and protein contents of root and tuber crops are minute (Eka, 1998); hence their impact on GI may be negligible. The amounts of fat and protein required to have significant effects are large compared with the amounts normally eaten or advised in dietary recommendations (Klein *et al.* 2004).

The GI of over 400 foods, mainly those eaten in developed countries, has been determined. However, this database seems to lack information on GI of foods indigenous to the Caribbean, except for the work of the University of the West Indies Yam Research Group and Ramdath *et al.* (2004). Therefore, the present study aims to determine the GI of some commonly eaten Caribbean carbohydrate-rich foods, processed by different traditional cooking methods (boiling, roasting, baking and frying) in non-diabetic healthy individuals.

## Materials and methods

### *Experimental*

The study was carried out at the University of the West Indies, Biotechnology Center, and Mona Campus, using the standard GI testing protocol as outlined by Wolever *et al.* (1991, 2003). The power of the tests with ten subjects (five males and five females) was set at 80 % to detect a 20 % difference in the incremental areas under the glucose response curves above the fasting level between the foods. This calculation assumed a variation of 22 % within subjects (Wolever *et al.* 1991). The reference food used was glucose with a GI assumed to be 100 and was tested in all the subjects, at the beginning, middle and end of the study. All subjects were appraised verbally and in writing of the study protocol and all gave written informed consent.

### *Sample collection and preparation*

Foods analysed were negro yam and lucea yam (*Dioscorea rotundata*), white yam and sweet yam (*Dioscorea alata*), round leaf yellow yam (*Dioscorea cayenensis*), coco yam (*Xanthosoma* spp.), dasheen (*Colocasia esculenta*), Irish potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*), green banana (*Musa sapientum*), green and ripe plantain (*Musa paradisiaca*), breadfruit (*Artocarpus altilis*) and pumpkin (*Cucurbita moschata*). Freshly harvested, matured foods were sourced from a local market in Kingston, Jamaica and were processed on the day of testing. The proximate compositions for the foods, outlined in Table 1, were determined using a standard Association of Official Analytical Chemists (1995) method and the available carbohydrate content was calculated by difference (Brand-Miller *et al.* 1992; Ramdath *et al.* 2004).

Food samples to be processed by frying, roasting and baking were thoroughly washed; foods to be fried were peeled, and then cut into 50 g wet weight available carbohydrate portions. Roasting was carried out using preheated charcoal, while baking was done in a preheated oven at 175°C for 45 min. Foods processed by frying were cut to 10 mm thickness and submerged in preheated, cholesterol-free vegetable cooking oil (Lider Brand, manufactured in Jamaica), until slightly brown. In all cases for the foods processed by boiling, the inedible portions of the roots and tuber crops were removed and discarded. The edible portions were washed and allowed to air dry at room temperature for 10 min; they were then cut into chunks of approximately 25 mm. Breadfruit, green plantain and green banana were boiled for 10 min; the other foods were cooked by gently boiling with the lid of the cooking vessel on for 20 min, followed by simmering heat and the lid off for a further 10 min, as outlined by Ramdath *et al.* (2004; with some modifications). After the boiling process, the available carbohydrate content was established, to assess the loss of carbohydrate that may have occurred by leaching. The foods were then cut into 50 g available carbohydrate portions, which were required for GI analysis.

### *Experimental design*

Available carbohydrate portions of test food (50 g) were consumed by each subject, in random order on separate mornings after a 10–12 h overnight fast. For individual subjects the tests

**Table 1.** Proximate composition of selected unprocessed West Indian foods (100 g)

| | Moisture content (g) | | Protein content (N × 6·25) (g) | | Fat content (g) | | Fibre content (g) | | Ash content (g) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Foods | Mean | SE | Mean | SE | Mean | SE | Mean | SE | Mean | SE | Carbohydrate content (by difference) (g) |
| Round leaf yellow yam | 66·35 | 0·41 | 1·94 | 0·03 | 0·15 | 0·01 | 3·78 | 0·01 | 0·96 | 0·03 | 26·82 |
| Negro yam | 68·83 | 0·29 | 1·69 | 0·07 | 0·24 | 0·01 | 2·87 | 0·03 | 0·63 | 0·03 | 25·74 |
| Lucea yam | 69·76 | 0·26 | 1·56 | 0·05 | 0·08 | 0·01 | 2·53 | 0·02 | 0·84 | 0·02 | 25·23 |
| White yam | 71·33 | 0·48 | 2·49 | 0·13 | 0·12 | 0·02 | 2·32 | 0·03 | 0·39 | 0·02 | 23·35 |
| Sweet yam | 68·39 | 0·19 | 2·35 | 0·03 | 0·20 | 0·02 | 2·46 | 0·05 | 0·63 | 0·02 | 25·97 |
| Coco yam | 64·77 | 0·19 | 2·57 | 0·05 | 0·22 | 0·01 | 0·74 | 0·05 | 0·92 | 0·03 | 30·78 |
| Dasheen | 71·74 | 0·41 | 1·88 | 0·04 | 0·23 | 0·01 | 1·99 | 0·05 | 0·22 | 0·02 | 23·94 |
| Breadfruit | 70·34 | 0·26 | 1·02 | 0·04 | 0·24 | 0·01 | 4·88 | 0·03 | 0·93 | 0·02 | 22·59 |
| Pumpkin | 84·01 | 0·34 | 0·97 | 0·04 | 0·10 | 0·01 | 0·52 | 0·04 | 0·81 | 0·03 | 13·59 |
| Sweet potato | 63·72 | 0·54 | 2·15 | 0·05 | 0·30 | 0·02 | 3·14 | 0·02 | 0·89 | 0·03 | 29·80 |
| Irish potato | 74·84 | 0·22 | 2·57 | 0·05 | 0·09 | 0·01 | 1·62 | 0·02 | 0·85 | 0·02 | 20·03 |
| Green banana | 71·17 | 0·20 | 1·42 | 0·18 | 0·33 | 0·03 | 0·59 | 0·04 | 0·89 | 0·03 | 25·60 |
| Green plantain | 68·06 | 0·18 | 1·67 | 0·02 | 0·24 | 0·02 | 0·48 | 0·03 | 1·13 | 0·04 | 28·42 |
| Ripe plantain | 72·13 | 0·35 | 1·90 | 0·02 | 0·25 | 0·02 | 0·30 | 0·03 | 1·79 | 0·03 | 23·63 |

**Table 2.** Available carbohydrate (CHO) in 100 g unprocessed food* and serving sizes† used for glycaemic index determination‡

| Food samples | Food processing methods | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Boiled | | Roasted | | Baked | | Fried | |
| | Available CHO (g) | Serving size (g) | Available CHO (g) | Serving size (g) | Available CHO (g) | Serving size (g) | Available CHO (g) | Serving size (g) |
| Round leaf yellow yam | 22·42 | 223·02 | 26·82 | 186·43 | NA | NA | NA | NA |
| Negro yam | 21·27 | 235·07 | 25·74 | 194·25 | NA | NA | NA | NA |
| Lucea yam | 18·22 | 274·42 | 25·23 | 198·18 | NA | NA | NA | NA |
| White yam | 20·92 | 239·00 | 23·35 | 214·13 | NA | NA | NA | NA |
| Sweet yam | 16·78 | 297·97 | 25·97 | 192·53 | NA | NA | NA | NA |
| Sweet potato | 21·31 | 234·63 | 29·80 | 167·79 | 29·80 | 167·79 | 29·80 | 167·79 |
| Irish potato | 21·65 | 230·95 | NA | NA | 20·03 | 249·63 | 20·03 | 249·63 |
| Dasheen | 17·90 | 279·30 | NA | NA | NA | NA | NA | NA |
| Coco yam | 10·36 | 482·63 | NA | NA | NA | NA | NA | NA |
| Pumpkin | 22·34 | 223·81 | NA | NA | NA | NA | NA | NA |
| Breadfruit | 18·08 | 276·55 | 22·59 | 221·34 | NA | NA | NA | NA |
| Green banana | 22·20 | 225·23 | NA | NA | NA | NA | 25·60 | 195·31 |
| Green plantain | 19·29 | 259·20 | NA | NA | NA | NA | 28·42 | 175·93 |
| Ripe plantain | 16·20 | 308·64 | NA | NA | NA | NA | 23·63 | 211·60 |

NA, food processing method not applicable.
* Except for 100 g of the boiled foods.
† Containing 50 g available carbohydrate.
‡ For details of procedures, see p. 477.

were given 7 d apart (Brand-Miller *et al.* 1992). Volunteers were asked not to perform any strenuous activities, take long walks or smoke on the day of GI determination. The foods were supplemented with 250 ml purified water (Catherine's Peak pure spring water) having no nutritional value. The foods were warmed for 1 min in a microwave oven and the volunteers were asked to consume it over a 7 min period. They were asked to remain seated for the 2 h duration of the test. Capillary pricked-finger blood samples were taken (three or four drops) at baseline (0 min), 15, 30, 45, 60, 90 and 120 min after consumption of the test food (Nehir, 1999). Blood samples were collected into heparin tubes and stored at −20°C, before glucose analysis by the glucose oxidase method using a UV–Visible Ultraspec spectrophotometer (Model 1100 Pro; Ultraspec, Cambridge, UK).

The incremental areas under the curve, excluding the area beneath the fasting level, were calculated geometrically (Wolever *et al.* 1991). The GI was calculated by expressing the glycaemic response area for the test foods as a percentage of the mean response area of the reference food taken by the same subjects (Wolever *et al.* 1991, 1994).

### *Statistical analysis*

The GI values are expressed as means with their standard errors. Statistical analyses between response areas were performed using one-way ANOVA and Duncan's multiple range tests. Differences were considered statistically significant at $P < 0·05$.

## Results

Ten healthy non-diabetic volunteers (age and sex matched) participated in the present study, with ages ranging between 18 and 40 years and BMI (kg/m$^2$) ranging between 21·63 and 27·26 kg/m$^2$. The proximate compositions of the foods analysed are shown in Table 1. The available carbohydrate content of the foods, together with the serving sizes containing the 50 g available carbohydrate portions, is shown in Table 2. The GI of the fourteen commonly eaten Caribbean foods, determined under different processing methods, are shown in Table 3. The GI of the boiled foods ranged from 37 (SE 5) to 79 (SE 4), with green banana having the lowest GI and sweet yam the highest GI. For the fried foods, GI values ranged from 35 (SE 3) for green banana to 90 (SE 6) for ripe plantain. The GI of baked Irish potato and sweet potato, which were the only two foods baked, gave high GI (83 (SE 6) and 94 (SE 8), respectively). Likewise for the roasted foods, the GI were all high (ranging from 72 (SE 8) for breadfruit to 82 (SE 7) for sweet yam).

Blood glucose response curves for a low, intermediate and high GI food (green banana, Irish potato and round leaf yellow yam, respectively) are shown in Fig. 1. In Fig. 2, a similar relationship is shown in the blood glucose response curves of boiled, roasted and fried sweet potato.

## Discussion

The GI values of commonly eaten Caribbean, carbohydrate-rich, root and tuber crops were determined in the present study using a standard protocol (Wolever *et al.* 1991, 2003).

**Table 3.** Glycaemic indices of selected West Indian food crops determined under different processing methods*

| | Food processing methods | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Boiled | | Roasted | | Baked | | Fried | |
| Food samples | Mean | SE | Mean | SE | Mean | SE | Mean | SE |
| Round leaf yellow yam | 68 | 3 | 80 | 7 | NA | | NA | |
| Negro yam | 73 | 4 | 73 | 6 | NA | | NA | |
| Lucea yam | 74 | 7 | 77 | 5 | NA | | NA | |
| White yam | 75 | 6 | 80 | 6 | NA | | NA | |
| Sweet yam | 79 | 4 | 82 | 7 | NA | | NA | |
| Sweet potato | 46 | 5 | 82 | 5 | 94 | 8 | 76 | 7 |
| Irish potato | 59 | 4 | NA | | 83 | 6 | 70 | 6 |
| Dasheen | 72 | 5 | NA | | NA | | NA | |
| Coco yam | 61 | 5 | NA | | NA | | NA | |
| Pumpkin | 66 | 4 | NA | | NA | | NA | |
| Breadfruit | 47 | 5 | 72 | 8 | NA | | NA | |
| Green banana | 37 | 5 | NA | | NA | | 35 | 3 |
| Green plantain | 39 | 4 | NA | | NA | | 40 | 3 |
| Ripe plantain | 66 | 2 | NA | | NA | | 90 | 6 |

NA, food processing method not applicable.
* For details of procedures, see p. 477.

The foods selected to be tested were based on commonly eaten foods reported by Samuda *et al.* (1998), with the main objective to generate GI data for Caribbean foods.

The results revealed marked differences in GI among the foods studied when processed traditionally by boiling, with approximately 64 % of the foods boiled found to have an intermediate or low GI and approximately 36 % with high GI. Green banana, green plantain, breadfruit and sweet potato were found to be low GI foods with GI values of 37 (SE 5), 39 (SE 4), 72 (SE 5), 47 (SE 5) and 46 (SE 5), respectively. Those that had intermediate GI were pumpkin, round leaf yellow yam, Irish potato, ripe plantain and coco yam with GI values of 66 (SE 4), 68 (SE 3), 59 (SE 4), 66 (SE 2) and 61 (SE 5), respectively. Boiled negro, lucea, white and sweet yams together with dasheen were all found to have a high GI, with values between 70 and 80.

Foods processed by boiling and frying were found to have the lowest GI. Overall boiled green banana, green plantain, sweet potato and breadfruit had the lowest GI, together with fried green banana and fried green plantain with GI values of 35 (SE 3) and 40 (SE 3), respectively. Conversely, all the foods processed by roasting and baking elicited the highest GI and resulted in significantly higher increases in postprandial blood glucose responses.

The present results suggest that the different processing methods used (boiling, roasting, baking and frying) may influence the GI of a particular food. During the boiling process, wet heat is used causing free sugars to leach into the liquid medium. Further leaching of glucose monomers occurs during amylase–amylopectin degradation. However, the loss of the readily digestible sugars due to leaching had no direct implication on the amount of carbohydrate used to calculate the GI of the boiled foods. This is because the 50 g available carbohydrate portion required for GI testing was calculated on the final cooked product. As a result of this, greater amounts of resistant starches (RS1, RS2 and RS3) may have been retained in the boiled foods. RS3 is produced when foods that have been boiled are cooled, as part of the starch dispersed during cooking undergoes re-crystallization as a result of intermolecular hydrogen bonds. Retrograded amylose is indigestible due to the presence of stronger hydrogen bonding in comparison to retrograded amylopectin (Englyst *et al.* 1983). Furthermore, the cook–cooling–re-warming to which the foods were subjected could have affected the amount of resistant starch they contained (Ramdath *et al.* 2004). About 7 % of starch in reheated boiled potatoes escapes digestion in the small intestine compared with about 3 % in freshly cooked potato (Englyst & Cummings, 1987).

This effect was reciprocated during roasting and baking. The foods were processed within the skin using dry heat, causing loss of water and concentrating free sugars within the food. Degradation of starches further increases the total sugar content resulting in high GI values.

The different carbohydrate contents of the foods may also explain the differences in GI. It was found that foods with similar levels of carbohydrate content do not necessarily have similar

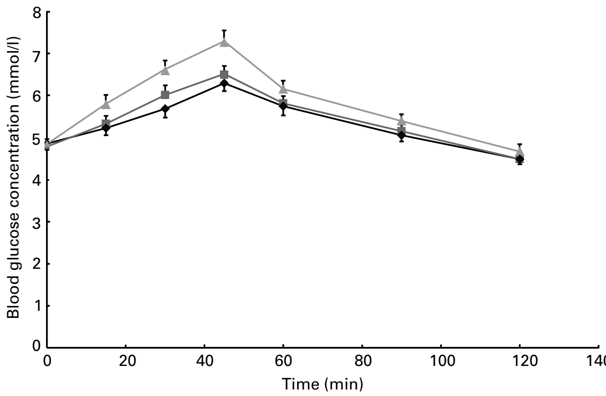


**Fig. 1.** Blood glucose responses of ten healthy subjects fed low (◆, green banana), intermediate (■, Irish potato) and high (▲, round leaf yellow yam) GI foods. For details of procedures, see pp. 477–478. Values are means with their standard errors depicted by vertical bars.

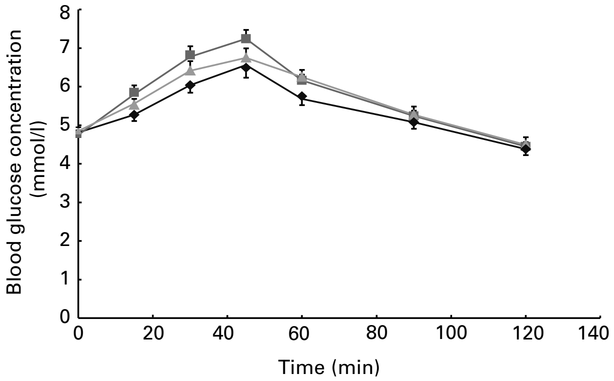


**Fig. 2.** Blood glucose responses of ten healthy subjects fed sweet potato processed by different methods (◆, boiled; ■, roasted; ▲, fried). For details of procedures, see pp. 477–478. Values are means with their standard errors depicted by vertical bars.

GI. This may be due to the difference in the types of starches and fibre content. Studies by Brand-Miller *et al.* (1992) showed that rice with higher amylose content (Doongara, 28 % amylose) gave a significantly lower GI and insulin index than did the normal amylose rice varieties (Calrose and Pelde, 20 % amylose).

It was also observed that changes in the physiologic state of the food, from green to ripe, influences GI. Boiled ripe plantain had a higher GI value of 66 (SE 2) when compared to boiled green plantain with a GI value of 39 (SE 4). When processed by frying, ripe plantain resulted in a significantly higher GI than green plantain of 90 (SE 6) and 40 (SE 3), respectively. This results from an increased conversion of complex polysaccharides to free sugars during the ripening process.

The range of GI between the staples is sufficiently large, and could result in beneficial health effects if those consuming a Caribbean diet reduced their intakes of staples with high GI and increased the consumption of those with intermediate (Ramdath *et al.* 2004) and low GI values. This is particularly important since epidemiologic studies have shown a positive association between dietary GI and the risk of type 2 diabetes (Salmeron *et al.* 1997). Similarly, increased consumption of low GI whole grains has been found to have a protective effect on the development of CVD (Ludwig *et al.* 1999) as well as cancer (Higginbotham *et al.* 2004). Also, low GI diets have been associated with higher HDL-cholesterol concentrations and decreased risks of developing diabetes and CVD (Jenkins *et al.* 2002). It is crucial that low-GI Caribbean foods be identified.

Therefore, it can be concluded that foods processed by boiling or frying are better to consume. Reducing the consumption of foods processed by roasting and baking is advisable. However, even though fried foods may result in lower GI values than roasted or baked foods, they are processed with increasing amounts of fats, which are unhealthy, and thus should not be promoted. As a result, the findings of the present study could be of use to encourage the use of GI by health care professionals, nutritionists and in diabetes education, in order to help diabetics and health-conscious individuals to better plan their diets so as to reduce the incidence of postprandial spikes in blood glucose levels.


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